HARBORVIEW

Illustrated Tips and Tricks in

FRACTURE SURGERY

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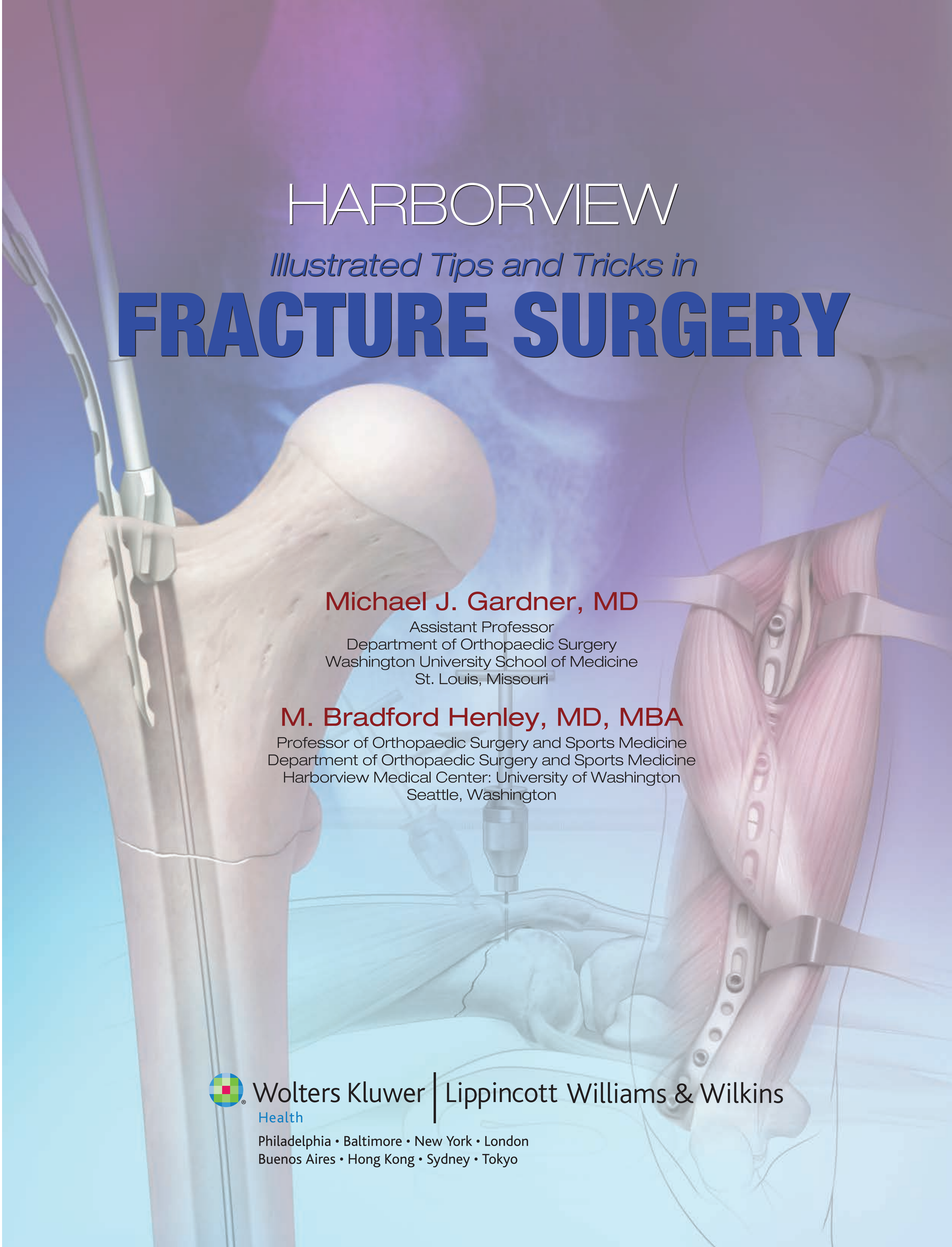

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Illustrated Tips and Tricks in FRACTURE SURGERY

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FOREWORD

Bruce Douglas Browner, MD, MS, FACS

When I was a resident during the mid-1970s, fracture management revolved around the use of plaster casts and traction. Young men with femur fractures remained hospitalized for weeks, lying in beds inclined on wooded boxes to counteract the pull of heavy weights. They were then placed in plaster spica casts for several months. Open fractures were treated with pins in plaster and the Orr method. Osteomyelitis and amputations were common. Some fractures were opened and fixed with straight nails or plates, but the indications were inconsistent and unclear. Custom-molded plastic bracing and functional treatment were introduced by Sarmiento and his fracture courses in Miami were very popular. The faculty at the one I attended as a senior resident included a little-known surgeon from Seattle named Sigvard “Ted” Hansen. He reported on the initial results from Harborview Hospital with the closed nailing technique they had learned when Gerhard Kuntscher visited. To support his case for the superiority of the technique, he argued that animals with endoskeletons were more advanced than those with exoskeletons. Ted later noted that this presentation I witnessed was the launching for closed nailing and the beginning of the transition to a new era of treatment for long bone fractures.

I traveled to Davos for the annual AO course as a chief resident. There was a small zealous group of mostly European surgeons who were developing a system of internal fixation that was not yet embraced by American orthopaedic surgeons. The precisely designed Swiss implants and equipment and highly organized approach to operative fracture care were very appealing. When this system was introduced in the United States, the emphasis on early rigid fixation and rapid mobilization caused a major shift in fracture care. During this period, external fixation had a revival in the United States and was used extensively for open fractures, which were prevalent as the United States reached the peak of road traffic deaths and injuries.

Working at the Maryland Shock Trauma Center, housed then in an old wing of the hospital, I was a participant in and a witness to the birth of a new field called orthopaedic trauma. The focus became optimal care of seriously injured patients and treatment of complex musculoskeletal injuries. We incorporated the new techniques and moved away from the old methods. A pivotal moment occurred at the 1983 AAOS meeting in Las Vegas when Bob Winquist presented the highly positive Harborview experience with the closed nailing of 504 femoral fractures. Because of its significance, the presentation was scheduled in the slot before the first vice presidential address and was heard by an audience of thousands in a massive rotunda ballroom. Gus Sarmiento the leading apostle of functional bracing, who was the discussant, acknowledged that the technique offered unprecedented advantages and would change the standard of care.

Over the subsequent 27 years, the field of orthopaedic trauma has evolved constantly and modern fracture management has spread throughout the world. The orthopaedic faculty at Harborview have been among the leading groups in the subspecialty. Serving as the trauma-referral center for surrounding states, they have consistently been receiving large volume of patients, which allowed them to develop a large group of orthopaedic trauma faculty. They have amassed a large collective experience and completed many important clinical studies. Their emphasis on excellence and constant pursuit of improved methods of care has enabled them to establish and refine a series of protocols for operative management. Surgeons from all over the world visit the center to observe their approach to trauma care. Their orthopaedic trauma fellowship is considered the premier experience in the country.

Brad Henley, MD, MBA, a veteran member of the Harborview Orthopaedic Trauma group, has used his clinical expertise and business leadership skills to organize an outstanding surgical technique atlas. Members of the Harborview Orthopaedic Trauma faculty and current and former orthopaedic trauma fellows created the various chapters. A consistent approach was used combining very high quality intraoperative photos and beautiful halftone line drawings. Details of surgical technique are conveyed in brief notes, which form legends for each illustration.

This treatise will provide valuable supplementation on surgical management and technique to the information contained in major fracture texts. There is a growing need for this type of detailed "how to do it" guidance. Successive global burden of disease and injury analyses document a growing prevalence of road traffic injuries, particularly in the developing world. The problem stems from vulnerable road travelers sharing the roads with heavy vehicles and public transportation that are overcrowded and dangerous. Increasing numbers of deaths and injuries result and disabling musculoskeletal disabilities are causing major social and economic impact. Rapid motorization in populous, economically powerful countries such as India and China is casing a surge in injuries to occupants of cars. Airbags, seat belts, and improved car design have decreased the fatality rate in developed countries, but severe lower extremity injuries are not prevented by current measures. Medical systems in many countries are evolving to levels where surgeons will be able to employ modern methods of internal and external fixation to avoid disabilities. This Harborview book will be an extremely useful resource that will assist them with the quest for optimal patient care.

PREFACE

I developed the idea for this book nearly 15 years ago. Like most orthopaedic surgeons, I learned surgical operations by reading about a specific or preferred technique. This was followed by observing the procedure as performed by a mentor. At some point in my training, I began performing these operations as the operating "surgeon," usually with the assistance of a senior physician. After I was awarded my first academic position at University of Texas Southwestern Health Science Center at Dallas (UTHSCD) and Parkland Hospital, I performed them independently. Also similar to most orthopaedic surgeons, after "reading one, doing one, and teaching one," I would frequently modify certain aspects of the operation to make it "better" and to improve my surgical efficiency. Throughout my career, I have continued to "refine" procedures, using what I believe are more effective and efficient methods of accomplishing the task of obtaining an anatomical reduction (an "ORIF" instead of an "OIF"[1]).

After leaving UTHSCD, I joined the University of Washington (UW) faculty at Harborview Medical Center (HMC). When I arrived in February 1988, the full-time faculty at HMC numbered only five: Sigvard "Ted" Hansen, Keith Mayo, Paul A. Anderson, Stephen K. Benirschke, and Bruce J. Sangeorzan. Steve and Bruce had recently completed fellowships in Trauma and Foot & Ankle, respectively. Later in 1988, Marc Swiontkowski joined our team expanding our number to seven. Ted, Bruce, and Paul had a nontrauma orthopaedic specialty as their primary clinical interest, though all took trauma call and cared for patients with musculoskeletal injuries. Over the next decades, the Harborview's Orthopaedic faculty contracted and expanded. Currently, we have eight full-time faculty trauma surgeons and Ted Hansen with more than 179 years of postfellowship trauma experience. Supplementing these core trauma surgeons are the other faculty based at HMC who share in covering trauma call, hand call, or spine call; I believe that the orthopaedic group at Harborview is the largest trauma group with the greatest accumulated experience treating musculoskeletal injuries in the nation (~280 physician years). Table 1 summarizes the orthopaedic faculty appointments and departures since my arrival at HMC.

The faculty at Harborview have a long history dedicated to graduate and postgraduate medical education. Beginning in the 1970s, they offered an opportunity for physicians desiring a greater trauma experience to spend time at the institution dedicated to the care of patients with musculoskeletal injuries. Both academic and community orthopaedists availed themselves of this experience and would spend either 3 or 6 months working with the residents and faculty. It was not until the mid-1980s that a few surgeons would stay for a year at a time. With the formation of the Orthopaedic Trauma Hospital Association (OTHA, the organization preceding the Orthopaedic Trauma Association [OTA; www.ota.org]), two 1-year long orthopaedic trauma fellowship positions were offered. By the late 1980s, after Marc Swiontkowski's and my arrival at HMC, three Advanced Clinical Experience (ACE) positions were offered per year. Over the next two decades, the number of positions expanded gradually from the initial three, to four, then five, and finally to the six trauma ACE positions we offer today. (Table 2 summarizes the chronology of HMC Orthopaedic Trauma ACEs.)

Being an orthopaedic trauma attending at Harborview Medical Center in Seattle allowed me to establish a practice devoted full time to musculoskeletal trauma. Performing operations, repetitively, provided many opportunities to devise my own set of tips and tricks. However, working at Harborview has also allowed me to work with some of the world's foremost thought leaders and best technical orthopaedic trauma surgeons. This environment has been conducive to collaboration and refinement of patient care. Our weekly fracture conference is renowned as it allows discourse and debate of the treatments for acute ortho trauma by six-twelve orthopaedic trauma surgeons. Additionally, my colleagues and I can often "visit" with each other in between cases to observe each other's techniques and technical tips.

[1]I ascribe this vernacular to the insights and surgical perfectionism of my partner and friend "Stevie B" (Stephen. K. Benirschke MD): ORIF — open reduction with internal fixation; OIF — open….with internal fixation.

Table 1. Harborview–Based UW Orthopaedic Faculty from 1988 to 2009

Last name, First name	Hire Date	Current or Depart Date
Hansen, Sigvard T.	7/1/1968	current
Winquist, Robert A.	7/1/1974	5/25/1980
Veith, Robert G.	7/1/1980	3/31/1984
Mayo, Keith A.	6/25/1984	11/12/1990
Sack, John T.	7/1/1984	current
Anderson, Paul A.	7/1/1985	4/30/1994
Benirschke, Stephen K.	1/1/1986	current
Sangeorzan, Bruce J.	4/1/1987	current
Henley, M. Bradford	2/1/1988	current
Swiontkowski, Marc	5/1/1988	9/1/1997
Routt, M. L. Chip	7/1/1989	current
Trumble, Thomas E.	7/1/1989	current
Smith, Douglas G.	7/1/1990	current
Chapman, Jens R.	8/1/1991	current
Hanel, Douglas P.	6/1/1992	current
Mirza, Sohail	9/1/1995	8/31/2008
Nork, Sean E.	8/1/1998	current
Allan, Christopher H.	9/1/1998	current
Mills, William J.	9/10/1998	7/2/2004
Bellabarba, Carlo	10/1/1999	current
Barei, David P.	8/1/2000	current
Taitsman, Lisa A.	8/1/2002	current
Bransford, Richard J.	10/6/2003	current
Beingessner, Daphne M.	8/1/2004	current
Dunbar, Robert P.	9/15/2005	current
Krieg, James C.	7/1/2007	current
Huang, Jerry I.	9/1/2008	current

This has allowed us to disseminate our own ideas and those of our colleagues by incorporating each other's tricks, tips, and treatment philosophies into the care of our own patients and our educational philosophy.

Over the past 15 years, I have often thought of codifying these tips and tricks in journal articles or book form. Some tips and tricks have been published by HMC ACEs in orthopaedic journals but many ideas of the HMC trauma faculty are unpublished. It has been a habit of the ACEs to keep a diary or record of their cases noting surgical tips, tricks, and techniques. In September of the 2007–2008 ACE year, I pitched my idea to our six trauma fellows (Mike Brennan, Andy Evans, Jason Evans, Mike Gardner, Zach Roberts, and Ray Wright). I was greeted with enthusiastic support. Each of the ACEs digitally recorded their observations and lessons learned after each case or at the end of the day. They illustrated their notes with digital images saved from the image intensifier and planar radiographs during their 1-year experience. Their hand drawings were converted to medical illustrations by Scott Bodell, a superb medical illustrator whom I met while at UTHSCD (1985–1988). These image files were appended to their recorded observations and serve to illustrate many of the tips and tricks. This book is therefore the result of a single year's observations of select cases made by six orthopaedic trauma ACEs (8/2007–7/2008), each of whom was assigned authorship of one or more chapters.

Over the course of the year, Mike Gardner demonstrated an affinity for this book concept. He used his leadership skills to help me organize the project and served as the liaison with his peers. Based on his academic interest and his early and sustained contributions to the manuscript, I suggested that he serve as coeditor with me. Each ACE was assigned authorship of one or more chapters.

Mike and I understand that HMC is an orthopaedic center for the germination and coalescence of ideas and techniques. This is facilitated by a continuing stream of scholars, visitors, and physicians who seek education and advanced training. Together with the faculty, these individuals help catalyze the refinement of ideas and techniques, which lead to new techniques and improved patient care. We know that musculoskeletal trauma care will continue to evolve in the future. It is our hope that HMC and our ACE disciples will continue to maintain leadership roles through research and collaboration.

The editors and authors make no claim to many of the techniques, "tips," and "tricks" described in this publication. Instead, we view it as a compilation of those techniques that were used by the HMC faculty and observed and chronicled in a 1-year period by our six orthopaedic trauma ACEs. Some of these techniques were learned from interactions with our national and international colleagues while others may be accurately ascribed to a specific HMC faculty member. Some of these ideas may have been published previously by other authors and this is referenced only if we were aware of the prior publication.

I would like to dedicate this book to all of my colleagues (orthopaedists and nonorthopaedists) who provide emergency medical services to humankind. Should family or friends need emergency trauma care, I am glad to know that I can depend on the many trauma surgeons and physicians who have trained at Harborview and at the other excellent trauma centers in the United States. I want to acknowledge, especially, all of my past and present teachers and mentors (especially Professor Dr. med. Bernd Claudi and Dr. Kenneth D. Johnson), current and former (UTHSCD and UW/HMC) faculty colleagues, OTA colleagues and members, and HMC ACEs [see Tables 1 and 2]. It is these individuals and their disciples who have dedicated their careers to providing the emergency trauma services and are continuing graduate and postgraduate education needed by our nation. Most importantly, I want to thank my domestic partner Ann Rutledge; my parents, Ernest and Elaine; my daughters, Taryn and Cailin; and my colleagues and friends for their support and help during this project.

Thank you very much
Brad Henley

When I first visited Harborview during my residency, I attended the weekly fracture conference. After witnessing the postoperative fracture conference and X-ray presentations, I knew immediately I wanted to learn and emulate the quality, techniques, and style of fracture fixation that seemed to be consistent among all faculty. During my fellowship at Harborview, this conference was among the many highlights. The postoperative review of many fluoroscopic images in succession, often 15 or 20, made it possible to follow along the progression of the procedure, step by step. The subtleties of clamp placements for specific fracture fragments, reduction sequences for common fracture patterns, and the rationale for particular implant choices and positions were often discussed. This was an extremely effective way to teach and learn the technical aspects of fracture surgery. My co-fellows and I began to jot down names of interesting patients during the conference, and would later review and save the images. A critical mass of particularly demonstrative cases was obtained, and formed the basis of the present text. I have subsequently revisited these chapters countless times prior to operations, and hope it can similarly provide other young fracture surgeons with useful techniques. Participating in this "extra-curricular" activity during my fellowship and early career would not have been possible without the endless support and understanding from my wife, Katie, and daughter, Kelsey.

I hope that you will enjoy this compilation of tips, tricks and surgical cases that my colleagues and I have compiled.

Thank you
Mike Gardner

Table 2. Chronology of HMC Orthopaedic Trauma ACEs

Name	Begin Date	End Date	Length (mo)
Stuyck, Jos	10/13/1978	9/17/1979	11
Weber, Michael	10/1/1979	12/31/1979	3
Jackson, Robert	1/1/1980	6/30/1980	6
Marcus, Randall	4/1/1980	6/30/1980	3
Johnson, Kenneth D.	12/1/1980	6/15/1981	6
Shammas, Sameer	7/1/1980	12/31/1980	6
Jacobson, Wells	1/1/1981	3/31/1981	3
Kellam, James	4/1/1981	6/30/1981	3
Burney III, Dwight	7/1/1981	9/30/1981	3
Burman, William	10/1/1981	12/31/1981	3
Ratcliffe, Steven	1/1/1982	3/31/1982	3
Gerhart, Tobin	4/1/1982	6/30/1982	3
Webb, Lawrence	7/1/1983	12/31/1983	6
Moody,Wayne	1/3/1984	2/29/1984	2
LaMont, Justin	7/1/1984	6/30/1985	12
Wilber, John	7/1/1984	6/30/1985	12
Cotler, Howard	1/1/1985	6/30/1985	6
Lhowe, David	7/1/1985	12/31/1985	6
Moye, Daniel	7/1/1985	6/1/1986	11
Carr, James	8/1/1985	7/31/1986	12
Cornell, Charles	1/1/1986	6/30/1986	6
Jonassen, E. Andrew	7/1/1986	6/30/1987	12
Keeve, Jonathan	7/1/1986	12/31/1986	6
Donovan, Thomas	1/1/1987	4/30/1987	4
Benca, Paul	7/1/1987	6/30/1988	12
Carr, Charles	7/1/1987	12/31/1987	6
Kaehr, David	7/1/1987	6/30/1988	12
Verdin, Peter	7/1/1987	6/30/1988	12
Mirels, Hilton	7/1/1988	1/31/1989	7
Routt, Chip	7/1/1988	6/30/1989	12
Gruen, Gary	1/1/1989	6/30/1989	6
Agnew, Samuel	7/1/1989	7/31/1990	13
Santoro, Vincent	7/1/1989	7/15/1990	12
Peter, Robin	7/16/1990	7/15/1991	12
West, Gregory	7/16/1990	7/15/1991	12
Chapman, Jens	8/1/1990	1/31/1991	6
Kottmeier, Stephen	1/1/1991	7/31/1991	7
Cramer, Kathryn	8/1/1991	7/31/1992	12

Table 2. *Continued*

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Patterson, Brendan	8/1/1991	7/31/1992	12
Grujic, Les	8/1/1992	7/31/1993	12
Ott, Judson	8/1/1992	7/31/1993	12
Selznick, Hugh	8/1/1992	7/31/1993	12
Brokaw, David	8/1/1993	7/31/1994	12
Handley, Robert	8/1/1993	7/31/1994	12
Teague, David	8/1/1993	7/31/1994	12
McNamara, Kevin	4/1/1994	7/31/1994	4
Hubbard, David	8/1/1994	7/31/1995	12
Schwappach, John	8/1/1994	7/31/1995	12
Twaddle, Bruce	8/1/1994	7/31/1995	12
Weber, Tim	8/1/1994	7/31/1995	12
Clark III, Carey	8/1/1995	7/31/1996	12
Desai, Bharat	8/1/1995	7/31/1996	12
Krieg, James	8/1/1995	7/31/1996	12
Thomson, Gregory	8/1/1995	7/31/1996	12
Harding, Susan	8/1/1996	7/31/1997	12
Harvey, Edward	8/1/1996	7/31/1997	12
Mormino, Matt	8/1/1996	7/31/1997	12
O'Byrne, John	8/1/1996	7/31/1997	12
Cole, Peter	8/1/1997	7/31/1998	12
Jones, Cliff	8/1/1997	7/31/1998	12
Nork, Sean	8/1/1997	7/31/1998	12
Russell, George	8/1/1997	7/31/1998	12
Kuo, Roderick	8/1/1998	7/31/1999	12
Sanzone, Anthony	8/1/1998	7/31/1999	12
Segina, Daniel	8/1/1998	7/31/1999	12
Tejwani, Nirmal	8/1/1998	7/31/1999	12
Barei, David	8/1/1999	7/31/2000	12
Hymes, Robert	8/1/1999	7/31/2000	12
Schildhauer, Thomas	8/1/1999	7/31/2000	12
Schwartz, Alexandra	8/1/1999	7/31/2000	12
Ertl, William	8/1/2000	7/31/2001	12
Fowble, Coleman	8/1/2000	7/31/2001	12
Ringler, James	8/1/2000	7/31/2001	12
Vallier, Heather	8/1/2000	7/31/2001	12
Camuso, Matthew	7/1/2001	8/31/2002	14
McNair, Patrick	7/1/2001	8/31/2002	14
Taitsman, Lisa	8/1/2001	7/31/2002	12
Wagshul, Adam	8/1/2001	7/31/2002	12
Wiater, Patrick	8/1/2001	7/31/2002	12
Coles, Chad	8/1/2002	7/31/2003	12
Dunbar, Robert	8/1/2002	7/31/2003	12
Hammerberg, Eric Mark	8/1/2002	7/31/2003	12
Polonet, David	8/1/2002	7/31/2003	12
Smith, Carla	8/1/2002	7/31/2003	12
Beingessner, Daphne	8/1/2003	7/31/2004	12

Table 2. *Continued*

Name	Begin Date	End Date	Length (mo)
Farrell, Eric	8/1/2003	7/31/2004	12
Howlett, Andrew	8/1/2003	7/31/2004	12
Molnar, Rob	8/1/2003	7/31/2004	12
Stafford, Paul	8/1/2003	7/31/2004	12
Conflitti, Joseph	8/1/2004	7/31/2005	12
Della Rocca, Gregory	8/1/2004	7/31/2005	12
Gomez, Arturo	8/1/2004	7/31/2005	12
Osgood, Gregory	8/1/2004	7/31/2005	12
Weiss, David	8/1/2004	7/31/2005	12
Bryant, Ginger	8/1/2005	7/31/2006	12
Graves, Matthew	8/1/2005	7/31/2006	12
Greene, Craig	8/1/2005	7/31/2006	12
Howard, James	8/1/2005	7/31/2006	12
O'Mara, Timothy	8/1/2005	7/31/2006	12
Yoo, Brad	8/1/2005	7/31/2006	12
Kubiak, Erik	8/1/2006	7/31/2007	12
Mehta, Samir	8/1/2006	7/31/2007	12
Mirza, Amer	8/1/2006	7/31/2007	12
Puttler, Eric	8/1/2006	7/31/2007	12
Summers, Hobie	8/1/2006	7/31/2007	12
Viskontas, Darius	8/1/2006	7/31/2007	12
Brennan, Michael	8/1/2007	7/31/2008	12
Evans, Andrew	8/1/2007	7/31/2008	12
Evans, Jason	8/1/2007	7/31/2008	12
Gardner, Michael	8/1/2007	7/31/2008	12
Roberts, Zachary	8/1/2007	7/31/2008	12
Wright, Raymond	8/1/2007	7/31/2008	12
Calafi, Leo	8/1/2008	7/31/2009	12
Maroto, Medardo	8/1/2008	7/31/2009	12
Morshed, Saam	8/1/2008	7/31/2009	12
Nwosa, Chinedu	8/1/2008	7/31/2009	12
Oldenburg, Frederick	8/1/2008	7/31/2009	12
Orec, Robert	8/1/2008	7/31/2009	12
Bishop, Julius	8/1/2009	7/31/2010	12
Cross, W. Woodie	8/1/2009	7/31/2010	12
Dikos, Greogry	8/1/2009	7/31/2010	12
Glasgow, Don	8/1/2009	7/31/2010	12
Maples, Allan	8/1/2009	7/31/2010	12
McAndrew, Christopher	8/1/2009	7/31/2010	12

Section 1

Patient Positioning

Lisa A. Taitsman

Chapter 1

Patient Positioning

Michael L. Brennan
Lisa A. Taitsman

- The goal of positioning a patient for surgery is to allow the surgeon unrestricted access to the extremity (surgical site) for the surgical procedure and for imaging.
- Prolonged soft tissue pressure and shear forces from improper positioning may compromise quality of care and patient safety, resulting in tissue injuries such as circulatory embarrassment, perioperative pressure ulcers, and neurological injury, even in routine surgical procedures.

Upper Extremity

ORIF Clavicle, Proximal Humerus, Humeral Shaft

- Supine on reversed radiolucent cantilever table.
  - Standard beach chair positioning is an alternative.
- Patient brought as proximal and lateral on the table as possible, with head at the top corner of the table, ipsilateral to operative extremity (Figs. 1-1 and 1-2).
  - Neck should be slightly extended and head turned slightly away from operative extremity and secured with tape over a forehead towel.
- Small folded towel beneath the ipsilateral scapula if needed.

Figure 1-1. Supine positioning for upper extremity procedure, C-arm from the head of the bed.

Figure 1-2. C-arm position for axillary lateral imaging.

- C-arm from the top of the table, parallel to the long axis of the bed; permits axillary lateral image of humerus in addition to standard imaging of the shoulder girdle.
- Radiolucent (e.g., Plexiglas) arm board placed under the mattress pad with sufficient board protruding to support the arm.
  - Add height to radiolucent Plexiglas arm support with blankets (secure with tape) to match table-pad height.
- Upper extremity is draped free.
- Wide prep and drape to contralateral side of midline (Figs. 1-3 and 1-4).
  - Include the sternal notch in field.

Figure 1-3. Supine positioning for upper extremity procedure after prepping and draping.

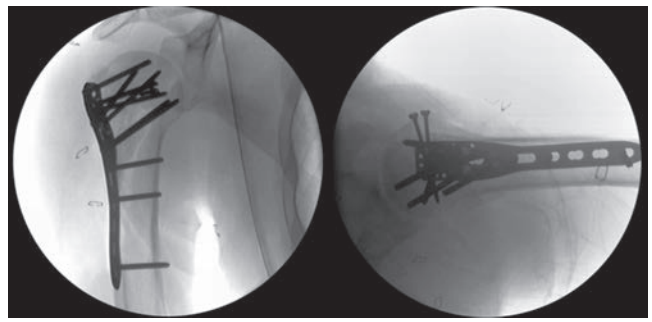


Figure 1-4. AP and axillary fluoroscopic imaging in supine position.

IM Nail Humerus (Supine)

- Radiolucent reversed cantilever or fully radiolucent table such that the patient's head/upper extremities are placed at the cantilevered end.
- Small bump (folded towel) beneath the scapula.
- C-arm from the opposite side of the table (use fluoroscope that goes 45 degrees beyond vertical ("over the top"), and 90 degrees in the other direction).
- Uninjured arm adducted along side the body so that it does not impede the C-arm moving parallel to the long axis of table/arm.
- Plexiglas arm board with stacked blankets to match table pad height.
  - Plexiglas board is placed on the table, under the mattress pad and the patient with its long axis parallel to the table.
  - It needs only to protrude from the side of the OR table by 4 to 6 inches to support the adducted operative extremity (Figs. 1-5–1-9).

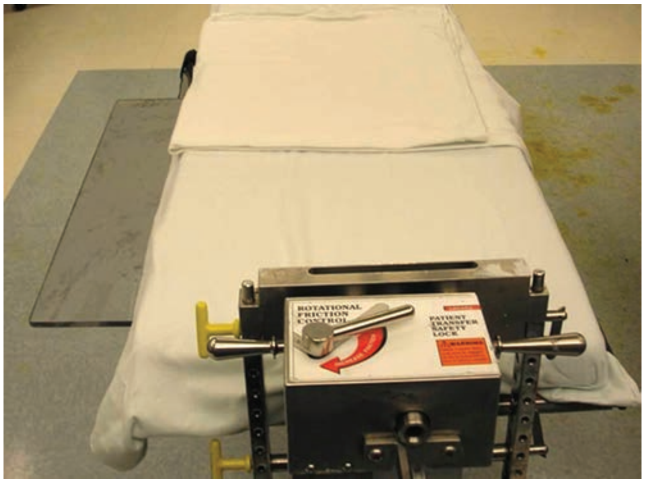


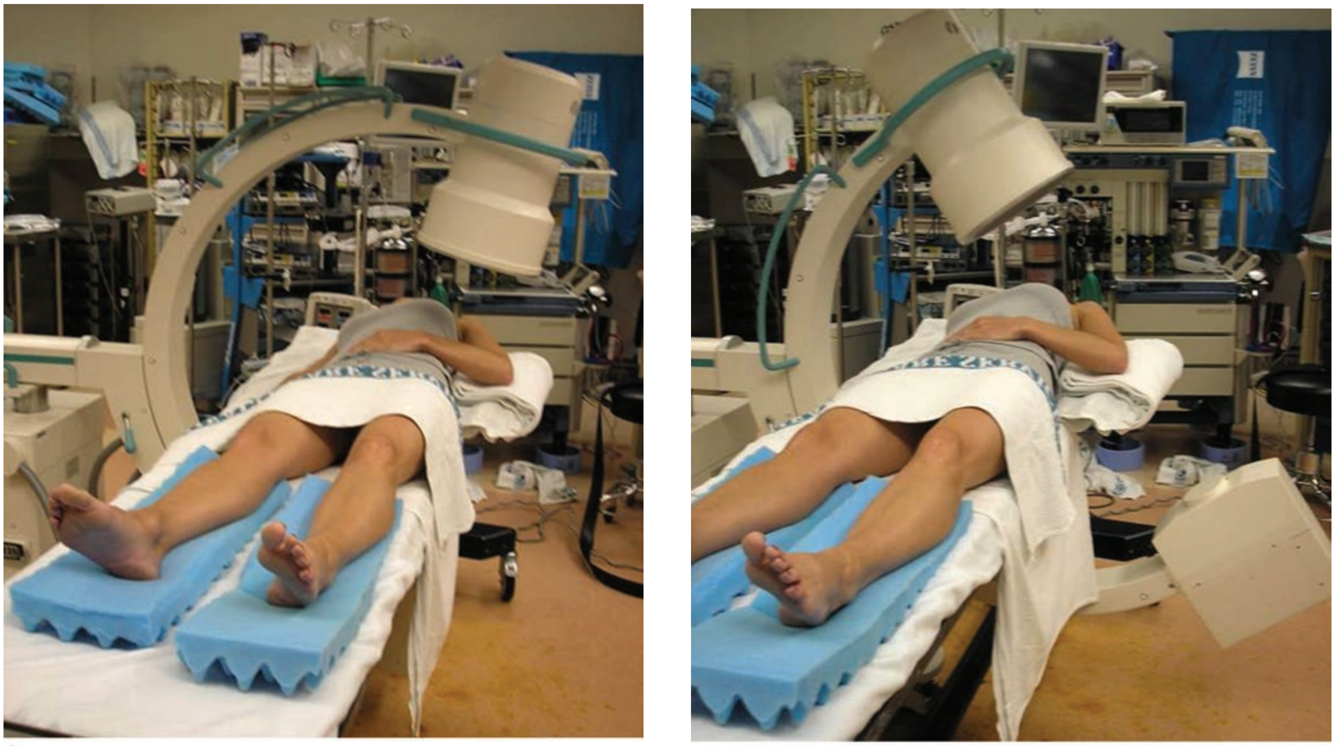
Figure 1-5. Radiolucent flat top table with Plexiglas arm support.

Figure 1-6. Radiolucent flat top table with Plexiglas arm support.

Figure 1-7. Plexiglas board to support injured upper extremity.

Figure 1-8. Supine position with upper extremity on blanket bolster and Plexiglas arm support.

Figure 1-9. Supine position with upper extremity on blanket bolster Plexiglas arm support, view from patient's head.



A B

Figure 1-10. Position of C-arm for lateral **(A)** and AP **(B)** images (less than orthogonal planes are shown).

- With arm adducted, internally rotated 40 to 60 degrees, and C-arm rolled back 30 to 60 degrees; AP of proximal humerus—a Grashey's AP image is preferred (Figs. 1-10B and 1-11).
- With arm adducted, internally rotated 40 to 60 degrees, and C-arm over the top 30 to 60 degrees; scapular "Y" lateral of proximal humerus is obtained (Figs. 1-10A and 1-12).

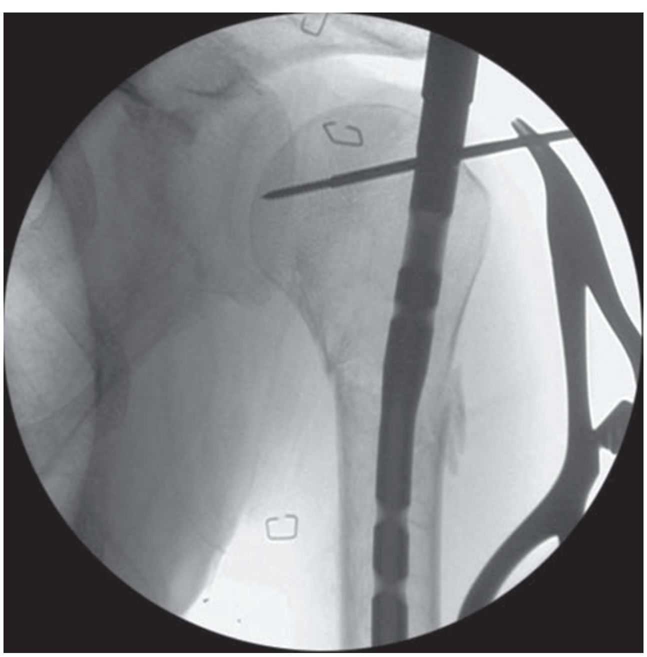


Figure 1-11. Intraoperative AP image of humerus.

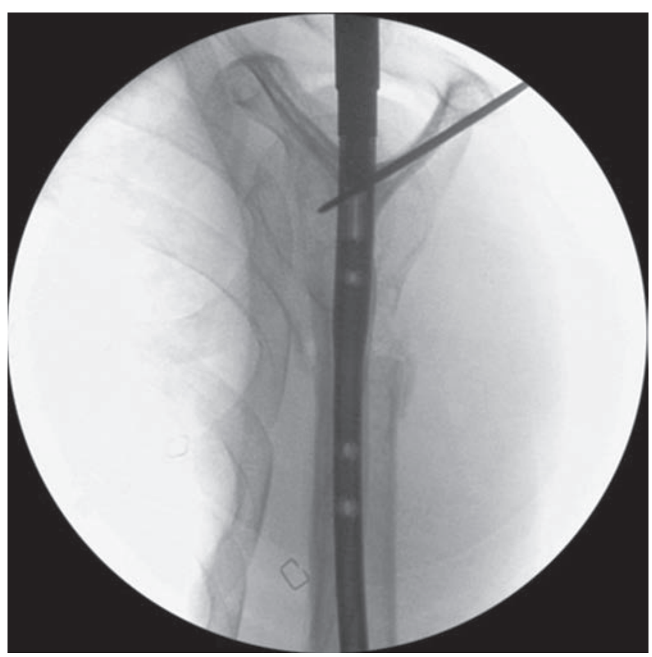


Figure 1-12. Intraoperative scapula "Y" lateral image of humerus.

- The C-arm should rotate in an arc of 90 degrees between the AP image and scapula “Y” lateral image to confirm orthogonal views.

ORIF Humeral Shaft: Anterolateral or Lateral Approach

- Supine.
- Radiolucent OR table.
- Small bump (folded hand towel) beneath the ipsilateral scapula.
- C-arm from opposite side (use C-arm fluoroscope that goes 45 degrees “over the top”).
- Uninjured arm adducted to side of body.
- Radiolucent arm table or Plexiglas arm board with blankets to match the table pad height.
- Arm internally rotated 40 to 60 degrees and C-arm over the top 30 to 60 degrees for lateral view.
- Arm internally rotated 40 to 60 degrees and C-arm back 30 to 60 degrees for AP view.
- The C-arm should rotate in an arc of 90 degrees between the AP image and scapula “Y” lateral image to confirm orthogonal views.

ORIF Humeral Shaft (Posterior Approach), Elbow Fractures (Lateral Decubitus Position)

- Radiolucent cantilever table reversed.
  - C-arm from the head (parallel to the long axis of the table).
  - Bean bag that stops at the axilla (so the down arm is free from the bean bag).
  - Rolled blankets may be used as torso supports in the front and back instead of a bean bag.
  - Plexiglas arm-board for the down arm, protruding only approximately 6 inches (Fig. 1-13).

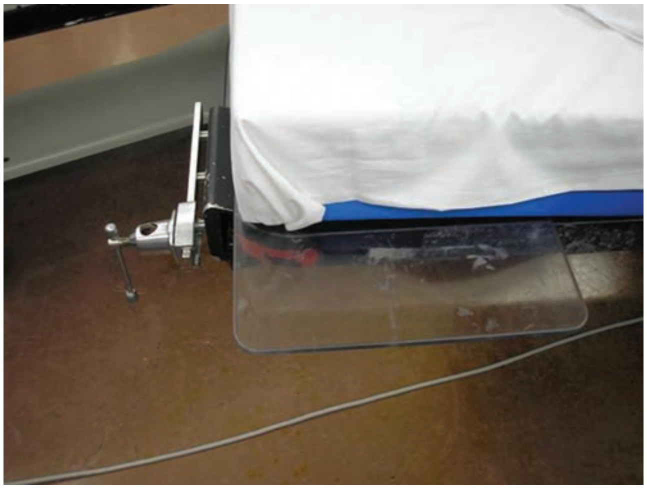


Figure 1-13. Plexiglas arm board for the uninjured arm, attachment to bed for radiolucent arm board for the injured arm.

  - Down arm should be at maximum 90 degree shoulder abduction and 90 degree elbow flexion.
  - Place a towel bolster or support to prevent excessive humeral external rotation (~70 to 80 degrees).
  - Radiolucent arm board on long post (used for prone positioning) attached to rail at the top of the table, in line with the table axis for injured arm (Figs. 1-14–1-20).

Figure 1-14. Elevated radiolucent arm board attached to rail for an operative arm, Plexiglas arm board for an uninjured arm, viewed from the head of the bed.

Figure 1-15. Radiolucent arm board for an operative arm, Plexiglas arm board for an uninjured arm, viewed from the side.

Figure 1-16. Lateral position (bean bag absent).

Figure 1-17. Lateral position, arms on radiolucent arm boards (bean bag absent).

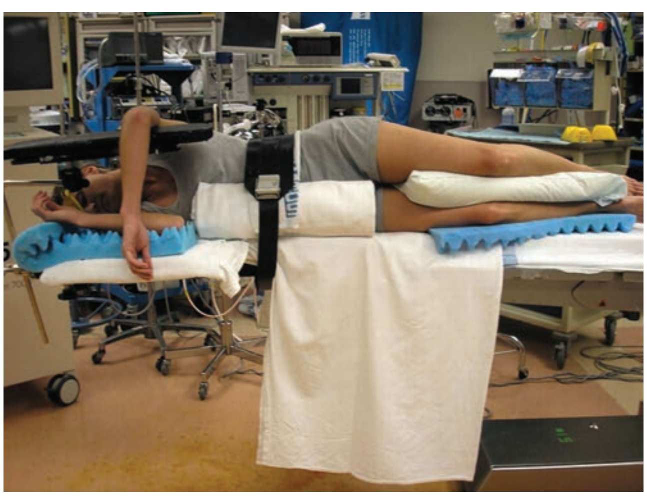


Figure 1-18. Lateral position, prior to draping.

Figure 1-19. Lateral positioning and C-arm placement for intraoperative AP imaging.

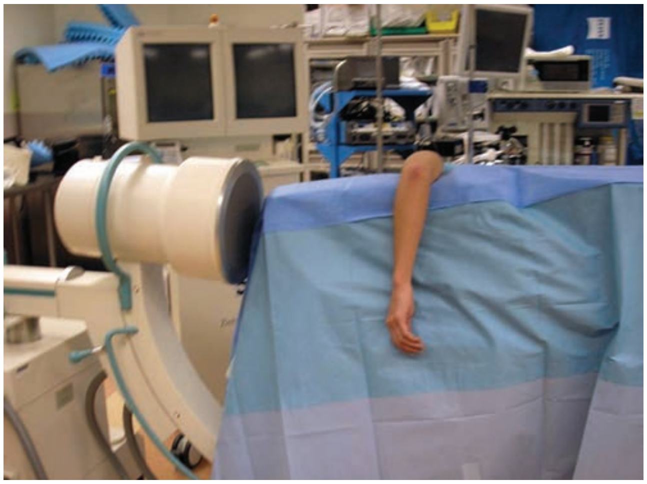


Figure 1-20. Lateral positioning and C-arm placement for intraoperative lateral imaging.

ORIF Humeral Shaft (Posterior Approach), Retrograde Nailing or Elbow Fractures with the Patient in a Prone Position

- Chest rolls (single rolled blankets) or Wilson frame (Fig. 1-21).
- Additional cross roll at iliac crests if on rolled blankets.
- Contralateral arm adducted to lay on arm board parallel to the table or abducted <90 degrees on a "prone" positioning arm board to prevent excessive external rotation.

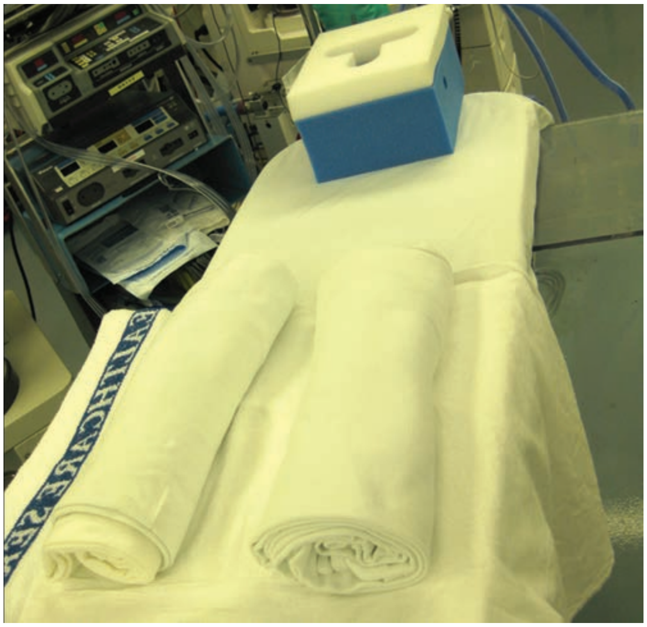


Figure 1-21. Radiolucent table with Plexiglas arm support at the upper right edge of the table.

- Operative arm abducted 90 degrees over the Plexiglas arm board padded with blankets taped on to match height of the table pad or shoulder level of Wilson frame (Figs. 1-22 and 1-23).

Figure 1-22. Arm and shoulder supported on bolster of blankets supported by radiolucent Plexiglas board. Elbow at 90 degrees.

Figure 1-23. Radiolucent table and arm support. Elbow and shoulder at 90 degrees.

- Place the Plexiglas board perpendicular to the table so that only approximately 5 to 8 inches of board are exposed to allow for >90 degrees of elbow flexion.
- Contralateral arm should be <90 degrees of shoulder abduction and externally rotated <70 degrees.
- C-arm from the head of the table (parallel to the long axis of the table) (Figs. 1-24 and 1-25).

Figure 1-24. C-arm positioning for AP imaging.

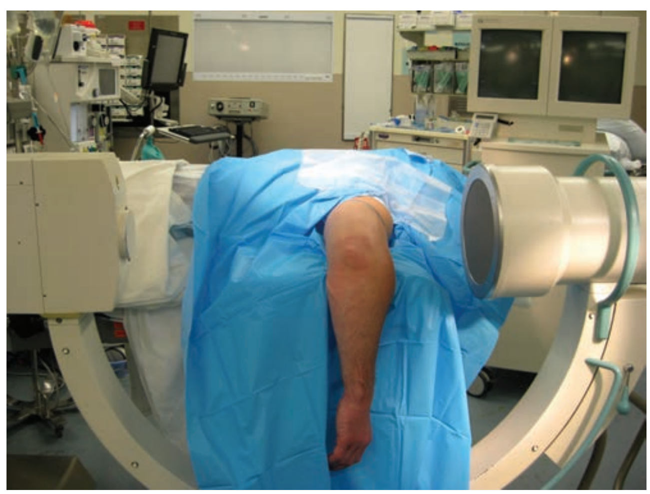


Figure 1-25. C-arm positioning for lateral imaging.

Pelvis and Acetabulum: Anterior Approaches, Percutaneous Procedures

- Supine.
- Radiolucent table.
- C-arm from opposite side.
- Two folded blankets centrally placed as lumbosacral support.
- Arms abducted 60 to 90 degrees on arm boards.
- Traction attachment as needed.
- Prep the ipsilateral leg in the field and both lateral flanks if iliosacral screws are needed (Figs. 1-26–1-30).

Figure 1-26. Radiolucent flat top table with folded blankets as central (lumbosacral) support.

Figure 1-27. Supine position on central blanket support.

Figure 1-28. Leg prepped free. Abdomen included to nipple line.

Figure 1-29. Supine position, leg included and wrapped sterile in stockinette and elastic bandage wrap.

Figure 1-30. Final supine positioning for pelvic and/or acetabular procedure.

- Prep low enough to allow iliosacral screws from both sides, even if anticipating unilateral procedure.
- Drape just above the base of penis or labia for retrograde superior rami screws.
- Include the scrotum/penis if combined urological procedure.

Pelvis and Acetabulum: Kocher-Langenbeck

- Prone
- Radiolucent table
- C-arm from opposite side
- Chest rolls (single rolled blankets)
- Additional cross roll at iliac crests
- Arms abducted 90 degrees, elbows flexed 90 degrees, on arm boards parallel to OR table
- Prep in the ipsilateral leg; both lateral flanks (Figs. 1-31–1-36)

Figure 1-31. Flat top radiolucent table with chest bolsters for prone positioning.

Figure 1-32. Flat top radiolucent table with bolsters and padding for prone positioning.

Figure 1-33. Patient in prone position on bolsters. To avoid excessive shoulder external rotation, special arm boards are available for prone positioning.

Figure 1-34. Prone position, legs supported on pillows.

Figure 1-35. Posterior pelvis and operative extremity isolated prior to sterile preparation.

Figure 1-36. Prone position after prepping and draping.

Lower Extremity

Antegrade Femoral Nailing, Hip Fractures, Subtrochanteric Fractures

- Radiolucent table to allow proximal imaging.
- Bump under the hip.
  - Single rolled blanket usually sufficient.
  - Ipsilateral buttock should hang free; that is, bump should be centrally placed.
  - Patient should be at the lateral edge of the table or just beyond the table's edge.
- Ramp pillow under the ipsilateral leg.
- C-arm from opposite side of the table.
- Traction attachment to end of the table on side of table opposite injured limb to allow for operative lower limb adduction and ease of access to piriformis fossa or trochanter (Figs. 1-37–1-40).
- Drape traction attachment with sterile impervious stockinette.

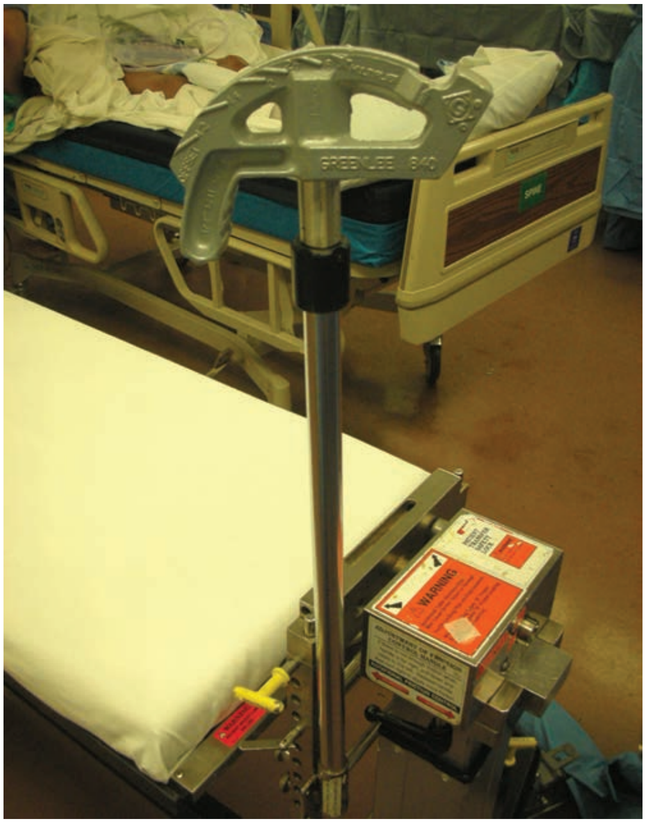


Figure 1-37. Traction post mounted to table.

Figure 1-38. Flat top radiolucent table with traction post mounted to foot of table.

Figure 1-39. Free legged femoral nailing on flat top table with traction attached to the Kirschner wire bow, sterile rope over post draped with impervious stockinette. Nonsterile weights and weight pan are attached to the other end of the rope.

Figure 1-40. Free legged femoral nailing on flat top table with traction post.

- Arm over the chest; not over the abdomen, to allow unencumbered access to hip and buttock for entry portal (Figs. 1-41–1-45).
- Remove all nonradiolucent table attachments on rails on the ipsilateral side.
- Place calf compression device tubing for contralateral leg and urinary drainage tubing under the table's mattress under uninjured extremity to permit C-arm access.
- Prep and drape as posteriorly as possible on flank and buttock to allow unencumbered access to starting point for C-arm imaging, instruments, and implants.

Figure 1-41. Supine position with central flank roll. Patient is moved to the edge of the table so the buttock hangs free. Ipsilateral arm is secured over the chest.

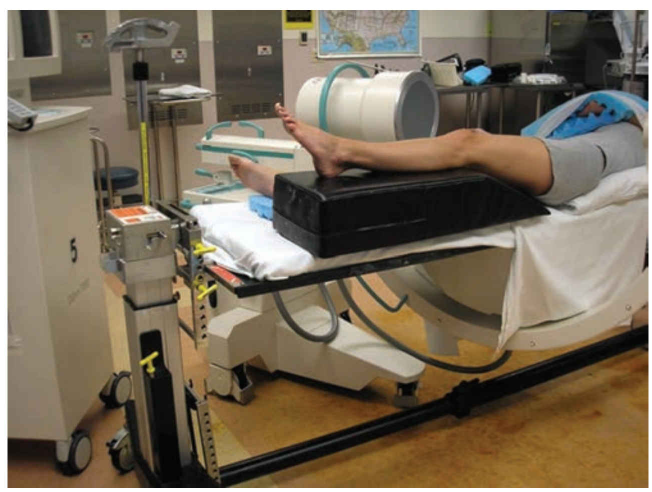


Figure 1-42. C-arm positioning for the lateral image.

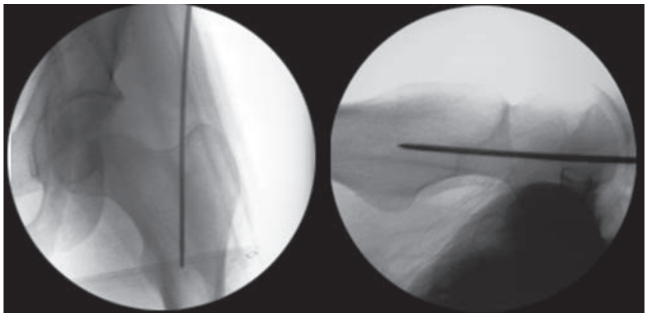


Figure 1-43. AP and lateral images are easily obtained.

Figure 1-44. Patient positioned with buttock free.

Figure 1-45. Patient positioned, view from the head noting the elevation and rotation of pelvis and torso as provided by the central bolster and shoulder support.

Retrograde Femoral Nail

- Radiolucent table.
- Bump under the hip.
- C-arm from opposite side.
- Knee flexion with wedge pillow or supporting radiolucent triangle.
    - Should permit 30 to 60 degrees of knee flexion to prevent reaming anterior tibial plateau or inferior patella.
- If traction is needed, a distal femoral or proximal tibial traction pin with traction attachment on table ipsilateral to injured femur to facilitate reduction (Fig. 1-46).

Figure 1-46. Intraoperative traction used with knee flexion for retrograde femoral nailing.

Distal Femur, Tibial Plateau, Patella, Ankle, Foot Fractures

- Radiolucent cantilever-type table.
- Bump under the flank (rolled towels, wedge, IV bag).
- C-arm from opposite side.
- Ramp style foam pillow to elevate the affected limb (Fig. 1-47).
- Patient at the end of the table.

Figure 1-47. Supine position for majority of lower extremity fractures. A flank bump is used such that leg is in neutral rotation (patella straight up).

- Consider lateral positioning for posterolateral approach to tibia (open reduction internal fixation [ORIF] of posterior malleolus); externally rotate the limb if access to medial malleolus is needed.
  - Check for sufficient external rotation of the hip prior to positioning for trimalleolar/pilon fractures.

- Prone position, if sole approach is either posterolateral or posteromedial tibia.
  - Feet and ankle should protrude over distal end of the table, permitting ankle dorsiflexion.
  - Protect patellae with gelfoam pads.
- Triangular pillow/ramp for metatarsal fractures to assist imaging. Consider positioning as with tibial nailing (Figs. 1-48 and 1-49).

Figure 1-48. Knee flexed on radiolucent triangle.

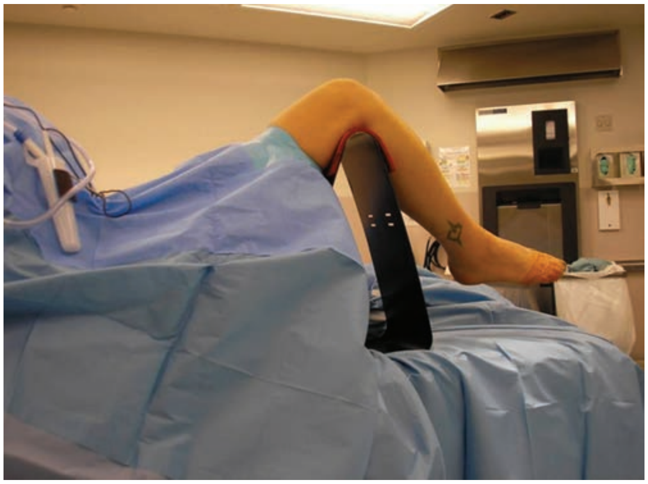


Figure 1-49. Knee flexed on radiolucent triangle.

Tibial Nail

- Radiolucent cantilever-type table.
- Bump under the flank (rolled towels, wedge, IV bag).
- C-arm from opposite side.
- Radiolucent triangle to facilitate knee flexion, and fracture reduction.

Calcaneus Fractures

- Lateral decubitus position.
- Radiolucent cantilever table.
- Patient as far distal on table as possible.
- C-arm from posterior side of patient.
- Up arm in “airplane” sling positioned with foam padding underneath the arm to protect ulnar nerve and bony prominences.
- Foam padding underneath down arm.
- Bean bag with “axillary” roll or thoracic wedge with down arm relief cutout.

Figure 1-50. Lateral position for lower extremity procedures.

Figure 1-51. Lateral position for lower extremity procedures, posterior view.

- Alternatively, use rolled blankets wedged against abdomen and spine to maintain lateral position (Figs. 1-50 and 1-51).

- Three foam pads around legs
  - First pad between table and patient to protect greater trochanter, peroneal nerve at fibular neck, and lateral malleolus.
  - Second pad surrounds the opposite lower limb, which is placed in “down-leg cutout” with calf compression device applied (Fig. 1-52).
  - Top pad is foam platform over the cutout and “down leg”, and serves as an operating table (Fig. 1-53).

Figure 1-52. Specialty foam pads for lower extremities, lateral position.

Figure 1-53. Specialty foam pillows for lateral positioning for lower extremity procedures. Flat top pillow for working operative platform.

- Blankets on top of foam pads and taped to minimize slipping (Figs. 1-54 and 1-55).

Figure 1-54. Lateral position, posterior view with blanket on foam pillows prior to securing with tape.

Figure 1-55. Final lateral positioning after draping.

Calcaneus: Percutaneous Reduction and Fixation

- Same patient positioning as ORIF calcaneus.
- C-arm from the foot.
    - For axial heel view, C-arm almost aligned with long axis of the table, but swivels just enough towards patient's posterior to allow transmitter to clear table and come parallel to the floor.

Section 2
Shoulder/Arm

James C. Krieg

Glenoid Fractures

Chapter 2

Zachary V. Roberts

Sterile Instruments/Equipment

- Sterile drapes, including impervious stockinette and 4 inch elastic bandage wrap for forearm and hand
- 1/4% bupivicaine, with epinephrine for posterior incision (minimizes skin bleeding)
- Large and small pointed bone reduction clamps (“Weber clamps”)
- Implants
  - 2.7- and 3.5-mm reconstruction plates and screws
  - 1/4 and 1/3 tubular plates
  - 2.0- and 2.4-mm plates and screws
  - Extra long screws (2.0, 2.4, 2.7, and 3.5 mm)
- K-wires and wire driver/drill
- Femoral distractor(s) if reducing displaced fractures, especially if >20 days after injury

Positioning

- Lateral: modified Judet approach
  - Lateral position is preferred to prone.
  - The lateral position allows for better palpation of the coracoid for screw placement, percutaneous “joystick” placement in the coracoid as needed, and facilitates reduction maneuvers.
  - Place the patient on the cantilevered end of a radiolucent operating table (reversed) which facilitates intraoperative imaging.
  - Chest roll for axillary protection, using a beanbag and appropriate padding.
  - A padded Plexiglas board supports the uninjured, dependent arm; the operative arm is prepped free and supported on a padded (pillow) sterile Mayo stand.
    - This enables intraoperative limb manipulation and positioning to aid in reduction and imaging.
    - Pad Mayo stand and tray with a taped pillow; cover with a sterile Mayo stand cover.
  - Alternatively, the operated upper extremity may be supported by an adjustable radiolucent arm board under the drapes (Figs. 2-1 and 2-2).
  - Fluoroscopy should be positioned perpendicular to the patient and table, entering from the patient’s anterior/front side, opposite from the surgeon.
    - This allows a rollover image for a scapular Y view, and a rollback to image a Grashey AP view.

Figure 2-1. The lateral decubitus position for Modified Judet surgical approach.

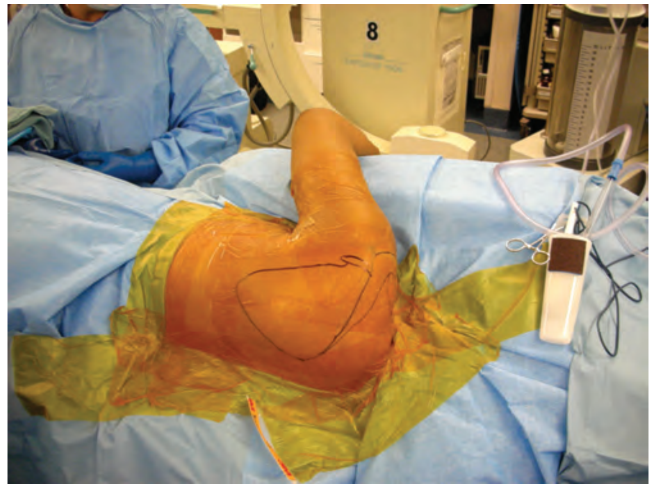


Figure 2-2. Prepped and draped. The arm is prepped into the field so it can be manipulated sterilely. There should be a clear path for the C-arm to come in from the opposite side.

Surgical Approach

- Modified Judet.[1]
- The incision is curvilinear, and parallels the scapular spine and the medial scapular border (Fig. 2-3).
- Prior to incision, injection of Bupivicaine 0.5% with epinephrine can help minimize cutaneous bleeding.
- Develop a full thickness skin and subcutaneous flap, taking care to leave the fascia intact over the posterior scapular muscles and latissumus dorsi (Fig. 2-4).

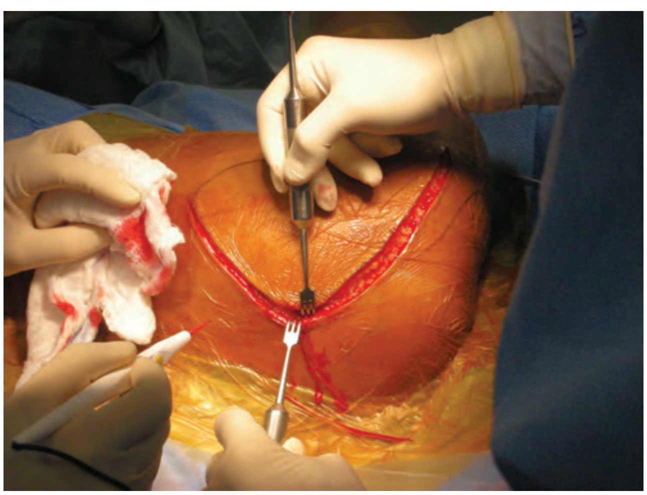


Figure 2-3. Curvilinear incision.

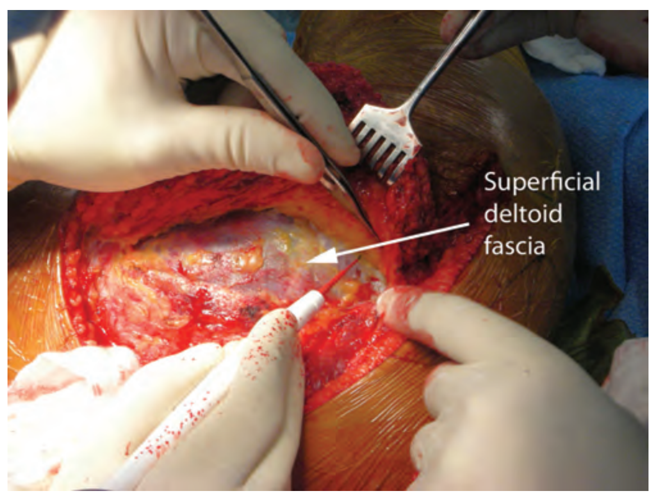
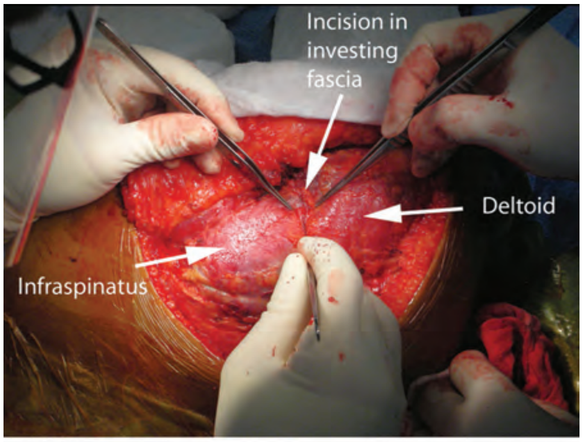
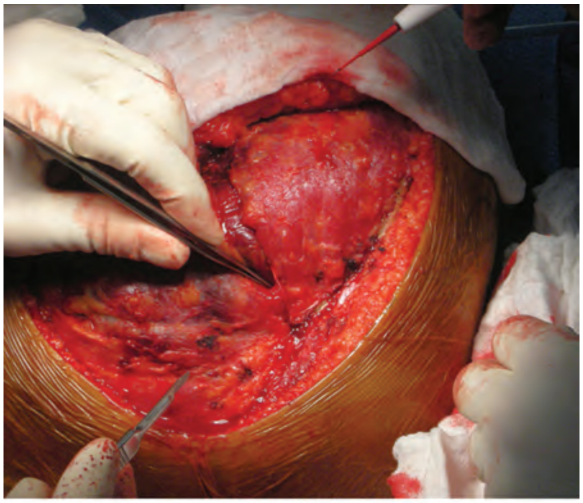


Figure 2-4. A full thickness flap is elevated from the deltoid fascia.

- Identify the lower border of the deltoid, and incise the fascia sharply (Fig. 2-5A,B).



A



B

Figure 2-5. **A,B:** The investing fascia is incised along the inferior border of the posterior deltoid.

- Separate the inferior border of the posterior deltoid from the infraspinatus from medial to lateral.
  - Keep the deep fascia with the deltoid as reflected (Fig. 2-6).

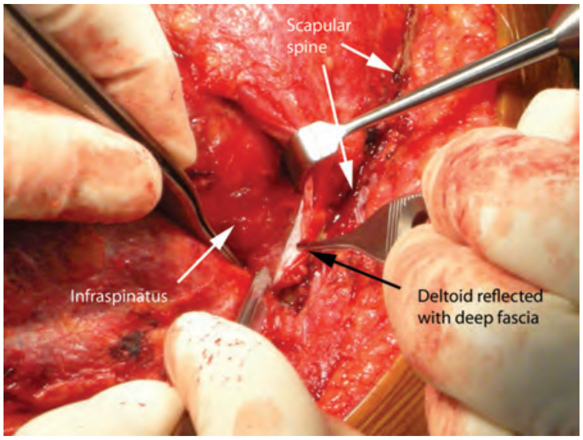


Figure 2-6. The deltoid is reflected from the infraspinatus with the deep fascia.

- Sharply release the deltoid origin from the scapular spine.
  - A tag stitch in the superomedial corner aids in retraction and identifies this area for later repair (Fig. 2-7).

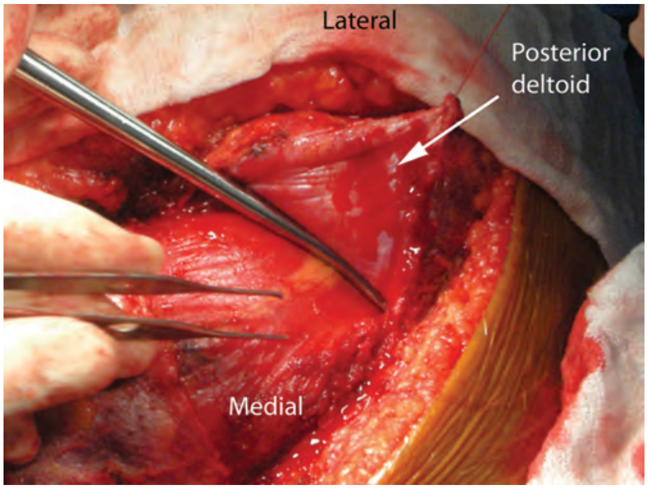


Figure 2-7. Once the fascial plane is developed, the posterior deltoid is incised from the scapular spine.

- Retract the posterior deltoid superolaterally (Fig. 2-8).

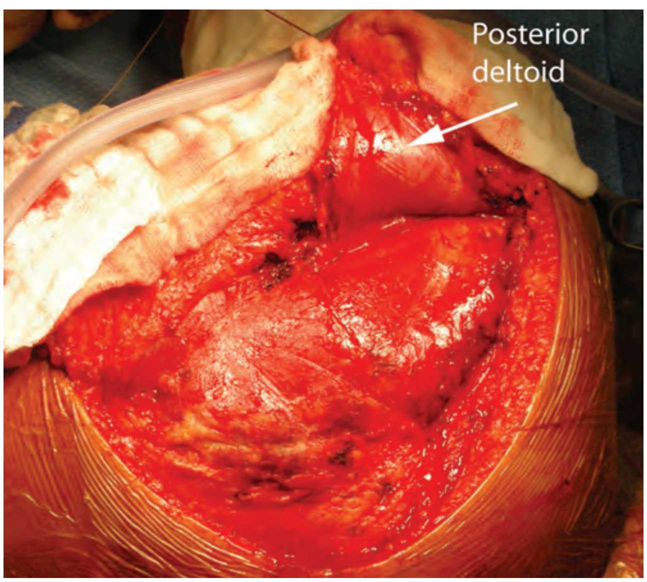


Figure 2-8. The deltoid is mobilized and reflected from medial to lateral, to the lateral border of the scapula.

- Developing the interval between teres minor and infraspinatus will allow exposure of the lateral border of the scapula and inferior glenoid neck (Figs. 2-9A,B and 2-10).
- To access the superomedial extent of the fracture line, elevate the origin of the infraspinatus to create a limited medial window as needed.
- If the fracture presents >2 weeks postinjury, a formal Judet approach, with reflection of the infraspinatus on its neurovascular pedicle, is usually necessary to clean and reduce the fracture.

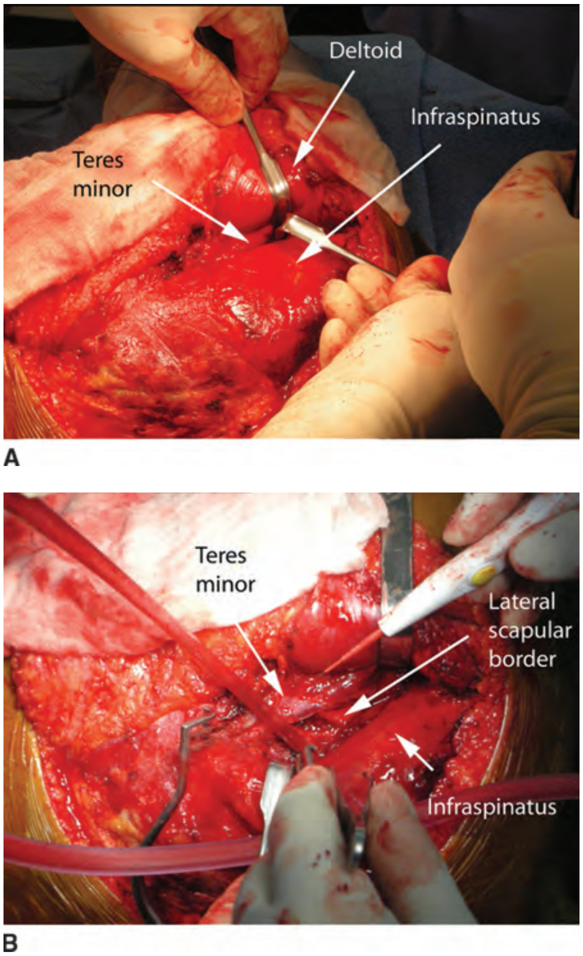


Figure 2-9. A,B: Deltoid reflection allows complete exposure of the infraspinatus-teres minor interval for lateral scapular access.

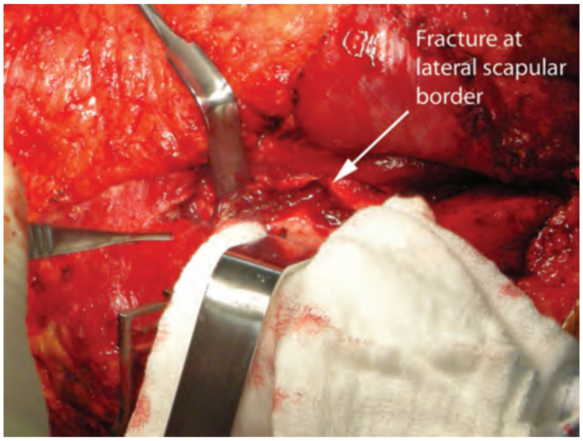


Figure 2-10. The fracture site is further exposed and cleaned of hematoma and periosteum.

Fracture Assessment

- Most operative scapula fractures involve a transverse fracture line caudal to the scapular spine with the caudal segment displaced laterally (Fig. 2-11).

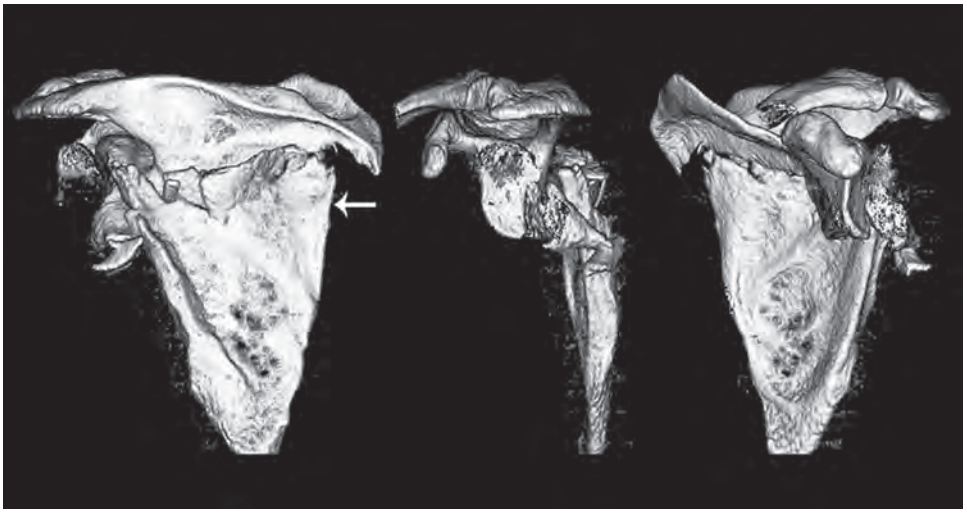


Figure 2-11. 3D CT reconstructions of a scapular body and neck fracture with a displaced glenoid component. Note that the caudal segment of the scapula is lateralized, owing to the pull of the infraspinatus, teres major and minor, and latissimus dorsi. In most cases, this displacement should be reduced initially to allow space for the articular reconstruction. The medial extent of the transverse fracture line at the medial scapular cortex often offers an excellent reduction assessment.

- Frequently, the lateral scapular border must be reconstructed to enable accurate reduction of the glenoid neck component.
  - This region should be scrutinized for the amount of comminution present, which can range from none to severe (Fig. 2-12).

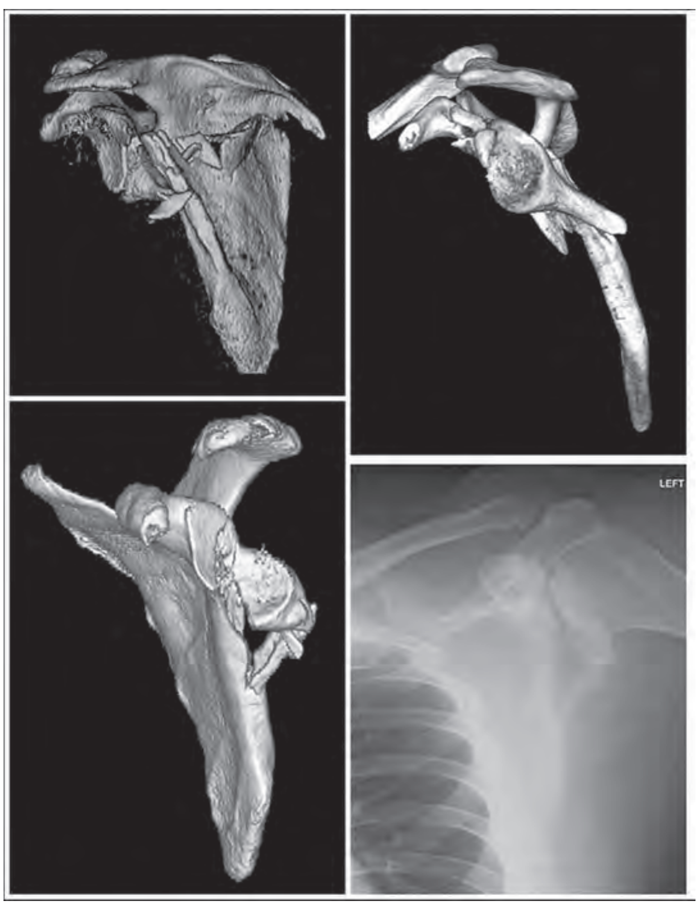


Figure 2-12. Comminution along the lateral margin of the scapula and inferior neck of the glenoid affects the ability to accurately reduce the extra-articular fracture lines and ultimately may determine the need for an arthrotomy to assess the articular reduction.

- Occasionally, the caudal scapular segment is divided into medial and lateral halves by a vertical fracture in the sagittal plane.
- These fractures will disrupt the relationship between the medial and lateral borders of the caudal scapular segment and should be recognized, since reduction of the medial scapular border alone will not affect an accurate reduction of the lateral margin of the caudal scapular segment.

Reduction and Fixation

- Clean the fracture of hematoma, granulation tissue, and infolded periosteum.
  - Because of its broad muscle origins and insertions, the scapula has a rich vascular supply.
  - Scapular fractures tend to heal quickly, and there can be considerable interfragmentary callus that will prevent reduction if left within or surrounding the fracture.
- Work from medial to lateral.
  - When a displaced transverse body component is present, accurate reduction of the vertebral border and scapular body component medially can improve the quality of reduction and restore the appropriate defect along the lateral border and at the glenoid neck for articular segment reductions (Fig. 2-13).
- Use mini-fragment plates (e.g., 2.0 mm, 1/4 tubular) or small fragment (e.g., 1/3 tubular) to provide provisional fixation (see Figs. 2-13 and 2-14).

Figure 2-13. The initial reduction and provisional plate fixation at the medial infraspinatus fossa (*arrow*) maintain the position of the caudal scapular body and allow the lateral margin and glenoid neck to be reconstructed accurately.

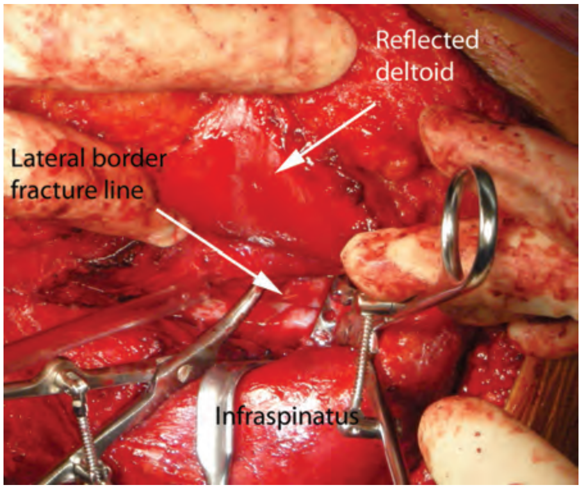


Figure 2-14. A typical clamp application is to place one tine on the lateral scapular border and the other clamp tine in a unicortical drill hole in the dorsal scapula. Mini-fragment plates provide adequate provisional stabilization and allow clamp removal.

- While a 3.5- or 2.7-mm plate along the lateral border of the scapula provides the strength of the construct, reduction clamps frequently utilize this surface as well, becoming an obstruction to the correct positioning of this implant.
- A strategy to allow use of the lateral border for both clamp application and implant placement employs the use of mini-fragment (2.0-mm) plates.
  - The smaller plates typically provide sufficient fixation to allow removal of the reduction clamps, for subsequent placement of larger, 1/3 tubular or similar plates.
  - The smaller plates can be left in place to supplement the construct.
- Use the coracoid for docking longer implants to improve stability.
  - Use the scapular Y view to assist with placing the coracoid screw.
  - Palpation of the coracoid is useful to triangulate the appropriate screw trajectory (Fig. 2-15).

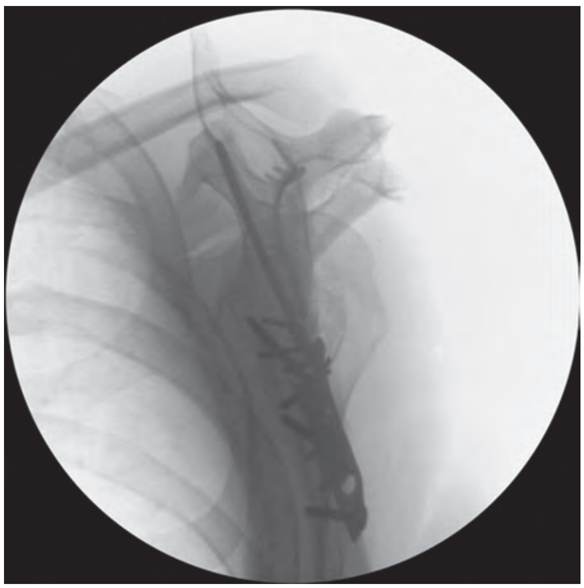


Figure 2-15. The scapular Y view is used to help direct the placement of the coracoid screw.

- A posterior sublabral glenohumeral arthrotomy can be used to visualize the articular reduction and ensure extra-articular position of implants.
  - The Grashey AP is also useful to confirm extra-articular screw location and articular reduction (Fig. 2-16).

Figure 2-16. The Grashey AP view confirms the extra-articular location of the coracoid screw.

Closure and Postoperative Management

- Anatomically repair the fascial deltoid origin to the scapula using drill holes in the scapular spine to prevent detachment.
- Use interrupted, nonabsorbable, or slowly resorbable sutures in the fascia.
- Close skin in layers over a closed suction drain.
- Rehabilitation should consist of Codman's exercises and passive range of motion only for 6 weeks to protect the deltoid repair.

Anterior Glenoid Fractures

- Typically occur during anterior glenohumeral joint dislocations and can be seen in isolation or concurrently with proximal humerus fractures (Fig. 2-17).

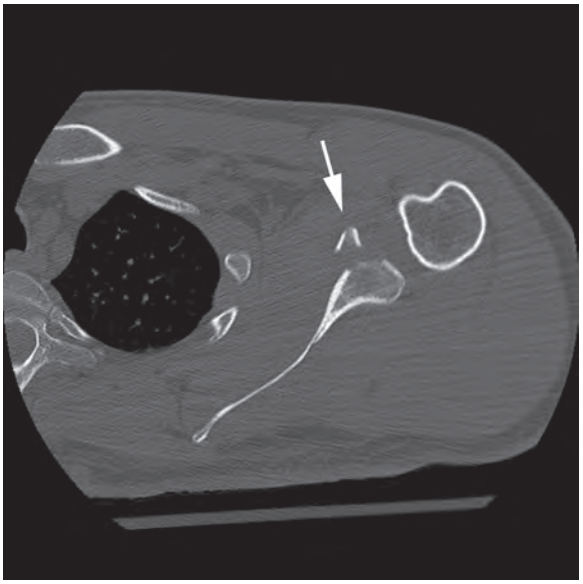


Figure 2-17. Anterior glenoid fracture (*arrow*).

  - They may include the coracoid process.
- The fragment can be of variable size, and the most common indication for surgical fixation is instability of the glenohumeral joint.

Position

- Supine or beach chair.

Surgical Approach, Reduction, and Fixation

- Deltopectoral.
- Visualization usually requires that the subscapularis be tenotomized.
  - The location of the subscapularis tenotomy should be 1 cm from its insertion on the lesser tuberosity to facilitate repair.
  - Stay sutures are placed to prevent medial retraction and to assist with retraction and reattachment.
- The glenohumeral capsule may be intact anteriorly, or may be avulsed from either the humerus or the glenoid labrum.
- If intact, an arthrotomy will be required to visualize the articular surface, and should be performed laterally to avoid damage to the labrum.

- Occasionally, the fragment will be of sufficient size so that a reduction can be obtained from cortical interdigitation at the anterior glenoid neck.
    - Fluoroscopic reduction assessment is usually difficult because of the relatively small size of the anterior inferior fragment, and if articular impaction is present it may go unrecognized if an arthrotomy is not performed.
- Fixation can often be accomplished using 2.7-, 2.4-, or 2.0-mm cortical lag screws, with or without buttress plates, depending on the fragment's size (Fig. 2-18).

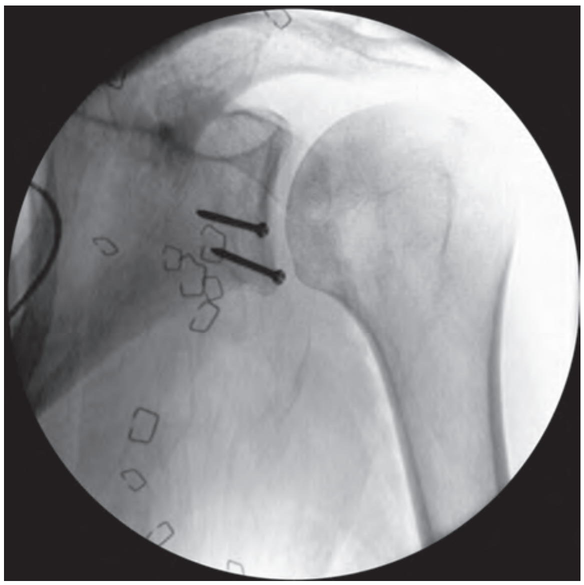


Figure 2-18. Fixation accomplished using 2.4-mm cortical lag screws.

- Anterior glenoid fracture pathology cannot be addressed through a deltoid splitting approach. Thus, combined injuries to the proximal humerus and anterior glenoid should both be repaired using a deltopectoral approach.

Reference

1. Nork SE, Barei DP, Gardner MJ, et al. Surgical exposure and fixation of displaced type IV, V, and VI glenoid fractures. *J Orthop Trauma.* 2008;22(7):487–493.

Clavicle Fractures

Michael L. Brennan

Chapter 3

Sterile Instruments/Equipment

- Draping to include impervious stockinette and 4 inch elastic bandage wrap for forearm and hand.
- Selection of bone clamps for reduction.
    - Large and small pointed bone reduction clamps ("Weber clamps")
    - Plate holding clamp (Verbrugge, self-centered)
    - Small serrated bone holding clamp (small "lobster claw")
- Threaded K-wires or 2.5-mm Schanz pins (e.g., from small external fixator) for manipulation and intramedullary fixation.
- Small distractor (especially for delayed treatment, nonunions or malunions).
- Implants.
    - Open reduction and internal fixation
        - Anatomically contoured plates
        - 3.5-mm compression or reconstruction plates
        - 2.7-mm compression or reconstruction (non–heat annealed)
    - Intramedullary fixation
        - Stainless steel or titanium small diameter flexible intramedullary nails typically 2.5- to 3.5-mm.
        - Intramedullary screw fixation: long 4.5-, 5.0-, 5.5-, or 6.5-mm cannulated screws (use largest size possible to gain endosteal purchase).
    - Consider partially threaded screws for compression or using cortical screws placed using a lag screw technique.
- K-wires and wire driver/drill.

Positioning

- Captain's chair (beach chair position) or supine, with patient on radiolucent table (e.g., a reversed position on radiolucent cantilever table).
    - A reversed cantilever table is used for clavicle fractures amenable to nail fixation.
    - A beach chair or reversed cantilever table is used for clavicle fractures amenable to either plating or intramedullary screw fixation.
        - A flat radiolucent table, typically supported at the head and foot, is not used for clavicle fractures due to difficulties obtaining "inlet" and "outlet" radiographs of the clavicle because of the table's end-based support structure.
- Entire ipsilateral extremity prepped and draped circumferentially to allow freedom of movement and facilitate reduction.

Surgical Approaches

Anteroinferior approach

- The incision is centered over the fracture site and extended in line with the inferior border of the clavicle.
- Care is taken to preserve the three to five branches of the supraclavicular nerve that run obliquely or perpendicular to the clavicle.[1]
- Laterally, the deltoid origin is taken sharply off the anterior border of the clavicle.
  - It should be repaired at closure.

Anterosuperior approach

- Skin incision similar to anteroinferior.
- Deep dissection elevates platysma from clavicle.

Intramedullary nailing approach

- Small incision 1.5 cm distal to ipsilateral sternoclavicular joint for medial to lateral flexible nail stabilization.
- Small incision posterior to the acromion, collinear with the lateral clavicular shaft, for lateral to medial intramedullary screw placement.

Reduction and Implant Techniques

- Use an anatomically contoured plate or contour a 2.7- or 3.5-mm compression plate, or a non–heat annealed (i.e., stiff) 2.7- or 3.5-mm reconstruction plate so that it lies on the superolateral or anteroinferior surface.
  - Plate selection depends on the patient size, anticipated patient compliance, fracture morphology, and acuity.
    - Avoid smaller (2.7-mm) or flexible (reconstruction) plates for larger patients and for delayed fracture treatments.
  - In general, anteroinferior plates are less prominent and may be better tolerated by patients (Fig. 3-1), especially those who carry loads on their shoulder and those wearing backpacks.
    - They have the added advantage of longer and perhaps less risky screws, by virtue of the cross-sectional anatomy.

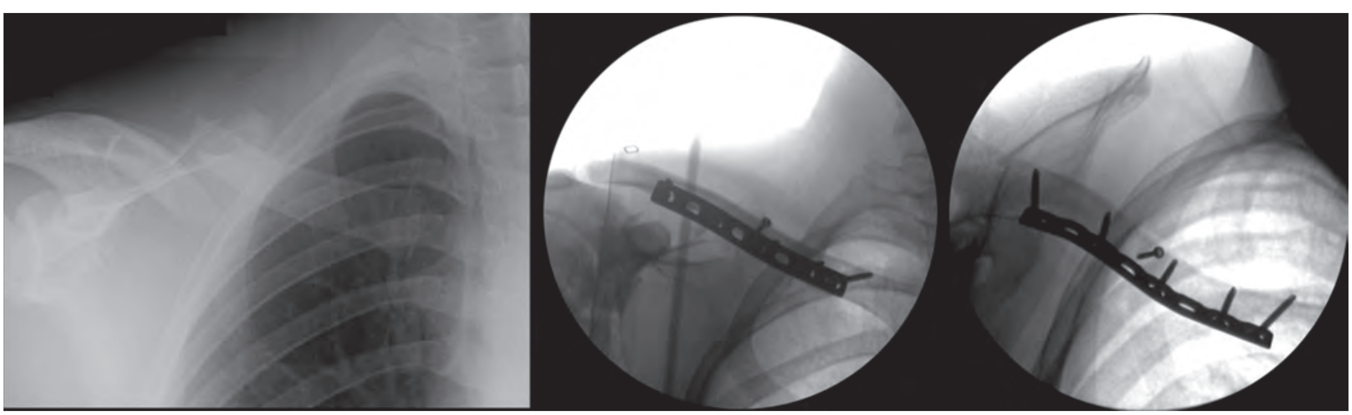


Figure 3-1. Use of a 3.5-mm compression plate for anteroinferior clavicle plating.

- Superior plate placement may provide some mechanical advantage, being on the tension surface, especially for some nonunions, and precludes the need to take down the deltoid laterally (Fig. 3-2).

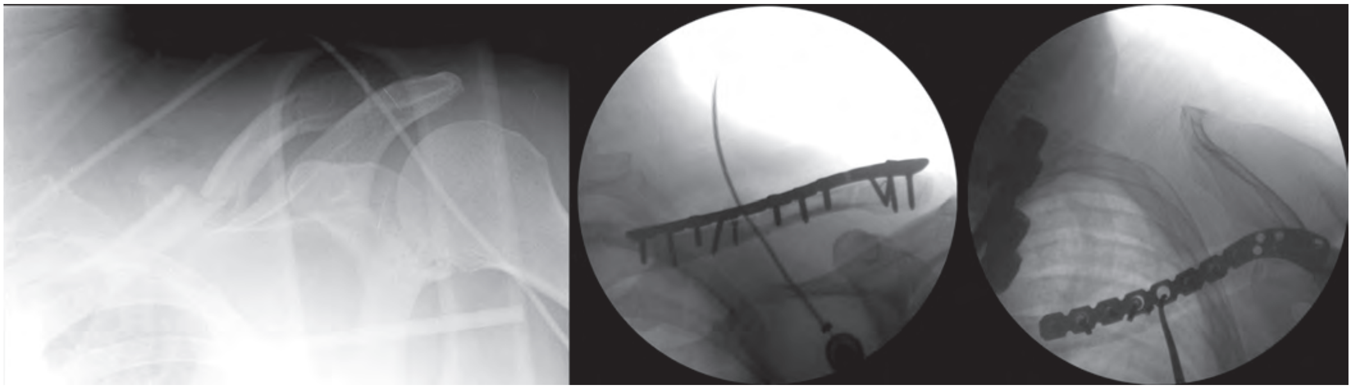


Figure 3-2. Segmental clavicle fracture treated with an anatomically contoured superior plate.

- Tips
  - Avoid annealed reconstruction plates that are flexible and deform easily.
  - If using a reconstruction plate, be aware that these plates are designed to be less stiff than their paired compression plates.
  - They are also weaker and may deform or break, especially in segmentally comminuted fractures, if several holes are left empty when used in a bridging application.
  - When using a 2.7- or 3.5-mm plate to bridge the comminution, it is best to choose a stiff plate, either compressed or anatomically contoured.
  - Consider contouring the plate to fit a skeletal model's clavicle before the procedure to save intraoperative time.
- On occasion, a plate can be torsionally contoured for placement on the superior surface laterally, and the anteroinferior surface medially.
  - This allows safe bicortical screws medially, and minimizes the deltoid reflection laterally (Fig. 3-3).

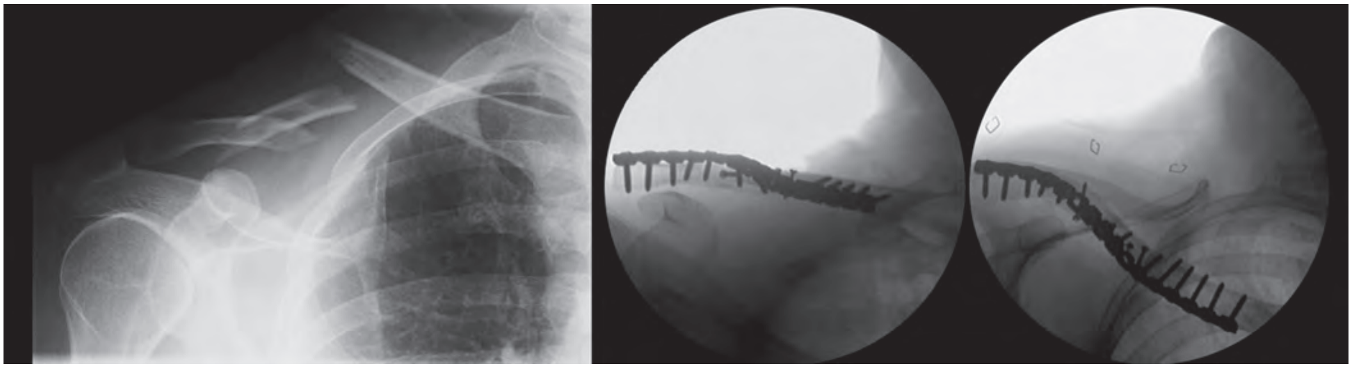


Figure 3-3. One clavicle plating option involves multiplanar contouring to allow the medial plate to sit anteroinferiorly and the lateral plate superiorly, avoiding interference with the anterior deltoid origin.

- Lateral to medial intramedullary screw (Fig. 3-4).
  - A small incision with clamp reduction may be necessary if unable to be reduced closed.
  - 4.5- to 6.5-mm cannulated screws.
    - Use larger diameter screws for patients with larger IM canals and osteoporosis.
    - In young patients with narrow IM canals, consider a 4.5- or 5.0-mm cortical screw placed using lag technique for fracture compression.

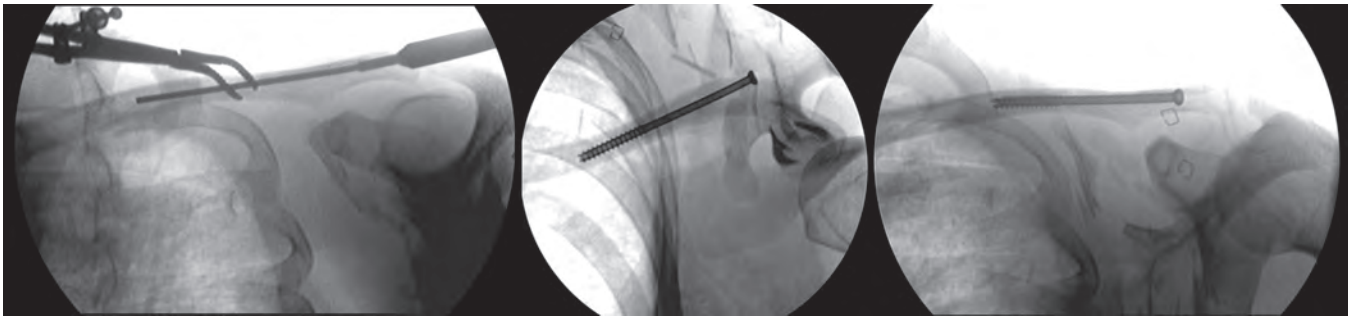


Figure 3-4. Example of a medullary screw for internal fixation of a clavicular fracture.

- If an open reduction is performed, consider using an "inside-out" technique by inserting the guide pin via the fracture into the medullary canal of the lateral fracture and out of posterolateral cortex until soft tissues are tented.
- Fracture is then reduced and the guide pin is advanced across the fracture site into the medial fragment.
- Cannulated drill bit and screws are inserted over the guide pin from lateral to medial, while maintaining the fracture reduction and compression (Fig. 3-5).

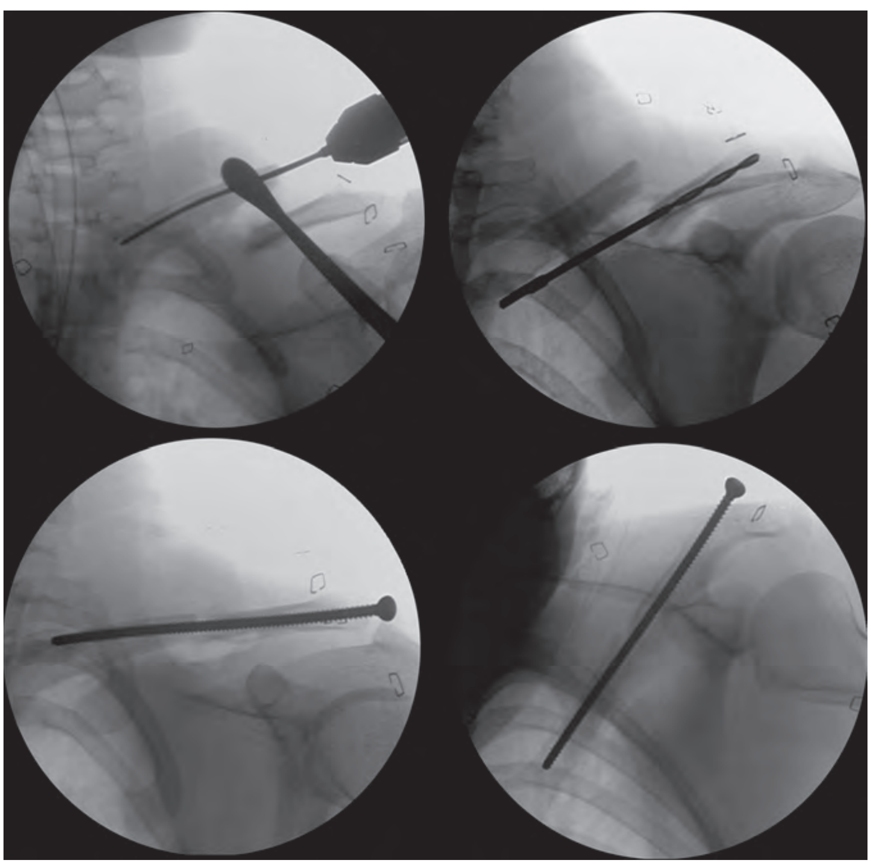


Figure 3-5. The medullary canal of the medial fragment is first cannulated through a small incision at the fracture site. Antegrade drilling of distal segment then helps localize lateral entry point.

- For lateral clavicle fractures with poor bone quality or difficult fixation due to peripheral comminution, consider several options.
  - Anatomically contoured distal clavicle plates with a cluster of screws distally (locking screws may be beneficial in osteoporosis).
  - Intramedullary screws or several threaded Steinmann pins to partially fill the canal.
    - The intramedullary device(s) can be inserted lateral to medial prior to reduction and plate fixation.
    - The screw or pins act as a stable post, such that the plate screws interdigitate with the IM wires, as well as the cortex to gain improved fixation (Fig. 3-6).

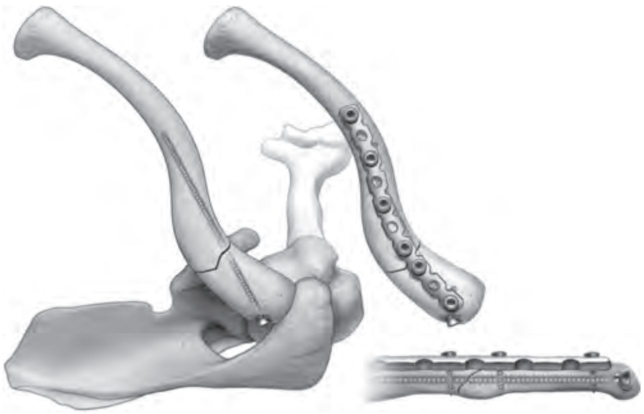


Figure 3-6. To augment fixation of lateral clavicle fractures, an intramedullary screw can be placed for interdigitation of subsequent plate screws.

- Extend the fixation (plate or IM screw) across the AC joint and include the acromion.
  - In general, hardware that spans the AC joint will need to be removed after healing.
- A hook-type plate may be positioned under the acromion (Fig. 3-7).

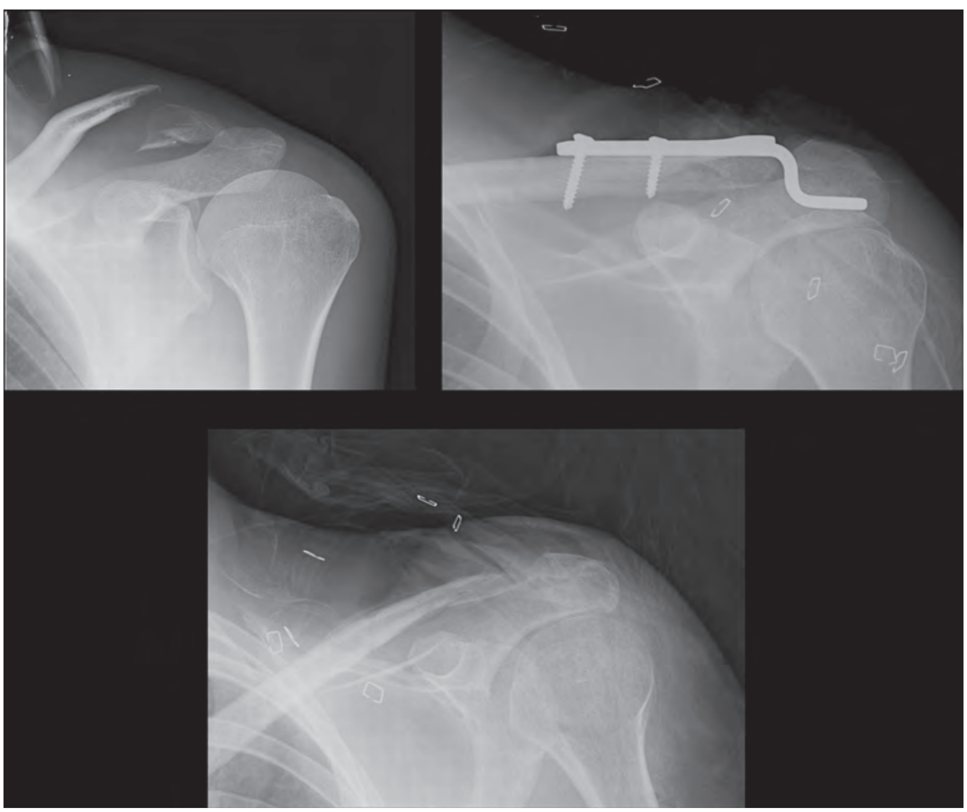


Figure 3-7. Hook plate used for distal clavicle fracture. After healing and plate removal, anatomic alignment is maintained.

- Flexible titanium nails (Fig. 3-8)
  - For nail insertion, the surgeon stands on the contralateral side and the assistant is ipsilateral to the fractured clavicle.
    - These roles may be alternated during different phases of the procedure.

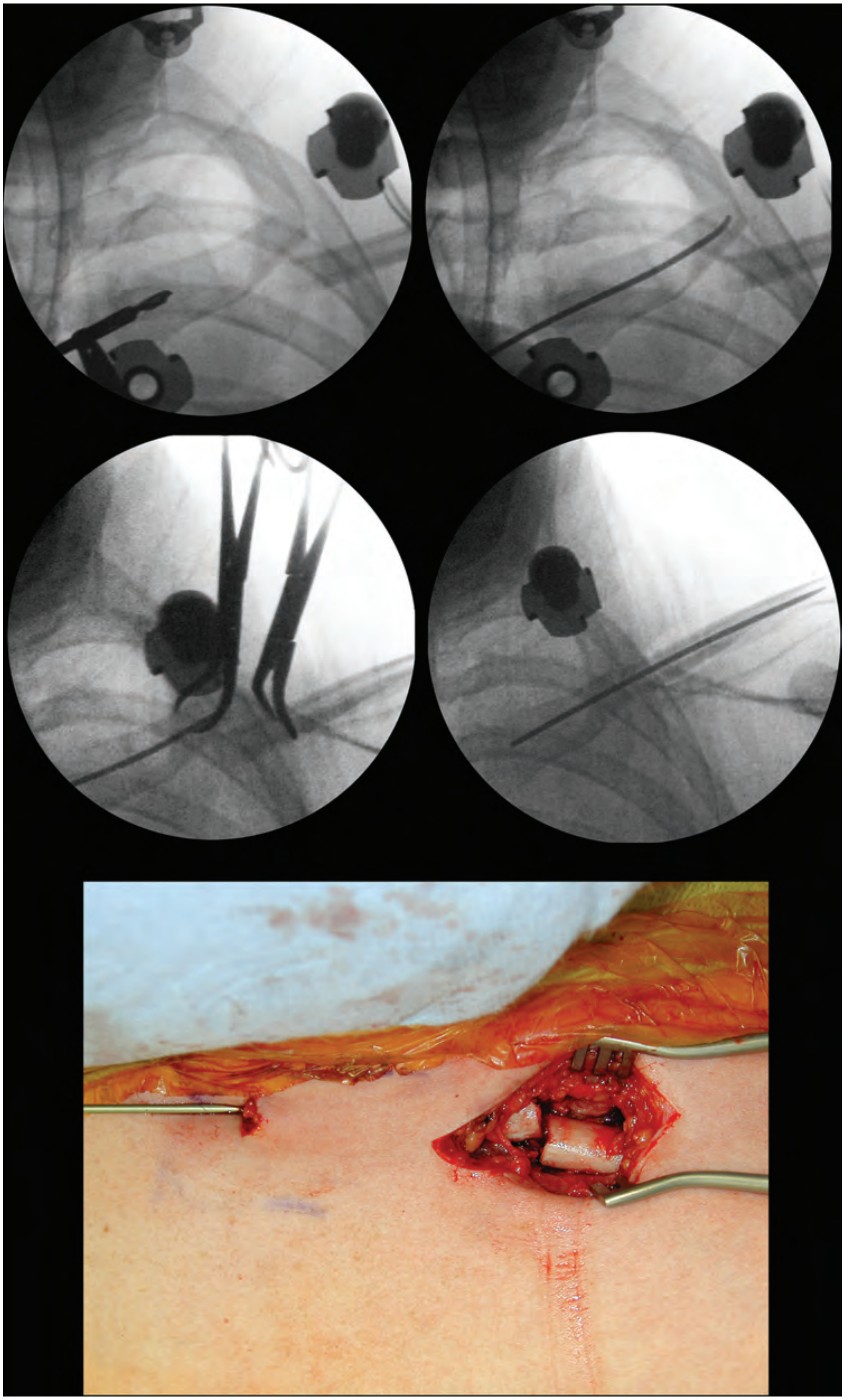


Figure 3-8. Medullary nailing of a left midshaft clavicle fracture. Through a small medial incision, the medial cortex is drilled and the nail is inserted to the fracture site. If closed or percutaneous reductions are unsuccessful, a mini-open approach is made for clamp placement and medullary canal realignment, followed by nail passage. The nail is cut short medially.

- Typically, a 2.5-, 3.0-, or 3.5-mm diameter flexible nail may be used.
- Select the largest titanium nail accepted by the medullary canal, or stack several flexible nails to fill the intramedullary canal for rotational and bending stability.
- Drill the anteroinferior medial cortex obliquely with a 2.5-, 3.0-, or 3.5-mm bit, depending on the diameter of the nail selected.
- If necessary, contour the nail prior to insertion then advance to the fracture.
- Reduce the fracture by manipulating the arm and confirming reduction on fluoroscopy with "inlet" and "outlet" views.
  - If reduction is difficult to obtain using a closed technique, consider placing threaded K-wires or small Steinmann pins (2.5 to 4.0 mm) into the distal and proximal segments as joysticks for manipulation of one or both fragments.
- If unable to obtain closed reduction, then proceed to an open reduction.
- Impact nail into distal segment near acromion.
  - Take care not to penetrate the lateral cortex.
- Confirm the position of the nail on orthogonal views.

Reference

1. Collinge C, Devinney S, Herscovici D, et al. Anterior-inferior plating of middle-third fractures and nonunions of the clavicle. *J Orthop Trauma*. 2006;20:680–686.

Chapter 4

Proximal Humerus Fractures

Michael J. Gardner

Sterile Instruments/Equipment

- Impervious stockinette and 4 inch elastic bandage wrap for arm, forearm, and hand
- Large and small pointed bone reduction clamps ("Weber clamps")
- Threaded K-wires, and 2.5/4.0-mm Schanz pins for fragment manipulation
- Implants
  - Anatomically contoured periarticular plates, consider locking plates for osteoporotic fractures
  - Mini-fragment screws and plates for provisional/definitive fixation of metaphyseal cortical or tuberosity fragments
  - Number 2 or larger non-absorbable suture for rotator cuff/tuberosity fixation augmentation, if required
  - Fibular strut allograft (fresh frozen) for deficient medial column, if required
  - Morcellized cancellous allograft bone, autograft, or osteobiologic substitute for metaphyseal bone defects (e.g., valgus impacted four-part fractures)
- K-wires and wire driver/drill

Surgical Approaches and Positioning

- Positioning for percutaneous pinning/plating or for ORIF using deltopectoral approach.
  - Supine with the patient reversed on cantilever radiolucent table (i.e., head and upper extremities at the cantilevered end of table).
  - Consider small bump under the ipsilateral shoulder.
  - Move the patient so that the head is at the proximal and lateral corner of the table, ipsilateral to operated extremity.
  - Place the arm on radiolucent Plexiglas sheet (70 cm × 40 cm × 1 cm).
    - Plexiglas is placed on the table, under the table pad and is supported by the patient's torso.
    - Approximately 1 ft of Pleixglas, protrudes beyond the table's edge.
    - Blankets or foam padding are taped to Plexiglas to match its height to that of the table's padding.
  - Rotate table 90 degrees so that the operative arm faces the main operating space.
  - C-arm should be placed at the head of the OR table to allow for axillary view with arm abducted 70 to 90 degrees (assess sagittal plane fracture alignment and plate position on humeral head and shaft) (Fig. 4-1).

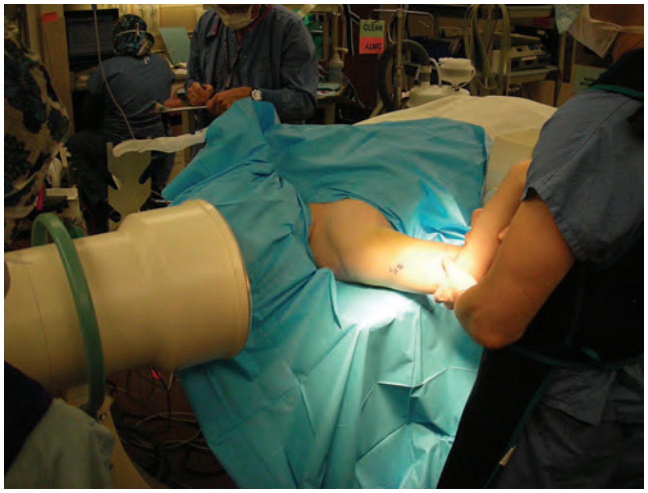


Figure 4-1. With the patient moved to the edge of the table and the arm on a radiolucent extension, a reliable axillary view can be obtained intraoperatively.

- Positioning for deltoid splitting approach for intramedullary nailing of proximal fractures and for repair/ORIF of greater tuberosity fractures.
  - Positioning for nailing
    - Use Jackson table which is narrow in width and allows C-arm to come in from the opposite side.
    - Scapular Y lateral view of proximal humerus is used instead of axillary lateral view, since arm cannot be abducted as implants (guide wire(s)/nail/targeting jig) interfere with acromion.
    - Patient is positioned in center of the OR table, or slightly to the side of the injured extremity so that contralateral arm can be adducted to the patient's side and rests on table top.
    - No arm board is attached to the side of the table for uninjured upper extremity.
      - This affords maximal C-arm excursion across OR table for AP/Grashey imaging views.
    - Patient is supine with bump under the ipsilateral scapula.
      - Either a foam wedge or folded blankets placed under both the shoulder and the hip can be used.
      - Alternatively, place the rolls/wedge under the contralateral side.
        - This rolls the patient's body toward the side of injury allowing an AP C-arm image without the same degree of "roll back."
        - This accommodates the normal retroversion of the humeral head and anteversion of glenoid, thereby obviating external rotation of the arm for an orthogonal view of proximal humerus and glenoid.
        - The scapular Y view is also improved in this position as long as the C-arm can roll forward, over-the-top far enough.
    - Place the radiolucent Plexiglas sheet between the table and the cushion, under the patient's torso and ipsilateral arm, protruding in long dimension approximately 4 to 6 inch to support arm in adduction if the patient is large or obese.
      - This may not always be necessary in thin patients, as both upper extremities can be placed on the table adducted, next to the patient's torso.
    - C-arm rotates between 45 degrees roll back and 45 degrees roll over views to obtain orthogonal AP and scapular Y views, respectively.
    - These views are important in confirming that the entry portal is collinear with intramedullary canal.

- If needed, a modified axillary view can be obtained by tilting the C-arm maximally such that the cathode (receiver end) of the image intensifier is near the patient's head.
  - This position looks like the C-arm position for a pelvic inlet view.
  - The arm can be extended at the shoulder to facilitate an axillary lateral of the proximal humerus.
- Use C-arm to guide the location of skin incision in anterior-posterior and medial-lateral planes relative to ideal entry portal in proximal humerus.

Reduction and Implant Techniques

- For proximal humeral fracture dislocations, reduction of the humeral head fragment is facilitated by manual manipulation, multiple K-wire joysticks, or one or more 2.5-mm terminally threaded Schanz pins (Fig. 4-2).

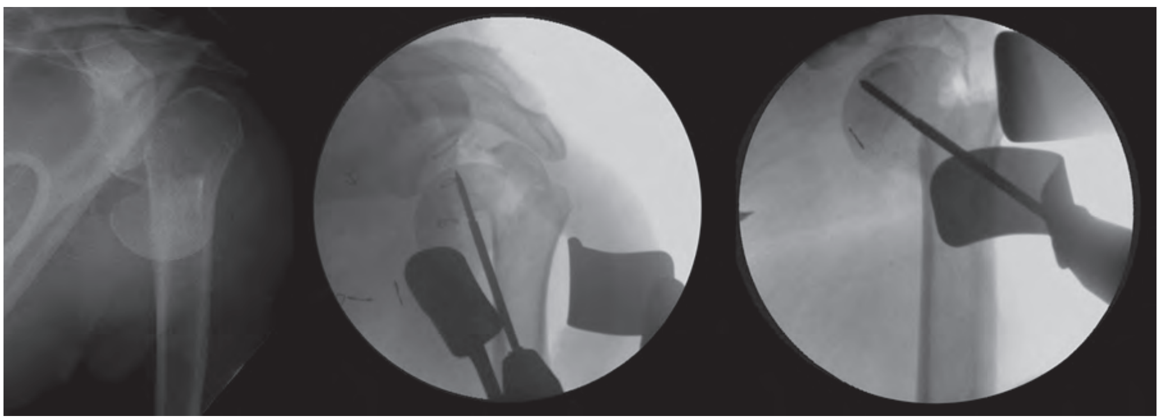


Figure 4-2. For proximal humeral fracture dislocations, the humeral head fragment can be manipulated using a small threaded Schanz pin.

- This is best accomplished by placing a Schanz pin through the fracture into the head fragment and using this to manipulate the fragment directly, while simultaneously facilitating a reduction with manually applied external pressure.
- Once the head fragment is reduced in the glenoid, reduction of the metaphysis to the head can proceed.
  - The metaphyseal fracture deformity is most often apex anterior at the surgical neck and in varus angulation (except in three- and four-part valgus impacted patterns).
  - The shaft is commonly adducted and shortened.
    - Fracture reduction is achieved by traction and forward flexion (elevating the arm) while simultaneously applying posterior and lateral pressure to the proximal end of the humeral shaft.
    - The laterally directed force vector applied to the proximal shaft will neutralize the deforming adducting force of the pectoralis major (Fig. 4-3).

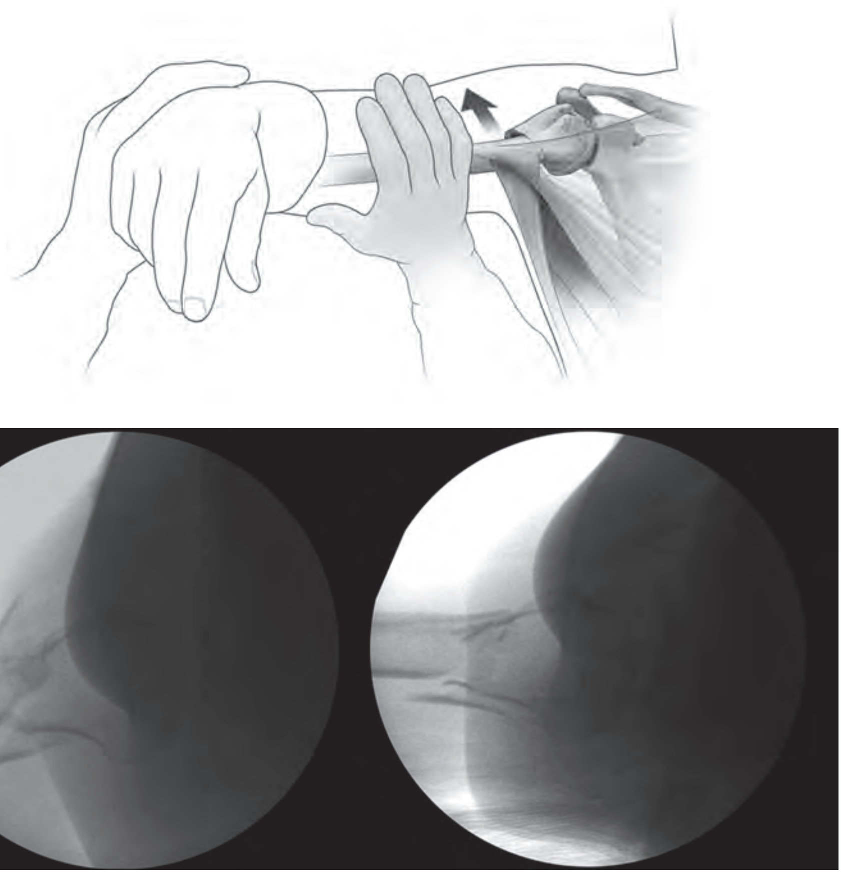


Figure 4-3. A common sagittal plane deformity includes apex anterior displacement. Thus, typical reduction maneuvers involve a laterally and posteriorly directed force on the proximal portion of the humeral shaft fragment to overcome muscle displacements (**top**). This reduction is visualized on the axillary fluoroscopic view (**bottom row**).

- Place several nonabsorbable sutures through the enthesis of the supraspinatus, infraspinatus, and teres minor tendons to mobilize and stabilize greater tuberosity or its composite fracture fragments.
  - Mobilize the greater tuberosity and provisionally reduce the tuberosity using the sutures for traction (Fig. 4-4).

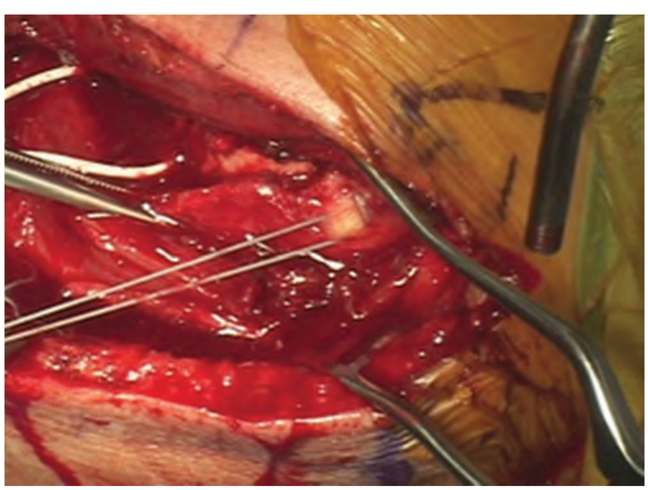


Figure 4-4. Several locking sutures are placed through the bone-tendon junction of the rotator cuff to mobilize and control the greater tuberosity.

- Place K-wires from the anterior humeral shaft, posteriorly into the humeral head fragment to provisionally stabilize the fracture, followed by a plate and screws (Fig. 4-5).

Figure 4-5. After reduction of the humeral head into the glenoid, manipulation can be used to reduce the diaphysis to the humeral head.

- For nondislocations, use K-wires to manipulate and reduce the humeral head fragment laterally and in valgus.
- Use a non–locking screw to draw the humeral shaft to the plate if required to indirectly reduce the greater tuberosity and humeral head (Fig. 4-6).

Figure 4-6. One strategy is to over-reduce the proximal fragment in valgus, with direct manipulation of the greater tuberosity using rotator cuff traction sutures. With the plate provisionally applied in the appropriate position, a non–locking screw is then inserted into the proximal shaft to complete the reduction, while elevating the head fragment. Fixation is concentrated in the inferomedial humeral head region.

- Provisional K-wires should be placed anteriorly to avoid conflict with subsequent lateral plate placement (Fig. 4-7).

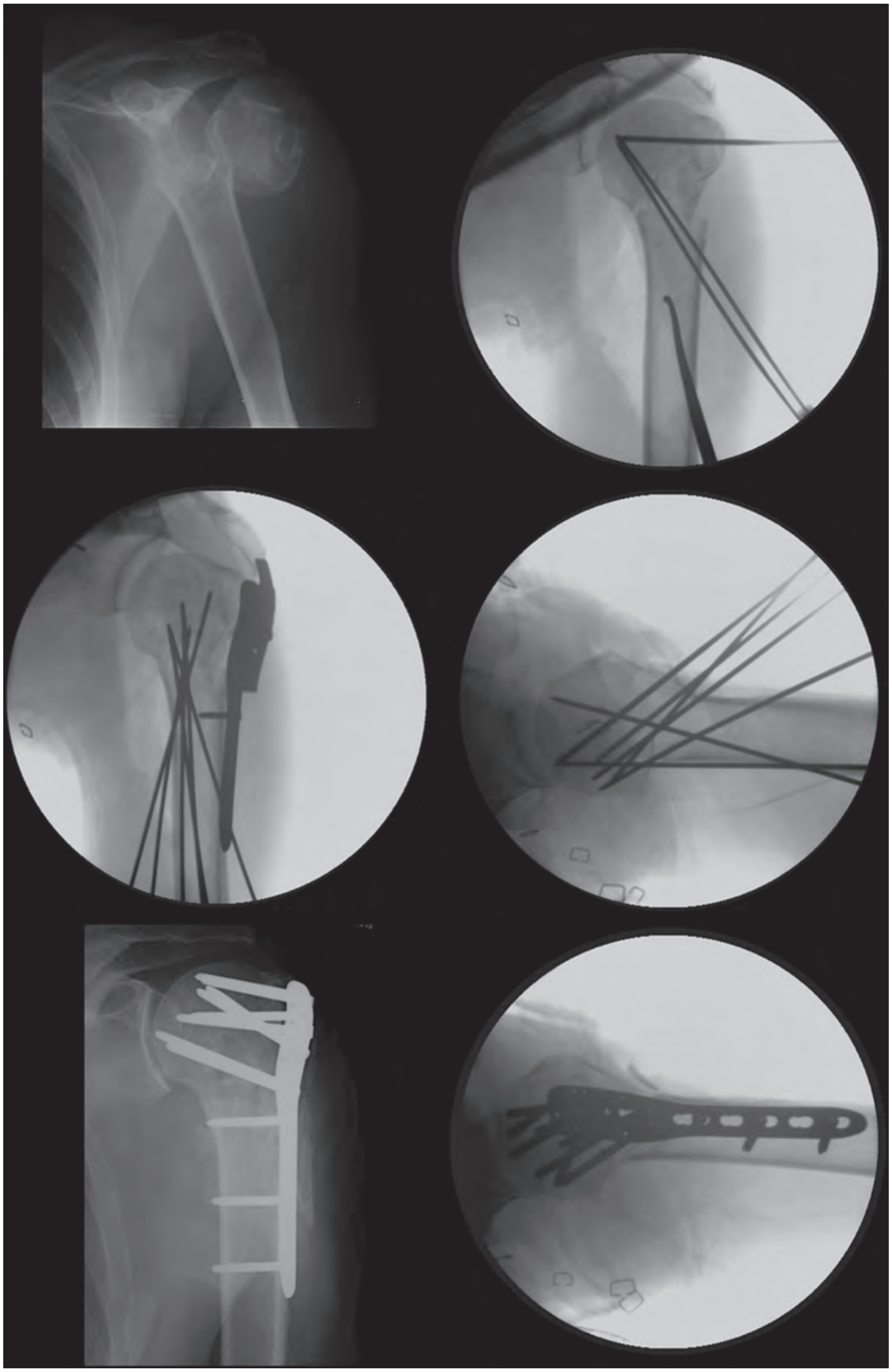


Figure 4-7. Provisional K-wires placed from the anterior aspect of the humeral shaft into the reduced humeral head greatly facilitate plate placement without K-wire removal.

- It is important to place screws into the inferomedial humeral head to optimize fixation stability.
  - The locking plate should be positioned such that the screws may be placed in this region.
  - If this is not possible due to plate design or other factors, a non–locking screw should be placed inferomedially (Fig. 4-8).

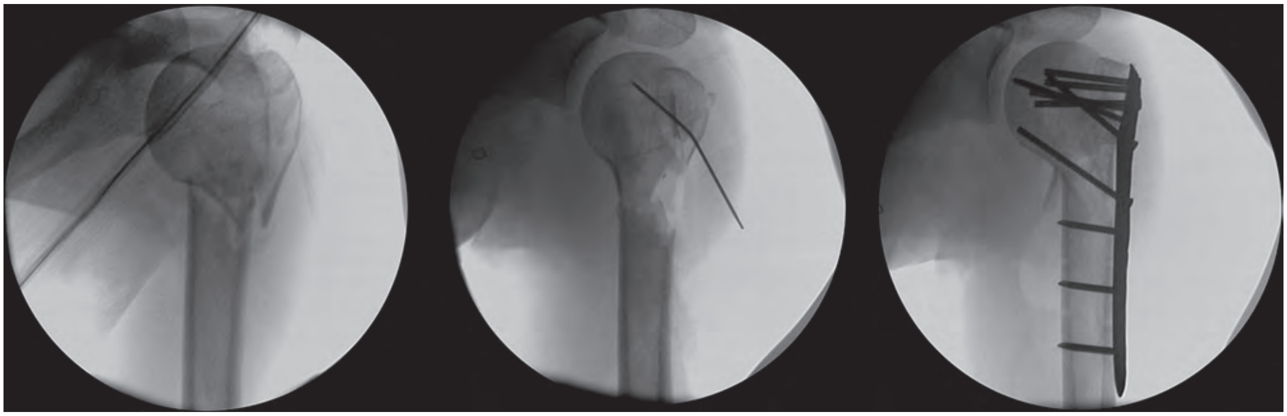


Figure 4-8. In this case, the plate was placed slightly too proximally for optimal locking screw placement into the inferomedial humeral head along the calcar. A non–locking screw was used instead.

- In four-part valgus impacted patterns, one strategy is to place clamp tines on the greater and lesser tuberosities to provisionally reduce to each other (Fig. 4-9).
  - Next, use an elevator or spiked pusher to disimpact and elevate the humeral head fragment while simultaneously reducing both tuberosities so that they begin to support the elevated head fragment.
  - Graft the underlying defect with allograft or bone graft substitute, if required.
  - Complete the tuberosity clamp reduction to support the humeral head.
  - Place additional K-wires and remove the clamp.
  - Lesser tuberosity screws or a separate plate may be placed independent of the lateral humeral plate, if lesser tuberosity fragment is large.
  - Support the tuberosity reduction with suture fixation.

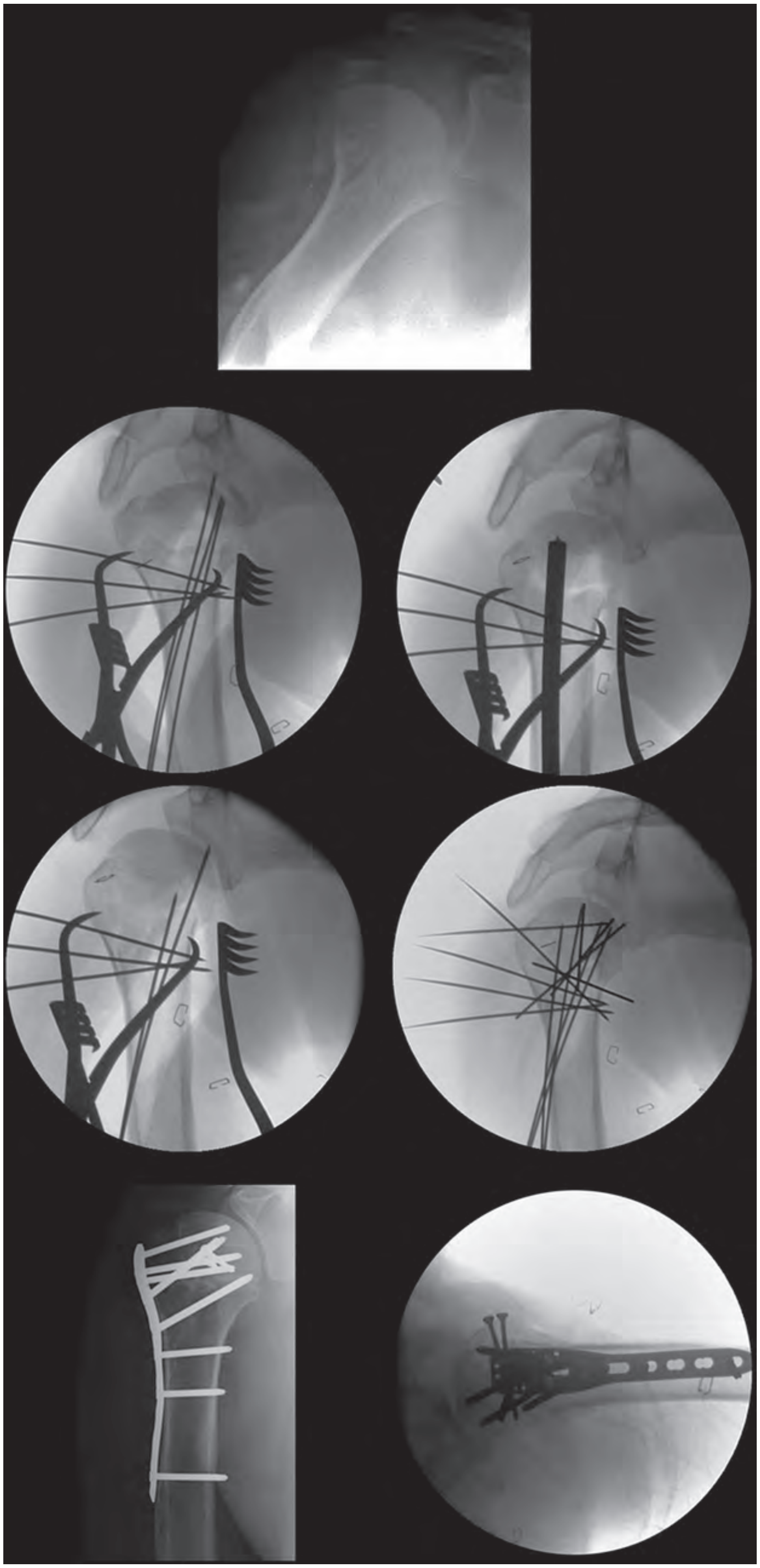


Figure 4-9. Four-part valgus impacted patterns can be reduced by first using a large Weber clamp on the tuberosities, with subsequent elevation of the humeral head fragment. Lesser tuberosity screws can be used in addition to sutures passed through rotator cuff bone-tendon junction if the fragment is large and unstable.

- If the greater tuberosity is a large fragment, it may be reduced and stabilized provisionally with 2.4- or 2.7-mm screws, placed posteriorly to the plate.
  - It is crucial to support the fixation with sutures through the rotator cuff enthesis which are then tied to the plate or through bone tunnels (Figs. 4-10 and 4-11).

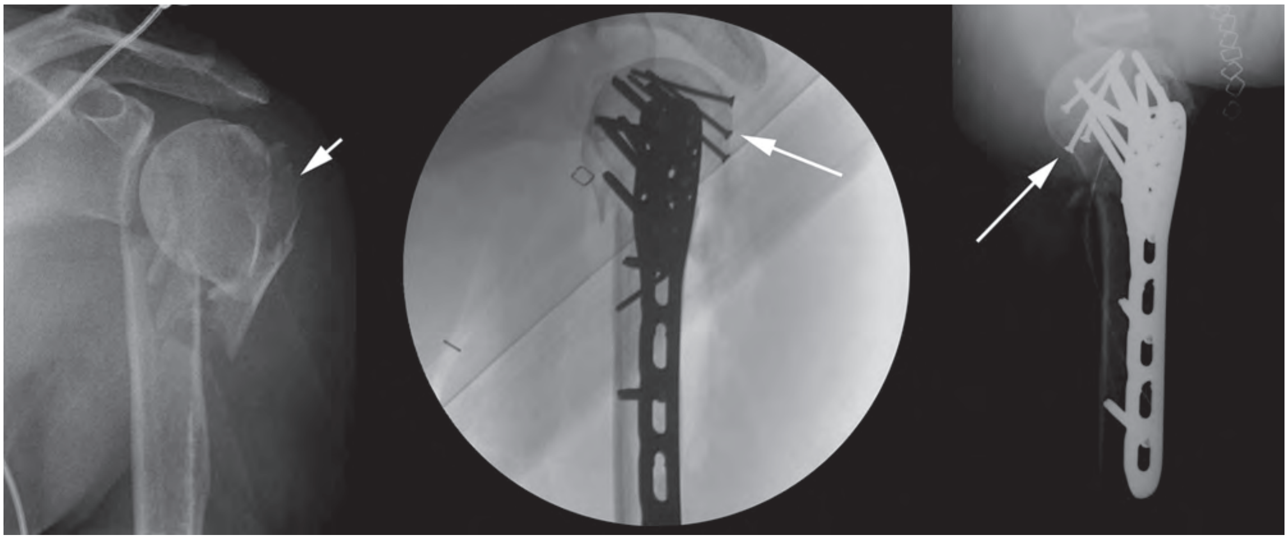


Figure 4-10. Using screws in addition to sutures for fixation of large greater tuberosity fractures (*arrows*) can supplement fixation.

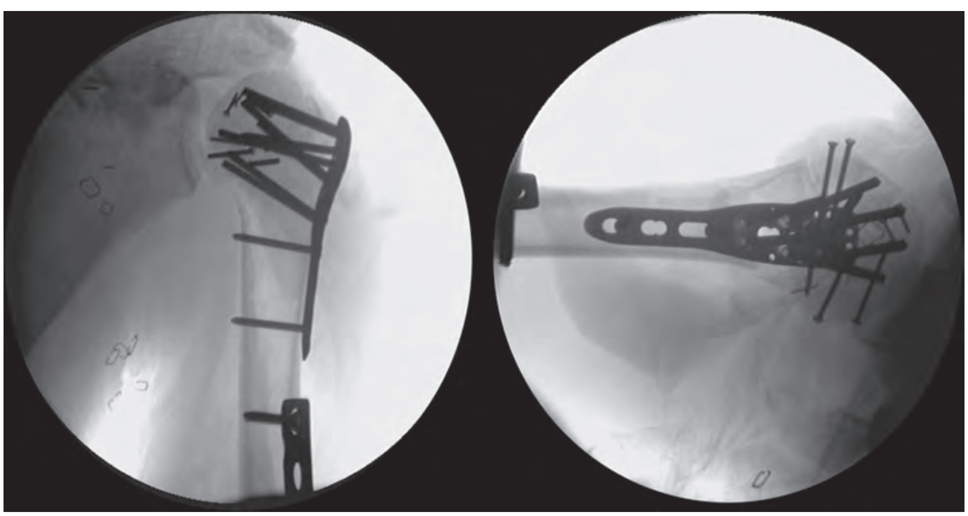


Figure 4-11. Another example of small screws used to stabilize a multifragmentary humeral neck and head fracture.

- In some instances, the fracture may be too short and it is difficult to manually restore appropriate length (Fig. 4-12).
  - A femoral distractor placed from the coracoid (4.0-mm Schanz pin) to the humeral shaft (4.0-mm Schanz pin) can greatly facilitate length restoration.

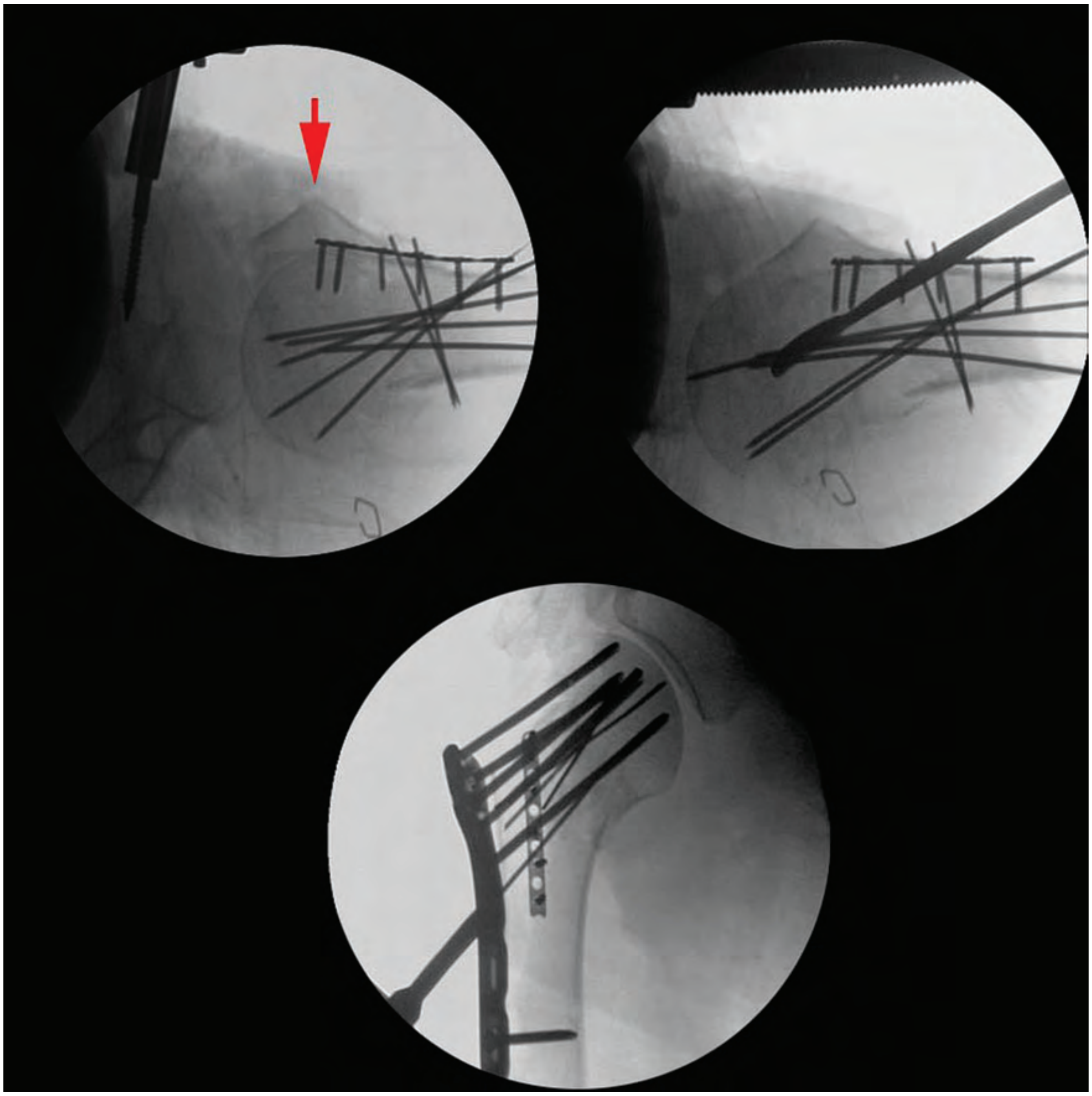


Figure 4-12. In this case, anatomic length was not achievable despite paralytic anesthesia. This was evident by the inability to reduce the lesser tuberosity (**upper left**, *red arrow*). A femoral distractor placed from the coracoid to the humeral shaft greatly facilitated anatomic length reduction (**upper right**).

Proximal Humeral Nailing

- Use guide wire on AP and scapular Y views to obtain precise starting point medial to the insertion of the rotator cuff, at the lateral edge of the articular surface and in line with the humeral shaft (Fig. 4-13).
- Make skin incision based on the radiographic starting point.
- Split deltoid and retract.

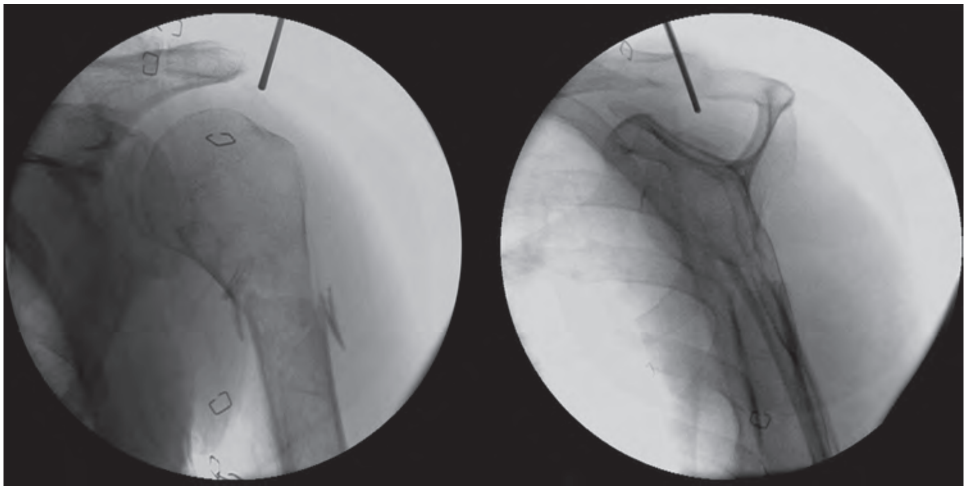


Figure 4-13. When placing a humeral nail, the starting point is assessed using AP and scapular Y orthogonal fluoroscopic views.

- Identify the starting point again radiographically with guide pin and confirm by subdeltoid palpation using anatomical landmarks.
- Incise the rotator cuff longitudinally, in line with its tendinous fibers and tag each side with heavy nonabsorbable sutures (e.g., no.2 Ticron) for retraction and cuff protection.
- Open canal with an awl or a cannulated drill bit (Fig. 4-14).

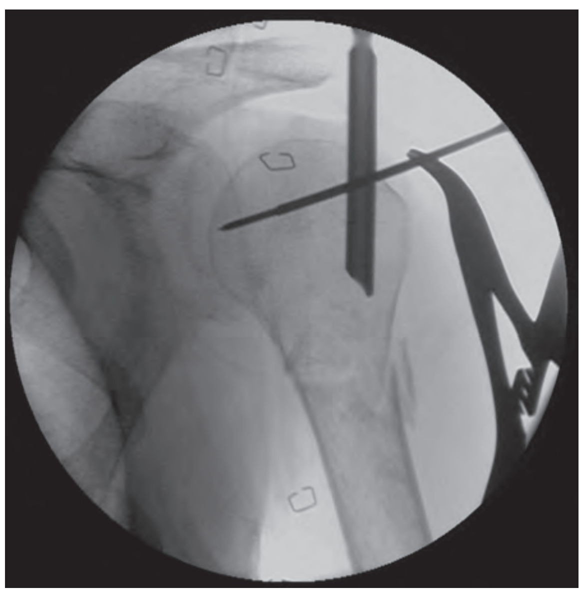


Figure 4-14. The starting point is opened with an awl.

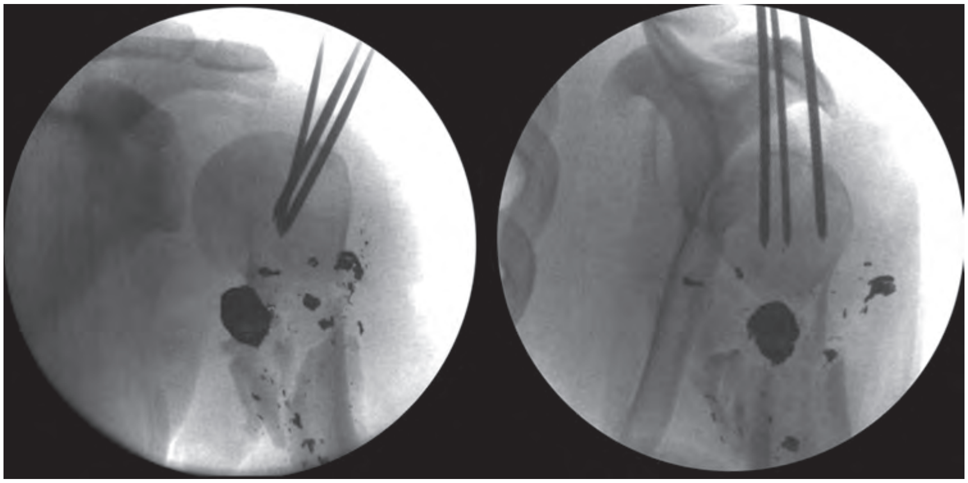


Figure 4-15. Two Schanz pins are placed in the humeral head on either side of the anticipated starting point. These are used for reduction, and also assist in soft tissue retraction. The starting guide wire is inserted between the two Schanz pins.

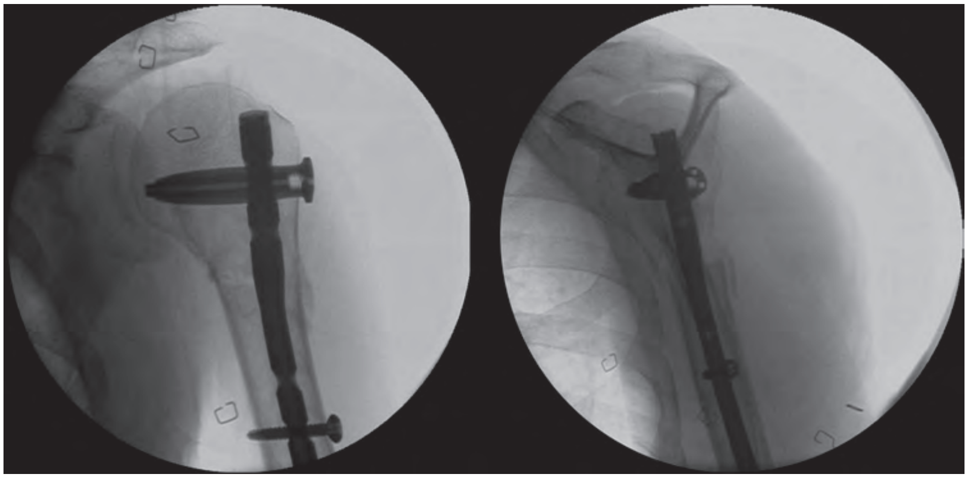


Figure 4-16. The nail path is then reamed with the fracture reduced, and the nail is placed.

- Reduce fracture using two Schanz pins as joysticks, or with manipulation of the arm and bump placement.
  - Schanz pins should be placed anterior and posterior to nail insertion site (as "goal posts" on either side of the entry portal) (Fig. 4-15).
- Ream and place nail (Fig. 4-16).

Chapter 5

Humeral Shaft Fractures

Andrew R. Evans

Sterile Instruments/Equipment

- Impervious stockinette and 4 inch elastic bandage wrap for forearm and hand
- 1/4% Marcaine with epinephrine for arm incision, if desired
- Sterile tourniquet for distal diaphyseal fractures, if desired
- Vessel loop for gentle retraction of radial nerve
- Articulated tensioner for transverse fractures
- Variety of bone reduction clamps, including large and small pointed bone reduction clamps ("Weber clamps")
- Extra Mayo stand cover or adhesive plastic bag to collect irrigation fluids
- Implants
    - 4.5-mm broad or narrow compression plates, depending on the humeral size
    - Anatomically contoured humeral plates
    - 3.5-mm compression plates for smaller stature individuals
    - Small (3.5-mm) and mini-fragment (2.0/2.4/2.7-mm) screws for lagging butterfly fragments
- K-wires and wire driver/drill

Surgical Approaches

Modified posterior approach to the humeral shaft

- Prone position
    - Patient is positioned at the cantilever end of a radiolucent table.
    - Use a Wilson frame or blanket rolls to prevent abdominal compression.
    - Alternatively, place two smooth double-blanket rolls or gelatin rolls longitudinally on each side of the torso, separated enough to accommodate the patient's abdomen and breasts.
        - Rolls should extend from the level of inferior axillary fold to anterior superior ilium.
        - Consider placing a transverse roll across the pelvis in patients with large abdomen, to decrease abdominal pressure and optimize respiration.
    - The affected upper extremity should be positioned with the shoulder abducted approximately 90 degrees and draped over a radiolucent arm board with the forearm hanging freely.
        - To prevent edema of the dependent forearm, place the operative forearm and hand in a stockinette and overwrap with an elastic bandage.
    - The unaffected upper extremity should be positioned with the shoulder either adducted at the side of the patient's body, or abducted <90 degrees and comfortably externally rotated (<70 degrees) to protect the brachial plexus and ulnar nerve.

- Build up the padding height of the arm board so that the arm rests at the level of the torso.
- The elbow, forearm, and hand should be well padded on an arm board with attention given to protection of the ulnar nerve.

- Place padding under the knees and a pillow under the distal legs to prevent pressure on the toes.
- Lateral decubitus position
    - Drape the affected arm over a radiolucent arm board anchored to the head of the table above the patient's head and oriented longitudinally to the table's axis.
    - Bean bag with gel pad or similar lateral positioning device; high chest roll to protect axilla.
    - Plexiglas table extension.
        - Inserted so that it protrudes 6 inches from the edge of the bed, under cushion to support down arm.
        - Position and protect the arm with blankets and foam.
    - Position down arm with elbow flexed to 90 degrees, with forearm and hand in "natural" position, and with shoulder forward flexed just enough so that down elbow does not interfere with affected humeral imaging (Fig. 5-1).

Figure 5-1. Lateral positioning for plate fixation of a humeral shaft fracture.

- For both lateral and prone positioning, rotate the OR table (usually 90 degrees) such that the affected extremity is maximally accessible by surgeons and fluoroscopy.
    - Fluoroscopy comes in from head of patient; AP and lateral imaging are accomplished by 90 degrees rotation of the C-arm without rotation of extremity.

Technique

- Make a longitudinal incision in the midline of the dorsal aspect of the arm.
    - Subcutaneous injection of 1:10,000 epinephrine, prior to the incision will help control bleeding of this vascular layer.
    - Curve incision slightly radially for distal extension beyond the olecranon process.
    - Access the distal diaphyseal and supracondylar regions of the humerus through the lateral paratricipital posterior approach.[1]
        - Dissect full-thickness skin/subcutaneous flap directly to the deep posterior compartment (triceps) fascia and then laterally to the intermuscular septum.
        - Identify the radial nerve as it penetrates the lateral intermuscular septum, approximately 10 cm proximal to the lateral epicondyle.
        - Follow the radial nerve course proximally and obliquely.

- Distal to the nerve, release the lateral triceps border and anconeus from intermuscular septum and lateral epicondyle, if distal exposure is required.
- Identify the course of the radial nerve, and decompress if displaced or dislocated with respect to the fractured humerus.

- Access proximal shaft and metadiaphyseal region posteriorly by splitting the long and lateral heads of the triceps proximally (Fig. 5-2).
  - Radial nerve is deep and distal to their confluence, generally near the medial border of the humeral shaft at this level.
  - Take care to avoid injury to the axillary nerve and posterior humeral circumflex vessels if a limited dorsal deltoid release is necessary.

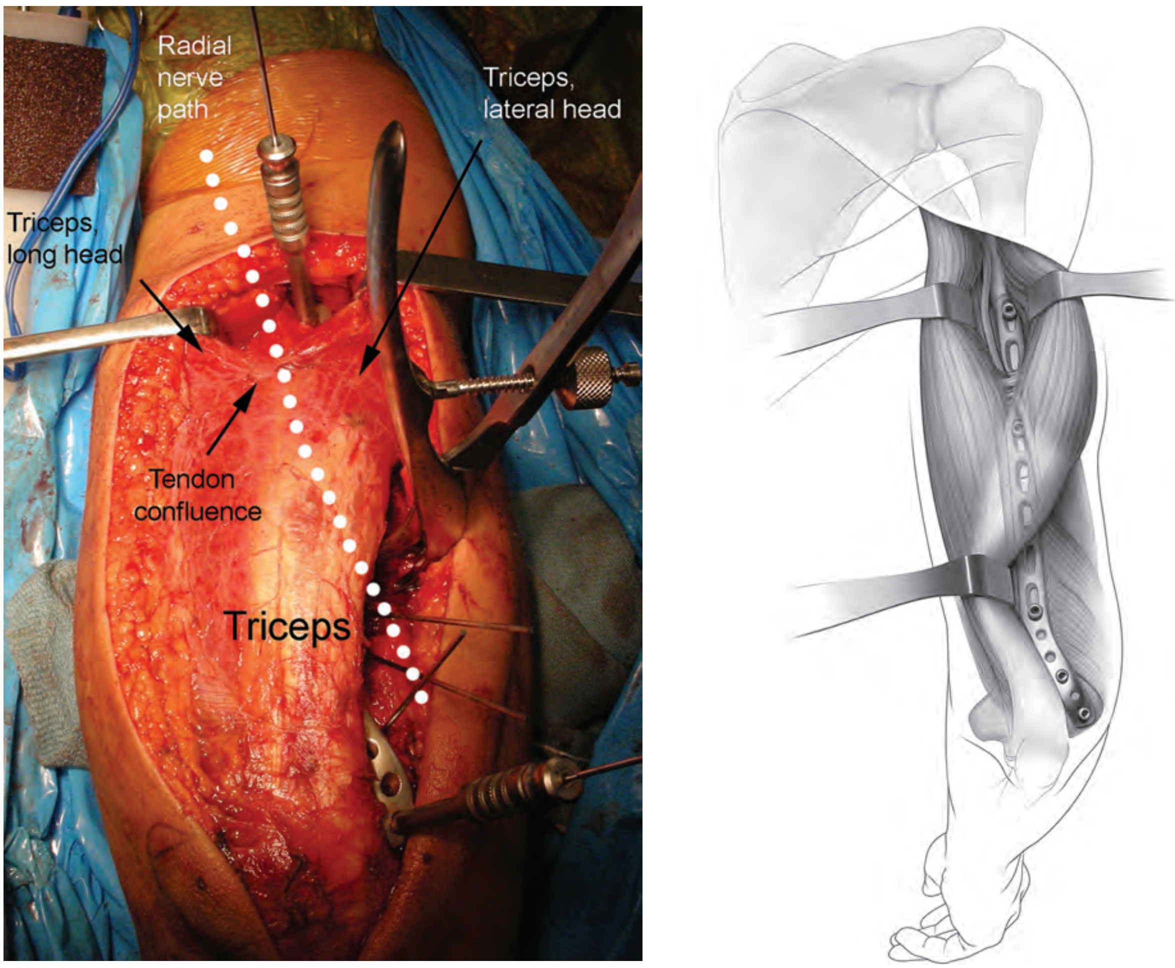


Figure 5-2. Using a modified posterior approach, the triceps can be reflected up to the level of the radial nerve and the fracture. To avoid additional dissection to the proximal extent of the plate, the interval between the long and lateral triceps heads can be developed proximally. At this proximal tendon confluence, the radial nerve is usually adjacent to the medial edge of the plate and humerus.

- Alternatively, continue reflecting triceps from lateral to medial proximally for full extension of modified posterior (Gerwin) approach.

Anterolateral approach to the humeral shaft

- Supine position.
  - Place small one-blanket bump beneath the patient's affected shoulder, posterior thoracic wall, and pelvis.

- Position the endotracheal tube to the side opposite the fractured extremity, and position the patient's head facing anteriorly or away from the affected extremity.
  - Secure the head to the table with foam and tape.
- Radiolucent Plexiglas extension with long dimension protruding 4-6 inches beyond the bed cushion; place blankets on Plexiglas to equal bed cushion height, and position patient such that affected extremity is supported by Plexiglas extension.
- The affected extremity may be positioned "naturally" over the torso.
- Rotate OR bed such that the patient's affected extremity is maximally accessible by surgeons and fluoroscopy.
- Place fluoroscope on the opposite side of the radiolucent table; AP and lateral imaging are accomplished by rotating the C-arm through a 90 degree arc (Fig. 5-3).

Figure 5-3. With the patient's scapula elevated on the blanket or towel bumps, a lateral fluoroscopic view of the humerus can be obtained by rolling the C-arm "over the top."

- An excellent approach for operative fixation of middle and proximal one-third fractures of the humeral shaft.
- Allows for extensile exposure of the humeral shaft.

Lateral approach to the humeral shaft[2]

- A small open lateral approach may be used for insertion of Schanz pins for humeral external fixation or for limited exposure during intramedullary nailing to avoid injury to the radial or axillary nerves.
- The radial nerve is easily identified throughout the length of a lateral approach.
- Patient positioned supine.
  - Plexiglas extension may be used as described above, (or a Mayo stand may be used as a broader, adjustable radiolucent working surface [Note: Mayo stands are metal and not radiolucent]).
- Incise the skin longitudinally along the line connecting the center of deltoid insertion and the lateral epicondyle (Fig. 5-4).

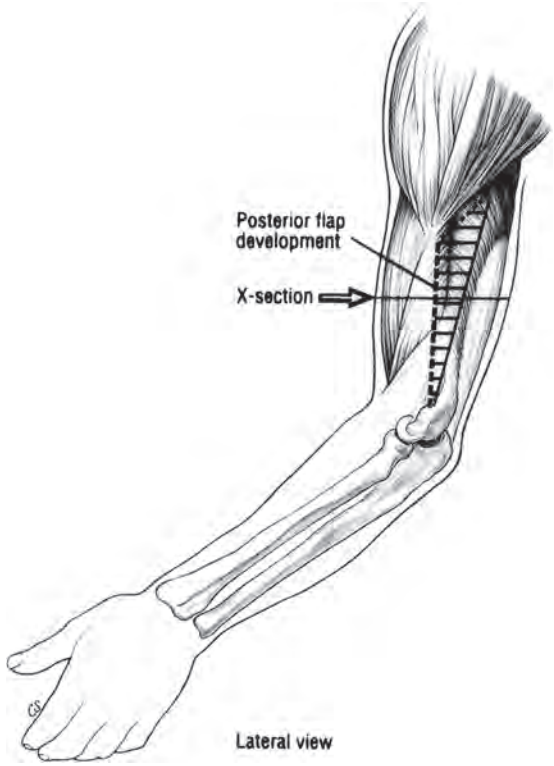


Figure 5-4. A skin incision is made in line with the center of the deltoid insertion and the lateral epicondyle. The posterior flap is developed to expose the underlying fascia and intermuscular septum. (Adapted from Mills WJ, Hanel DP, Smith DG. Lateral approach to the humeral shaft: an alternative approach for fracture treatment. *J Orthop Trauma.* 1996;10(2):81–6. With permission.).

- Create a small posterior skin flap, and incise the fascia of posterior compartment, approximately 1 cm posterior to intermuscular septum (Fig. 5-5).

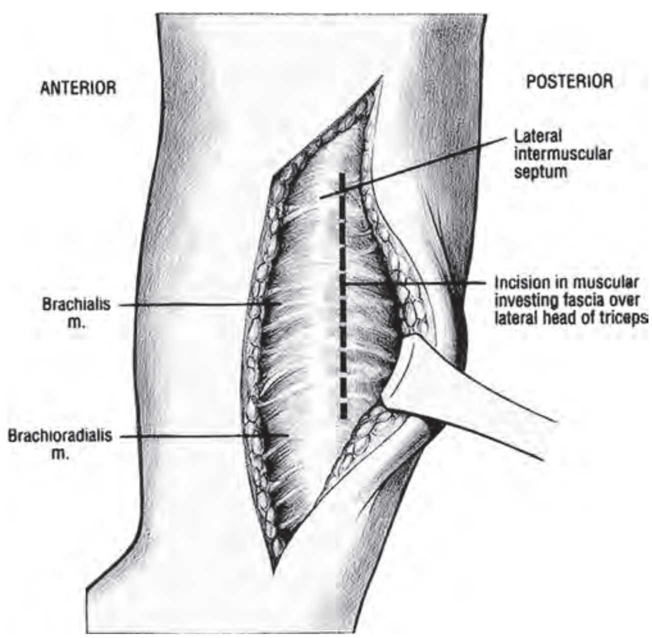


Figure 5-5. Incise the fascia ≈1 cm posterior to the intermuscular septum, ensuring that the dissection proceeds in the posterior compartment of the arm. (Adapted from Mills WJ, Hanel DP, Smith DG. Lateral approach to the humeral shaft: an alternative approach for fracture treatment. *J Orthop Trauma.* 1996;10(2):81–6. With permission.)

- Dissect the lateral head of triceps off of the septum down to the level at which radial nerve pierces lateral intermuscular septum (Fig. 5-6).

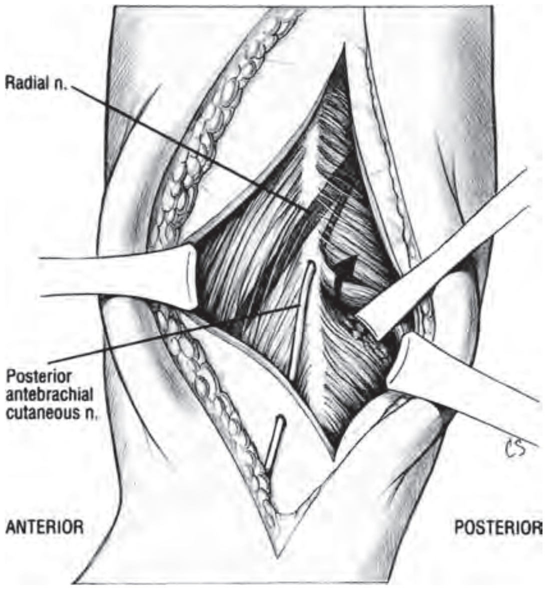


Figure 5-6. Sharply elevate the lateral head of the triceps from the intermuscular septum, dissecting down to the humerus. The radial nerve will be found within investing fat in the proximal extent of the incision. The posterior antebrachial cutaneous nerve may be found in the distal subcutaneous dissection or as it pierces fascia; follow it proximally to its origin from the radial nerve proper. (Adapted from Mills WJ, Hanel DP, Smith DG. Lateral approach to the humeral shaft: an alternative approach for fracture treatment. *J Orthop Trauma*. 1996;10(2):81–6. With permission.)

- Identify and protect the posterior cutaneous branch of the radial nerve, and motor branches of the radial nerve innervating the lateral head of the triceps.
- Retract radial nerve and associated branches carefully to expose the distal two-thirds of the humerus as needed for reduction of fractures or the placement of Schanz pins for external fixation (Fig. 5-7).

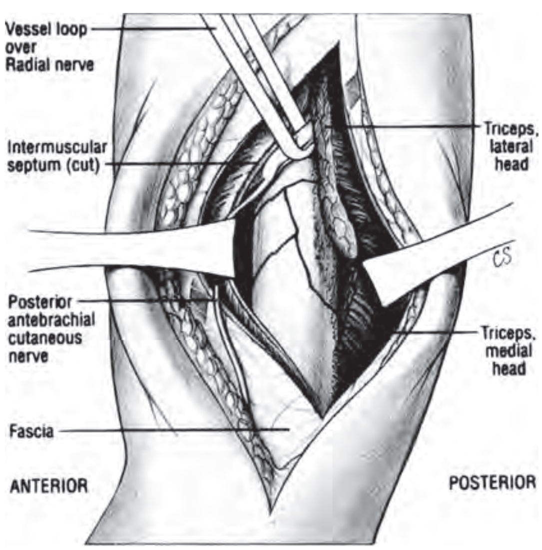


Figure 5-7. Complete elevation of the triceps from intermuscular septum, retraction of the brachialis and brachioradialis anteriorly, and isolation of the radial nerve with a penrose drain; the humerus fracture is exposed. Division of the intermuscular septum allows visualization of the radial nerve distally. (Adapted from Mills WJ, Hanel DP, Smith DG. Lateral approach to the humeral shaft: an alternative approach for fracture treatment. *J Orthop Trauma*. 1996;10(2):81–6. With permission.)

- The anterior, lateral, and/or posterior surfaces of the humerus may be exposed as potential sites for plate application.
- The exposure is extensile, both proximally (anteriorly) and distally, although access is limited to the proximal third of the humeral shaft by the deltoid insertion

Anterolateral approach to the shoulder (antegrade humeral nailing)

- For full technique, see the chapter (4)

Implant/Reduction Techniques

Humeral Shaft Plating

- Dissect to humerus, clean fracture edges of hematoma, and infolded periosteum; avoid devitalization of comminuted or intercalary fracture fragments.
- Use small or large Weber or serrated reduction clamps to obtain an anatomical reduction.
- Recommend lag screw fixation with countersunk 2.0, 2.4, or 2.7-mm cortical lag screws between fragments that can be anatomically reduced, depending on the fragment size.
- Use large plates for fixation of diaphyseal fractures, when possible.
  - 4.5-mm narrow plates fit most humeri, but 4.5-mm broad plate is best in large male patients.
  - Posterior plates must be positioned under the radial nerve after sufficient nerve mobilization.
  - The radial nerve typically drapes directly over the plate (Fig. 5-8).

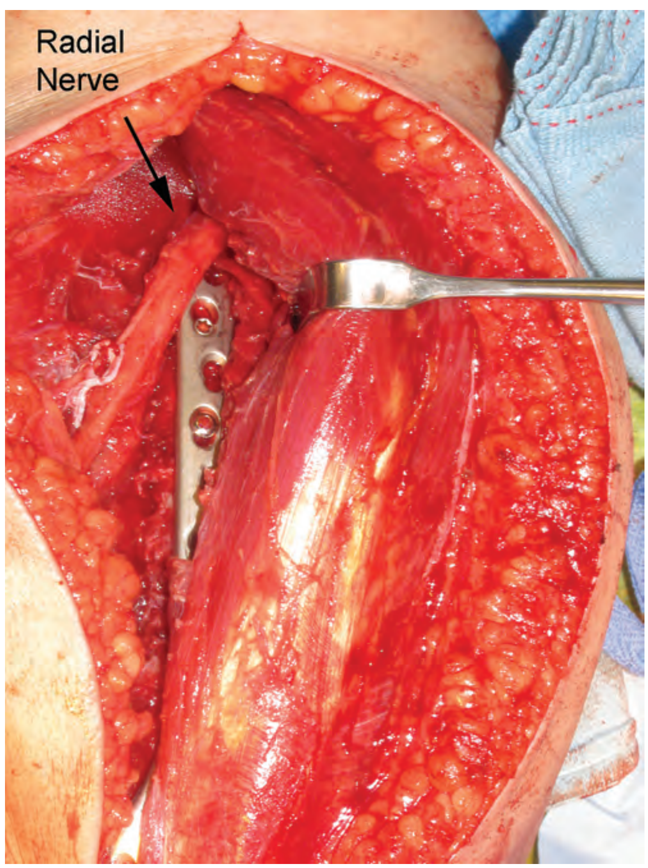


Figure 5-8. For posterior plating of the humerus, the plate must be carefully placed deep into the radial nerve.

- At the conclusion of the procedure, it is helpful to dictate the position of the radial nerve relative to the plate by noting over which plate hole it lies.
  - This facilitates identification, if future surgery is required.
- Consider using a lateral column distal humeral metaphyseal plate for distal one-fourth to one-third diaphyseal or metadiaphyseal fractures in which distal fixation options using conventional large fragment plates are limited (Fig. 5-9).

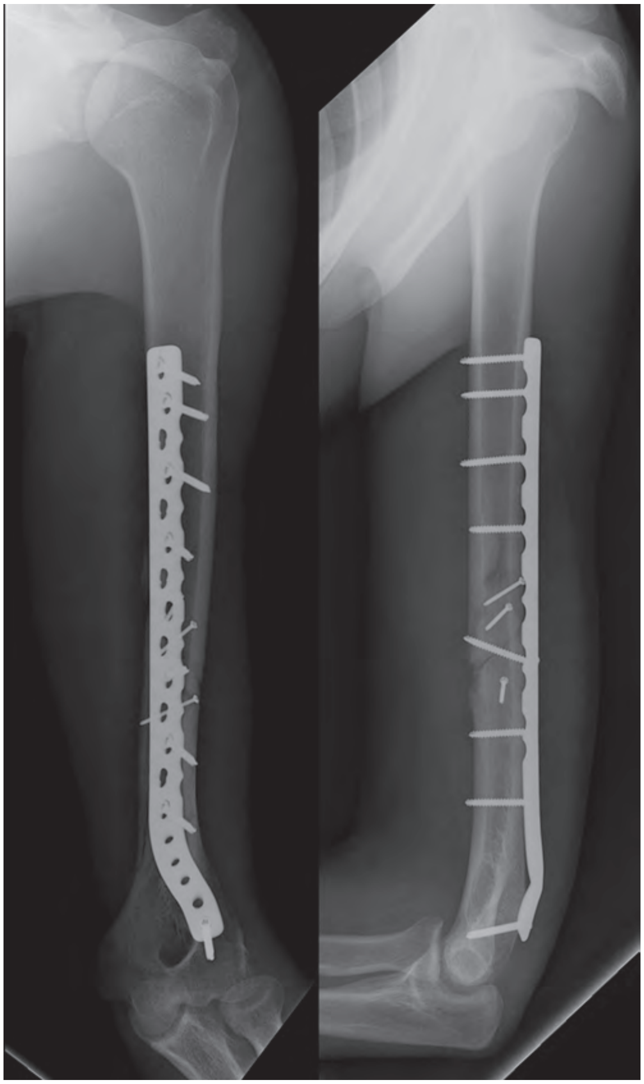


Figure 5-9. Extra-articular distal humeral diaphyseal fractures are often treated effectively with specialty plates that extend to the lateral condyle.

- When contouring a compression plate for a simple fracture pattern, it should be overbent slightly in the sagittal plane in order to obtain interfragmentary anterior cortical compression.
  - In addition, plate contouring may require a torsional bend in the plate to fit the humeral contour anatomically.
- Bridge plating of the humeral shaft may be preferable for extensively comminuted fracture patterns, as long as the radial nerve is identified and protected.

Antegrade Humeral Nailing

- (For full technique, see the chapter (4)
- Prior to humeral nailing, consider the radial nerve function and the potential for shoulder discomfort.
- Transverse or short oblique fractures which can be anatomically reduced prior to reaming may be nailed using closed technique.
  - Otherwise, consider making a small lateral incision posterior to the intermuscular septum for radial nerve identification and protection during a nailing procedure.
- Antegrade technique (Fig. 5-10).

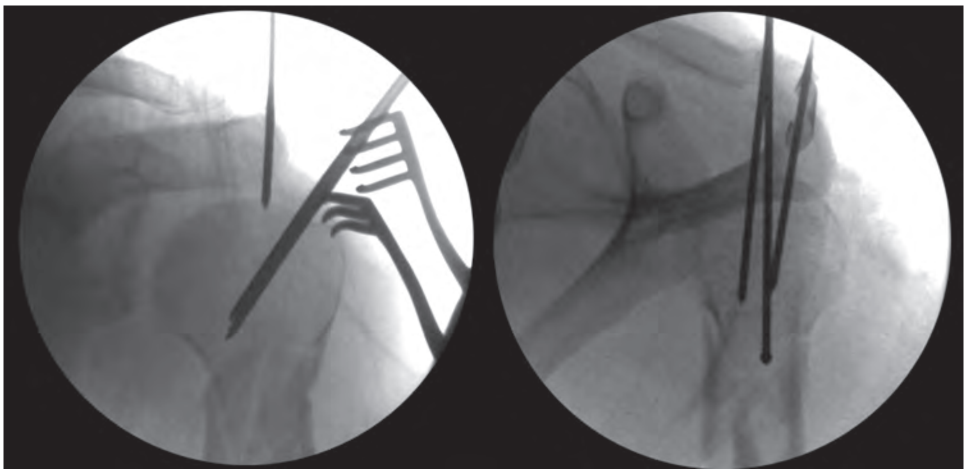


Figure 5-10. The intramedullary nail starting point is determined based on the AP and scapular Y views. This should be medial to the sulcus of the greater tuberosity on the AP view (**left**) and collinear with the diaphysis on the lateral view (**right**).

- Skin incision should begin at the anterolateral corner of the acromion, extending at least 1 to 2 centimeters distally.
- Incise the deltoid fascia, at the junction of the anterior and middle thirds of the muscle.
- Insert guide wire fluoroscopically to identify the nail insertion point.
- Incise rotator cuff at the point of entry, splitting the supraspinatus tendon in line with its fibers.
  - The edges of the tendon should be retracted with sutures, which can later be used for repair.
  - The starting point should be just posterolateral to the biceps tendon.
  - Usually one can palpate the bicipital groove.
- Overream guide wire with cannulated drill bit.
- For segmentally comminuted humeral shaft fractures, measure length, alignment, and rotation based on the contralateral humerus if not fractured as a guide to fracture reduction.

- Length—radiolucent ruler to measure from top of humeral head to trochlea.
- Alignment—normal humeral diaphyseal alignment has minimal varus/valgus or flexion/extension angulation.
- Rotation—may assess through comparison of greater and lesser tuberosity morphology with the contralateral side.

- For fractures with proximal extension, two 2.5-mm Steinmann pins can be useful to control the proximal segment.
  - These are placed anterior and posterior to the anticipated nail start point.
  - Guide wire and nail are placed between pins like "goal posts."
  - Pins also retract rotator cuff (Fig. 5-11).

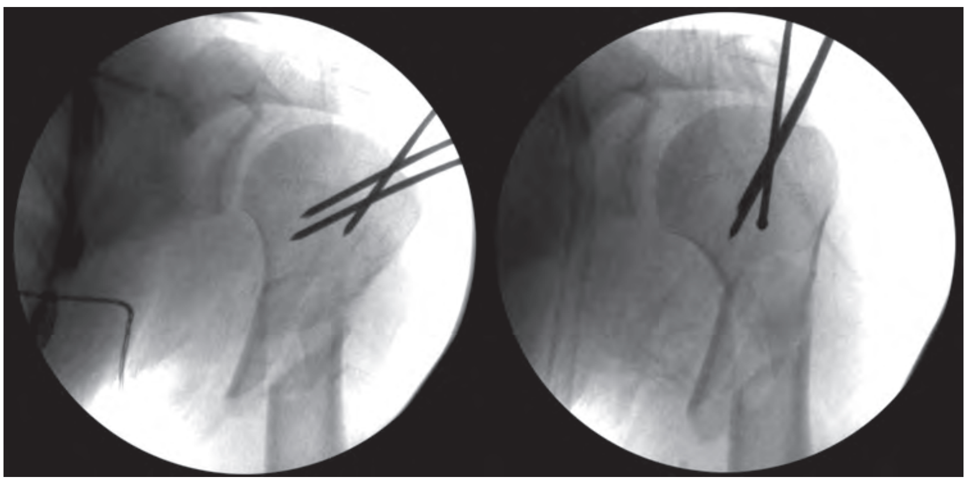


Figure 5-11. For more proximal fractures, 2.5-mm Steinmann pins are very useful for manipulation of the proximal fragment. These are positioned such that the guide wire, reamers, and nail are placed between the pins.

- Avoid eccentric reaming of the canal by reaming the humerus with the fracture reduced.
- When considering nail length, remember that the humeral canal narrows and tapers just proximal to the olecranon fossa.
  - Using a nail that is too long will result in distraction and/or iatrogenic extension of the fracture.
  - Avoid retracting the nail and positioning it prominently the subchondral bone of the humeral head.
- In open fractures, or if a fracture is opened to identify/protect the radial nerve, consider placing a modified small Weber clamp in two 2.0-mm drill holes to maintain reduction of transverse or oblique fractures during reaming[3] (Fig. 5-12).
- When locking proximally, create safe paths for drilling and interlocking using a blunt muscle splitting technique to avoid injury to the axillary nerve.
  - Alternatively, extend the proximal incision, used for nail entry, to the anterolateral deltoid until the nerve is identified by palpation or visualization.

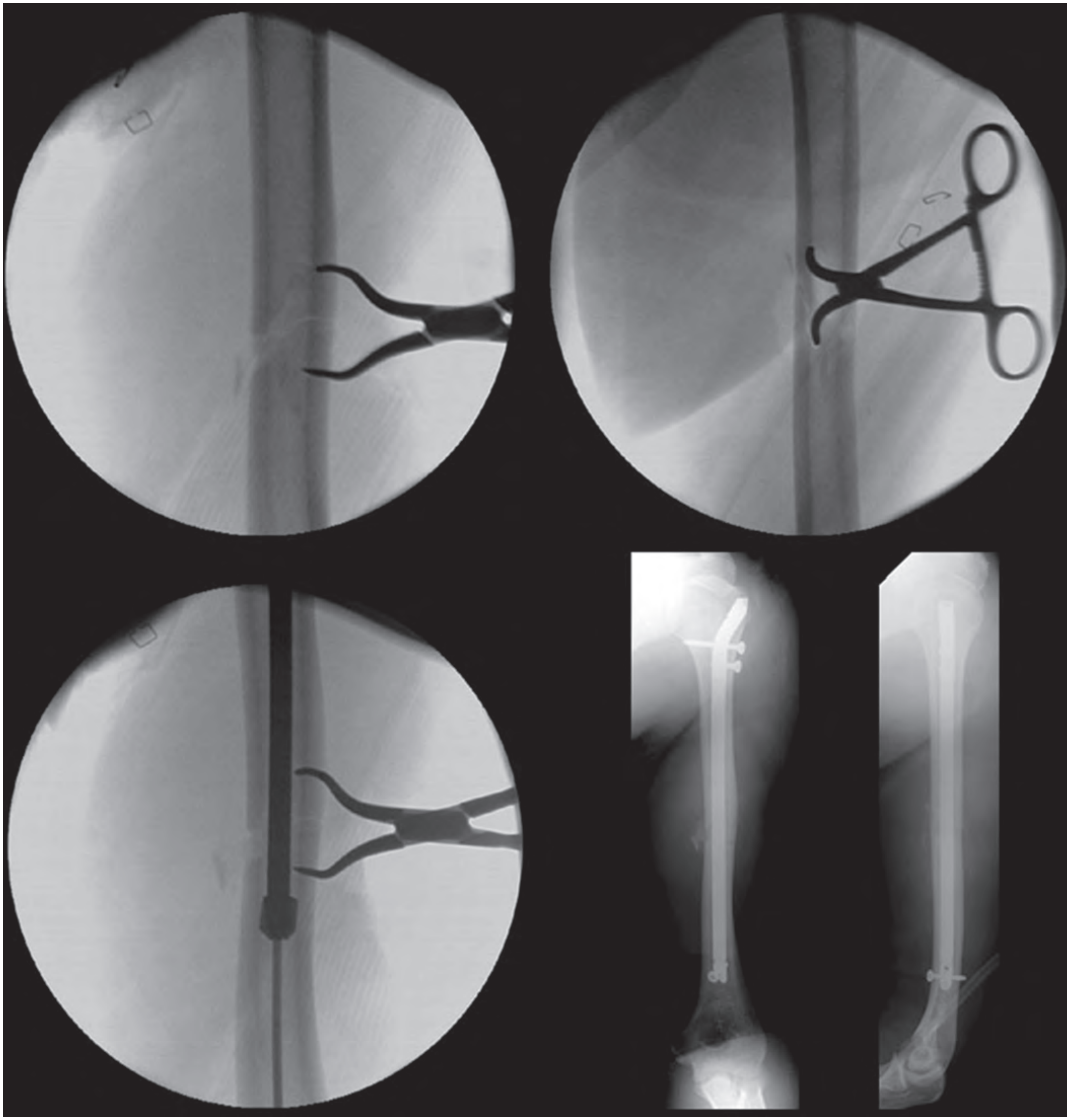


Figure 5-12. Direct identification of the fracture site with clamp placement allows for anatomic reduction and ensures that the radial nerve is not at risk with reaming.

- When locking distally, anterior to posterior, use a sleeve system or ample exposure with retraction; consider an oscillating drill to protect surrounding soft tissue structures.
  - When placing distal interlocking screws from lateral to medial, make an incision to allow sufficient visualization of the humerus to avoid injury to the lateral antebrachial cutaneous or radial nerves.
  - Distally, the lateral humeral border has a narrow border and drill bits tend to slip off of this ridge.

External Fixation of the Humeral Shaft

- An option for provisional or definitive treatment of humeral shaft fractures, particularly in mangled upper extremity injuries (Fig. 5-13).

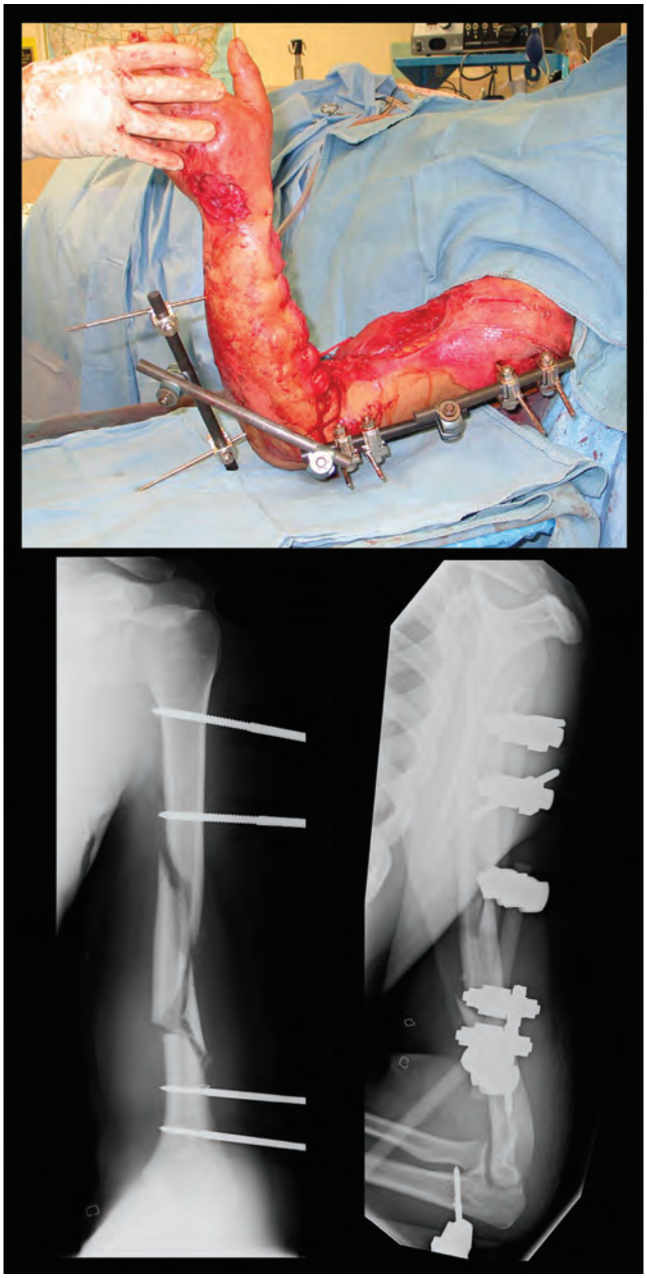


Figure 5-13. Typical external fixation pin positions in the humerus. Proximally, the axillary nerve must be avoided around the surgical neck. Distally, the radial nerve must be protected.

- Perform a limited lateral approach to the distal humeral shaft for pin placement to avoid injury to cutaneous or deep nerves (e.g., radial nerve).
- Avoid injury to the axillary nerve through blunt dissection and use of sleeve systems for proximal pin placement.

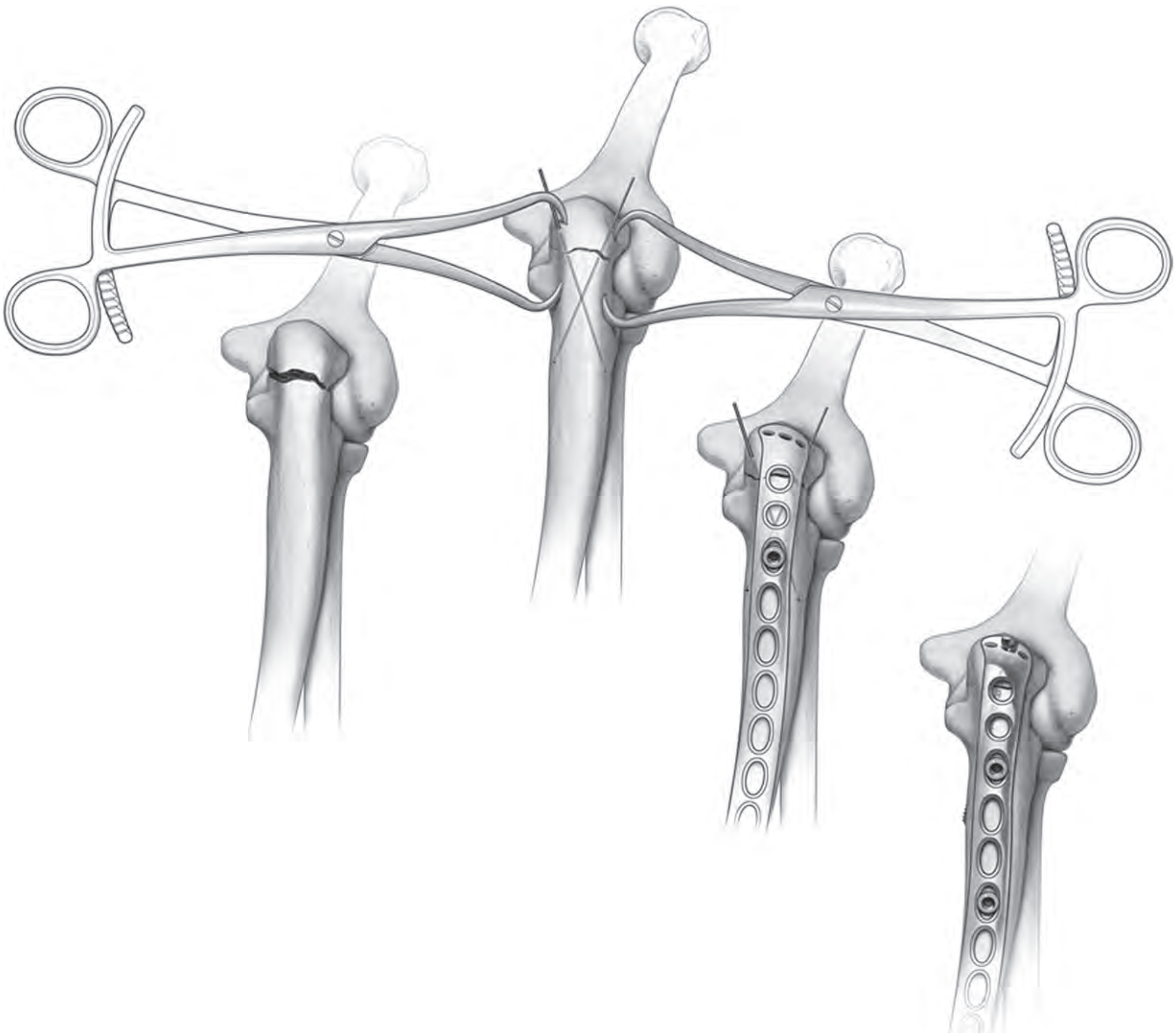
References

1. Schildhauer TA, Nork SE, Mills WJ, et al. Extensor mechanism-sparing paratricipital posterior approach to the distal humerus. *J Orthop Trauma*. 2003;17(5):374–378.
2. Mills WJ, Hanel DP, Smith DG. Lateral approach to the humeral shaft: an alternative approach for fracture treatment. *J Orthop Trauma*. 1996;10(2):81–86.
3. Schoots IG, Simons MP, Nork SE, et al. Antegrade locked nailing of open humeral shaft fractures. *Orthopedics*. 2007;30(1):49–54.

Section 3

Elbow/Forearm

Daphne M. Beingessner



Distal Humerus Fractures

Chapter 6

M. Bradford Henley
Michael J. Gardner

Sterile Instruments/Equipment

- Extra Mayo stand cover or adhesive bag as fluid collection drape
- Impervious stockinette and 4 inch elastic bandage wrap for forearm and hand
- Bipolar cautery for ulnar neurolysis dissection, if required
- 1/4% Marcaine with epinephrine for posterior arm skin and subcutaneous tissues prior to incision
- Tourniquet if desired
- Large and small pointed bone reduction clamps ("Weber clamps")
- If planning proximal ulnar osteotomy: micro oscillating saw, small osteotomes (e.g., Hooke osteotomes)
- Implants:
  - Anatomically contoured periarticular plates for application to the medial and lateral humeral columns, 2.7/3.5 reconstruction plates, 3.5 compression plates
  - Consider cannulated 3.5- or 4.0-mm screw(s) for stabilizing the intercondylar split.
  - Consider small and mini-fragment screws and mini-fragment plates (2.0/2.4 mm) if comminuted medial and/or lateral columns.
- K-wires and wire driver/drill

Patient Positioning

- Position the patient either prone or lateral.
  - Radiolucent table extension; cantilever-type.
  - Patient is placed backwards so that the patient's head is toward the radiolucent and "foot end" of the table.
  - U-drape to exclude the axilla and thorax.
  - If prone, support fractured arm by radiolucent (e.g., Plexiglas) board placed orthogonally to table so that board is supported by patient's torso and weight; Plexiglas board is placed under table's "mattress pad."
    - Most arm tables are too long and do not permit sufficient elbow flexion when patient is prone.
    - Center Plexiglas on patient's shoulder so that arm is abducted at a right angle to torso; this aids in obtaining lateral images.
  - If positioned laterally, an elevated arm board that can be adjusted for height is needed.
  - In either position, the contralateral arm is supported by an arm board designed for prone positioning, so excessive abduction and external rotation are avoided.
- OR table is rotated 90 degrees with respect to usual position in room, to provide unimpeded access to shoulder, arm, and elbow.
- C-arm is positioned above patient's head, parallel to long axis of patient's body and perpendicular to the injured extremity which is abducted 90 degrees. This permits AP and lateral imaging without moving the extremity (Figs. 6-1 and 6-2).

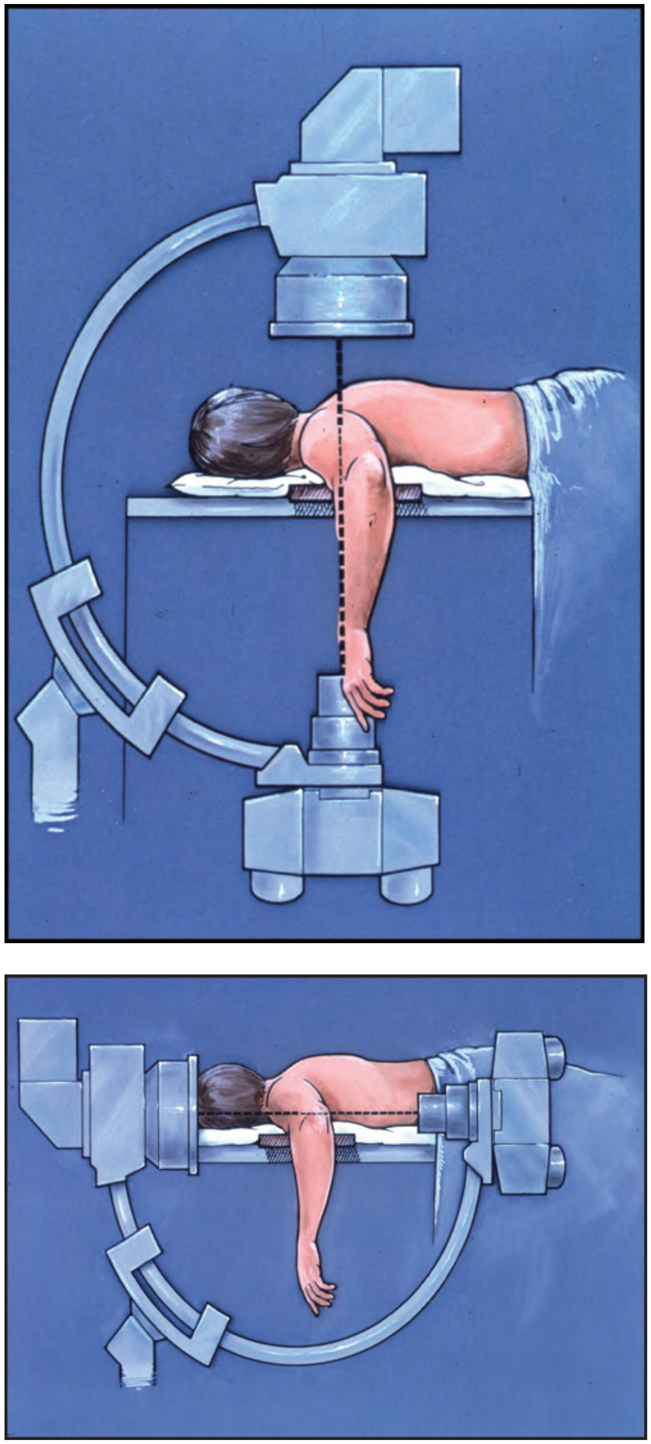


Figure 6-1. Prone positioning with arm supported by radiolucent Plexiglas board allows for unimpeded AP and lateral images from shoulder to elbow. The contralateral upper extremity may be positioned at the patient's side or abducted comfortably. Also, it is not near the operative field being imaged with X-ray.

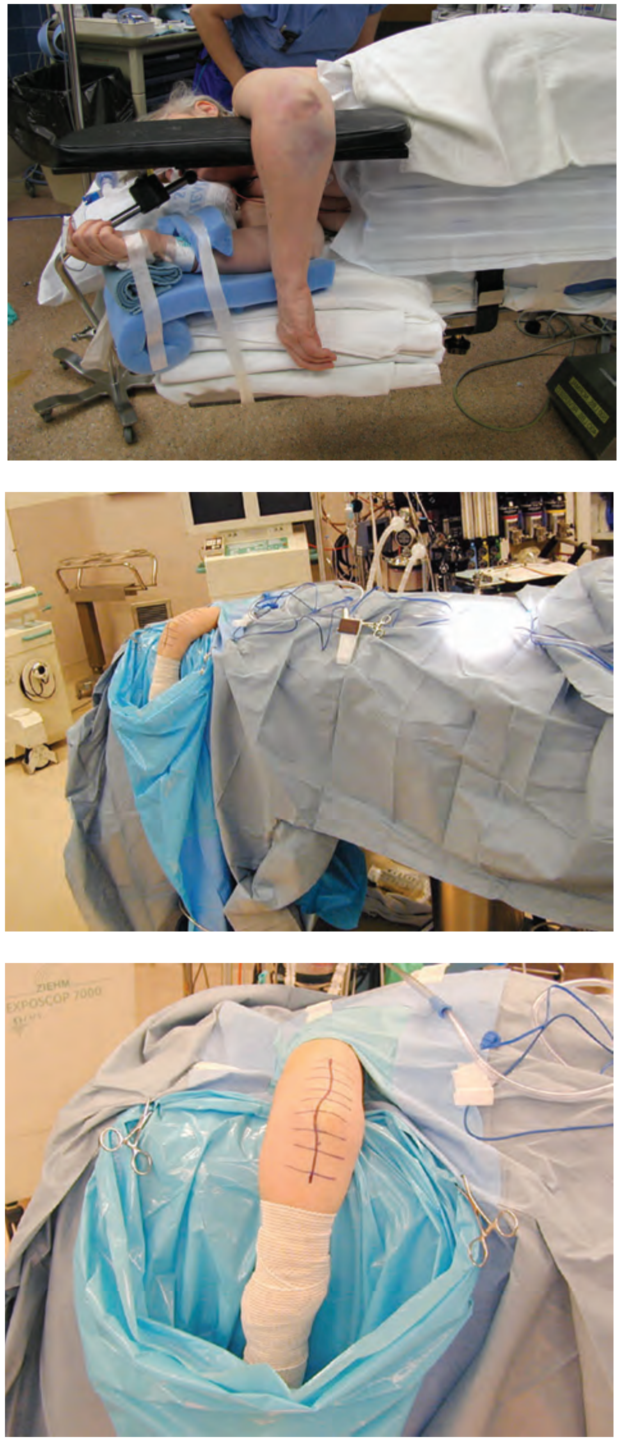


Figure 6-2. In the lateral position, the contralateral upper extremity may impede some AP images. This can be avoided by carefully positioning the contralateral extremity and by canting the C-arm anode toward the patient’s torso. After draping, the forearm and hand of the injured extremity are placed in an impervious stockinette and over wrapped with an elastic bandage to reduce dependent edema. The extremity is contained in a second Mayo stand cover which is used to collect irrigation fluid and to keep the operative field tidy. A fenestration is made in the dependent end of the Mayo stand cover; it is weighted with a clamp and placed in a kick bucket as a fluid collection reservoir.

Surgical Approaches

- Place hand and forearm in impervious stockinette, over wrap with ACE.
  - Take extra Mayo stand cover and create fenestration at the closed end.
  - Attach weighted clamp (e.g., Ochsner/Kocher) at this fenestration (to keep it open and dependent).
  - Place this dependent portion of the Mayo stand cover, with clamp, into a kick bucket to collect irrigation fluids.
  - Place extremity in normal opening of Mayo stand cover (Fig. 6-2).
  - Alternatively, use commercially available, triangular, irrigation fluid collecting drape.
- Posterior midline incision skirting the radial side of the olecranon (Fig. 6-3).

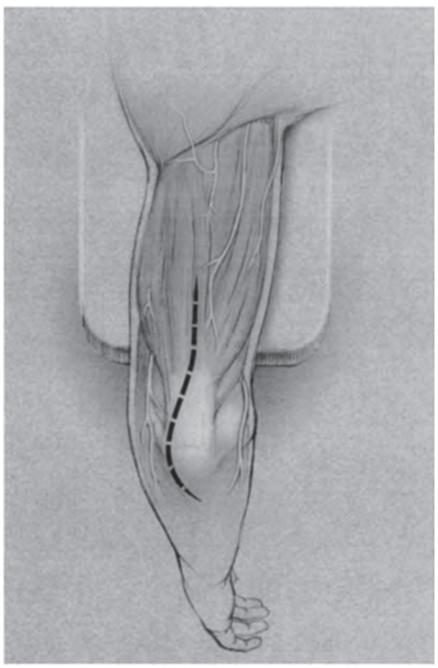


Figure 6-3. Posterior midline skin incision between the lateral and medial brachial cutaneous nerves, curving laterally around the olecranon. (Adapted from Schildhauer TA, Nork SE, Mills WJ, et al. Extensor mechanism-sparing paratricipital posterior approach to the distal humerus. *J Orthop Trauma*. 2003;17(5):374–378. With permission.)

- Develop medial and lateral soft tissue flaps.
  - Open in the midline and retract skin and subcutaneous tissues in flap.
  - Over the elbow and forearm, include the olecranon bursa in the radial flap, but exclude the anconeus fascia.
    - Medially, the flap is superficial to the fascia/tendinous insertion of the flexor-pronator muscle mass.
- Identify and protect the ulnar nerve and superior and inferior ulnar collateral arteries.
  - Consider using a vessiloop or small Penrose drain around the nerve (Fig. 6-4).

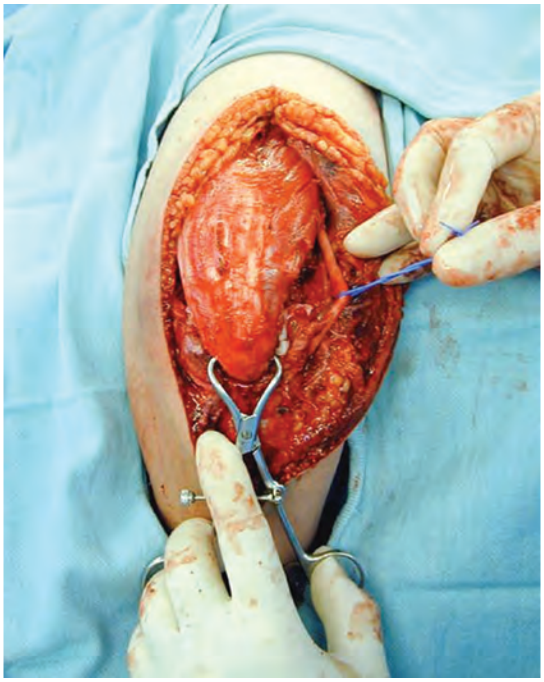


Figure 6-4. The ulnar nerve is protected with a vessiloop.

- If an olecranon osteotomy is not needed (Type A and Type C1 fracture patterns)
  - Elevate the triceps and anconeus off of the lateral and medial intermuscular septae to the posterior aspect of the humerus (Figs. 6-5 and 6-6).

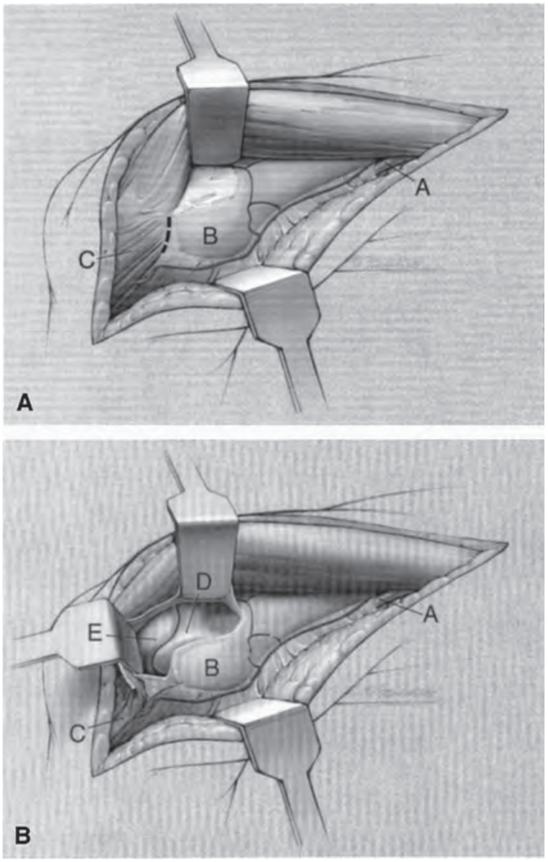


Figure 6-5. Lateral dissection along the lateral triceps border to the intermuscular septum with an elevation of the triceps muscle off the lateral humerus. In the proximal wound, the radial nerve can be identified (**top**). The deep dissection can be distally extended anterior to the anconeus muscle (*dotted line*). Lateral view presenting the arthrotomy. The anconeus muscle is elevated in conjunction with the triceps muscle (**bottom**). *A,* radial nerve; *B,* lateral epicondyle; *C,* reflected anconeus muscle, and capsule; *D,* trochlea; *E,* olecranon tip. (Adapted from Schildhauer TA, Nork SE, Mills WJ, et al. Extensor mechanism-sparing paratricipital posterior approach to the distal humerus. *J Orthop Trauma.* 2003;17(5):374–378. With permission.)

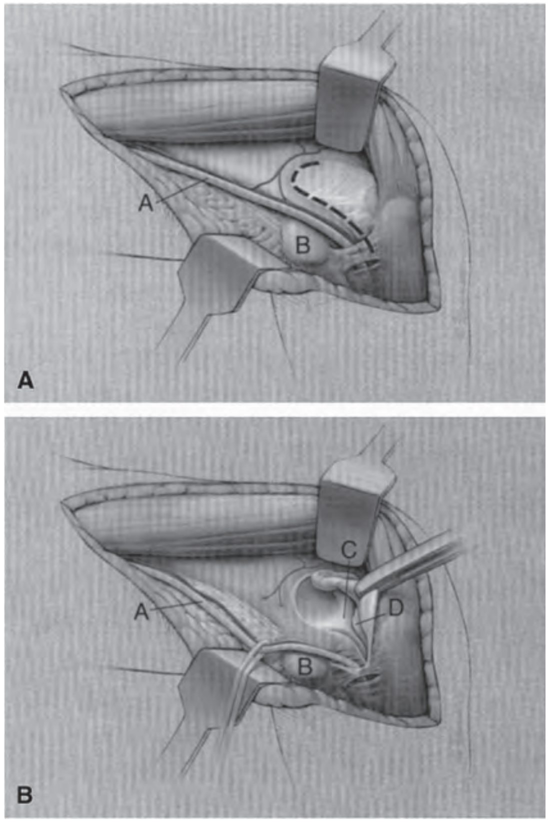


Figure 6-6. Medial dissection along the medial triceps border to the medial intermuscular septum. The ulnar nerve is released from the cubital tunnel and dissected distally to its first motor branch (**top**). Medial deep dissection and arthrotomy. The arthrotomy is performed posterior to the humeroulnar ligaments (**bottom**). *A,* ulnar nerve; *B,* medial epicondyle; *C,* trochlea; *D,* olecranon tip. (Adapted from Schildhauer TA, Nork SE, Mills WJ, et al. Extensor mechanism-sparing paratricipital posterior approach to the distal humerus. *J Orthop Trauma*. 2003;17(5):374–378. With permission.)

- Locate and protect the radial nerve and profunda brachii (deep brachial) artery and its branches (radial and medial collateral arteries).
- In the distal arm and elbow, elevate the anconeus off of the posterior aspect of the lateral epicondyle.
  - May dissect through the proximal portion of the anconeus, but avoid straying too radially or joint visualization becomes difficult.
- Perform lateral and medial elbow joint arthrotomies until the olecranon fossa, olecranon, posterior-inferior portion of the capitellum, and posterior trochlea are all visualized.
- A bone clamp placed on the proximal ulnar allows elbow joint distraction for the medial and lateral capsulotomy and improved joint visualization.

- If an olecranon osteotomy is needed, the paratricipital approach can be converted to an olecranon osteotomy.
  - Use an apex distal chevron osteotomy.
    - Place a 2.0-mm drill hole in the dorsal ulnar cortex at the anticipated apex under lateral fluoroscopy to ensure apex is at the appropriate position.
    - If preference is for modified tension band wire repair with intramedullary screw, consider predrilling and tapping the proximal ulna prior to osteotomy.
    - If preference is to repair the osteotomy with a tension band plate, drill at least one hole through the plate in each fragment to facilitate fixation during osteotomy repair.
    - Using a micro-oscillating saw with a thin saw blade and keeping the osteotomy shallow, allow for a controlled fracture of the articular (volar) subchondral bone and articular cartilage (break in tension).
      - This makes reduction easier and enhances its stability as it permits fracture interdigitation.
      - It also aids in the identification of complete healing postoperatively.

- Reflect olecranon, posterior fat pad, and triceps proximally.
  - Suturing the reflected olecranon and triceps to proximal skin or soft tissues aids in its retraction.
  - Wrapping or covering with a moist saline sponge will prevent desiccation (Fig. 6-7).

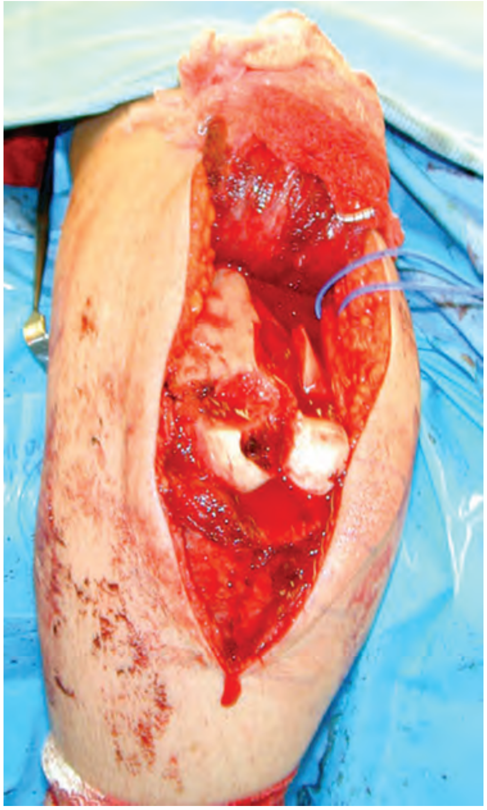


Figure 6-7. The olecranon osteotomy fragment is retracted with a moist laparotomy sponge.

Reduction and Implant Techniques

- For fractures with a simple intercondylar split, the joint reduction is usually performed first.
  - A large Weber clamp is useful to obtain an interfragmental compression when placed from lateral epicondyle to medial epicondyle or just below the medial epicondyle at the medial aspect of the trochlea's epicenter (Fig. 6-8).

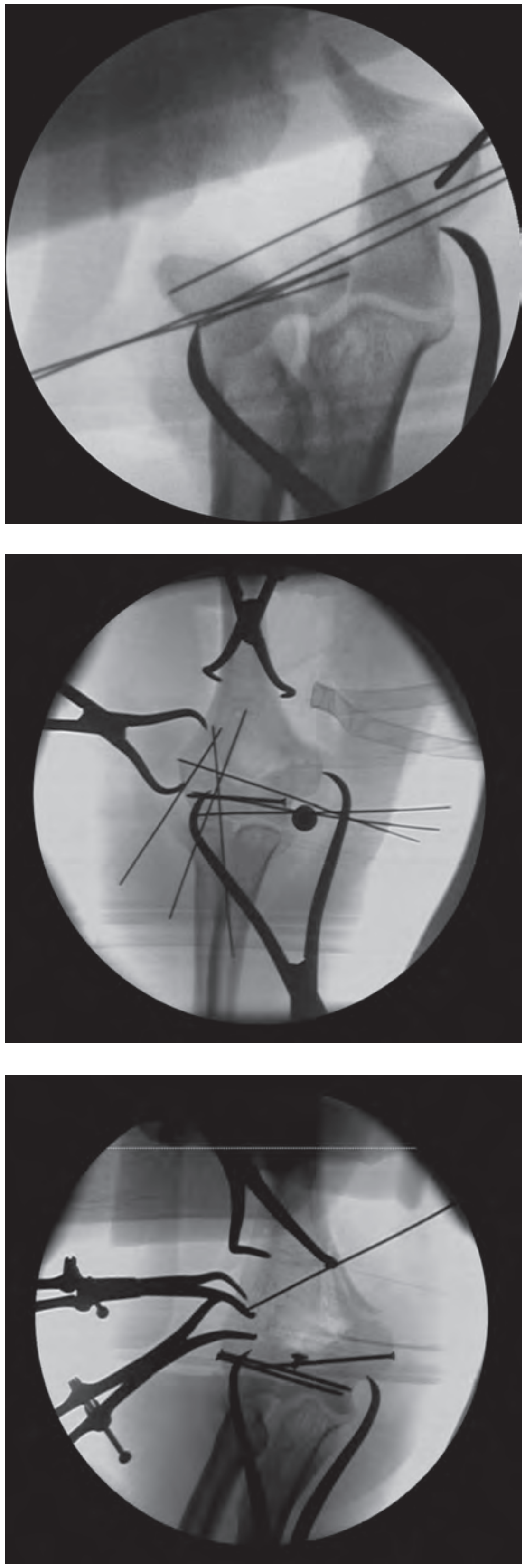


Figure 6-8. Several examples showing clamp placement between the trochlea and capitellum.

- Two transcondylar K-wires or a screw and K-wire are used for provisional stability, followed by definitive bicolumnar plate and screw fixation (Fig. 6-9).

Figure 6-9. Several case examples demonstrating definitive bicolumnar plate fixation of distal humerus fractures.

- For fractures with intercondylar comminution or bone loss, if associated with relatively simple epicondylar fracture patterns, the reduction of the medial and/or lateral epicondyles will aid in the reduction of the intercondylar components (in terms of length, width, and rotation).
  - Modified small Weber clamps may aid in the reduction when placed dorsally, medially, or laterally in unicortical 2.0- or 2.5-mm drill holes.
  - Provisional 0.062 inch K-wires can be inserted up the medial and lateral columns, from the distal aspects of the epicondyles, into the shaft.
    - These will usually provide sufficient stability to allow for definitive fixation without encumbering the plates.
  - Small osteochondral screws can be countersunk for articular fixation, but must be placed strategically to avoid transverse screws (Fig. 6-10).

Figure 6-10. Small osteochondral fragments stabilized with mini-fragment screws as the initial step.

- If comminution or bone loss of the medial or lateral epicondyles, consider supplementing the provisional axial 0.062 inch K-wire fixation with 2.0-mm plate(s) and screws prior to definitive plate and screw fixation (Fig. 6-11).

Figure 6-11. Two case examples with multifragmentary articular surfaces stabilized with provisional mini-fragment plates. The plates were left in place following a definitive plate fixation.

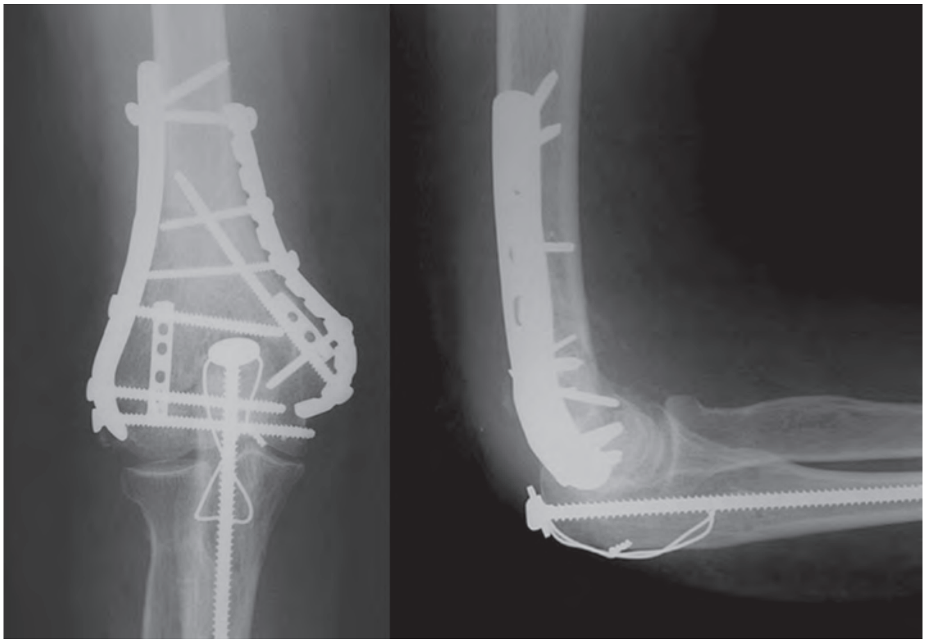


Figure 6-11. continued

- For fractures with supracondylar comminution, it is imperative that one of the definitive plates is at least a 3.5-mm compression plate or of equivalent thickness.
- Repair olecranon osteotomy with plate or modified tension band wire technique (Fig. 6-12).

Figure 6-12. Repair of olecranon osteotomy with periarticular plate.

- Repair triceps fascia, anconeus fascia, subcutaneous tissues, and skin.

Proximal Radius and Ulna Fractures

Chapter 7

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Sterile Instruments/Equipment

Proximal Ulna Fractures

- Dental picks
- Freer elevators
- Small Hohmann retractors (narrow and wide)
- Small point-to-point clamps
- Kirschner wires
- Implants:
  - 3.5/2.7-mm head screws
  - 2.0- and 2.4-mm plate and screw sets
  - Proximal ulnar periarticular plating sets
  - 18-gauge stainless steel cerclage wire or cable
  - 5.0-, 5.5-, 6.0-, or 6.5-mm cancellous intramedullary screw

Radial Head and Neck Fractures

- Dental picks
- Small point-to-point clamps
- Kirschner wires
- Implants:
  - 2.0- and 2.4-mm screw sets
  - Mini-fragment plate/screw set with T- and L-shaped plates
  - Radial head arthroplasty system of choice

Terrible Triad Injuries of the Elbow

- Dental picks
- Small point-to-point clamps
- Kirschner wires
- In-line ACL drill guide
- Implants:
  - 2.0- and 2.4-mm screw sets
  - Mini-fragment plate/screw set with T- and L-shaped plates
  - Nonabsorbable suture material (Ticron or Fiberwire)
  - Radial head arthroplasty system of choice
  - Suture anchors

Surgical Approaches

- *Dorsal extensile approach to the proximal ulna.*
  - For Monteggia fracture/dislocations, comminuted proximal ulna fractures, and olecranon fractures
  - Lateral or prone position
    - Drape affected arm over radiolucent arm board with the shoulder in a forward flexed (~90 degrees) and partially abducted (~90 degrees) position.
    - Verify that adequate C-arm imaging is possible prior to draping (Fig. 7-1).
      - The prone position provides improved C-arm access and imaging over the lateral position as there are fewer anatomical and positioning impediments (e.g., the opposite extremity, metal arm board support).

Figure 7-1. Lateral positioning for a proximal ulna fracture.

  - Skin incision located directly over subcutaneous border of the ulna, deviating radial to the olecranon process, and returning to the dorsal midline.
    - Avoids dissection of the olecranon bursa.
    - Places incision away from contact with desks and tables when extremity is resting on these surfaces.
  - Create full-thickness skin flaps radially and ulnarly to visualize the proximal ulnar shaft and olecranon process.
  - If visualization of the medial aspect of greater sigmoid notch (semilunar fossa) is required, the ulnar nerve should be identified in the cubital tunnel and protected.
    - Ensure that the path of the ulnar nerve is known, either by palpation or direct visualization.[1]
  - Avoid dissection of soft-tissue attachments to fracture fragments.
- *Posterolateral (Kocher) approach to the elbow joint.*
  - For terrible triad injuries and radial head fractures, and posterolateral elbow dislocations.
  - Supine position
    - Radiolucent hand or arm table.
    - Shift patient to the edge of the table so that elbow rests away from the junction of the hand table and OR table.
    - Prep and drape the entire involved upper extremity.
    - Be sure that the patient has adequate shoulder abduction and external rotation if access to the medial joint is required.
  - Two possible skin incisions to access the deep Kocher interval
    - Obliquely across the radial head and radiocapitellar joint.
    - Posterior midline incision used with distal skin incision located directly over the subcutaneous border of the ulna.

- Deviate radially around the tip of the olecranon.
- Return incision to central dorsal location just proximal to lateral epicondyle.
- Elevate a full thickness flap laterally (radially), sufficiently to locate the fascial septum separating the extensor carpi ulnaris and anconeus, and incise the fascia sharply just ulnar to the septum.

- Gently elevate anconeus off of the fascial septum, which often leads directly into the elbow joint if the capsule has been traumatically compromised due to the dislocation.
- In terrible triad injuries, the lateral humeral epicondyle will often be "bald" due to avulsion of the lateral ligament complex.
  - The superficial fascial layer may be intact and thus the injury may appear to have an intact lateral ligament complex.
  - Raising full thickness flaps will ensure that the full extent of the deep soft tissue injury is appreciated.
- Identify the annular ligament, lateral ulnar collateral ligament, and the origin of the mobile extensor mass.

Reduction and Implant Techniques

Radial Head Fractures

- Locate all fractured fragments of the radial head (reassemble to confirm restoration of full head circumferentially).
  - Check olecranon, radial, and capitellar fossae for any unaccounted fragments, or other fracture debris.
  - Take care while retracting distally over the radial neck and keep the forearm pronated.
    - This relaxes the posterior interosseous nerve (PIN) and rotates it into a safer position.
    - Do not place Hohmann retractors blindly around the radial neck or retract excessively, especially anteromedially.
  - If radial head is multifragmentary and fragments are displaced, remove displaced fragments and place on the back table in a saline moistened gauze or saline solution.
  - On the back table, attempt to reconstruct the radial head fragments such that they may either be stabilized to the intact portion of the radial head/neck, or sized appropriately for radial head arthroplasty.
    - Reassembling the radial head also confirms that all fracture fragments have been identified (Fig. 7-2).

Figure 7-2. The radial head is reassembled either in preparation for arthroplasty replacement (**left**), or for reduction and fixation (**right**).

- Determination of the height of the radial head implant should be made based upon AP and lateral fluoroscopic views of the elbow confirming that the articular surfaces of the coronoid (at the level of the trochlear groove) and radial head are at the same level.
  - On the AP view, the medial half of the ulnotrochlear joint should be concentric to avoid "overstuffing."
  - The joint space across the ulnohumeral articulation should be symmetric, accounting for the thickness of the articular cartilage on the coronoid portion of the greater sigmoid notch (Fig. 7-3).
- When the patient is supine, positioning of the arm for posterolateral access to the radial head causes an obligatory varus moment across the elbow.
  - This can improve access, but care must be taken to neutralize this stress when assessing the radial head height relative to the capitellum.

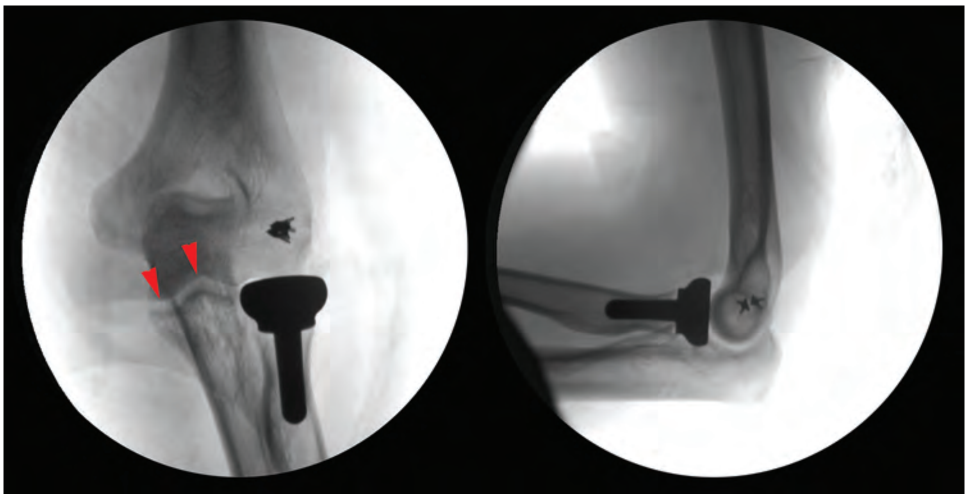


Figure 7-3. Radial head arthroplasty. To ensure that the radiocapitellar joint is not "overstuffed," the medial ulnotrochlear joint should be symmetric (**left**, *arrowheads*).

- The indication for radial head fixation versus arthroplasty is based upon intraoperative assessment of comminution, the ability to achieve an anatomic reduction with stable fixation of fracture fragments, and overall stability of radial head within the elbow joint.
  - In the setting of gross elbow instability associated with radial head fracture, secure fixation of the radial head is mandatory to maintain elbow stability during rehabilitation.
    - If it cannot be achieved, then radial head arthroplasty should be performed.

Olecranon Fractures and Transolecranon Fracture/Dislocations

- Fixation of the olecranon process
  - Modified tension band wiring
    - Only for noncomminuted simple transverse or short oblique fracture patterns proximal to the center of the greater sigmoid notch.
    - Either paired intraosseous K-wires or an intramedullary lag screw and washer may be used in combination with the tension band wire or cable.
    - Currently, plates are generally preferred over either tension band wire technique as plating provides secure fracture fixation with early ROM and a reduced chance of fixation failure.

- Olecranon and proximal ulnar plating (Fig. 7-4)
  - Unicortical drill holes in on either side of the ulnar crest allow for anchorage of medial and lateral pointed reduction clamps for concentric reduction force.
  - K-wires to provisionally stabilize plate to bone
    - The reduced fracture is then stabilized provisionally with two or more 0.062 inch K-wires placed across the fracture in an oblique fashion. Ideally these enter the medial and lateral proximal corners of the olecranon in an area that will not impede plate placement.
  - Alternatively a centrally placed point to point reduction clamp may be used to achieve an interfragmentary reduction
    - After provisional stabilization with two crossed K-wires, the centrally placed bone reduction clamp may be removed and the chosen plate is then applied to the proximal ulna relying on the two crossed 0.062 inch K-wires to maintain fracture reduction.
  - Small longitudinal split in triceps insertion allows plate to lie flush with bone to avoid hardware prominence and tendon necrosis
  - Unicortical screw is placed through proximal portion of the plate, usually at the bend of plate as it curves around the olecranon. If this is placed at 45 degrees to the long and vertical (proximal olecranon) axes of the plate, it will nestle the plate to the olecranon tip.
    - Ideally this screw will exert an equal force in the anterior and distal directions, orthogonal to the surface at the tip of the olecranon, thereby positioning the plate in intimate contact with the proximal ulna.
  - The second screw should be placed in the metadiaphysis, just distal to the fracture.
    - This screw is effective in neutralizing any anterior displacement of the proximal radius and ulna as is seen in Monteggia and transolecranon fracture dislocation patterns.
    - The plate's dorsal position will assist in neutralizing the deforming forces of the brachialis and biceps.

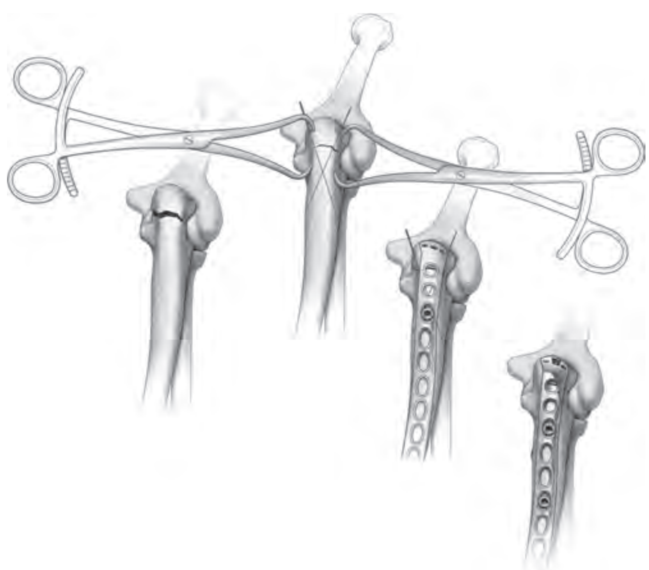


Figure 7-4. Typical reduction and fixation sequence for facilitating plate fixation of olecranon fractures.

- Save all articular and cortical bone fragments, even when displaced in surrounding soft tissues or loose in fracture hematoma, so that they may be used to as aids in achieving an anatomical reduction.
  - Place an appropriately sized K-wire into small articular or cortical fragments for joystick manipulation to assist with reduction.
- Use mini-fragment plates on the lateral or medial surface of the proximal ulna for provisional metaphyseal fixation (Fig. 7-5).

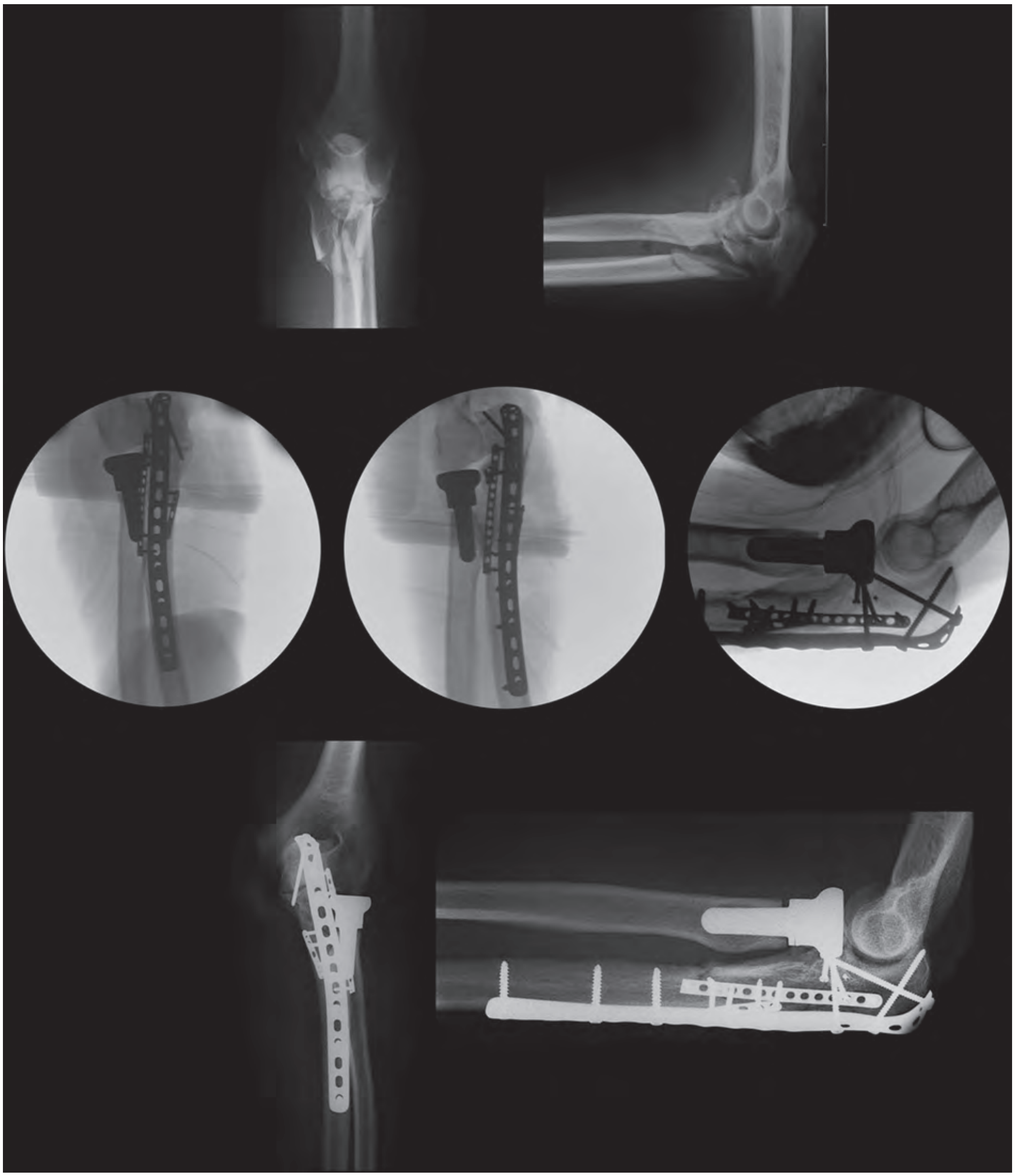


Figure 7-5. Mini-fragment plates are frequently used in the reconstruction of the metadiaphyseal component of complex proximal ulnar fractures.

- Restore the articular congruity of the greater sigmoid notch prior to reduction and compression of fracture lines in the dorsal ulnar cortex.
  - Visualization of the articular reduction is accomplished through mobilization of the elbow capsule radially and/or ulnarly off of the proximal ulna as needed.
  - Do not detach the collateral ligaments.
  - Use the humeral trochlea as a "template" for articular reduction of the greater sigmoid notch/olecranon.
  - Bone graft osseous defects, using structural autograft, allograft, or an osteobiologic substitute, and then reduce the main olecranon fragment to the reconstructed articular segment.
  - Place a screw from the posterior olecranon anteriorly towards the coronoid.
    - This screw can be subchondral to support the articular surface, if previously impacted.
    - This screw should end on the anteromedial ulna to avoid the proximal radioulnar joint (Fig. 7-6)
    - Alternatively, a long intramedullary screw can be inserted from this site or through one of the other proximal plate holes.
  - Place a bicortical screw into the proximal tip of the olecranon fragment to ensure rotational control and secure fixation, particularly when that fragment is small.
- By restoring the sigmoid notch in transolecranon fracture/dislocations, elbow stability is restored.
  - Ligament injuries are rare with this fracture pattern.
  - The proximal radioulnar joint remains reduced.

Figure 7-6. Transolecranon fracture/dislocation. The articular surface of the sigmoid notch was reconstructed initially, and supported with a subchondral screw into the coronoid. A bicortical screw was also placed into the tip of the olecranon.

Monteggia Fractures

- Provisionally reduce and stabilize the proximal ulna initially to allow for accurate sizing of radial head arthroplasty if necessary.
    - Anatomical restoration of ulnar length is also important in assuring stability and congruity of radio-ulnar and radiocapitellar articulations (Fig. 7-7).

Figure 7-7. Provisionally reducing the ulna is necessary prior to sizing the radial head arthroplasty to ensure proper height restoration.

- After radial neck cut has been made and trial components have been sized, disassemble the ulna and implant the definitive radial head prosthesis.
- Mini-fragment plates can be helpful to sequentially stabilize selected fracture lines and cortical fragments containing ligament insertions (Fig. 7-8).

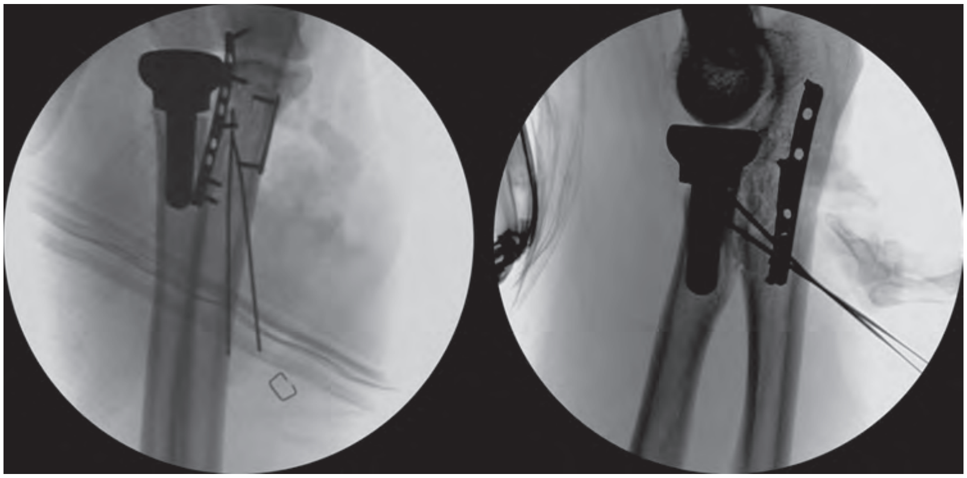


Figure 7-8. Following placement of the final radial head implant, the ulna is progressively reduced and stabilized.

- Finally, definitive ulnar fixation is applied (Fig. 7-9).

Figure 7-9. Definitive ulnar fixation.

- In most Monteggia fracture/dislocations, reduction and fixation of the proximal ulnar shaft fracture reduces the dislocated radial head indirectly.
  - The malreduction of the ulnar shaft can contribute to persistent subluxation or dislocation of the radial head after ulnar shaft reduction and must be addressed (Fig. 7-10).

Figure 7-10. In this Monteggia fracture/dislocation, the initial ulnar reduction attempt led to subluxation of the radiocapitallar joint, indicating ulnar malreduction (**middle row**, **left**). Improving the ulnar reduction resulted in a concentric radiocapitellar reduction.

Terrible Triad Injuries

- A wrist examination and wrist radiographs should be performed routinely, to identify an Essex-Lopresti injury pattern.
- Treatment of the radial head fracture with fixation or arthroplasty should be deferred until after the coronoid fracture has been addressed.
  - However, if the radial head cannot be repaired, then perform the neck cut for the arthroplasty to improve visualization of the coronoid fracture reduction.
  - With partial articular radial head fractures that will undergo open reduction and internal fixation, address the coronoid injury anterior to the radial head/neck (e.g., through the displaced fracture).
- May subluxate the elbow dorsally to facilitate visualization of the coronoid fracture bed for preparation of drill holes for sutures or screws.
  - Fracture reduction is carried out with the elbow joint reduced (Fig. 7-11).

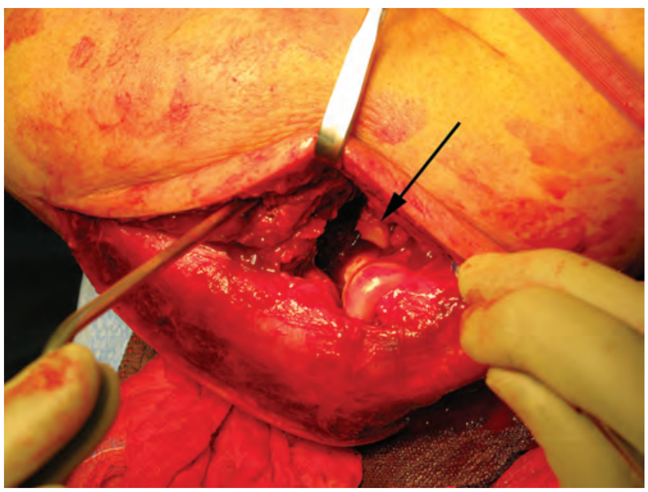


Figure 7-11. With the elbow joint reduced, the coronoid fragment can be visualized though the resected radial head defect (*arrow*).

- Evaluate the size of the coronoid fracture fragment by direct visualization to determine whether it is sizeable enough to accept screw fixation (e.g., 2.0- or 2.4-mm lag screws × 2), or whether it will require wire or suture fixation.
  - A head lamp is helpful.
- Clean the fractured surface of the proximal ulna and reduce the coronoid fragment(s) to it and maintain reduction with Kirschner wires and/or clamps.
  - Confirm cortical and articular surface reduction reads.
  - When performing this reduction, reduce the elbow and flex it to reduce tension on the displaced coronoid (Fig. 7-12).

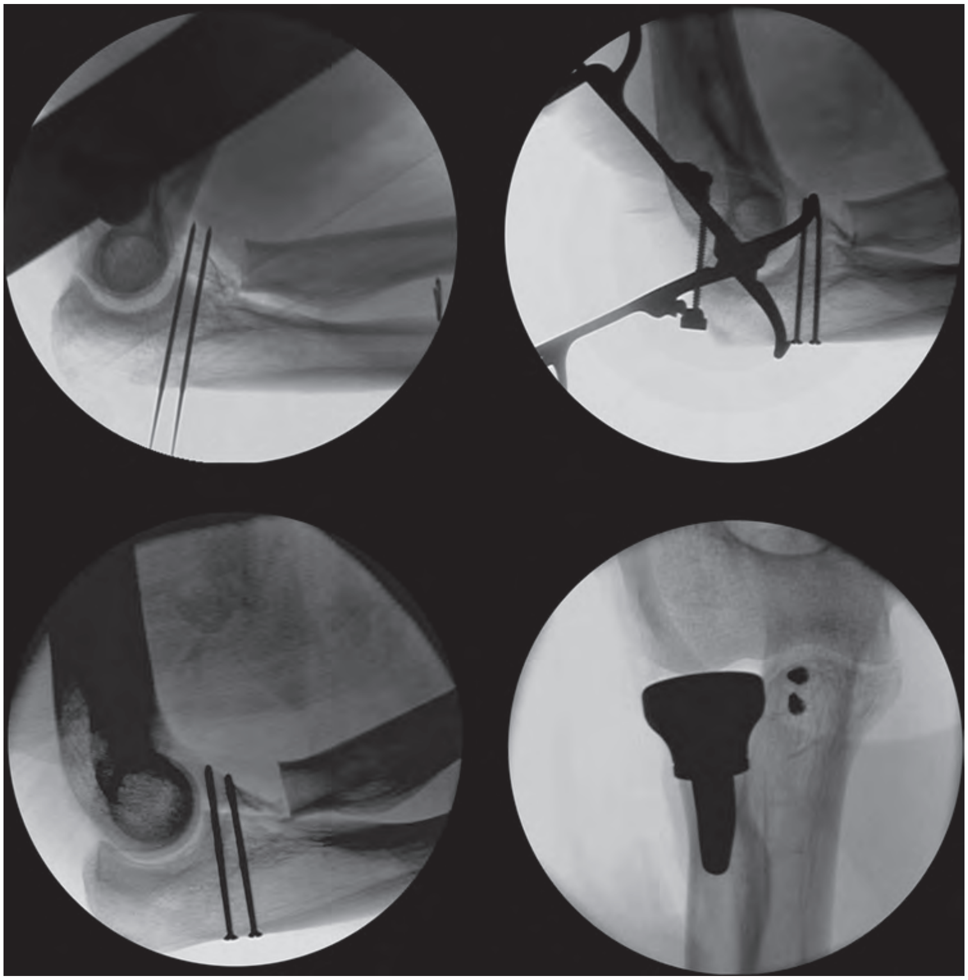


Figure 7-12. Through the radial head defect, the coronoid can be clamped with K-wires. Definitive screws are placed from the dorsal cortex of the ulna.

- Place drill holes through the dorsal ulna and into the coronoid fragment if possible for screw placement or for the passage of suture.
  - Drill hole placement for screw or suture fixation of the coronoid can be facilitated by the use of an in-line ACL drill guide to accurately position the gliding and pilot drill holes for lag screws or the two to three drill holes for suture(s) repair (Fig. 7-13).

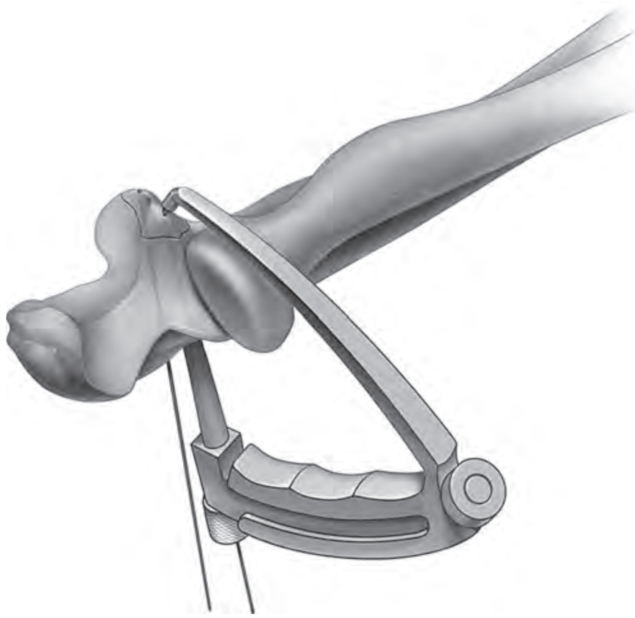


Figure 7-13. An in-line ACL guide can be used to assist in coronoid reduction and for directing drill holes from the dorsal ulna for suture fixation.

- For suture fixation of the coronoid and/or anterior elbow capsule use a durable, nonresorbable suture, such as Ticron or Fiberwire.
  - Drill two 2.0-mm holes with the in-line ACL drill guide (as above for screw fixation).
    - Suture should be passed through the ulna and the coronoid fragment.
      - Often helpful to also repair anterior capsule to extraarticular portion of coronoid.
      - If the bone fragment is too small or comminuted, then a suture placed into the anterior capsule and around the fragments will often suffice.
    - May use suture passer (e.g., Huson suture passer) to assist in passing suture from the coronoid through the proximal ulnar drill holes.
  - If using a nonmodular radial head replacement system or if operative fixation of radial head is facilitated through the visualization gained by elbow subluxation, perform those steps prior to definitive reduction of the elbow joint and securing of the coronoid sutures.
  - Secure fixation through the ulna into the coronoid fragment and/or anterior elbow capsule (Fig. 7-14).

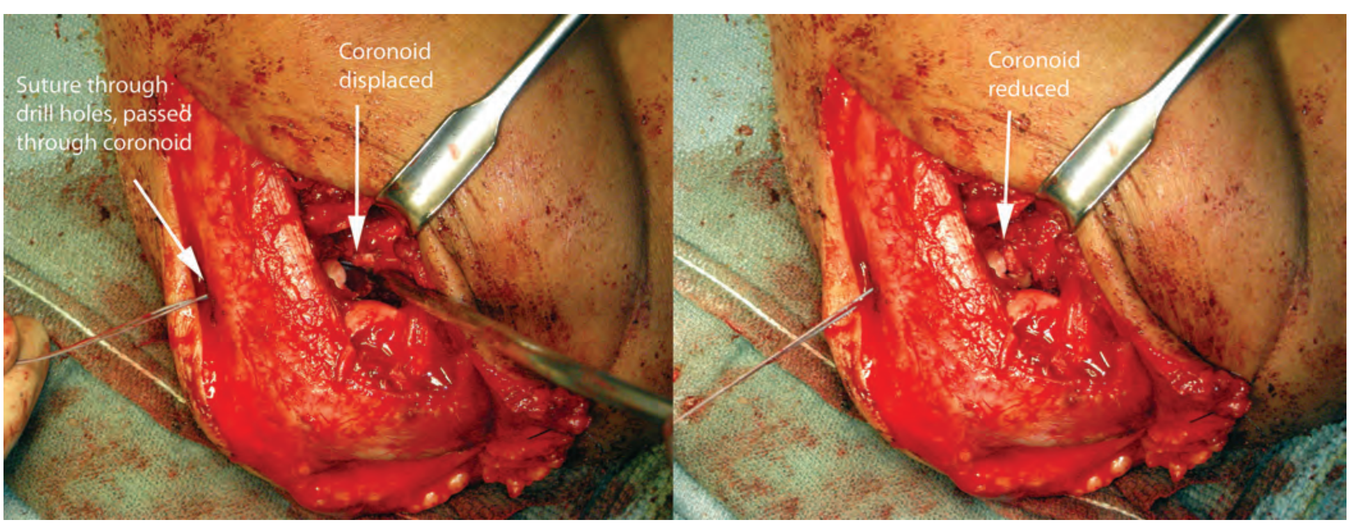


Figure 7-14. Sutures placed though the dorsal ulnar cortex can be used to capture and reduce the anterior capsule and coronoid.

- Tie sutures over cortical bridge between drill holes on the dorsal ulna with the elbow flexed.
  - Do not tie these sutures until radial head fixation or arthroplasty is complete, to avoid stressing the suture fixation or losing fracture reduction during implantation of radial head and reduction.
  - Several knots in heavy braided suture can cause discomfort when knot is subcutaneous.
  - To avoid this, make a small incision in the adjacent fascia, tuck the knots below the fascia, and oversew the fascia with absorbable suture.

- The repair of the lateral ligamentous complex is critical for elbow stability.
  - Identify the lateral ulnar collateral ligament (LUCL) remnant.
  - Gain sufficient visualization of extracartilagenous portion of lateral condyle and lateral epicondylar ridge to identify placement points for bone fixation through drill holes or with suture anchors within the lateral epicondyle.
  - Typically, one of these anchor points is placed at the center of rotation of the lateral epicondyle, and another proximally, on the epicondylar ridge for fixation of the extensor/supinator/anconeus conjoined muscle-fascial origins.
    - For the repair of the avulsed soft tissues from the lateral epicondyle, spread the epicondylar fixation point(s) apart from the center of the condylar fixation point sufficiently.
      - If bone tunnels or suture anchors are used, this will avoid interference of fixation points for each suture or suture anchors.
  - Determine the appropriate location/tension for LUCL repair, and perform suture fixation of the LUCL to its lateral epicondylar origin.
    - Avoid a varus or valgus moment across the elbow joint when tying these sutures to achieve anatomic ligament repair.
    - Forearm mid-pronation also allows the sutures to be tied with the appropriate ligamentous tension.

- Clinically and fluoroscopically, evaluate elbow joint stability in the flexion/extension, varus/valgus, and pronation/supination axes.
  - Posterolateral rotatory instability must be assessed.
  - Ulnohumeral stability is assessed on the lateral view with the elbow taken through a full arc of motion in flexion and extension, in both supination and pronation to confirm stability.
  - If any subtle subluxation is present in one position, note this so as to determine the most appropriate static and/or dynamic splinting parameters (e.g., range of motion; extension block bracing).
  - The elbow should be stable through an arc of at least 20 to 130 degrees with the forearm in neutral rotation prior to leaving the operating room.
    - The most unstable position typically is full extension, with the forearm supinated with posterolateral dislocations.
  - Do not force the last 10 to 20 degrees of extension motion intraoperatively to avoid disruption of the coronoid repair, particularly if suture fixation was used.
    - Passive extension using gravity is the best test for terminal extension.

- Clinically and fluoroscopically evaluate the radial length at the wrist, as well as the distal radio-ulnar joint (DRUJ) stability.
  - Instability at the wrist or DRUJ may occur in the presence of an Essex-Lopresti injury to the forearm.
  - Repair this if necessary.

- If elbow remains unstable, proceed to the medial elbow through the same skin incision to evaluate the integrity of the flexor-pronator origins, the medial collateral ligament, all of which may be persistent sources of elbow instability.

- Instability requiring medial ligament repair is uncommon, if the coronoid and medial aspect of the ulno-humeral articulation are unfractured or anatomically repaired and stable.
- Valgus instability alone is not an indication for medial ligament repair.
- If instability persists, verify the integrity and accuracy of the lateral repair.

Anteromedial Coronoid Facet Fractures

- Often require plating with a small four to six hole 2.0-mm plate, or an anatomically precontoured plate, with or without bone grafting of the articular impaction injury[2] (Fig. 7-15).

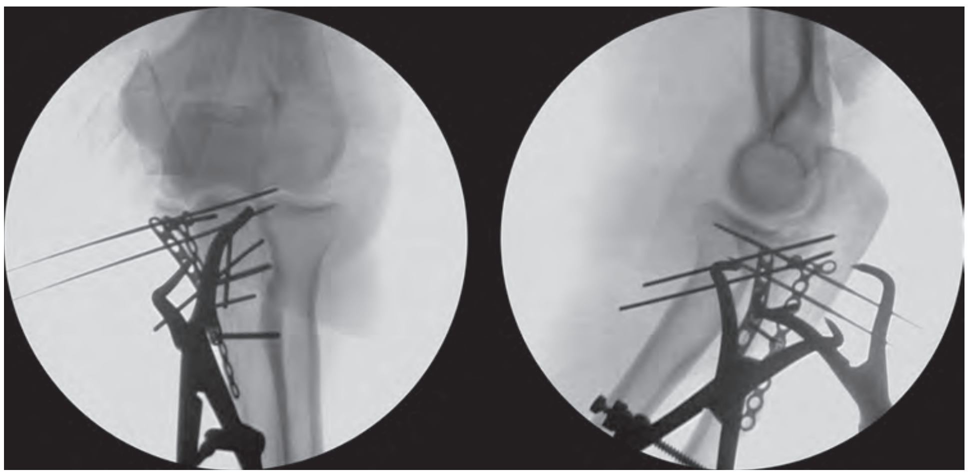


Figure 7-15. Reduction and provisional fixation of a displaced anteromedial coronoid fragment.

- Posterior midline incision used and then medial approach is used to access the coronoid base, medial collateral ligament (MCL) insertion, medial elbow capsule, and anteromedial facet.
  - Supine position.
  - Ulnar nerve identified, dissected free, and protected.
  - Elevate or split flexor-pronator mass taking care to avoid injury to the MCL.
- Suture anchors may be required for suture fixation of the MCL which is most commonly avulsed from its ulnar attachment onto the base of the coronoid process.
- Additionally, the lateral ligaments may be injured concomitantly, so stability assessment and ligament repair should be performed if necessary.
  - Can elevate lateral full thickness skin flap through same incision if lateral ligament repair is needed (see above for technical tips) (Fig. 7-16).

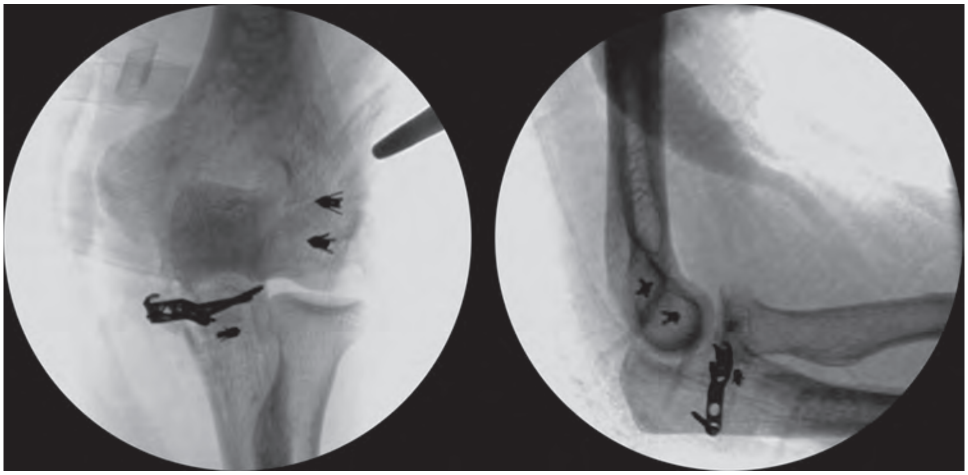


Figure 7-16. Anteromedial coronoid fracture with concomitant lateral ligament repair.

References

1. Lindenhovius AL, Brouwer KM, Doornberg JN, et al. Long-term outcome of operatively treated fracture-dislocations of the olecranon. *J Orthop Trauma*. 2008;22(5):325–331.
2. Ring D, Doornberg JN. Fracture of the anteromedial facet of the coronoid process. Surgical technique. *J Bone Joint Surg Am*. 2007;89(Suppl 2 Pt.2):267–283.

Chapter 8

Forearm Fractures

Raymond D. Wright

Sterile Instruments/Equipment

- 3.5-mm compression plates with 3.5-mm cortical screws
- 2.7-mm plates, especially for distal ulnar diaphyseal fractures
- 2.0- and 2.4-mm screws
- On-table plate bending press or hand-held bender and torquing irons
- Small pointed bone reduction clamps
- Small serrated bone reduction clamps
- K-wires and wire driver/drill

Patient Positioning

- Supine position with a radiolucent arm table.
- May use proximal arm tourniquet, if desired.
- Surgeon is usually seated in the patient's axilla.

Surgical Approaches

- Ulna: direct approach to subcutaneous border of ulna, use interval between ECU and FCU.
    - If the ECU or FCU has been traumatically disrupted, continue elevation of this muscle to avoid plating directly on the subcutaneous ulnar ridge.
    - Plate may be placed on the volar surface (under FCU), on the dorsal surface (under ECU), or directly on the subcutaneous border of ulna.
        - The ideal location should depend primarily on the fracture morphology.
- Radius: Volar Henry approach for exposure of the radius.
    - Allows extensile exposure from proximal to distal radial shaft.
        - Retract radial artery ulnarly.
    - Alternatively, through sheath and bed of FCR tendon, then retract radial artery radially.

Reduction and Fixation Techniques

- For both bone forearm fractures, usually approach and reduce the fracture with the simpler pattern first.
    - Restores length of the forearm anatomically.
    - This facilitates anatomic reduction with the other bone and subsequently facilitates reduction of the more complex fracture.

- Multiple independent 2.0- or 2.4-mm lag screws are useful for fractures with comminution (e.g., butterfly, segmental). After interfragmentary lag screw fixation, a neutralization plate is applied spanning the area of injury.
- Usually place plates on the volar surface of the ulna (under FCU, in the flexor compartment) to avoid implant irritation as patients rest their forearms on their direct ulnar border.
  - However, if either extensor carpi ulnaris or the flexor carpi ulnaris is stripped/disrupted more than the other, this muscle should be elevated preferentially.
  - The plate should be placed under the elevated muscle, preserving the soft tissue attachments and hence, the blood supply of the intact muscle (Fig. 8-1).

Figure 8-1. Ulnar plate placed on the flexor surface.

- For distal one-fourth ulnar fractures, consider a 2.7- or 2.4-mm compression or locking plate, especially for individuals of small stature or with osteoporosis.
  - Hole spacing of the plate will allow more points of fixation in a short distal segment.
  - Additionally, a 2.7-mm plate may have a better coronal plane fit than a 3.5-mm plate (Fig. 8-2).

Figure 8-2. A segmentally comminuted ulnar fracture stabilized with two plates. A smaller plate was used for distal ulnar shaft fracture as it permitted fixation with more screws and offered a lower profile plate fit.

- Once length and stable fixation is obtained in one bone, the wound should be closed prior to performing the second approach to the other forearm bone.
  - In acute trauma, generally only the skin and subcutaneous tissues are closed over the plate, to avoid compartmental syndrome.
  - However, in subacute fractures, consideration may be given to closing the fascia of the FCU to the fascia of the ECU over the border of the ulna.
  - If an anatomic reduction cannot be verified (e.g. in a comminuted fracture), the first incision may be left open to allow adjustment after reduction and fixation of the other bone.

- For segmental radial shaft fractures, for example, with distal extension, consider applying two overlapping plates.
  - Reconstruct the anatomic radial bow.
  - Fully supinated AP view with contralateral comparison is helpful to confirm symmetry of radii.
  - Additionally, account for several degrees of apex dorsal bow in contouring plate(s) (Fig. 8-3).

Figure 8-3. Overlapping plates for a segmental radius fracture with distal extension. The distal plate is a thinner buttress plate, and shaft is stabilized with a thicker compression plate.

- A plate bending press can be used to bend a 3.5-mm LC-DCP "on the flat" to contour the plate to match the radial bow and to allow a segmentally comminuted fracture to be stabilized with a long plate placed on its volar surface (e.g., 12 to 18 holes) (Fig. 8-4).

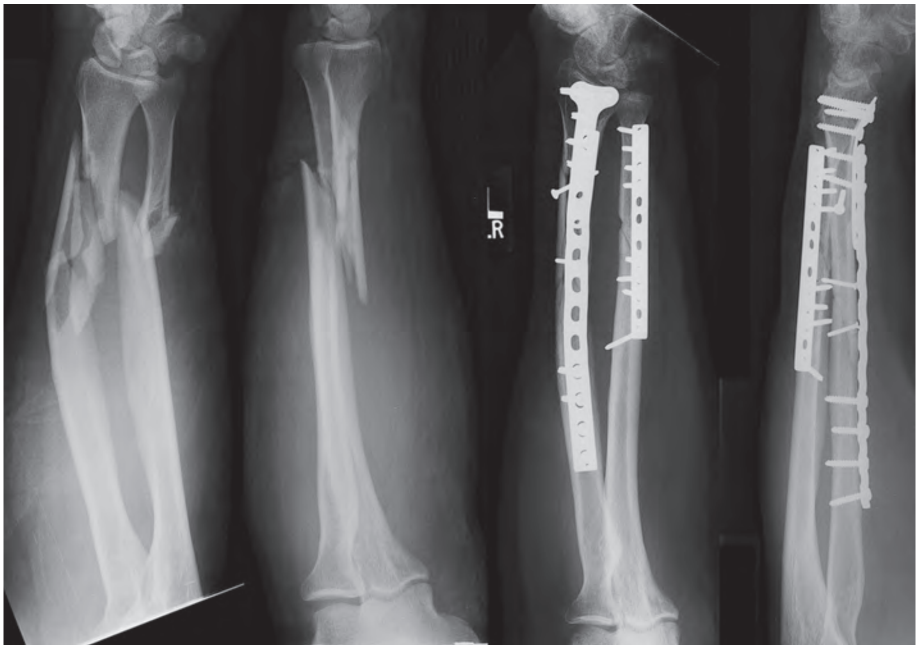


Figure 8-4. A 12-hole 3.5-mm compression plate can be contoured to match the radial bow. In this case, the 12-hole plate overlaps a short plate buttressing the distal radius. The contouring may also be achieved preoperatively using a skeletal model so that only a minimal amount of additional contouring is required intraoperatively.

- If segmental comminution is spanned using a bridge plating technique, plate contouring may not be necessary.
  - When long straight plate is applied to the volar aspect of the radius in a bridge plating mode, it should be translated slightly radially at each end, so that it is centered over the medullary canal of the radius in its central portion.
  - This will permit bicortical screws to be inserted in both fracture fragments, close to the fracture and at each end of the plate.
    - Because the radius is wider distally than proximally, the plate can be translated radially in its distal extent to a greater degree than it can be translated proximally.
  - This technique allows for restoration of the anatomic radial bow (Fig. 8-5).

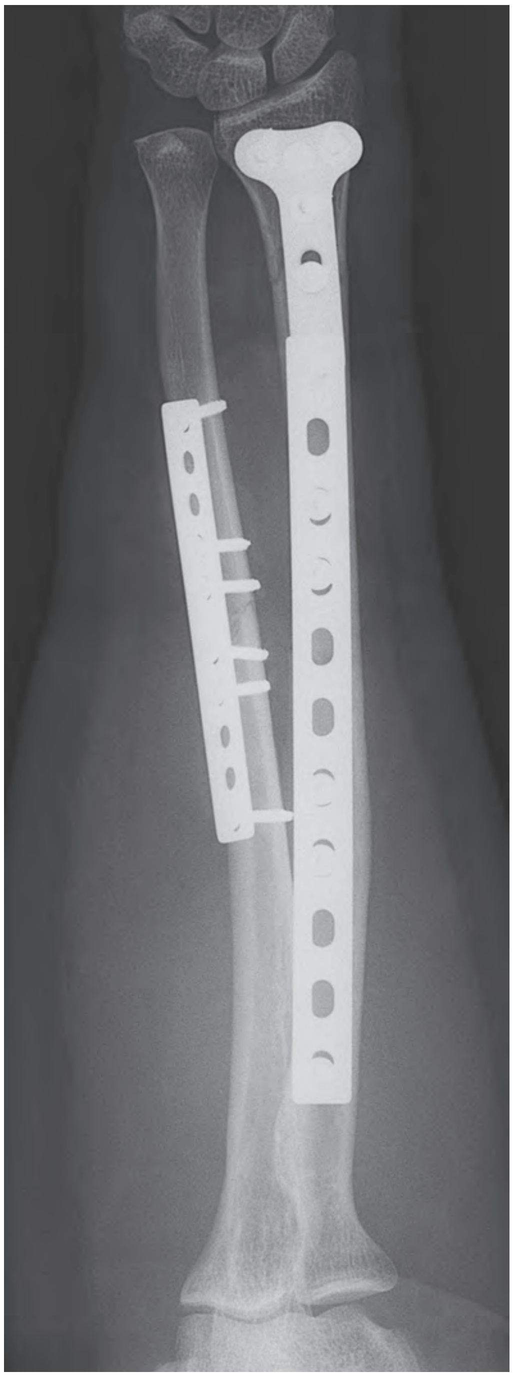


Figure 8-5. If a straight plate is placed over a long curved segment of bone, and the radial bow is restored, the plate should be translated slightly radially so that it overlies the bone and not the interosseous membrane. This will permit the insertion of bicortical screws though nearly any hole in the plate.

- Alternatively, use a long anatomically contoured meta-diaphyseal plate for the radius with the concomitant restoration of radial bow (Fig. 8-6).

Figure 8-6. A segmental forearm fracture with a distal fracture line treated with an anatomically contoured plate assists with the restoration of anatomical radial bow.

- Sometimes a mismatch between the contour of the plate and the surface of the bone will cause a malreduction when the screws are tightened (Fig. 8-7).
  - This is usually a torsional problem and can be avoided by initially stabilizing the plate distally to the "flattest" volar portion of the radius.
    - If the flat undersurface of the plate is perfectly parallel to this flat osseous surface (after placing two or more screws through the distal portion of the plate), then screws placed perfectly orthogonally to the plate through the holes proximal to the fracture will not cause bone rotation as these screws are tightened.

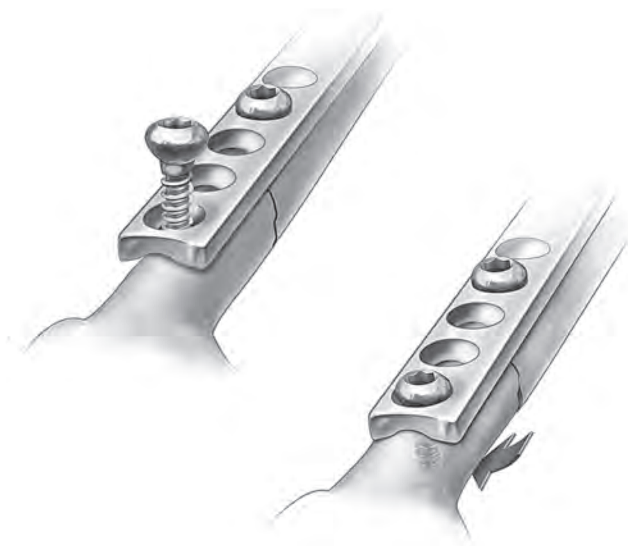


Figure 8-7. Due to the relatively small ratio of the plate width to forearm bone shaft width, plate-derived malreductions can occur easily (*arrow*). Care should be taken to place the ends of the plate centrally on the bone, and to place the plate on the flat portion of the radius to minimize this effect. If screw tightening causes fracture malreduction, this screw should be loosened and a different screw placed first in that fragment.

- Additionally, clamps placed on the plate near the fracture and their subsequent replacement by screws will minimize the torsional and translational malreductions.

- In oblique fracture patterns, it is preferential to place the first screw in the plate that creates an acute angle "plate-bone axilla."
- If the plate contour is acceptable and an anatomic or nearly anatomic provisional reduction has been achieved, place the far screws on both sides of the plate first, accommodating for the radial bow.
  - The fracture pattern must be amenable to this technique (e.g., transverse or segmentally comminuted).
  - This allows the plate to be centered precisely on the bone, so that all screws are bicortical, along the length of the plate.
  - Screws can be placed in compression mode but not fully tightened.
  - Clamps can then be placed near the fracture site to "fine tune" the reduction (usually translational), followed by tightening of screws for fracture compression (Fig. 8-8).

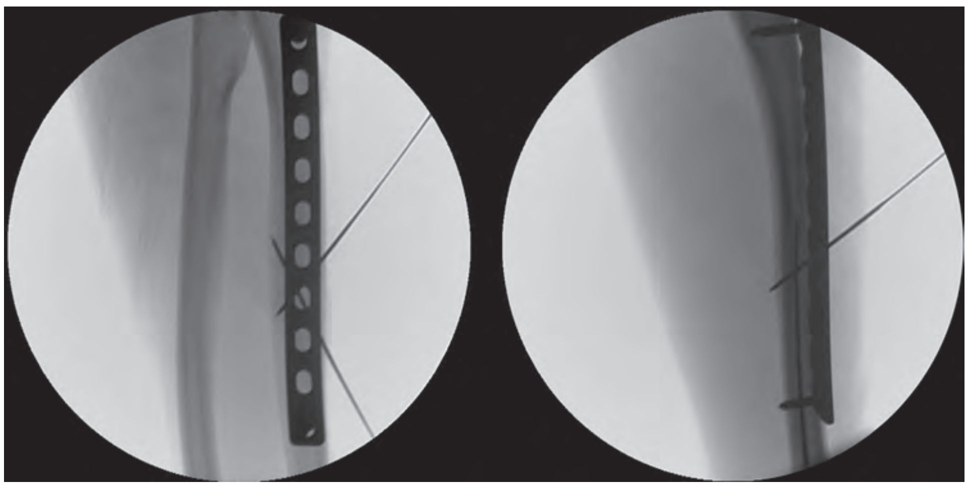


Figure 8-8. With a nearly anatomical reduction stabilized by crossed K-wires, screws are placed at each end of the plate. One is placed in a neutral mode, and the other in a compression mode. The screws are not fully tightened. The fracture reduction is then fine tuned under the plate and the screws are tightened, providing interfragmentary compression, after achieving an anatomical reduction.

- Alternatively, place small bone reduction clamps so as to straddle each end of the plate such that the plate is contained between the two "arms" of the clamp.
  - This centers the plate on the bone directly.
  - The small serrated bone reduction clamps work best in this application.

- For long segmental fractures, particularly with distal extension, AO wrist fusion plates allow for a low profile distal implant with appropriate screw hole clustering (Fig. 8-9).

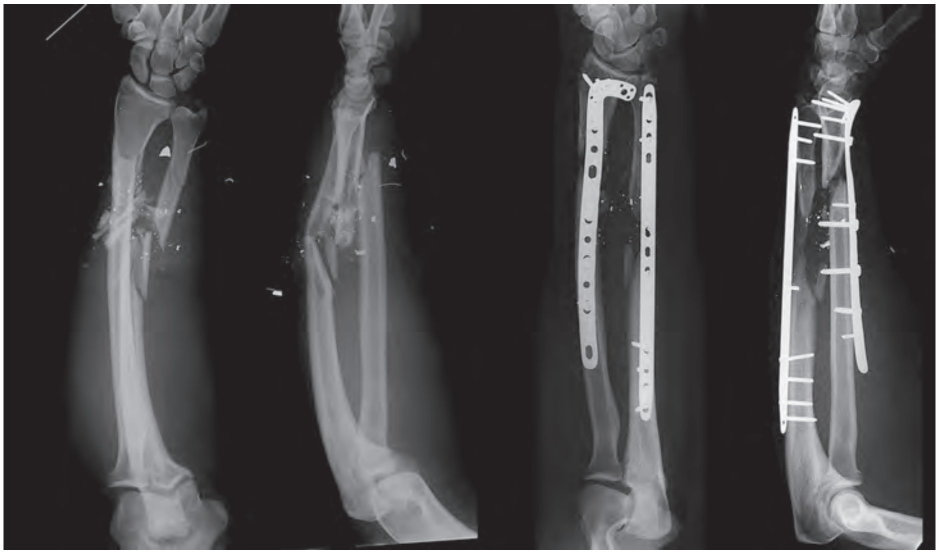


Figure 8-9. A wrist fusion plate for a segmental ulnar fracture with bone loss.

- In proximal radial shaft fractures, avoid placement of the plate too ulnarly on the bicipital tuberosity, since it may cause impingement of the biceps tendon insertion (Fig. 8-10).
  - Range of motion should be checked, particularly in pronation, prior to closing.

Figure 8-10. Proximal radial plates should be placed so as to avoid the bicipital tuberosity. In this position, the plate is more likely to impinge on the proximal ulna in full pronation. This plate should have been translated more radially in its distal extent. Doing so would have allowed for screw placement in its central portion.

- For comminuted proximal ulnar shaft fractures, removing the proximal (olecranon) extension of a periarticular precontoured plate allows for a better plate fit over the diaphyseal portion of the plate.
  - This is particularly helpful in revisions, when a new plating surface over the dorsal ulnar spine is selected (Fig. 8-11).

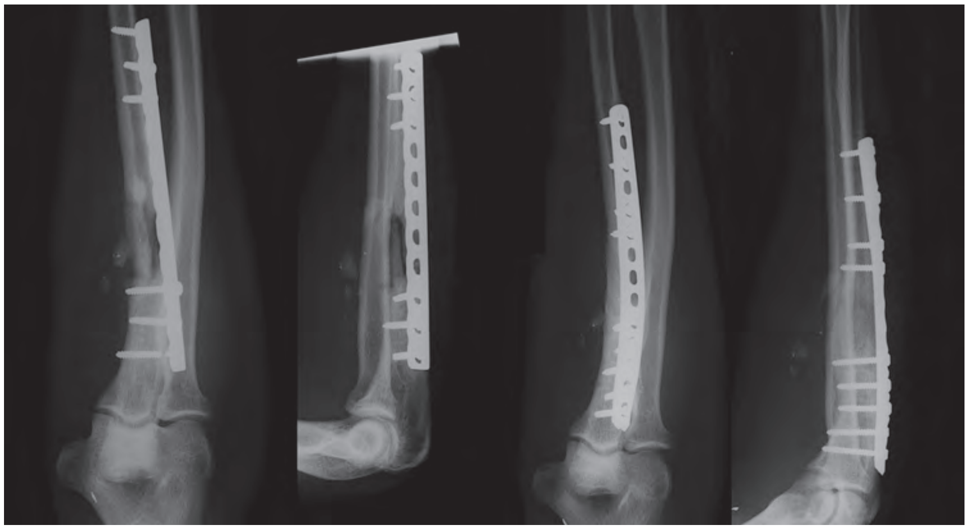


Figure 8-11. In this revision case, the first two radiographs show a compression plate applied to the proximal ulna, under the ECU. This plate was removed because of inadequate fixation to the proximal fracture fragment. The plate was replaced with an anatomically contoured periarticular proximal ulnar plate applied to the dorsal, subcutaneous border of the ulna. The proximal olecranon portion of the plate was removed as sufficient fixation could be achieved without this portion. This may be beneficial as the olecranon portion of a dorsal plate is often subcutaneous and has the propensity to cause patients discomfort in this location.

Chapter 9

Distal Radius Fractures

Sarah Pettrone
Douglas P. Hanel

Sterile Instruments/Equipment

- Finger traps
- Sterile rope for on-table traction
- Small pointed reduction clamps ("Weber" clamps)
- Implants
    - External fixator if necessary
    - Small fragment plates and screws, locking or nonlocking (distal radius-specific helpful but not essential)
    - Mini-fragment screws for free fragments
    - Wrist fusion plate, 3.5-mm locking plates, or custom locking plate made specifically for spanning technique
- K-wires and wire driver/drill

Positioning

- Supine on a radiolucent hand table.
- Bring the patient to the lateral edge of the bed.
- Center the shoulder/elbow/hand on the hand table, with the shoulder abducted 90 degrees.
- Place a pneumatic tourniquet on the ipsilateral arm, if desired.
- A sterile traction device may be applied after draping (Fig. 9-1).

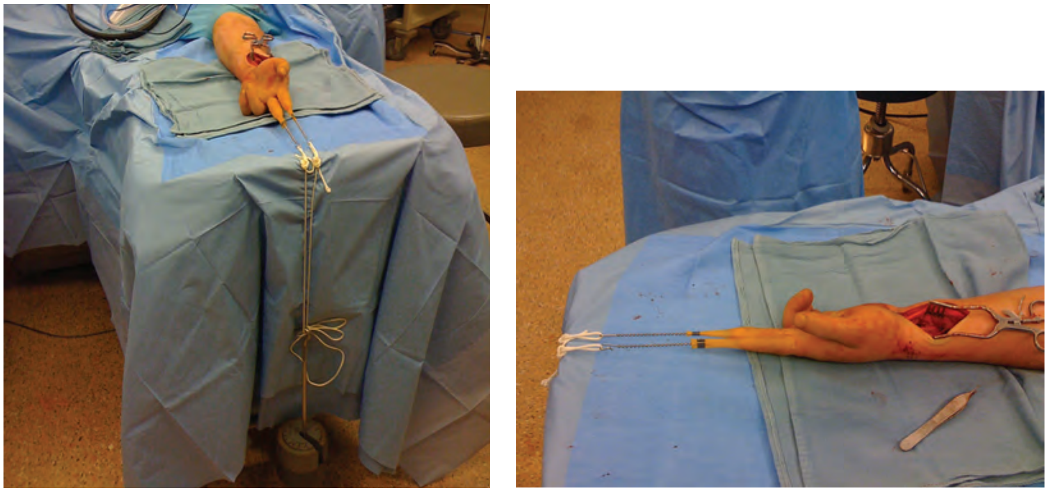


Figure 9-1. A sterile traction device for reduction assistance. Two "overhand" knots are tied at the ends of a 3 ft (100-cm) rope. One end is attached to finger traps, and 10 lb of weight is hung from the loop of the rope at the other end.

Reduction and Fixation Techniques

- Typical reduction maneuvers (described by Agee).
  - Longitudinal traction to restore length.
  - Palmar translation of the hand-carpus, relative to the forearm, restores palmar tilt and demonstrates volar instability, when present.
  - Slight pronation of the hand relative to the forearm, combined with ulnar deviation, corrects the supination deformity of a great majority of distal radius fractures.
- After reduction maneuvers, repeat fluoroscopic fracture assessment (AP, lateral, and oblique).
- Determine the fracture involvement of the three columns of the wrist (Rikli and Regazzoni).
  - Medial—ulnar head.
  - Intermediate—sigmoid notch, volar, and dorsal ulnar lunate fossa, lunate fossa dye-punch.
  - Lateral—volar and dorsal scaphoid fossa, and radial styloid.
  - Assess metaphyseal comminution.
- Determine the overall fracture stability.
  - Stable fractures are generally defined prior to reduction.
    - No articular step off or gap >2 mm
    - No metaphyseal comminution >1/3 of AP width (on lateral projection)
    - No involvement of the volar medial corner (Critical Corner)
    - Stable distal radial ulnar joint (DRUJ)
  - All other fractures are considered unstable and are indicated for operative fixation.
    - Also, consider whether there is adequate bone quality to allow pin implant purchase.
- Treatment of stable fractures.
  - Cast or splint immobilization
    - If fracture reduction tenuous, then long arm with forearm in supination, otherwise short arm.
    - Wrist in neutral or slightly extended position.
    - Check X-rays weekly for a minimum of 3 weeks.
    - Compare the most recent X-ray with the immediate postreduction film.
      - Comparing X-rays from one week to the next can result in failing to recognize gradual loss of reduction. Follow up X-rays must be compared to the initial reduction films.
    - If reduction becomes unacceptable, then proceed to re-reduction and fixation.
- Three basic types of fixation for unstable fractures.
  - Closed manipulation with percutaneous fixation, with or without external fixation.
  - Open reduction with large plates for large fragments.
  - Open reduction with fragment-specific implants, also referred to as "column specific" or "fragment specific."
- Closed techniques.
  - Percutaneous K-wire (interfocal through fracture fragments)
    - 1.5 mm or 0.062 inch
    - At least two pins, one in the radial column and the other in the dorsal aspect of the intermediate column (either through Lister's tubercle or between fourth and fifth dorsal compartments)
  - Percutaneous K-wire (intrafocal through fracture site)
    - The Kapandji technique of intrafocal pinning involves placement of biplanar K-wires.
      - Introduce a coronal plane K-wire into the fracture site in a radial to ulnar direction on the AP radiographic view.
      - A second sagittal plane K-wire is placed into the fracture site in a dorsal to volar direction.

- Once in the fracture site, the wires are used as a lever to elevate the distal fragments, restoring the radial inclination, length and volar tilt.
  - The wires are then driven into the opposite cortex of the radius.
  - Supplemental K-wires may be inserted to secure the fracture reduction and improve the fixation stiffness (Fig. 9-2).

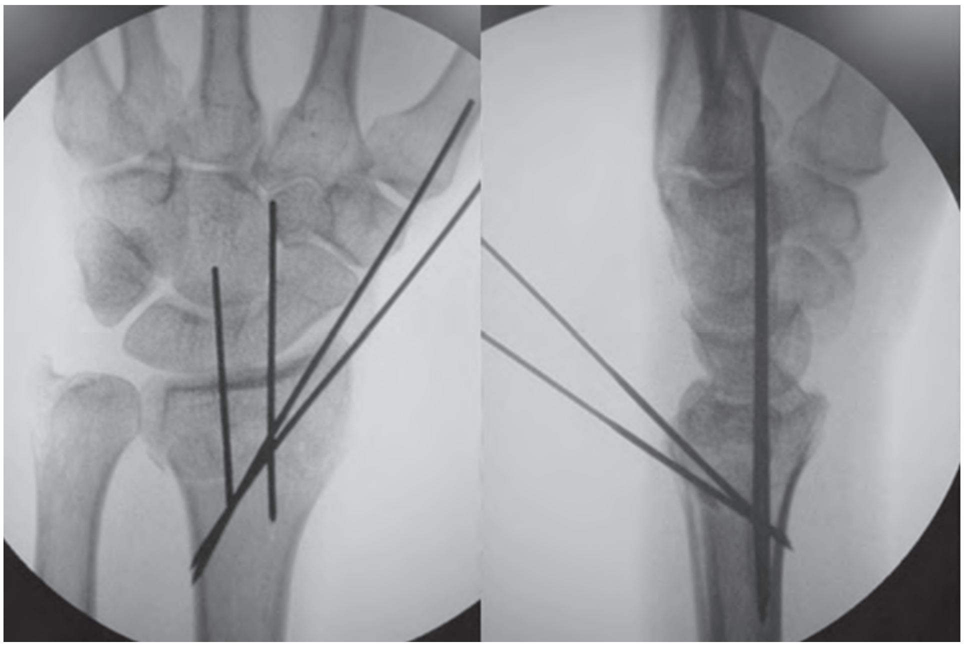


Figure 9-2. AP and lateral radiographs demonstrating the combined intrafocal and interfocal percutaneous pinning. Two pins were placed using the Kapandji technique to restore the volar tilt. Two additional percutaneous pins were placed in the radial styloid.

- Supplemental fixation (external fixation) is often required in older patients or in those with poor bone quality.

- Wrist joint spanning external fixation
  - Bridging external fixation may be used as a temporizing measure or as a definitive fixation for distal radius fractures.
  - Indicated for severe open fractures with soft tissue defects, as a temporizing measure in a polytrauma patient, unstable extraarticular fractures, and non-displaced intra-articular fractures.
  - Spanning external fixation may be combined with internal fixation techniques to maintain length and added stability with internal fixation.
  - Contraindicated as isolated fixation of displaced intra-articular fractures, unless those fractures are irreparable and serves as a preamble to fusion.
  - The reduction maneuver described by Agee is performed (described above).
  - Pin placement.
    - Exposure to bone and soft protection is required.
    - Most fixator systems have a drill guide to ensure placement of parallel, bicortical pins spaced 3 to 5 cm apart.
    - Free hand systems also work well, although less convenient.
    - Forearm pins are placed in the bare area of the radius just proximal to the muscle bellies of the abductor pollicus longus (AbPL) and extensor pollicus brevis (EPB).
      - This is approximately 10 to 12 cm proximal to the radial styloid.
      - A 3 to 5 cm dorsal radial incision is made just proximal to the EPB and AbPL.
      - Using the interval between the extensor carpi radialis longus (ECRL) and the extensor carpi radialis brevis (ECRB), the superficial radial nerve is protected.

    - The interval between the ECRL and BR can also be used but has an increased risk of injury to the superficial branch of the radial nerve.
  - Hand (distal) pins are placed in the second metacarpal, parallel to the proximal pins.
    - The more proximal pin is placed through the metaphysis of the second metacarpal.
    - If this pin does not have adequate purchase, advance it through a third cortex into the third metacarpal.
    - The more distal pin is placed in the diaphysis of the second metacarpal.

- Fracture length and wrist alignment are restored with traction and fixator clamps, and bars are applied.
- After the fixator is applied, examine the midcarpal and radiocarpal joints to be sure that the extremity is not overdistracted.
  - The fingers should fully flex and extend without excessive tightness.

- Residual dorsal angulation is difficult to correct.
- But can be managed by palmar translation of the hand relative to the forearm, prior to tightening the clamps and bars.
  - Increased traction often worsens the dorsal angulation.
  - Supplemental K-wires used as joysticks may be necessary to achieve reduction.

- Intra-articular depression.
  - Limited internal fixation may be necessary to reduce and maintain articular fragments (Fig. 9-3).

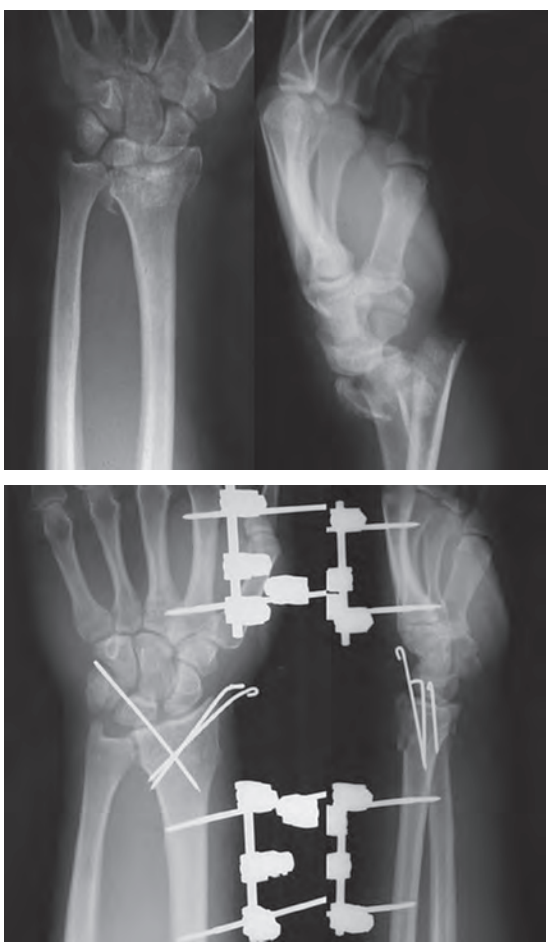


Figure 9-3. Compression fracture involving all three columns, treated with closed reduction, percutaneous pin fixation, and external fixation. Final radiographs taken 2 years after injury demonstrated healing in accurate position.

Figure 9-3. continued.

- Nonspanning (joint sparing) external fixation
  - Indicated for unstable extraarticular distal radius fractures.
  - Contraindicated when the distal fragments are too small for pin placement.
    - At least 1 cm of intact volar cortex is required for pin purchase.
  - A small external fixation set is recommended with 2.5-mm threaded tip pins.
  - A transverse incision is made over Lister's tubercle, tendons adjacent to the tubercle are retracted.
  - The dorsal cortex is predrilled and threaded tip pins introduced.
  - The pins are placed slightly convergent in the sagittal (dorsal to palmar) plane.
  - It is critical that the pins purchase the volar cortex.
  - Alternatively, one pin may be placed from dorsal to volar as described above and a second pin may be placed in the subchondral bone, from radial to ulnar.
    - This pin cannot penetrate the medial cortex of the radius, the sigmoid notch.
  - The proximal pins are placed proximal to the muscle bellies of the EPB/AbPL, in line with and between the tendons of the radial wrist extensors.
  - The pins in the distal fragment are used to manipulate the fragment and reduce the fracture.
  - A standard frame is then applied (Fig. 9-4).

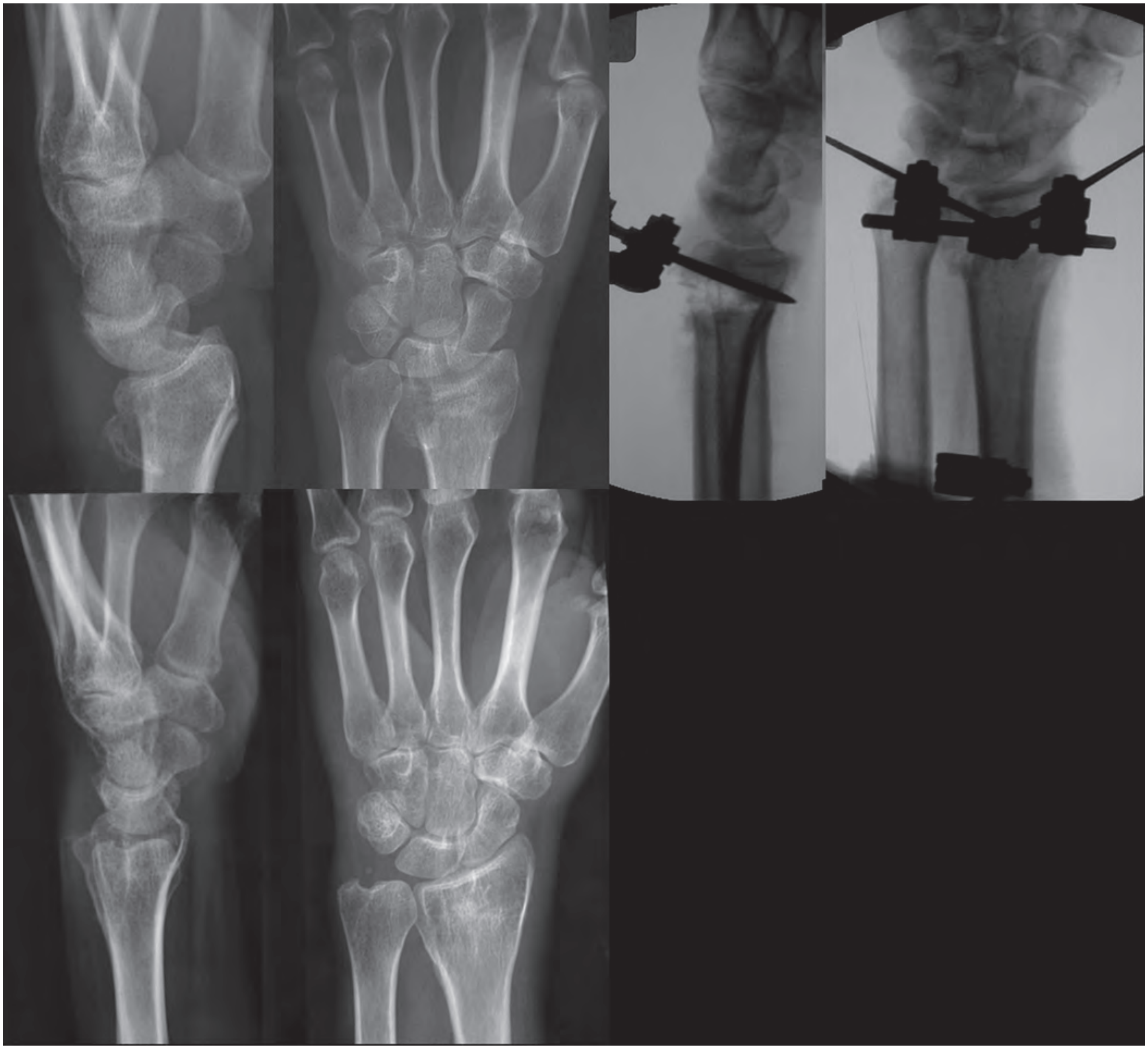


Figure 9-4. Example of a joint sparing external fixator for an extraarticular distal radius fracture.

- Open techniques
  - Surgical approaches
    - Volar "FCR" approach (also called "modified Henry's")
      - Most extensile for application of volar plates to all but volar medial corner, used for the great majority of radius fractures and volar plating techniques.
      - Longitudinal incision centered over the flexor carpi radialis (FCR).
      - Incision may be curved 45 degrees radially at the level of wrist crease.
      - Incise the sheath of the FCR, retracting the FCR medially and the radial artery laterally.
      - Avoid the palmar cutaneous branch of the median nerve by staying radial to the FCR.
      - A longitudinal incision is made in the floor of the FCR sheath.
      - Proximally, the flexor pollicus longus (FPL) is retracted ulnarly.

- Distally, the pronator quadratus (PQ) is elevated sharply off the radial border of the radius.
- The insertion of the brachioradialis (BR) is divided.

- Volar Henry's approach
  - Most extensile for application of fragment-specific fixation to radial styloid volar, lateral or dorsal, most commonly used for combined wrist and radius shaft fractures.
  - Longitudinal incision centered between FCR and radial styloid, this is directly over the radial artery.
  - Incision may be curved 45 degrees radially at the level of wrist crease.
  - Dissect down to investing fascia and then mobilize all superficial structures as one flap.
    - The radial nerve is then protected.
  - Incise forearm fascia, mobilize radial artery laterally at the wrist but medially in the proximal forearm.
  - FPL tendon is retracted ulnarly.
  - Distally, the PQ is elevated sharply off the radial border of the radius.
  - The insertion of the BR is divided.
  - Dorsal radial styloid can be approached by dividing all but the distal 1 cm off the first dorsal compartment.

- Volar ulnar approach
  - Best exposure for unstable volar medial distal radius fractures involving the intermediate column, which are rare injuries but vexing if missed.
  - Longitudinal incision just radial to the flexor carpi ulnaris (FCU) to the distal wrist crease.
  - If distal extension is required, direct the incision radially at a 60 degree angle until encountering the hypothenar crease, and then extend distally between the thenar and hypothenar eminences.
  - The contents of the carpal tunnel are retracted radially and the ulnar neurovascular bundle is retracted ulnarly.
  - The PQ is elevated either from its ulnar insertion or from its radial insertion.
    - Leave the joint capsule attachments on the volar medial fracture fragment.

- Dorsal approach (fourth extensor compartment)
  - Although supplanted by the FCR approach, it still has application in the management of "dye punch" fractures that cannot be reduced from volar approach.
  - Longitudinal incision centered over the wrist, midway between the radial and ulnar styloids in line with the third metacarpal.
  - Blunt dissection down to the retinaculum of the extensor tendons and raise skin flaps that include all structures superficial to it.
    - Take care to elevate crossing branches of the superficial radial and dorsal ulnar nerves.
  - Incise the distal forearm fascia just distal to the muscle bellies of the EPB/AbPL and radial to the ECRL/ECRB tendons.
  - The radial most structure in the depths of this wound is the muscle belly of the extensor pollicus longus (EPL).
    - The EPL is followed distally and the extensor retinaculum divided over the third compartment.

    - Mobilize the EPL and retract it radially.
        - The EPL is left out of its sheath during closure.
    - The interval between the residual second and fourth extensor compartments is developed.
    - The fourth compartment is retracted ulnarly and the second compartment radially.
    - Ulnar dissection stops when the fifth compartment is encountered.
        - Care is taken to leave soft tissues attached to the dorsal ulnar fragment.
- Dorsal approach (fifth extensor compartment)
    - Exposure used to reduce and fix isolated dorsal ulnar "dye punch" or avulsion fractures.
    - Incision in line with the fourth metacarpal at the level of the distal radioulnar joint.
        - Avoid damage to the dorsal cutaneous branch of the ulnar nerve.
    - Incise fifth compartment to mobilize the extensor digit quinti (EDQ) ulnarly, leave soft tissues on the floor of compartment attached to bony structures.
    - Identify the ulnar dorsal border of distal radius and follow distally into the fracture site.
    - Leave all soft tissue attachment to the dorsal ulnar fragment intact.
- Approach to ulnar head/styloid fractures
    - Indications: upon completion of radius reconstruction and in the setting of continued DRUJ instability.
    - This dissection is carried out with the elbow flexed 90 degrees and the forearm in maximum supination.
        - Doing so places the ulnar styloid collinear with the subcutaneous dorsal border of the ulna.
    - An incision is made along the dorsal ulnar subcutaneous border of the ulna, stopping at the ulnar styloid.
    - Elevate skin flaps from proximal to distal.
        - Avoid damage to the dorsal cutaneous branch of the ulnar nerve.
    - Identify fracture fragments but do not dissect soft tissue attachments.

Implants: Clinical Indications and Examples

Dorsal Spanning Plate

- Indicated for patients with high-energy injuries, who have fracture extension into the radius and ulnar diaphysis, and in patients with multiple extremity injuries who require load bearing for mobilization.
    - Acts as an "internal fixator" with the mechanical advantage of being immediately adjacent to the fracture with optimal pin (in this case screw) spread, and is a closed system that is particularly helpful in eliminating the pin tract infections in critically ill trauma patients.
    - May also be used as an adjunct to internal fixation or percutaneous fixation in highly comminuted fractures.

- Uses a plate that spans the radiocarpal joint, from the intact radial diaphysis to an intact metacarpal.
  - If the plate is passed through the second retinacular compartment, it is fixed to the second metacarpal.
  - If the plate is passed through the fourth compartment, it is fixed to the third metacarpal.
- The choice of compartments is dictated by closed reduction maneuvers.
  - If the articular fracture reduces and can be held with simple wire fixation, use the second compartment.
  - If not, the articular fracture can be exposed through the fourth compartment, reduced, and secured with a plate and screws in this compartment.
- Reduction is performed as described previously (Agee's reduction maneuver).
  - The plate length and position are confirmed by fluoroscopy, by placing the plate on the dorsal skin of the distal forearm/wrist/hand.
  - The plate should be aligned such that at least three bicortical screws can be placed proximal to and three distal to the fracture.
  - More screws or increased screw spacing may be required in osteoporotic bone or in anticipation of diminished fixation strength.
- An incision is made at the base of the second or third metacarpal.
- A second incision is made just proximal to the EPB/AbPL.
- When the second compartment is used for passage of the plate, the interval for plate placement is between the ECRL and the ECRB.
  - The plate is introduced in the proximal incision and advanced distally between the ECRL and ECRB,
- When the fourth compartment is used, the muscle belly of the EPL is retracted from the dorsal ulna aspect of the radius metadiaphysis and the plate is passed deep into the muscle in the fourth compartment, to rest on the third metacarpal.
- The plate is secured with a 2.7-mm nonlocking screw in the distal and proximal most screw holes.
  - Although 2.4-mm screws can be used for plate fixation, we have found them to break with unacceptable frequency.
- The remaining holes may be filled with locking screws.
- At least three proximal and three distal screws are recommended in good quality bone.

- Plates are removed after fracture healing, at approximately 8 to 12 weeks (Fig. 9-5)

Figure 9-5. Spanning plate used to secure fixation in a patient who sustained multiple injuries and required this limb to assist with weight bearing.

Volar Plate Fixation

- Indicated for most intra-articular distal radius fractures.
- Acts as volar buttress and with locking screws or preformed blades functions as a fixed angle device (Fig. 9-6).

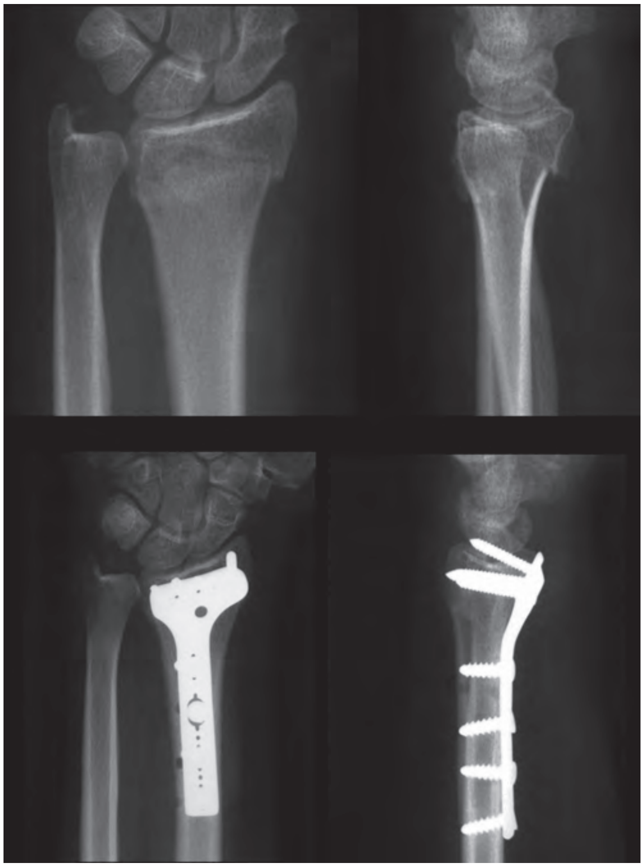


Figure 9-6. Volar locking plate fixation of a distal radius fracture.

- Contraindicated in dorsal shear fractures or as sole fixation in complex dorsally displaced fractures.
  - Dorsal buttress plating preferred in this fracture pattern.
- Sterile traction may be applied to aid in the initial reduction.
- Place the hand on rolled towel(s), with supinated forearm flat on the table to help restore volar tilt.
- The choice of incision is based on the location of the most complex and most comminuted fracture.
  - Comminuted intermediate column fractures are best exposed and fixed through previously described volar ulnar approach.
  - All other fractures are approached through the "FCR" or Henry exposure.

- Release the BR when radial column is involved.
- Do not open the volar wrist capsule when reducing the articular fragment.
  - This leads to radiocarpal instability and significant postoperative stiffness.
- Reduction and fixation sequence depends on the fracture location and size.
  - The largest and least comminuted fragments are reduced first.
  - The remaining fracture fragments are subsequently reduced.
- K-wires assist in the initial reduction and can be driven out the back of the wrist if they interfere with the placement of plate.
- Bone graft, or a bone graft substitute, may be needed to fill the metaphyseal defect.
- With large plates and large fracture fragments, a precontoured plate is applied.
  - There is no superior plate or plating system.
  - All of the newer distal radius plates offer locking screw fixation and variable angle placement.
  - With comminuted fractures, or osteoporotic bone, there is little difference in the distal locking screws versus locking pegs.
    - Both function simply to buttress the articular surface and provide a modest degree of rotational stability, especially in the coronal plane.
- Stabilizing the distal fragment first, followed by fixation to the radius metadiaphysis aids in restoring the volar tilt in dorsally angulated extraarticular fractures.
  - This does not apply to volar shearing fractures.
- Verify that the distal screws or pins are not intra-articular.
  - This is best viewed on the lateral X-ray, with the wrist elevated on roll towels forming a 10 to 15 degree angle with the table, so that the fluoroscopic beam is tangential to the wrist joint in PA and lateral projection.
  - Do not be confused by the radial styloid screw, which often appears to be intra-articular.
  - 45 degree pronation oblique view visualizes the subchondral bone and reveals the fixation screw penetration.
- Verify that the diaphyseal screws are of the correct length.
  - Long screws that penetrate the dorsal cortex by more than 1 to 2 mm will irritate the extensor tendons.

Fragment-Specific Fixation

- Indicated for complex intra-articular fractures.
- Individual fracture fragments are fixed through multiple smaller incisions.
- Fracture fragments are fixed with mini-screws, 2.0-mm mini-plates, or 2.0-mm pin plates.

- The radial styloid fragment is fixed first, followed by the volar and/or dorsal fragments.
- The rigidity of the construct depends on placing implants in orthogonal positions (Fig. 9-7).
- Fragment-specific fixation for volar ulnar fracture fragments.

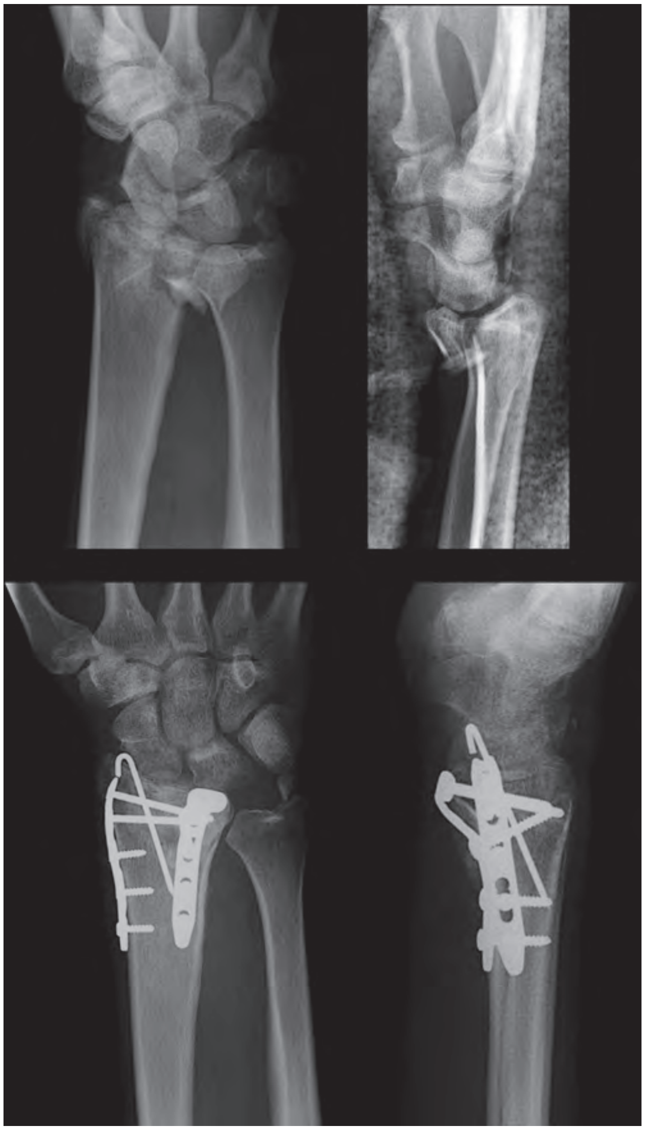


Figure 9-7. Example of fragment-specific fixation used for a distal radius fracture. The volar implant supports the intermediate column fracture, while the radial implant supports the lateral column.

- Larger plates often fail to capture the volar ulnar fracture fragments, resulting in delayed radiocarpal dislocations.
- These fracture fragments are best managed with "wire-form" or fragment-specific fixation (Fig. 9-8).

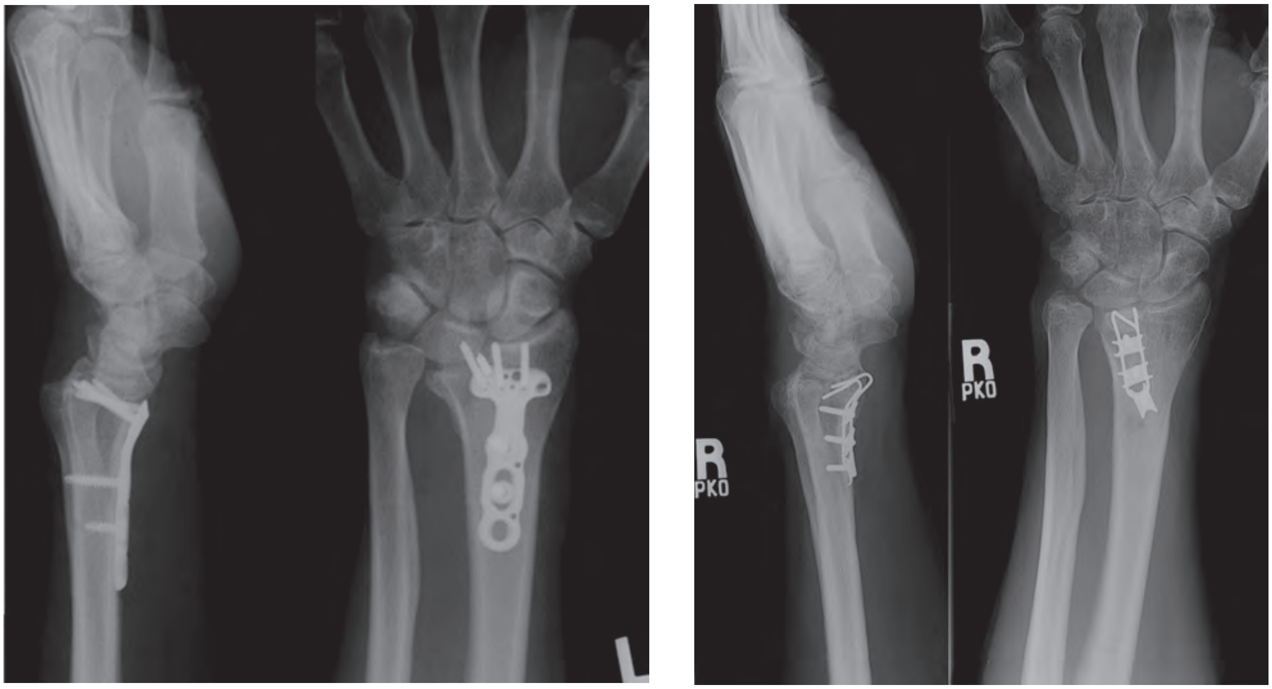


Figure 9-8. After failed fixation of the volar medial corner fracture (**left** X-rays), the plate was removed, the fracture reduced, and definitive fixation performed with wireform fixation (**right** X-rays).

Dorsal Plate Fixation

- Indicated for complex intra-articular fractures, with lunate dye punch fractures or dorsal ulnar fractures that do not reduce with closed manipulation or volar manipulation.
- Lunate facet approached through the fourth compartment, with incision over 4 to 5 compartment interval.
- Fracture fragments are fixed with mini-screws, 2.0-mm mini-plates, or 2.0-mm pin plates.
- The radial styloid fragment is fixed first, followed by dorsal fragments.
- The rigidity of the construct is increased by placing the radial styloid plate 90 degrees to the volar and/or dorsal implants. (Fig. 9-9).

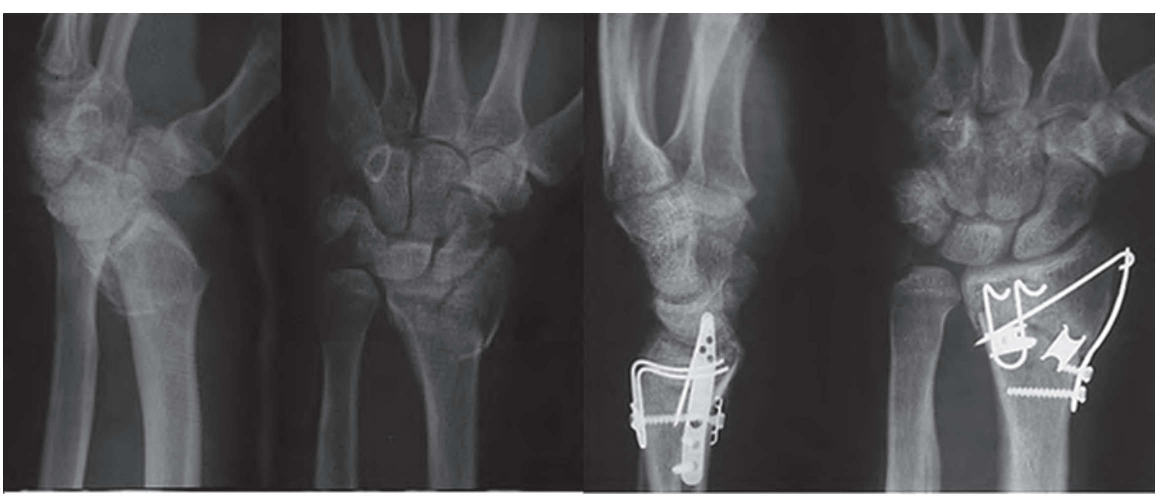


Figure 9-9. A dorsal depressed dye punch fracture could not be adequately reduced from volar exposure. The dorsal fracture was approached, reduced, and transfixed through the dorsal 4 to 5 interval.

Distal Radioulnar Joint

- With reconstruction of the intermediate column, specifically the sigmoid notch, DRUJ instability is rarely an issue.
- If the sigmoid notch is reconstructed, there is no relationship between the ulnar styloid fracture size and instability.
- If after radius reduction DRUJ instability persists, ensure that tendons, the triangular fibrocartilage complex (TFCC), or even the ulnar neurovascular bundle are not interposed between the ulnar head and radius.
- Arthroscopy (dry scope) will determine the integrity and location of injury to TFCC.
- If sigmoid notch is reduced, the TFCC in continuity with radius and the DRUJ is still unstable, then consider fixation of ulnar styloid fragment and attached soft tissues.
- Easiest exposure of the ulnar head and styloid is through an incision placed along the subcutaneous border of ulna while the elbow is flexed 90+ degrees and the forearm is in maximum supination.
    - By using blunt dissecting from proximal to distal, the dorsal cutaneous branch of the ulnar nerve is retracted distally and the fracture line will become obvious.
    - Once the fracture line is identified, the soft tissue dissection is complete.
    - Manipulate and reduce the fracture with a dental pick and secure the fracture with a K-wire and tension band.

Soft tissue Injuries Associated with Wrist Fractures

- Nerve injuries: median or ulnar
- Contusion, hematoma, and swelling following wrist fractures can cause median and ulnar nerve dysfunction.
- It may be impossible to distinguish between direct median nerve injury and nerve compression due to increased carpal tunnel pressure.
    - Best method is clinical examination and to correlate prereduction and postreduction examination.
- Prevention
    - Avoid splinting the wrist in flexion and ulnar deviation.
    - Avoid narrow retractors when reducing fractures and applying volar plates.
- Treatment
    - Acute contusion—reduce the fracture, clear the carpal tunnel of all bone fragments.
    - Progressive sensory loss—urgent carpal tunnel release and fracture reduction.
        - If this occurs after reduction, return to OR for carpal tunnel release.
- Nerve injury: radial sensory
    - Most commonly occurs from direct injury from pin placement.
    - Prevention
        - Place fixator pins on interval between ECRL and ECRB in the forearm.
        - Expose radial column fractures with longitudinal skin incisions and blunt dissection down the dorsal retinaculum and elevate soft tissue in the plane between the retinaculum and overlying soft tissues.
- Compartment syndrome
    - This has been reported in the setting of closed reduction and circumferential casting.
    - Treatment—remove cast, decompress the forearm, reduce and fix fracture.

- Complex regional pain syndrome
  - Prospective studies report much higher incidence than retrospective studies.
  - Frequently associated with untreated compression, neuropathy, and immobilization of the wrist in flexion.
  - Treatment
    - Avoid splinting in wrist flexion.
    - Recognize decompressed nerve injury.
    - Institute aggressive stress loading.
- Tendon injury: rupture
  - Flexor and extensor tendon ruptures have been reported with both volar and dorsal plates, resulting from prominent screws and prominent plate edges.
    - Can occur months after fracture healing.
    - Best prevented with attention to detail as described above.
  - Patient education in the development of tendons "grinding."
  - Most surprising case is the EPL rupture that occurs after healing of minimally displaced fractures.
    - There is an apparent stenosis of the third dorsal compartment.
  - Treatment—remove offending structures, decompress tendon compartments, and repair tendon ruptures with grafts or transfers.
- Hand/wrist/forearm stiffness
  - Very little hand stiffness reported in recent literature compared to past.
  - Previously reported as a result of swelling, wrist flexion splinting, and cast constriction.
  - Presently, the greatest difficulty is in restoring supination (may take up to 1 year).

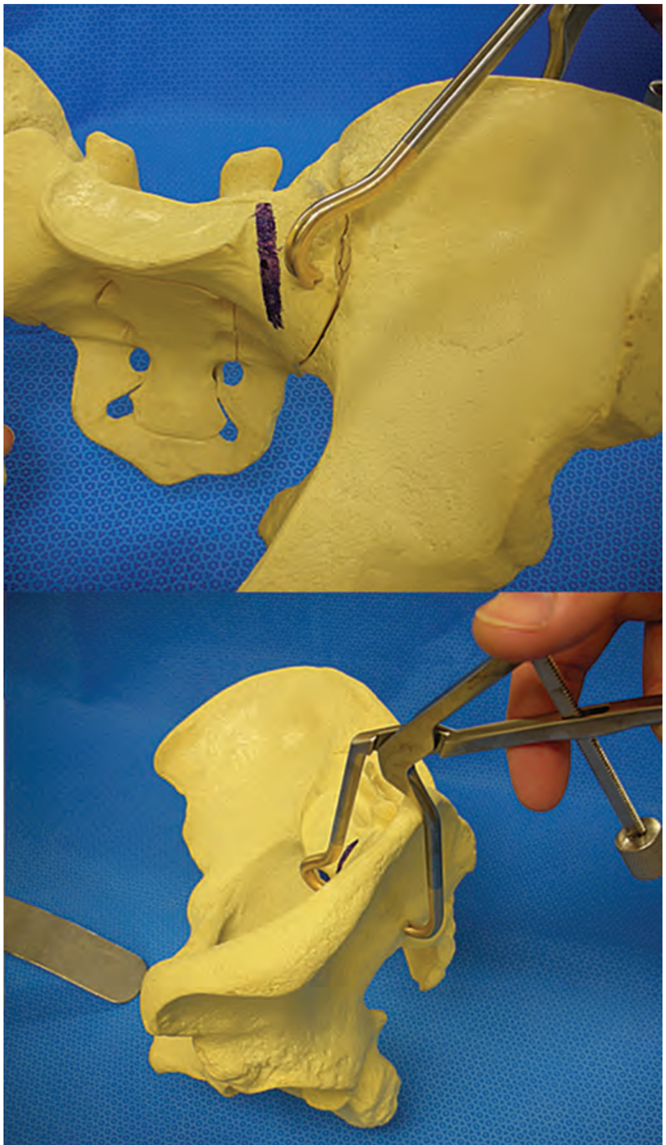
Postoperative Care of Wrist Fractures

- Immobilize wrist in slight extension (never in flexion).
- If intermediate column repaired, especially sigmoid notch fractures, rest forearm in supination for first 2 weeks.
- Start "Six-Pack" exercises in recovery room.
  - Assess for progressive nerve deficit during each office visit.
- Progress from cast to splint to nothing, as fracture heals (usually 4 to 8 weeks).
- Strengthening started after regaining digit and forearm motion and evidence of fracture healing.
- DRUJ usually the last to resolve and may take several months.

Section 4

Pelvis/ Acetabulum

Milton L. Chip Routt



Pelvic Ring Injuries

Jason M. Evans
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Milton L. Chip Routt

Chapter 10

Sterile Instruments/Equipment

- Large and small pointed bone reduction clamps (Weber clamps)
- Assorted pelvic reduction clamps
- Universal manipulator (femoral distractor)
- Hand-held plate bender
- Implants
  - Extra-long 3.5-mm screws
  - Extra-long 4.5-mm screws
  - Extra-long 7.0-mm cannulated screws, partially and fully threaded
  - 5.0- and 4.0-mm Schanz pins
  - 3.5-mm pelvic reconstruction plates
- K-wires and wire driver/drill

Patient Positioning

For additional details see the chapter (1)

- Supine position
  - Radiolucent table.
  - Use a clean sheet, folded into thirds, as a patient pelvic lifting and positioning device.
    - Assure that the folded sheet is wide enough to be positioned under the patient from the low lumbar level to the upper third of the thigh when placed transversely across the table.
    - This folded sheet remains beneath the patient and should be without any wrinkles that could cause skin injury.
  - Once on the OR table, the folded sheet is then used to suspend the patient's pelvis from the table several inches.
    - A bump consisting of two folded and stacked OR blankets, again folded into thirds, is placed posterior to the patient's pelvis and centered on the dorsal sacral area extending distally to the proximal thigh.
    - This double-stacked blanket bump elevates the supine patient from the table to allow iliosacral screws to be inserted easily without interference from the OR table.
  - Avoid patient tilting on the bump.
    - An obliquely oriented patient frustrates and complicates accurate imaging during the surgery.
  - If traction is desired, an apparatus can be fashioned out of a pipe bender to be affixed to the end of the operating table.
    - This can be draped into the sterile field using an impervious stockinette.

- Thorough patient prep is essential, since multiply injured patients routinely have had insufficient in-hospital hygiene.
  - Take time to remove dirt and debris prior to the sterile preparation.
  - Shave the perineal hair and cleanse the skin and genitals with isopropyl alcohol or similar antiseptic agent.
  - Isolate the perineum as necessary from the planned operative field with plastic adhesive drapes.
  - Utilize Mastisol or other skin adherent prior to applying the isolation drapes in order to create a secure seal that may otherwise be violated during the prep.
  - These should be placed posteriorly enough to allow unobstructed access to the iliosacral screw starting point, but not be stuck to the OR table or folded on itself allowing a puddle of prep solution to form.
  - Drape widely, including the entire abdomen from the xyphoid process to the penis in men to allow for placement of retrograde superior ramus screw, if necessary.
  - Prepare and drape both flanks for iliosacral screws, even if the preoperative plan only calls for unilateral insertion.
- This positioning and draping allows access to perform iliosacral screw insertions, open reduction of sacroiliac joint dislocations through an anterior approach, symphyseal and anterior ring open procedures, acetabular fractures through an ilioinguinal approach, and femoral head fixation using the Smith-Petersen exposure.
- A Pfannensteil approach is used for symphyseal disruptions.
  - Avoid placing the incision in the intertriginous area of a pannus as this can be fungal infected and a difficult area for successful wound healing.
  - Incision is approximately 2 cm cranial to the palpable superior aspect of the symphysis.
  - Visualization of the superior ramus is enhanced by incomplete anteromedial elevation of the rectus abdominus insertion from the anterior aspect of the pubis without a tenotomy.
  - Use an appropriate sized malleable retractor for retraction of the bladder and avoid deep placement of the retractor.

- Prone position
  - Radiolucent table.
  - Double rolled OR blankets used for chest rolls.
  - Position each arm such that the shoulders are slightly forward flexed and slightly abducted, and the elbows are flexed with forearms supported and the ulnar nerve unencumbered (Fig. 10-1).
    - Special articulated arm supports make this physiological positioning easy.

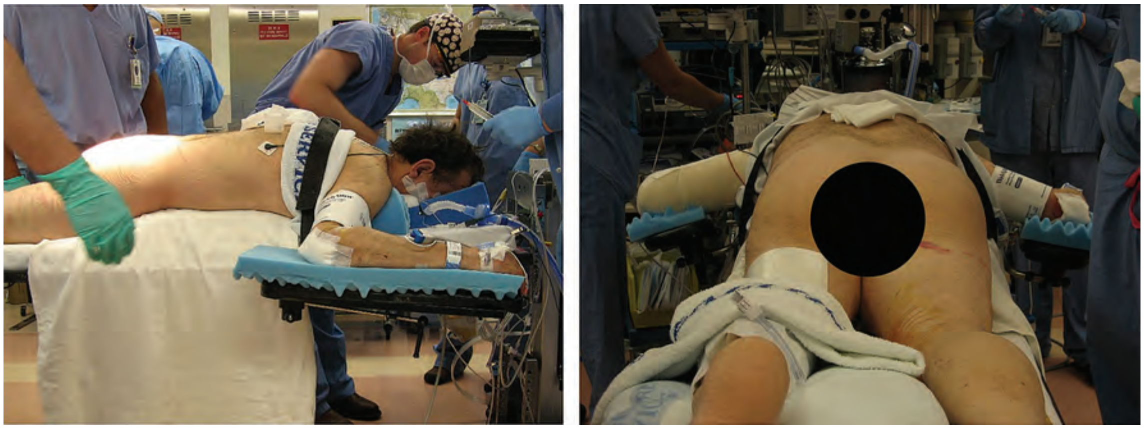

Figure 10-1. The prone positioning process is done sequentially and carefully. The face and neck are positioned anatomically and without pressure points. If a cervical collar is indicated for the patient, it is removed once prone and sand bags are applied during surgery. A cervical collar left on with the patient in the prone position risks chin necrosis. The chest rolls suspend the abdomen allowing normal anesthetic ventilation routines. The sheets are smoothed to avoid wrinkles and potential skin injury. The shoulders are slightly abducted, forward flexed, and internally rotated. The elbows are also slightly flexed and placed on padded articulated forearm supports. Blue foam can be used as padding but the solid side should be exposed to the extremity (as seen on the left patient) rather than the "egg crate" side (as seen on the right side patient) to avoid pressure points. If the upper extremity has been splinted due to injury, the upper extremity positioning is adjusted accordingly, or in some situations the splint is removed during surgery if the reduction is stable without a splint while under anesthesia. The splint is reapplied after surgery and radiographs assure no changes. The male patient's genitals should hang freely. The urinary catheter tubing is located anterior to the uninjured thigh-hip region and padded to avoid skin problems. The catheter-drainage tubing junction should be accessible for irrigation if necessary. The uninjured lower extremity is slightly flexed at the hip due to the chest roll suspension, and the knee is flexed slightly while the leg-ankle-foot are supported on a pillow. The uninjured limb is padded anteriorly and taped securely. A sequential compression device may be applied but the air hoses should be located remote from the bone or nerve prominent areas.

- A rolled egg crate foam pad under the anterior aspect of the shoulders prevents excessive shoulder sag and keeps the arm from abutting the OR table.
- Thoroughly shave, then cleanse with isopropyl alcohol, and then isolate the perineum with plastic adhesive drapes prior to prepping.
  - Mastisol or other skin adherent seals the barrier drapes well, but avoid overapplication of the adherent onto the operative field.
- A laparotomy drape with a plastic bag is used, with the operative leg placed through the opening, and scissors are used to enlarge the opening to provide access for the posterior approach.
  - This is again sealed with iodine-impregnated adhesive strips after marking the proposed incision.

Reduction and Implant Techniques

- *Circumferential pelvic antishock sheeting (CPAS)*
  - Quickly decreases the pelvic volume and stabilizes the bony pelvis and the hematoma.
  - A hospital sheet is folded into thirds centered between the iliac crests and greater trochanters secured with towel clamps (Fig. 10-2).

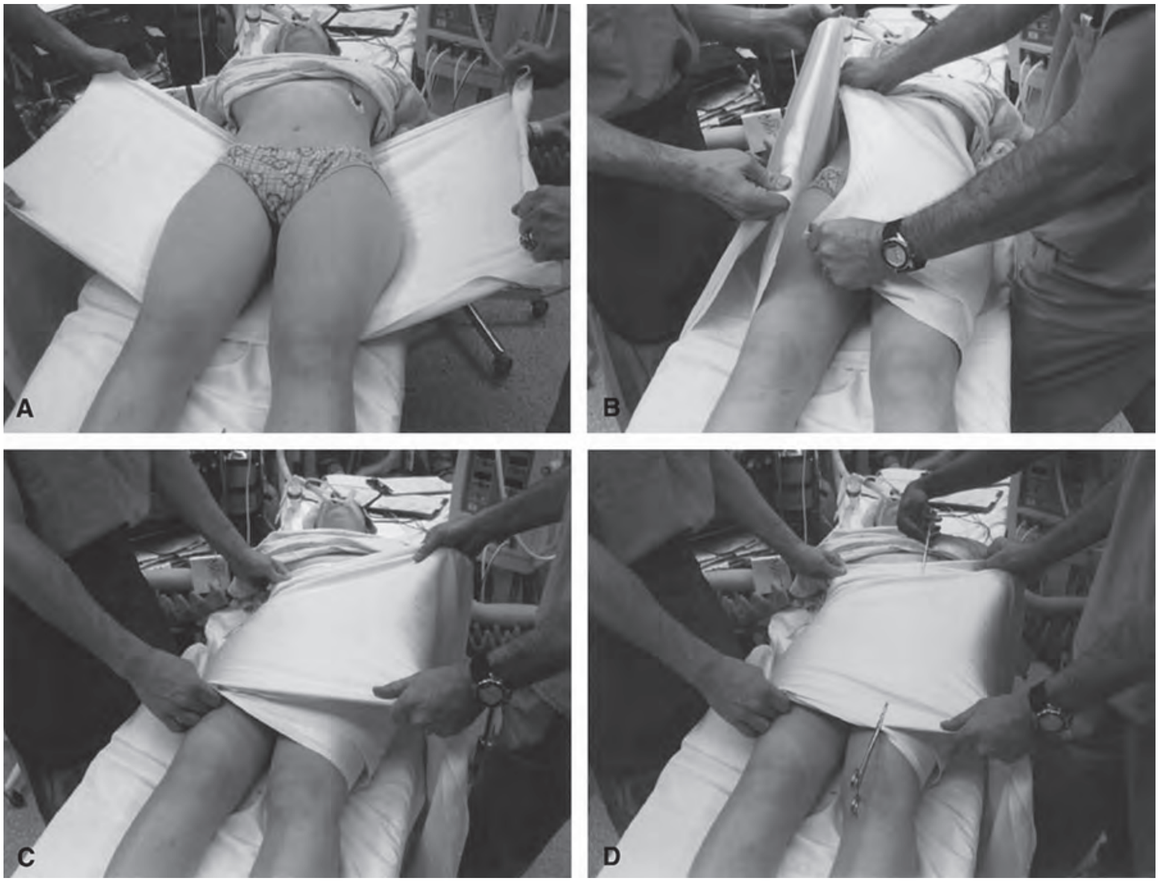

Figure 10-2. Circumferential pelvic antishock sheeting is applied in this patient. The patient's clothing should be removed before application. The sheet is positioned beneath the patient's pelvis smoothly **(A)**. The ends of the sheet are crossed in an overlapping manner anteriorly **(B)** and are pulled taut **(C)**. Clamps secure the smooth and snug sheet **(D)**. (From Routt MLCR, Falicov A, Woodhouse E, et al. *J Orthop Trauma*. 2002;16:45–48. With permission.)

- Portals can be cut into the sheet for vascular access, or placement of external fixator pins or percutaneous screws (Fig. 10-3).

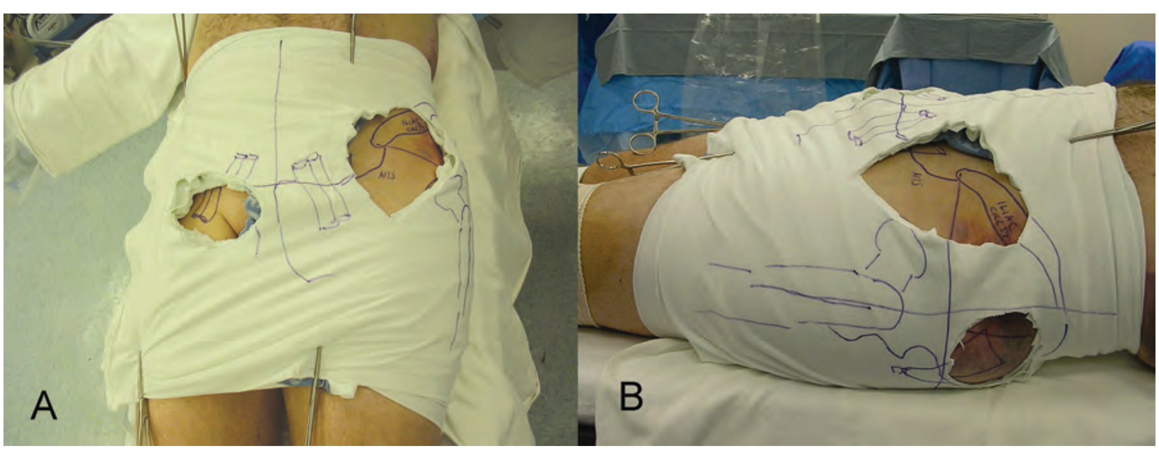

Figure 10-3. Anterior view of the femoral vascular and anterior external fixation pin working portals **(A)**, and lateral view demonstrating the iliosacral and antegrade ramus screw portals **(B)**. Working portals cut in the CPAS do not diminish the sheet function, yet allow pelvic angiography, simple anterior pelvic external frame application, or percutaneous screw fixation to proceed while the sheet maintains the reduction. (Adapted from Gardner MJ, Osgood G, Molnar R, et al. Percutaneous pelvic fixation using working portals in a circumferential pelvic antishock sheet. *J Orthop Trauma*. 2009;23:668–674. With permission.)

- *Pubic symphyseal plating*
  - The skin, local soft tissues, and rectus abdominus muscles assist in the reduction of the symphysis widening by providing a leverage point for Hohmann retractors.
    - The points of the retractors are placed just lateral to each pubic tubercle and posterior to the rectus insertions.
    - Alternatively, pointed reduction clamps may be used to reduce the pubic symphysis (Fig. 10-4).

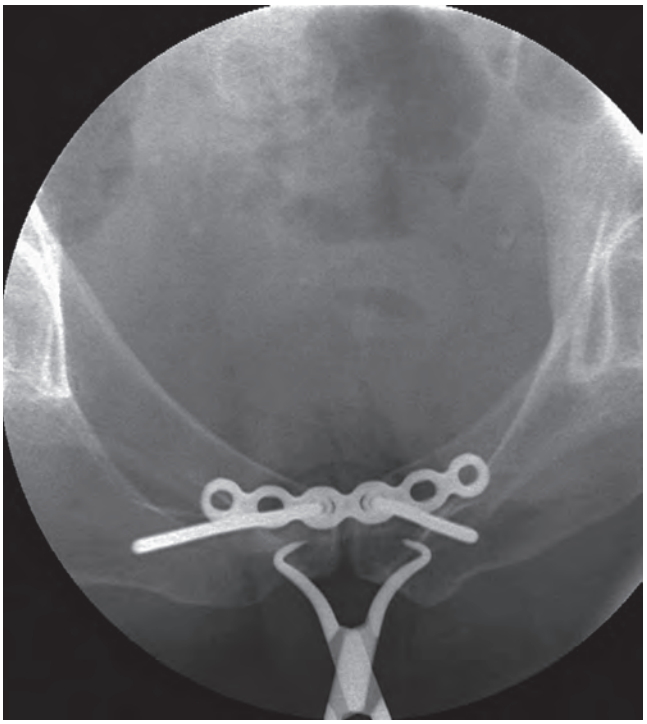

Figure 10-4. A small reduction clamp was applied to the pubic tubercles bilaterally to maintain the symphyseal reduction while the plate was attached. Clamp application into the obturator foramen is essentially never necessary although historically advocated.

  - A straight six to eight hole 3.5-mm reconstruction plate is easily contoured to fit well and provides reliable symphyseal fixation.
  - Place a slight prebend in the center and again just medial to both peripheral holes so that the peripheral screws can be directed toward the inferomedial symphyseal areas. This improves fixation by allowing triangulation of implants and allows for longer screws (Fig. 10-5).

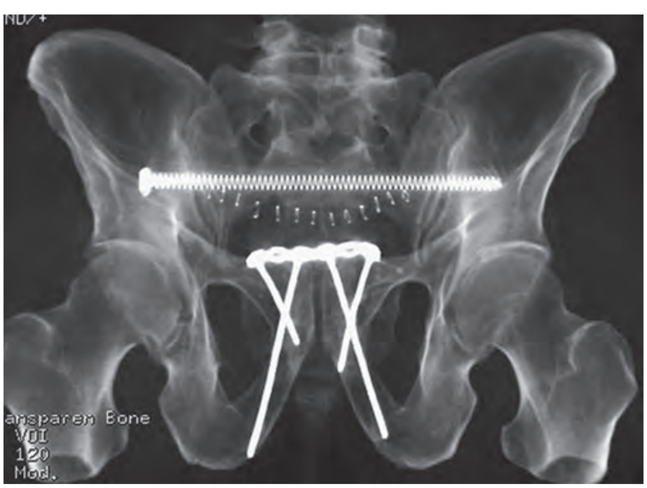

Figure 10-5. Long central hole medullary screws are bilaterally directed toward the ischium to improve fixation. The peripheral screws are directed toward the inferomedial symphyseal arcuate areas to triangulate each side of the symphyseal fixation construct.

- The plate can be used to assist with the reduction of slight residual symphyseal widening.
  - Predrill a hole on each ramus adjacent to the subchondral surface with the screw aimed slightly away from the midline.
  - Elevate the cartilage cap for direct visualization of the subchondral surface to ensure precise screw positioning.
  - Place the screws through the central two holes and sequentially tighten them, alternating from one to the other.
    - As the screw heads are tightened and contact the plate, the plate functions to reduce the disrupted symphysis.
  - Be cognizant when using this technique that small inaccuracies in predrilled hole locations near the midline are magnified at the ends of the plate, potentially leading to a plate being off of the bone laterally.
- Transsymphyseal screws through the plate are used when routine screw placement fails due to poor bone quality, fracture comminution, or other issues (Fig. 10-6).

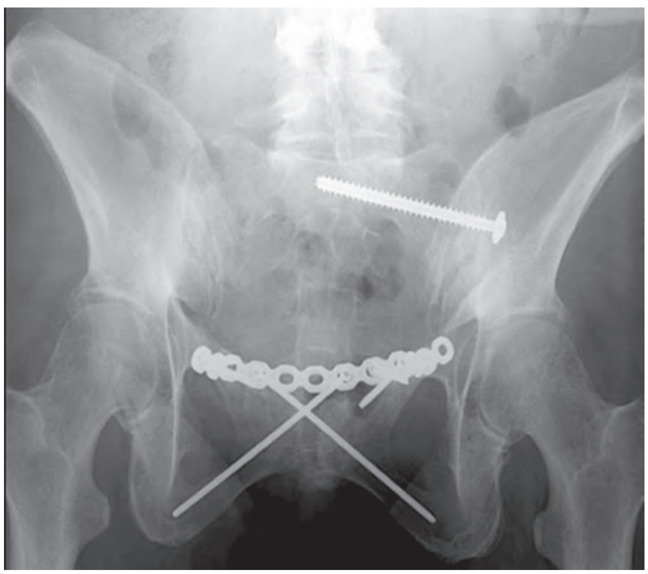

Figure 10-6. This patient was injured in an equestrian accident and had routine symphyseal plating. Three days after surgery, the routine plate fixation failed and was revised successfully to this construct using an anteriorly located and longer symphyseal plate with transsymphyseal screw fixation.

- Transsymphyseal retrograde ramus screws can be used to stabilize disruptions of the symphysis when it is desirable to have as little exposed surface implants as possible, such as in treatment of open pelvic disruptions (Fig. 10-7).

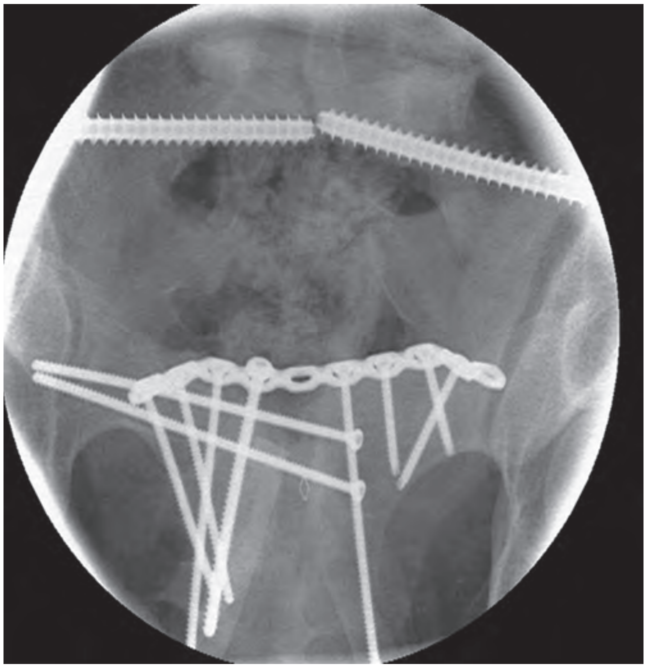

Figure 10-7. This patient developed early routine symphyseal plate fixation failure due to a deep anterior pelvic infection. The failed implants were removed, the wound was debrided, and the symphysis reduced and stabilized using this plating technique with supplemental transsymphyseal medullary ramus screws.

- Heavy, nonabsorbable suture may also be used to stabilize the symphysis in children or in open fractures to minimize the foreign body load.
  - This is not as biomechanically sound and should be augmented with posterior fixation in most cases (Fig. 10-8).

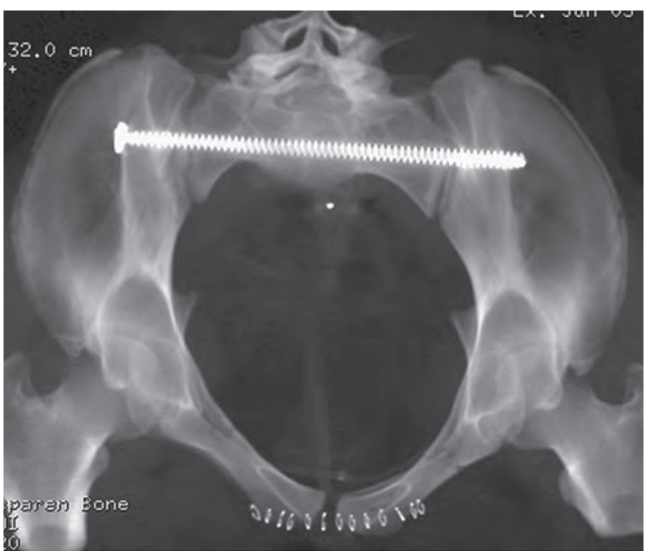

Figure 10-8. This 14-year-old female had an unstable pelvic ring disruption due to an automobile crash. Her complete symphysis pubis disruption was treated with open reduction, and then suture fixation through parasymphyseal anterior to posterior bone tunnels was done.

- Unstable and displaced posterior pelvic injuries are often best treated with open reduction; however, review of the CT scan may reveal a corresponding sacral crush injury significant enough to preclude a good reduction read through an anterior approach (Fig. 10-9).
  - This also creates a problem when trying to position clamps to obtain and hold the reduction, as the clamp in the sacrum will inevitably be in a comminuted fracture zone with little stable cortical bone available for the clamp.

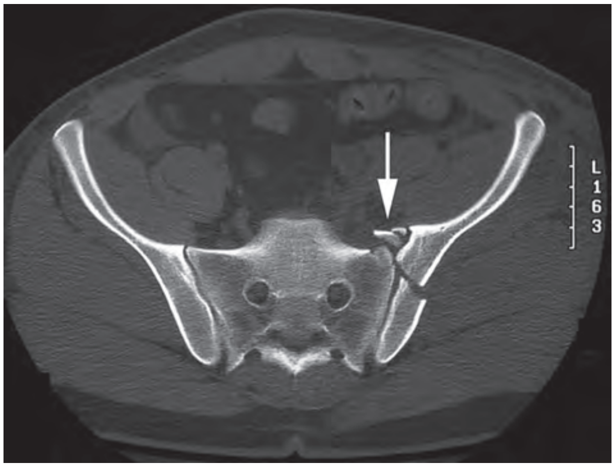

Figure 10-9. This patient had a crescent fracture dislocation with significant ventral sacral impaction (*arrow*). This must be accounted for when considering the available reduction assessments through an anterior approach.

- *External fixation*
  - Anticipate the direction of deformity correction when planning the pin insertion site and skin incisions to minimize the skin tension and avoid the need for relaxing skin incision after the reduction maneuvers.
    - Insert a K-wire percutaneously aimed parallel with the center of the bone pathway from the anterior inferior iliac spine (AIIS) to the posterior ilium using the obturator outlet view (Fig. 10-10).

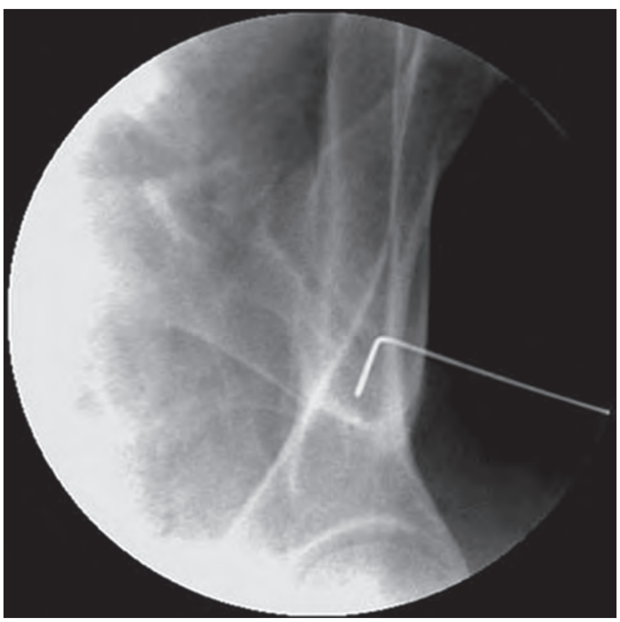

Figure 10-10. An obturator outlet view is used to obtain a starting point for supraacetabular external fixation pins.

    - When the K-wire is on bone, bend wire 90 degrees several centimeters above the skin to allow simple C-arm imaging.
    - When tip of the wire is in the desired position, cut the bent portion and advance the K-wire using a wire driver into the AIIS several centimeters.
    - Incise the skin around the wire in the direction of the deformity correction.
    - Overdrill the K-wire with a cannulated drill and remove both the wire and the drill.
    - Insert 5.0-mm Schanz pin by hand.
      - Pin often needs to be at least 250 mm long.

   - Confirm trajectory using the obturator inlet (the pin remains between the tables) (Fig. 10-11) and the iliac oblique (the pin is cranial to the greater sciatic notch).

Figure 10-11. This obturator inlet combination image reveals the osseous pathway for screw or pin insertion from the AIIS towards the posterior ilium between the iliac cortical tables. The pin is applied cranial to the greater sciatic notch and should not be too deep within the ilium that iliosacral screws are obstructed. These pins should also be applied so that antegrade ramus screws can be inserted beneath them, if necessary.

   - A similar technique can be used to insert screws from the AIIS to the posterior superior iliac spine (PSIS).
- When placing reduction pins in the AIIS, a universal manipulator can be used as a pelvic compressor or distractor.
   - The advantage of using AIIS pins is that the angle of the pins relative to each other can be locked when using the distractor arms, effectively increasing the posterior closing effect of the pins.
- Alternatively, a surgical sponge can be used around each pin to achieve a provisional reduction, and then the sponges clamped together at the midline to hold the reduction while the carbon rods and pin/bar clamps are applied (Fig. 10-12).
   - This technique is much simpler and cheaper than using a manipulative device.
   - The sponges do not obstruct the frame assembly as a manipulative device does.

Figure 10-12. After the anterior pelvic pins are inserted, two individual surgical sponges are lashed around the pins and gathered centrally. The pins are then manipulated to achieve the needed compressive closed reduction and the overlapping sponges are clamped together. The reduction is maintained as the frame is built above the sponges. Once the frame is assembled and tightened, the sponges and clamp are released.

- For external fixation frames mounted on AIIS pins that will be retained definitively, a cranial starting point and a caudally directed pin will facilitate patient mobilization and upright positioning by allowing slightly more hip flexion before the frame impinges on the thigh (Fig. 10-13).

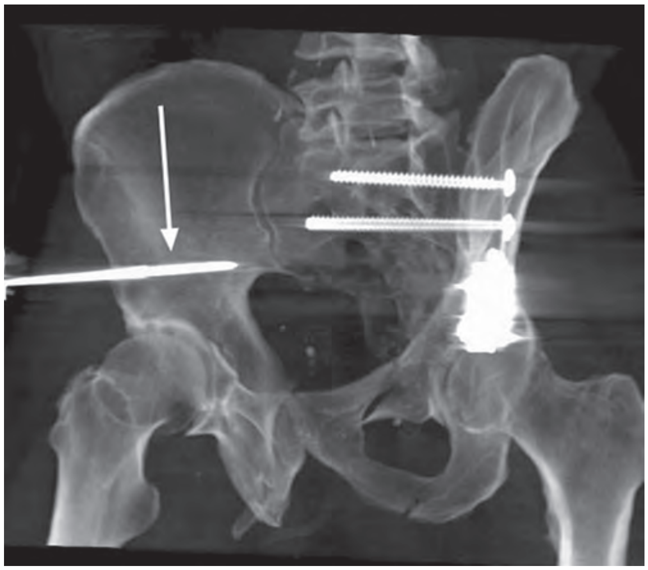

Figure 10-13. The right-sided iliac oblique view confirms the pin depth and obliquity. The pin is inserted beginning at the cranial aspect of the AIIS between the iliac cortical tables, and is aimed to end just cranial to the greater sciatic notch (*arrow*). This small amount of pin "flexion" allows improved hip flexion and therefore eases sitting and patient mobility.

- *Iliosacral screws*
  - Critical evaluation of the morphology of the upper sacral segments is imperative to proper screw positioning.
  - The space available for a screw can be determined using the axial images at the level of the upper sacral nerve root tunnel.
    - The "safe zone" is measured from the anterior portion of the upper sacral segment's tunnel to the anterior cortex of sacrum (Fig. 10-14).

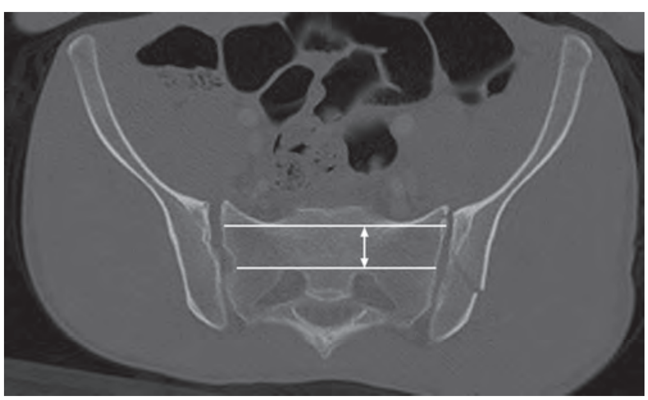

Figure 10-14. Preoperative planning for iliosacral screws using axial CT allows for safe zone determination (*double arrow*).

- It should also be determined if the screw can be safely oriented as a "sacral-style" screw.
- Some patients have substantial safe zones and pathology that permits screws to be directed across the midline up to or through the contralateral sacroiliac joint and ilium (transiliac-transsacral screws) (Fig. 10-15).

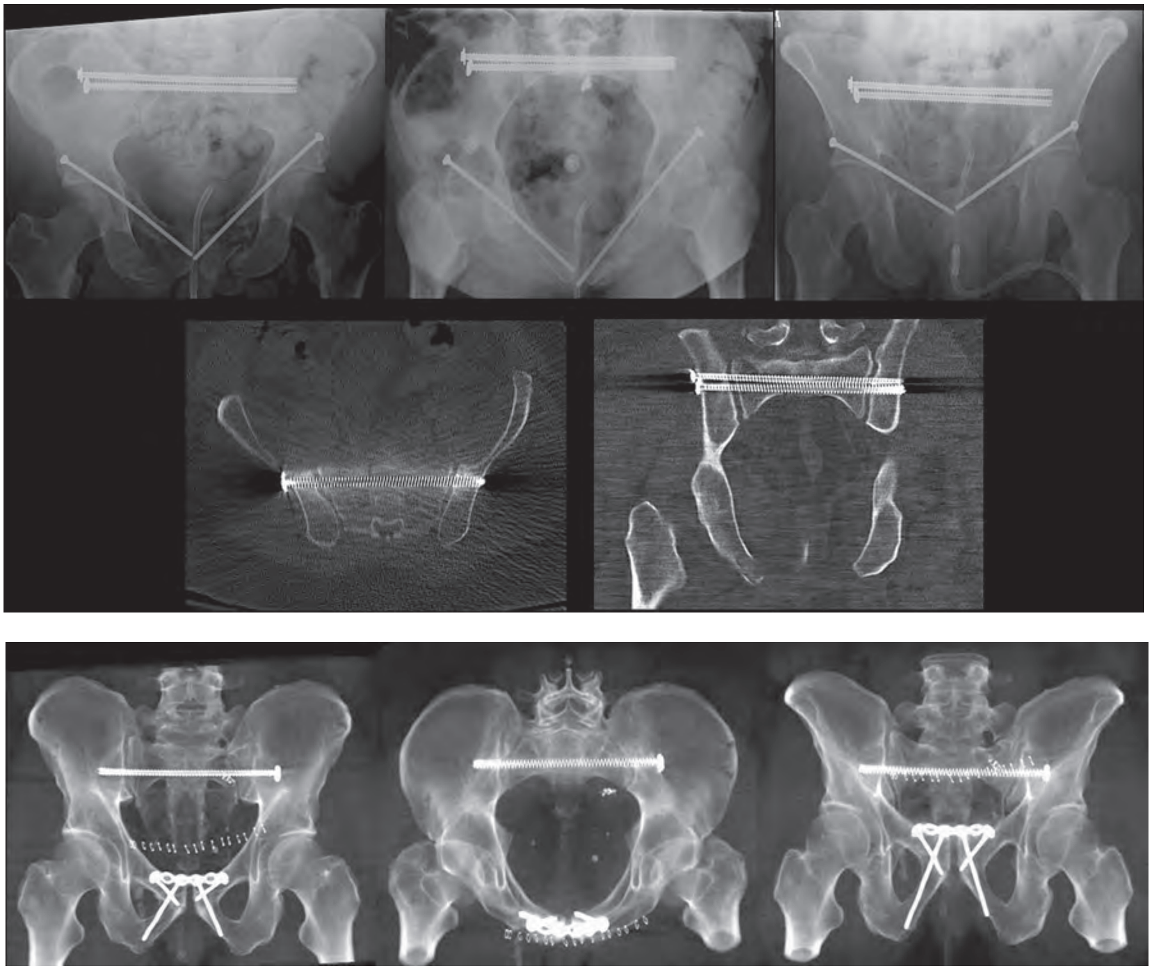

Figure 10-15. Transiliac-transsacral screws are used to stabilize the bilateral posterior pelvic injuries. Long screws up to 180 to 190 mm lengths are necessary for these applications.

  - Usually, this requires a screw length >170 mm and the longer screws may only be available with larger diameters.
    - This may impact the ability to place these screws in narrow safe zones.
- Distal femoral traction (10 to 15 lb) is helpful to improve the reduction of many posterior pelvic ring deformities.
- Flexion/extension and internal/external rotation deformities can be manually addressed or reduced with the aid of an external fixator or pelvic manipulator attached to Schanz pins placed in each ilium.
  - For this method to be maximally effective, an intact hemipelvis is required.

- After reduction, three views are used to guide safe iliosacral screws: pelvic inlet, pelvic outlet, and true lateral sacral views (Fig. 10-16).

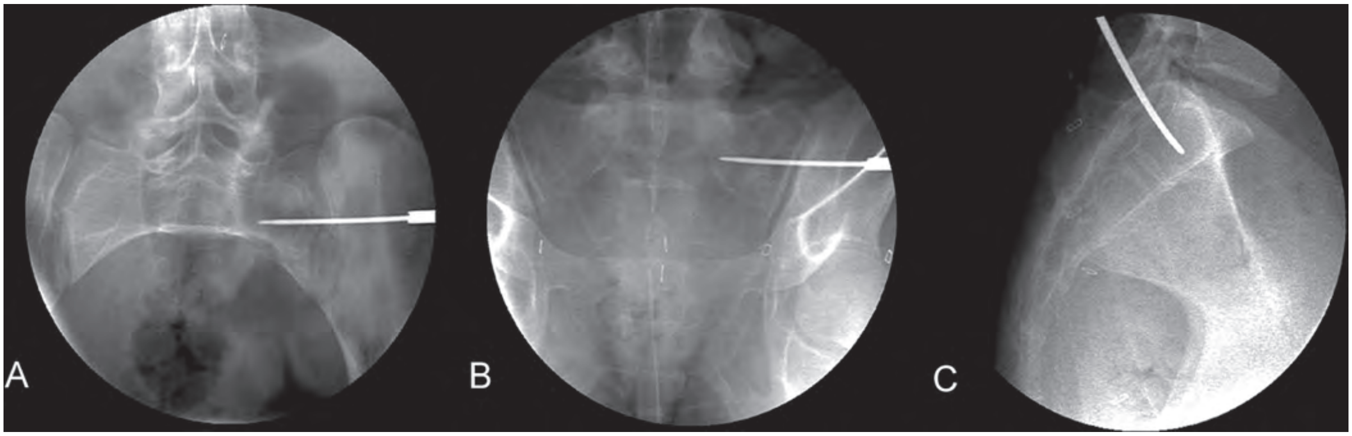

Figure 10-16. The initial upper sacral segment iliosacral screw is positioned low and anterior to allow simple subsequent screw insertions if needed. A guide wire is drilled to the lateral aspect of the sacral neural tunnel as seen on the inlet **(A)** and outlet **(B)** images. The true lateral image **(C)** is then assessed to assure that the wire tip is cranial to the neural tunnel, posterior to the anterior vertebral cortical limit, and appropriately directed before it is inserted further. On the true lateral sacral image after reduction, the iliac cortical densities are superimposed and reveal the alar slope for most nondysmorphic sacral ala. The upper sacral neural tunnels are also well seen on this image.

  - If bowel gas or contrast is obstructing, slight additional C-arm obliquity can be used to clarify the field of vision (Fig. 10-17).

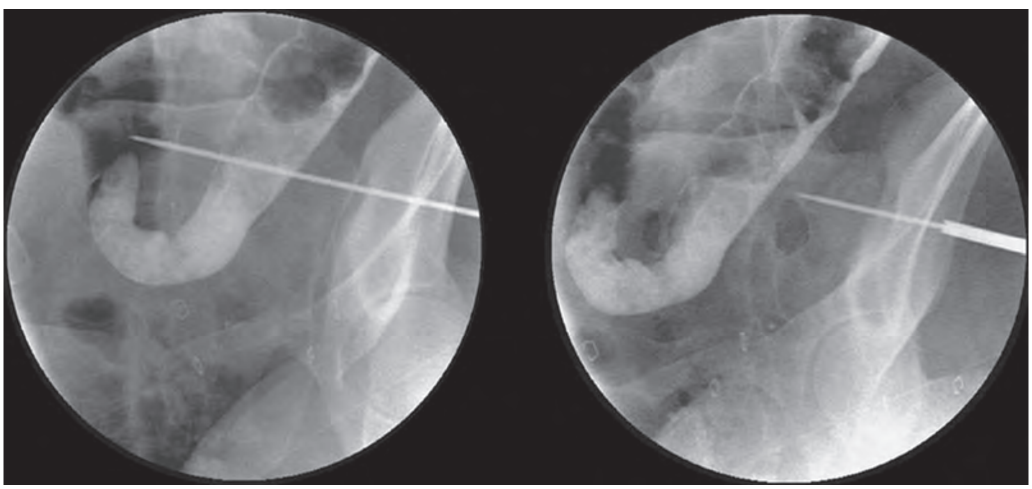

Figure 10-17. In this patient, evaluative bowel contrast agents were administered prior to transfer. The loop of contrasted bowel obstructs routine outlet imaging of the upper sacral segment specifically at the neural tunnel exit or foramen. By simply rolling the C-arm intensifier slightly to an obturator oblique-outlet combination image, the ventral foramen and guide wire tip are well seen.

- Prior to prepping, obtain pelvic inlet and pelvic outlet views and mark the position of the C-arm with tape on the C-arm and/or on the floor.
  - This sets the appropriate angles and the views remain consistent and easily reproducible as long as the OR table height stays constant.
- There are many subtleties to the inlet view.
  - Some upper sacral segments are fairly linear with the anterior borders of S1-3 superimposing to form a clear cortical density at the same inlet tilt.

- Other sacra have significant kyphosis through these levels, and determining which segment's cortical border is imaged can be difficult.
- This can be anticipated by viewing the lateral scout image from the CT scan, from which the level of maximum kyphosis and the approximate tilt for the correct inlet view can be estimated.

- The radiographic "indentations" of the dysmorphic upper sacral segment must be clearly visualized on the pelvic inlet view prior to placing the screws (Fig. 10-18).
  - These indentations represent the anterior cortical limit of the upper segment.
  - These will be obstructed by a second sacral segment screw, and make safe placement challenging. Therefore, the upper screw should be placed first.

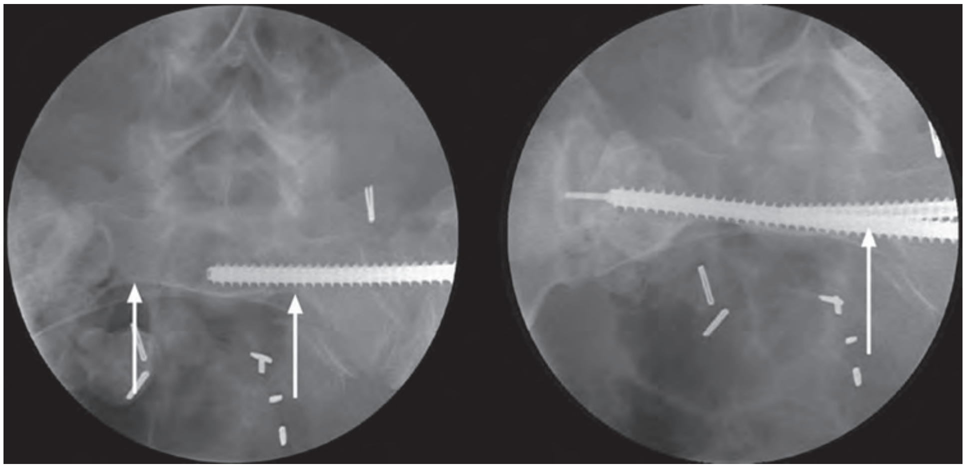

Figure 10-18. On the pelvic inlet fluoroscopic image, this dysmorphic upper sacral segment's anterior cortical indentations represent the alar cortical limits (*arrows*). The second sacral segment screw direction and location obstruct these upper sacral important cortical markers, so the upper segment screws should be inserted initially in dysmorphic patients.

- Starting point.
  - The entry point in the skin is different for a sacroiliac-style screw compared to a sacral-style screw.
  - It is helpful to obtain both the inlet and outlet views and draw a line perpendicular to the beam with each view (parallel to the receiver of the C-arm) and draw them on the surgical field for reference.
  - The anterior/posterior plane is adjusted from the pelvic inlet view, and the cranial/caudal plane is adjusted based on the pelvic outlet view.
  - Intersecting lines drawn from the ASIS perpendicular to the floor and along the axis of the femur create quadrants as visual cues to appropriate skin starting position.
  - The correct skin entry point is often in the posterior and cranial quadrants (Fig. 10-19).

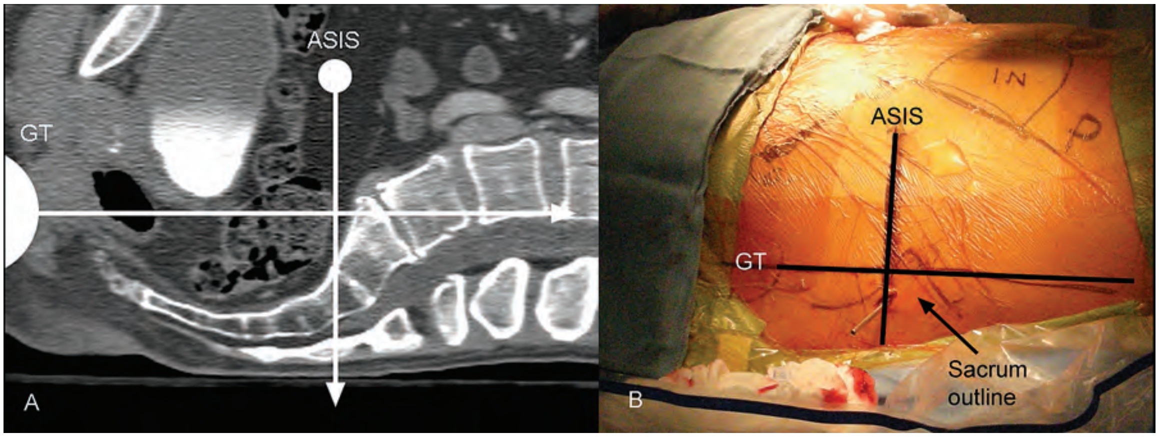

Figure 10-19. **A:** Approximate palpable bony anatomy overlying a sagittal CT scan demonstrating their relationships. **B:** Skin/surface markings using palpable bony landmarks: the anterior-superior iliac spine (ASIS) and greater trochanter (*GT*) help to guide initial pin insertion position.

- In addition to these, obtain an inlet view and insert a 0.062 inch K-wire into the skin in the proposed path of screw insertion so that the tip of the wire is along an imaginary line drawn between the center points of the faces of the C-arm.
- Once satisfied with the wire position on this view, check the pelvic outlet view.
  - Commonly this places the cranial aspect of the symphysis at the level of the second sacral segment.
  - If the pin position is excellent on the pelvic outlet view, the skin can then be incised parallel to the axis that requires slight correction.
  - Be sure to incise the tensor fascia lata in order to create a single soft tissue tunnel for repeated instrument insertion, otherwise several punctures in the deep fascia can prevent reliably finding the same starting point.
- Insert the guide wire sleeve over the K-wire, and hold the guide steady on the lateral ilium while exchanging the K-wire for the 2-mm threaded guide wire.
- Secure the 2-mm guide wire to the drill with a Jacob's chuck.
- The insertion point can be adjusted slightly by translating the pin and guide in the desired direction.
- For maximal control of direction of the wire, use the nondominant hand placed securely on the OR table, underneath the drill similar to a camera's stabilizing tripod.
  - Rest the driver on this forearm just proximal to the wrist.
  - This provides a stable "tripod" to maintain direction of insertion and also provides the ability to make small corrections with flexion and extension of the wrist.
- The guide wire can then be advanced if both the starting point and the trajectory are perfect.
- Alternatively, advance the guide wire several millimeters into the ilium without entering the SI joint space to anchor the pin.
- The cannulated drill can be inserted and oscillated to just past the tip of the pin, and small corrections can be made with the drill.
- The aim can also be slightly redirected by removing the drill and placing a guide wire into the hole at one edge of the drilled hole, and then tapped forward into the cancellous bone.
- The drill is then reinserted over this guide wire and is slowly advanced forward to etch out one side of the hole and effectively alter the trajectory.
- The true lateral sacral view should superimpose the iliac cortical densities (ICD's) and greater sciatic notches, which mark the sacral ala in nondysmorphic sacra, and is confirmed on preoperative CT scans.

- If the guide wire or screw is
  - Caudal and posterior to the ICD when at the level of the lateral edge of the upper sacral nerve root tunnel, and
  - Cranial and anterior to the nerve root tunnel, the screw is safely contained within the bone (Fig. 10-20)

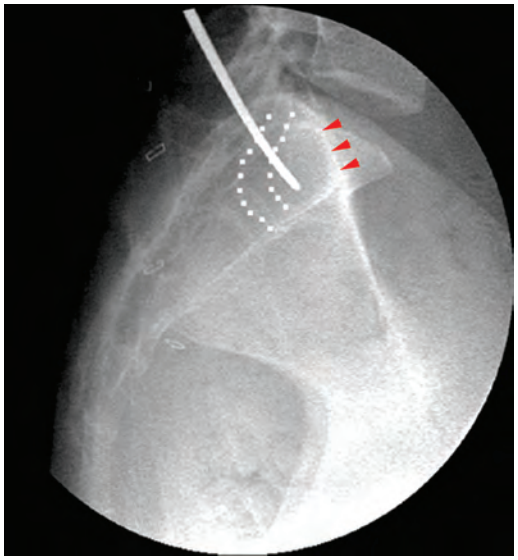

Figure 10-20. This true sacral lateral fluoroscopic view is taken with the guide wire just lateral to the nerve root tunnel. On this view, the wire is seen posterior and caudal to the superimposed iliac cortical densities (*arrow heads*), and cranial and anterior to the nerve root tunnel (*dotted line*), indicating safe position. (Adapted from Farrell ED, Gardner MJ, Krieg JC, et al. The upper sacral nerve root tunnel: An anatomic and clinical study. *J Orthop Trauma*. 2009;23:333–339. With permission.)

- Obtain an AP view with a 20 degree rollover, to image down the ilium and confirm the washer is fully seated and not intruded through the cortex (Fig. 10-21).

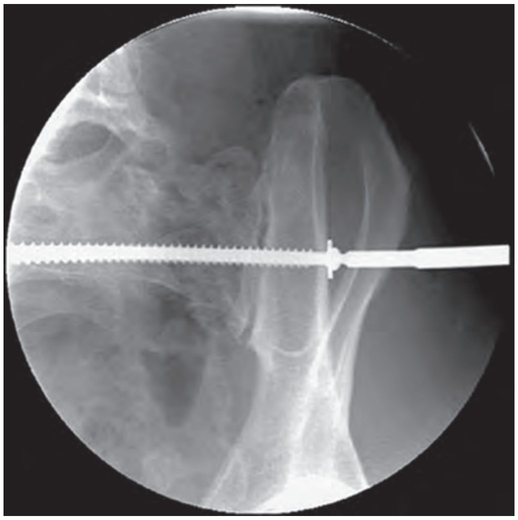

Figure 10-21. This view "down the ilium", obtained by approximately 20 degrees of C-arm roll over, images the washer as it is fully seated.

- Sacral dysmorphism
  - It is critical to recognize the presence of sacral dysmorphism, as well as preoperatively plan when placing an iliosacral screw into a dysmorphic sacrum.[1]
  - One feature of sacral dysmorphism is a greater upslope of the sacral ala.
    - This can be screened using the lateral scout view of the CT scan (Fig. 10-22).

Figure 10-22: This lateral CT scout view demonstrates the marked upslope of the sacral ala associated with sacral dysmorphism (*arrow*).

- This often narrows the safe zone for screw placement, and changes the obliquity (Fig. 10-23).
  - The upper sacral segment screw generally needs to be angled more caudal to cranial and more posterior to anterior.
  - This usually precludes a transiliac-transsacral type screw in the upper sacral segment.
  - When the guide wire is at the level of the sacral nerve root tunnel on the outlet view, the true lateral sacral view may demonstrate the wire anterior to the ICDs.
    - This may still be a safe screw, as dictated by the preoperative plan, as the ICD's are not collinear with the anterior sacral ala, and cannot be used as an indicator for the anterior sacral ala on the true lateral sacral view.

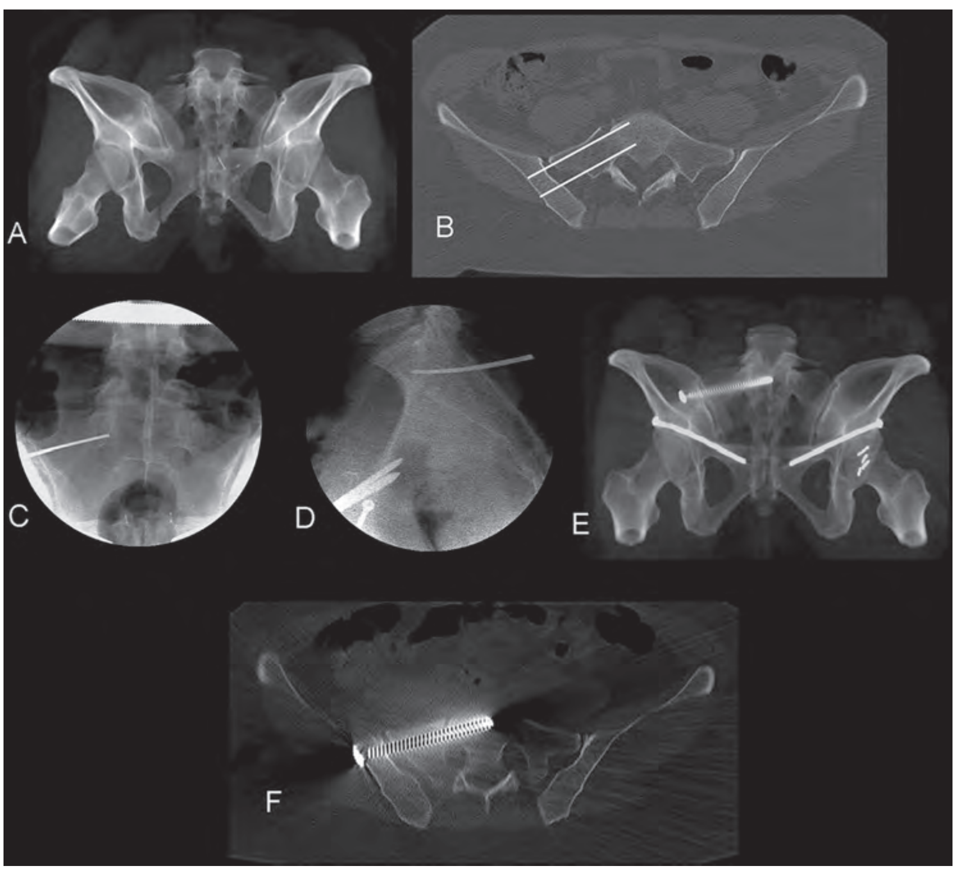

Figure 10-23. The typical iliosacral screw position in the upper sacral segment of the dysmorphic sacrum is more oblique, from caudal to cranial and posterior to anterior on the pelvic outlet and inlet views, respectively.

- When an oblique screw is necessary in a dysmorphic sacrum, often this results in suboptimal fixation in the sacral body.
  - A second segment screw is often desirable to reinforce the construct (Fig. 10-24).

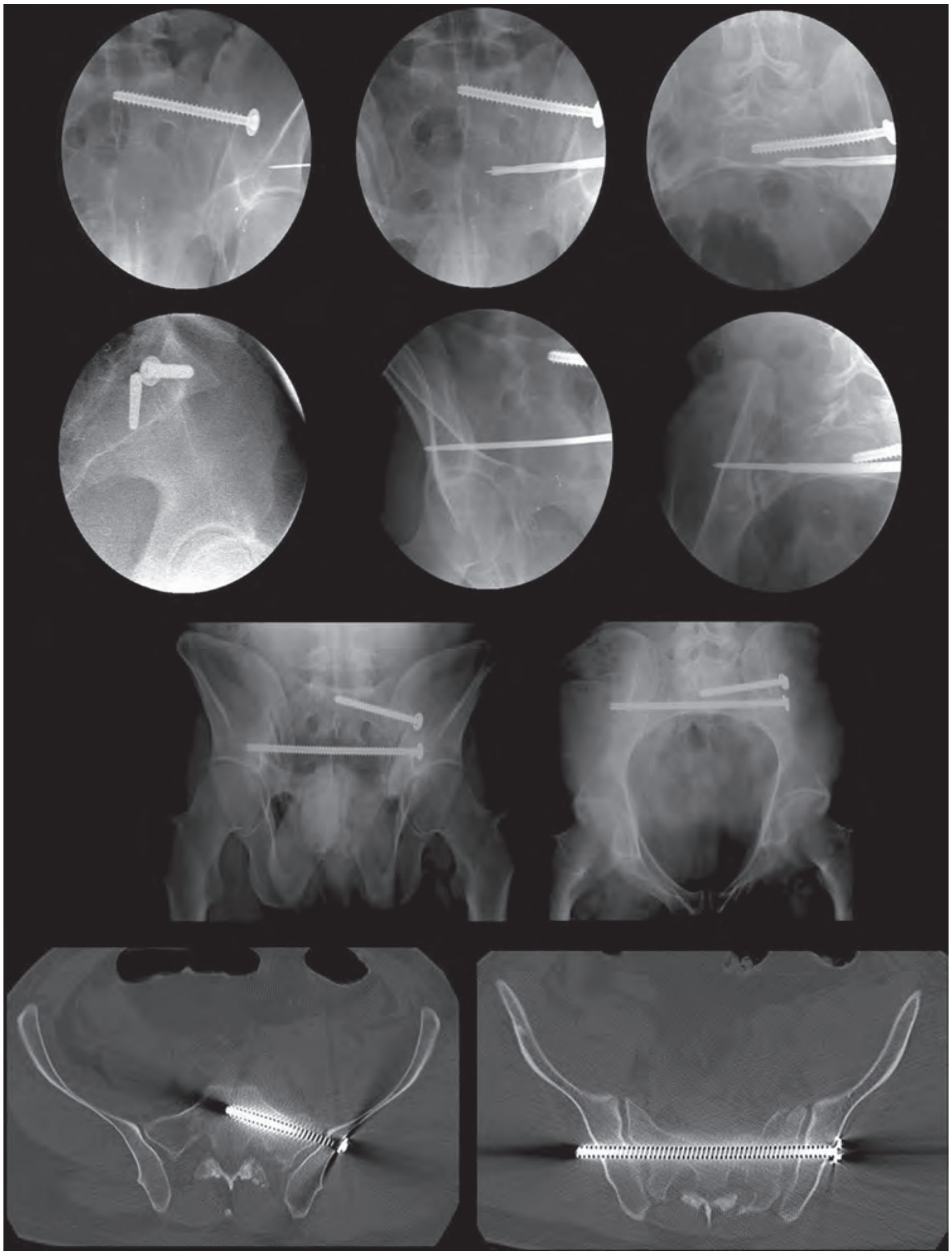

Figure 10-24. In many patients with sacral dysmorphism, a short oblique upper sacral segment iliosacral screw is not relied upon as the sole implant for posterior pelvic fixation. The second sacral segment is typically larger in sacral dysmorphism, and offers a good opportunity for fixation augmentation.

- *Reduction and fixation of iliac crest fractures*
  - The fracture fragment can be held with a small pointed reduction clamp through small drill holes in the crest, or with a Farabeuf clamp.
  - Screw path drilling is facilitated by placing a Hohmann retractor over the posterior iliac crest and predrilling the glide hole, to avoid penetrating the lateral ilium with the screw.

- Drill so that the drill path can be seen just under the inner table, then reduce the fracture.
- A 2.5-mm drill is then used to complete the drilling.
  - A calibrated drill allows for direct measurement and quick exchange with the appropriate screw.
- Often the ilium fracture fragment is displaced in extension and external rotation due to the pull of the abductor and tensor muscle origins.
  - To counteract this force, use of a small fragment plate as a tension band along the inner table, with supplemental intertable screws creates a mechanically sound construct (Fig. 10-25).

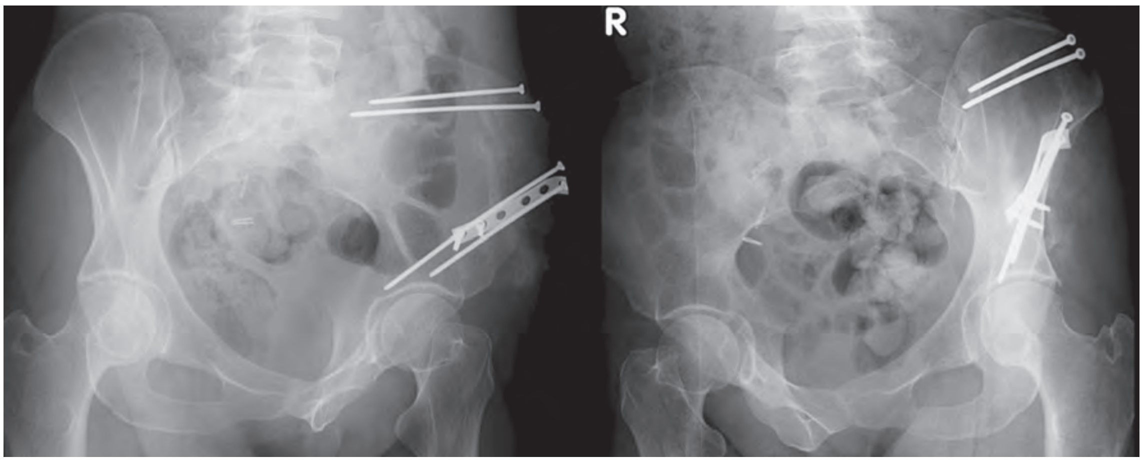

Figure 10-25. In this iliac crest fracture, a small fragment plate is placed on the inner table with an antitension function. This is supplemented with intertable lag screws.

- *Sacroiliac joint ORIF*
  - During an anterior open reduction with plate fixation of the SI joint, a screw placed into the sacrum is facilitated by drilling with the joint unreduced so there is direct visualization of the cartilage of the joint so that it is parallel (Fig. 10-26).

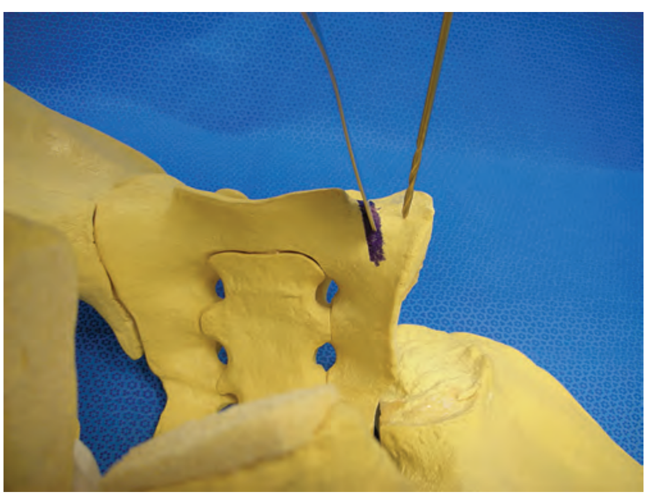

Figure 10-26. During open reduction of the SI joint from an anterior approach, the sacral screw path should be drilled prior to joint reduction to maximize the accuracy. The blue mark indicates the approximate path of the L5 nerve root.

- This screw should exit posterolaterally from the dorsal sacrum due to the kyphosis of the sacrum, at approximately the S3 level (Fig. 10-27).

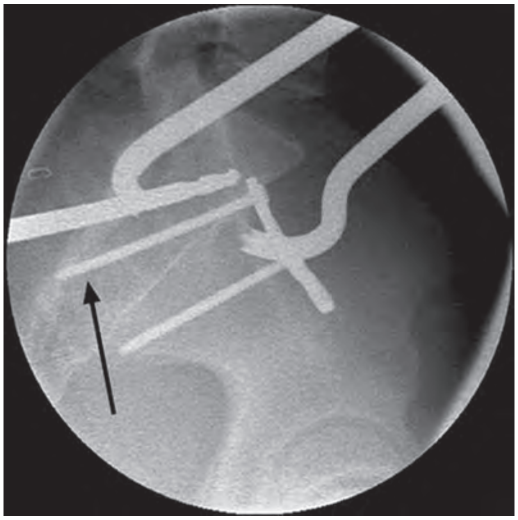

Figure 10-27. The sacral screw inclination typically exits dorsally around the S3 level (*arrow*).

- For SI joint clamp application through an anterior approach, a small incision is made in the tensor fascia lata origin, and a clamp tine is passed deep to the muscle along the outer table of the posterior ilium.
- The anterior second tine is placed on the sacral ala, lateral to the L5 sacral nerve root (Fig. 10-28).

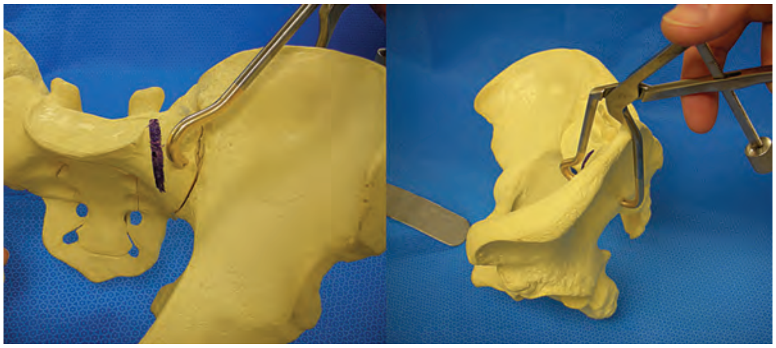

Figure 10-28. Clamp application for open reduction of the SI joint from an anterior approach. The blue mark indicates the approximate path of the L5 nerve root.

- *Antegrade superior ramus/anterior column screw.*
  - The starting point is generally along the gluteus medius pillar and first identified on the pelvic inlet view.
  - The guide wire position on the obturator outlet view demonstrates the cranial/caudal trajectory and position of the drill and screw, but its anterior/posterior position can be inferred by observing its relationship to the lateral ilium cortical stripe—an anterior position will be medial to the stripe and a posterior pin will be lateral to the stripe (Fig. 10-29).

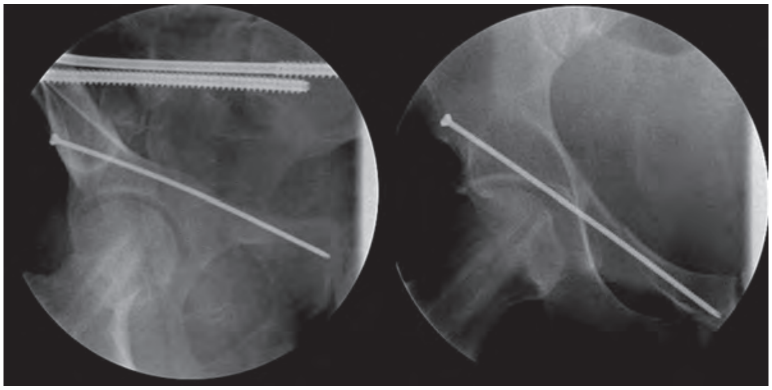

Figure 10-29. Ramus screw position is visualized on the obturator-outlet view (**left**) and the inlet view (**right**).

- Finding the starting point for repeated instrumentation insertion is facilitated by completely incising the fascia of the tensor fascia lata once the appropriate starting position has been achieved.
  - This helps create one soft tissue tract for the repeated insertion of the guide pin, drill, and screw.
- After drilling the gliding hole, remove the 3.5-mm drill and use the blunt end of a guide pin to feel the superior pubic ramus anteriorly and superiorly all the way to the fracture site.
  - This can help determine if the current path remains contained in bone.
  - Oscillating a 2.5 drill will allow the drill bit to "bounce" off the cortex and deform to remain intraosseous, rather than penetrating cortex.
- Drill until final resistance of the far cortex is met, remove the drill, and place the guide wire for direct measurement of screw length.
- Careful attention when obtaining the starting point will help when trying to seat the final screw.
  - The original image of the starting point should be saved and later referred to when seating the screw.
  - The screw head should rest at the same level as the tip of the guide wire which should mark the lateral ilium.

- *Retrograde superior ramus screw*
  - Start with 0.062 inch K-wire and check the starting point on the pelvic inlet view of the symphysis and the obturator oblique views (Fig. 10-30).

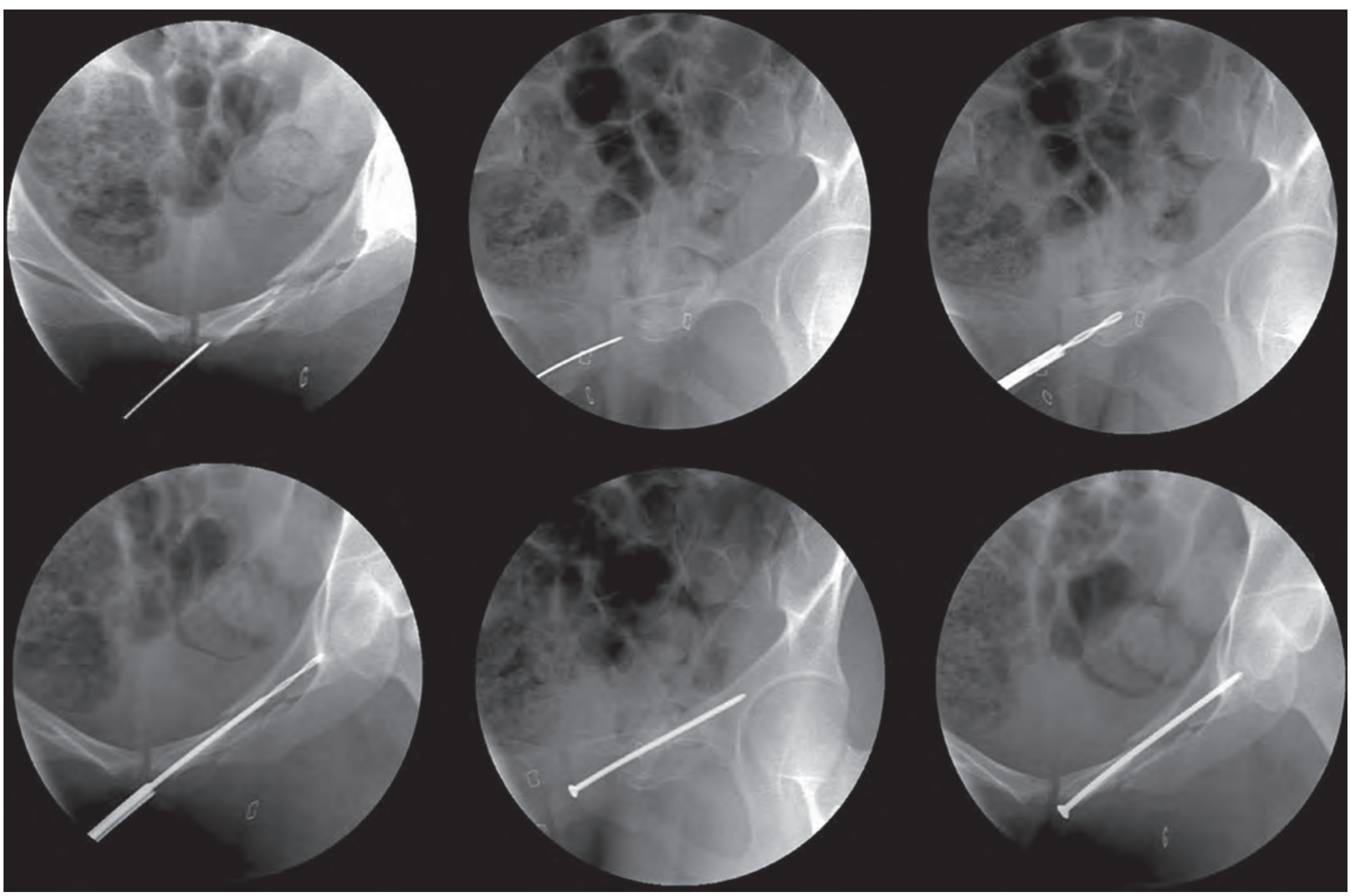

Figure 10-30. Progression of drilling and insertion of a retrograde superior ramus screw.

- A cranial and anterior screw or drill position risks penetrating the cortex in the pectineal gutter.
- A caudal screw that is too anterior will penetrate the hip joint, whereas a screw just as caudal that is more posterior may stay intraosseous.

- Place a 3.5-mm drill sleeve over the K-wire and exchange for the drill after pushing the drill guide into symphyseal cartilage to maintain its position.
- Attempt inserting the screw long enough to penetrate the lateral ilium, and leave several screw threads proud to facilitate removal, should the screw break and removal is necessary.
- Drill with the 3.5-mm drill to fracture line to create a glide hole to facilitate finding the hole with the 2.5-mm drill and screw percutaneously.
- Drill the remainder of the tract with a 2.5-mm-long calibrated drill.
- Direct measurement can be made by subtracting the length of the drill guide from the reading on the calibrated drill.
- If planning on placing a ramus screw in addition to an AIIS frame, the AIIS pins should be placed more cranially to prevent the Schanz pin from blocking the path of the ramus screw (Fig. 10-31).
  - Placing the superior ramus screw first decreases the chance of error.

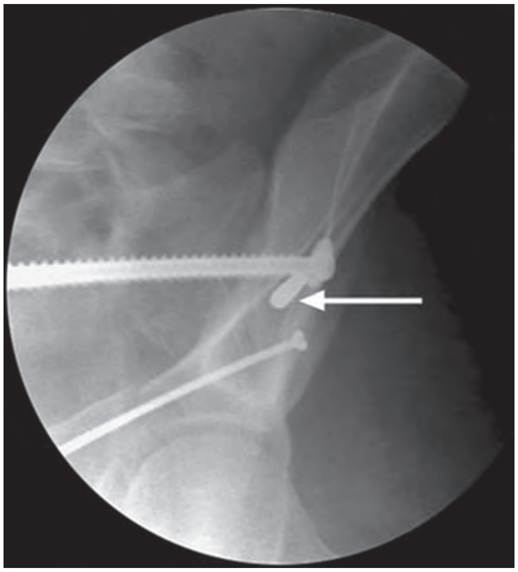

Figure 10-31. In this case, the AIIS pin was placed initially, and was intentionally placed superiorly (*arrow*), so as not to interfere with the subsequent superior ramus screw.

Reference

1. Routt ML, Jr, Simonian PT, Agnew SG, et al. Radiographic recognition of the sacral alar slope for optimal placement of iliosacral screws: A cadaveric and clinical study. *J Orthop Trauma*. 1996;10:171–177.

Chapter 11

Acetabular Fractures

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Sterile Instruments/Equipment

- Large and small pointed bone reduction clamps (Weber clamps)
- Assorted pelvic reduction clamps
- Femoral distractor
- Plate bender
- Implants
    - Long 3.5-mm screws
    - Long 4.5-mm screws
    - Long 7.0-mm cannulated screws
    - Mini-fragment screws for free osteochondral fragments
    - 3.5-mm reconstruction plates
- K-wires and wire driver/drill

Patient Positioning

(For additional details, see the chapter (1))

Prone

- Radiolucent table.
- Chest rolls are made from two blankets folded into thirds without wrinkles.
    - Gel rolls are not radiolucent.
- Prep the leg free, clean and scrub the perineum with alcohol, and drape out with plastic adhesive drapes prior to the betadine prep.
- After prepping, towel out the surgical field and drape.

Supine

- Radiolucent table.
- Two blanket bump under the sacrum to allow access for iliosacral screw placement if needed.
- Prep down to the table, from the genitalia to the xiphoid process. Include the lower rib cage in surgical field.

Surgical Approaches

Kocher-Langenbeck

- The Kocher-Langenbeck approach is the most common approach used for treating acetabular fractures involving the posterior wall and column.
- Incision comprises an oblique limb from the posterior superior iliac spine (PSIS) to the greater trochanter and a vertical limb that continues distally over the lateral aspect of the femur.

- The vertical limb is made first by incising the skin and subcutaneous fat to identify the fascia of the iliotibial (IT) band.
  - The IT band is then incised longitudinally from distal to proximal until fibers of the gluteus maximus are encountered at the level of the greater trochanter.
- The oblique limb of the incision is then begun at the cranial portion of the vertical limb and continued in a direction toward the PSIS.
  - The fascia overlying the gluteus maximus is identified and incised, and the muscle fibers are split bluntly.
  - The orientation of the oblique limb should parallel the gluteus maximus muscle fibers, allowing this muscle to be split more easily.
- The superior gluteal neurovascular bundle and its major branches can be identified by palpation in the interval between the gluteus medius and the gluteus maximus and should be preserved if possible.
- Identify the sciatic nerve dorsal to the quadratus femoris.
  - Displaced fracture fragments will often distort or disrupt the anatomy of the piriformis, gemelli, and obturator internus tendon, making identification of the sciatic nerve difficult in this traumatized zone.
- With the sciatic nerve identified, debride the trochanteric bursa.
- Identify and tenotomize the piriformis and obturator internus.
  - Place a retention suture in these tendons for later repair.
- Follow the obturator internus tendon to the lesser sciatic notch.
- With the knee flexed, retract the obturator internus tendon and sciatic nerve.
- Debride the injured superior and inferior gemelli muscles from the lateral ischium.
- The caudal portion of the gluteus minimus is often significantly damaged and should be debrided back to the level of the caudal branch of the superior gluteal neurovascular bundle.
  - This debridement will improve exposure to the supra-acetabular region of the ilium.
  - This can also minimize the risk of postoperative heterotopic ossification development.[1]

Ilioinguinal approach

- The surface landmarks for the incision are the pubic symphysis, anterior superior iliac spine (ASIS), and the iliac crest.
- The incision begins 1 to 2 cm cranial to the pubic symphysis, extends toward the ASIS, and follows the iliac crest to the level of the gluteus medius pillar, where it continues cranially for several centimeters.
- Identify the fascia along the length of the incision; also identify and preserve the spermatic cord/round ligament and external inguinal ring.
- Which window is opened first is a matter of preference.
  - Important considerations include the location of major fracture components; whether certain windows are needed to visualize, clean, clamp, or apply fixation to fracture components; and, finally, anticipated bleeding issues.
- The iliac window is frequently associated with significant fracture bleeding upon exposure (particularly when there is iliac wing comminution), and often this bleeding is controlled only by fracture reduction.
  - Thus, if the middle or Stoppa windows are needed for the reduction or fixation, it is reasonable to expose them first.

- The fracture often must be cleaned to obtain anatomic reduction; however, this should be the last step of the exposure.
  - Debridement of clot from fracture planes tends to produce bleeding from the cancellous surfaces, which often can only be controlled by fracture reduction.
  - Thus, be ready to implement the reduction and fixation plan immediately after cleaning the fracture to avoid excessive bleeding.

Iliac window

- The common insertion of the abdominal obliques joins the origins of the tensor fascia lata and gluteus medius at the lateral edge of the iliac crest.
  - This tendinous structure should be divided from ASIS to the gluteus medius pillar, leaving the abductor origin intact on the ilium.
- The gluteus medius pillar roughly marks the equator of the pelvic ring (in the supine position).
  - Roughly at this landmark, the exposure may either be continued posteriorly along the iliac crest or extended cranially, splitting the fibers of the external oblique muscle.
  - If the latter is performed, the transversus abdominis and internal obliques are released from their insertion using electrocautery, working from the inner table of the iliac crest outward.
- Elevate the iliacus from the iliac fossa subperiosteally.
- Bleeding is often encountered from the nutrient vessel that enters the ilium just lateral to the pelvic brim and anterior to the sacroiliac joint.
  - Bone wax may help provide hemostasis for bleeding associated with this nutrient foramen.
  - Fractures in this region can also bleed vigorously.

Middle window

- The external oblique fascia is incised from the ASIS to a point 1 cm cranial to the external inguinal ring and reflected inferiorly to identify the inguinal ligament.
- The internal oblique and transversus abdominis insertions on the inguinal ligament are incised along the length of the ligament with a 1-mm cuff to facilitate repair.
  - This will expose the iliopectineal fascia, which needs to be carefully dissected and incised to open the middle window and allow mobilization of the iliac vessels and iliacus muscle.
- The iliopectineal fascia is an oblique fascial structure that spans the superior ramus and the inguinal ligament anteriorly.
  - It becomes confluent with the periosteum of the ilium as it courses dorsally along the pelvic brim to the sacroiliac joint.
  - It separates the lacuna vasorum containing the iliac vessels, lymphatics, and pectineus origin from the lacuna musculorum containing the iliopsoas and femoral nerve.
- Adequate release of the iliopectineal fascia increases the utility of the iliac and Stoppa windows.
  - The intact iliopectineal fascia will limit medial retraction of the iliacus while working in the iliac window and anterolateral retraction of the iliac vessels while working in the Stoppa window.

Stoppa window

- Use of this window requires the surgeon to stand on the opposite side of the patient than the side of injury and provides access to the quadrilateral surface, the upper surface of the superior ramus, and the pubic symphysis.
- The fascia between the rectus abdominis muscles is divided longitudinally in the midline.

- Frequently, one or both rectus abdominis muscles may be avulsed from their insertion on the pubis.
  - If not, 2 to 3 cm of the insertion can be elevated from the anterior surface of the pubis to increase exposure.
  - As long as the distal insertion is left intact, it can be repaired easily to the contralateral side without tension.
- Malleable retractors are used to retract the bladder.
- The periosteum overlying the superior ramus is incised and dissection proceeds medial to lateral in a subperiosteal fashion.
- Retropubic vascular anastomoses between the superficial and deep iliac vascular systems are common and should be identified, ligated, and divided in a controlled manner, if present.
- The obturator neurovascular bundle is tethered distally by the obturator membrane and thus limits the caudal extent of the Stoppa window's exposure.
- The upper extend of the Stoppa window merges with the medial extent of the middle window after the iliopectineal fascia insertion is released from the pelvic brim.

Fracture Assessment Tips

- According to the system developed by Emile Letournel, acetabular fractures are classified by fracture morphology and location into elementary or associated fracture patterns.
- Collectively understanding the fracture morphology and the behavior of its component fragments is vital to developing and executing a successful operative plan.
- The pelvis fractures along predictable fault planes, producing several commonly recurring fracture fragments.
  - Fragment displacement is often asymmetric along the fracture plane, being tethered at one edge by intact soft tissues that act as a point of rotation or hinge between the two fragments.
  - These soft tissue hinges are helpful in that they can allow a strategically placed clamp to compress the entire fracture surface, despite its relatively large area.
  - Likewise, indirect reduction of a secondary fragment may be accomplished upon reduction of the primary fragment, if intact soft tissues span the two.

Reduction and Fixation Techniques

The Posterior Wall Fragment

- It is the most common elementary acetabular fracture pattern but has extremely variable morphology.
- It may be caused by axial load applied through an intact femur (Fig. 11-1), as in a posterior hip fracture dislocation, or it may be caused by avulsion mechanism in associated patterns (Fig. 11-2) where there is significant medial displacement of the femoral head relative to the posterior wall of the acetabulum.

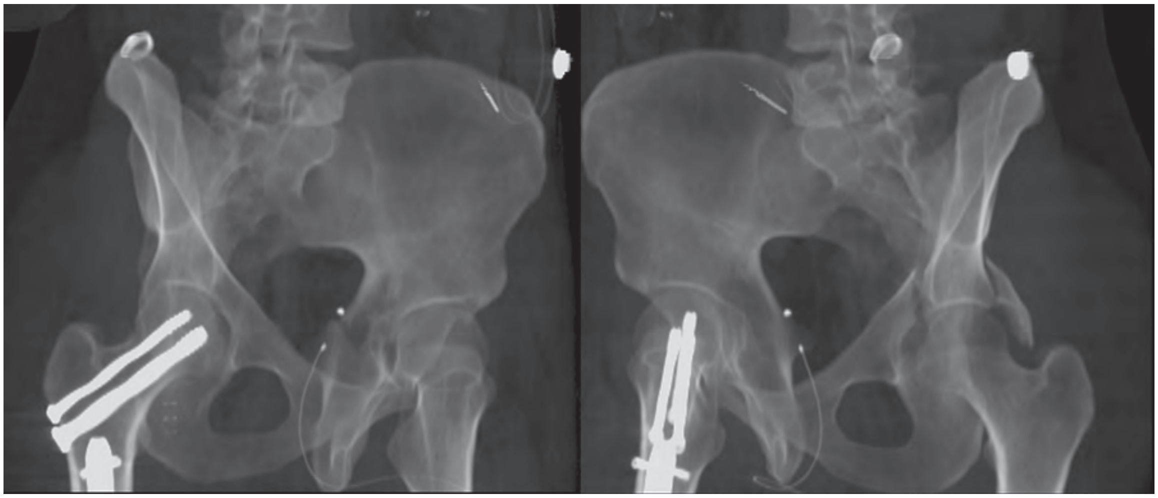


Figure 11-1. The posterior wall component of this associated transverse and posterior wall acetabular fracture demonstrates the type of fracture that is "pushed off" by the femoral head during axial load, with tension failure of the caudal labrum and an intact cranial labrum.

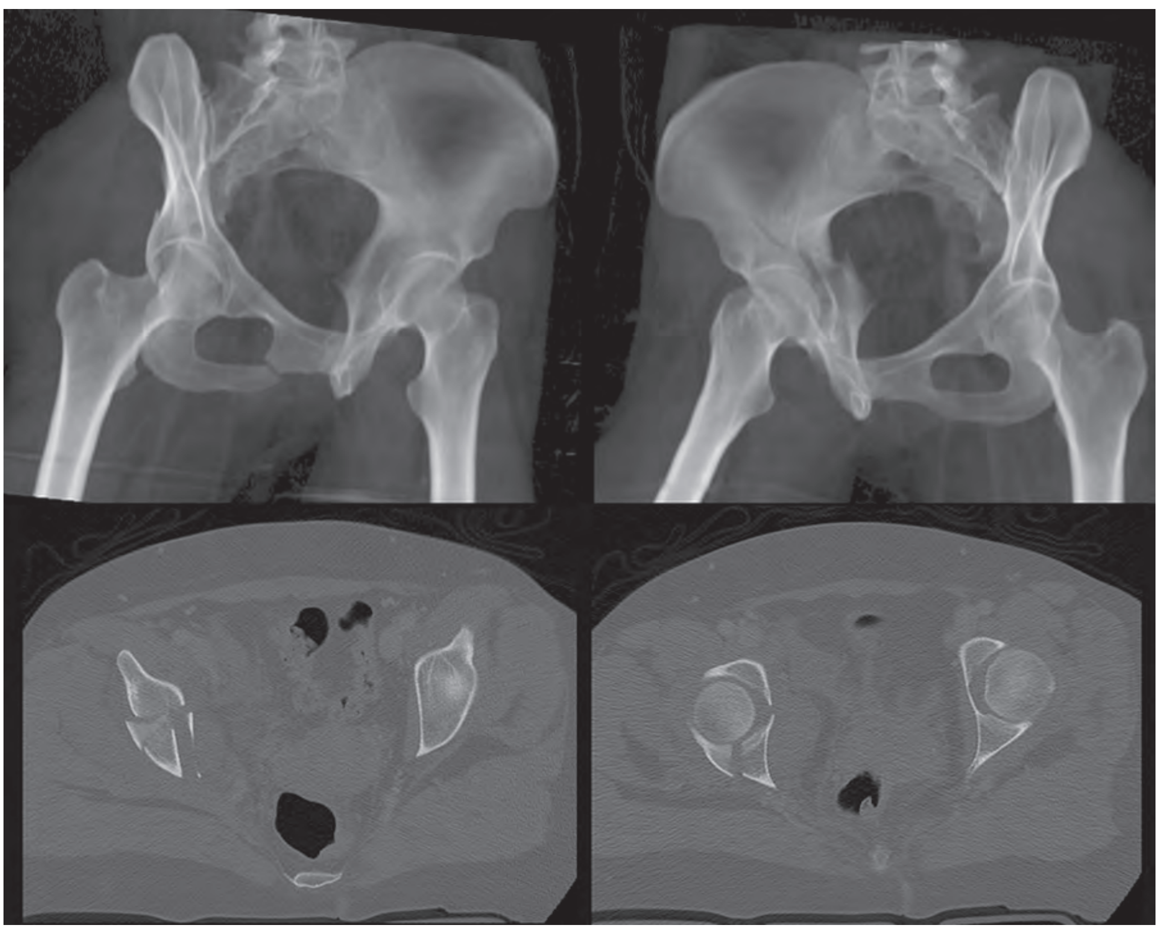


Figure 11-2. "Avulsion" posterior wall. In addition to having an incomplete anterior column component, this associated both-column acetabular fracture has a large posterior wall fracture component. In this type of posterior wall fracture, the fragment is avulsed from the intact ilium as the femoral head dislocates medially. The labrum and capsule are typically intact; however, the stability of the hip joint should be assessed after repair of the column components to determine the need for reduction and fixation of this posterior wall fragment.

- Posterior wall fracture fragments typically have an intact labral attachment.
  - In fractures with a single dominant wall fragment produced by an axial force, this attachment is typically cranial, allowing the fragment to displace primarily by rotation around this tethered point (Fig. 11-3).

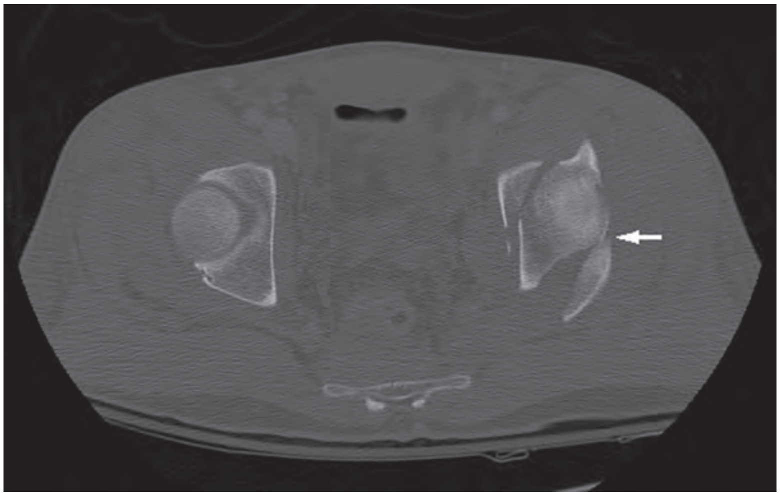


Figure 11-3. The CT scan demonstrates rotatory displacement of a "pushed-off" posterior wall fragment around an intact cranial labrum.

  - Comminuted posterior wall fractures produced by axial force may have both cranial and caudal labral attachments, allowing the fragments to rotate open similar to a saloon door.
  - Avulsion posterior wall fractures are usually found to have an intact labrum and a capsule.
- Marginal impaction is frequently present and can occur on the intact portion of the acetabulum or on the fractured wall (Fig. 11-4).

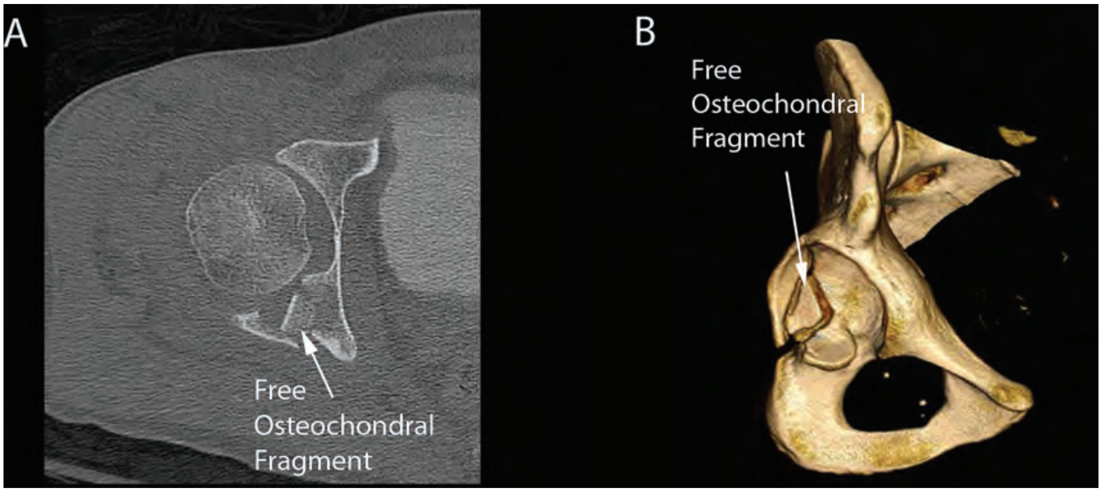


Figure 11-4. Preoperative axial **(A)** and 3D **(B)** CT scans demonstrating marginal impaction.

  - Impacted articular segments should be reduced to the femoral head and their cancellous defects bone grafted.
    - Mini-fragment intraosseous screws may be useful for stabilization of these small osteochondral fragments (Fig. 11-5).

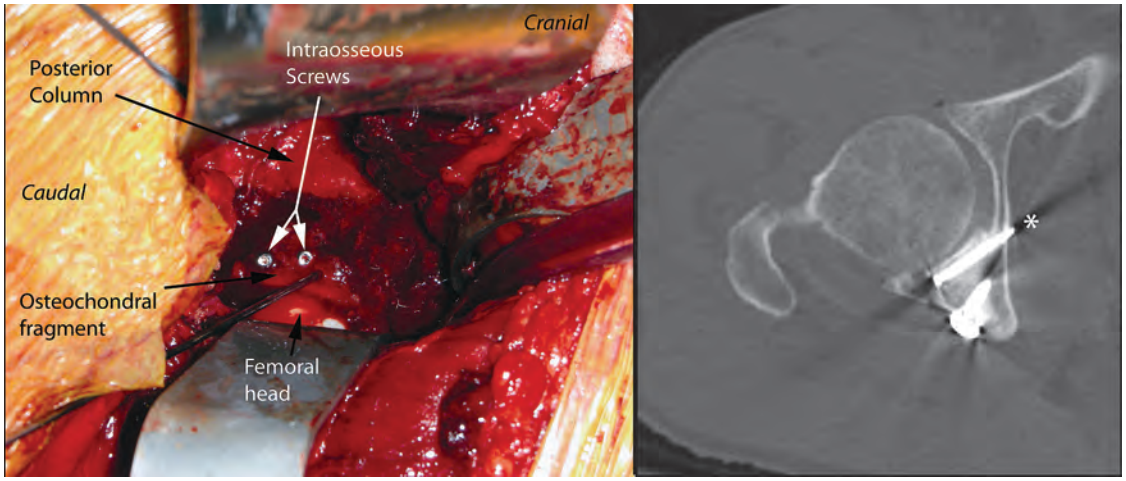


Figure 11-5. Intraoperative view of marginal impaction and intraosseous screw stabilization. The postoperative CT scan demonstrates the reduction and position of the screw.

- In addition, the femoral head may cause impaction of the cancellous fracture bed, which will result in an imperfect fit between the cancellous portions of the fracture fragments during reduction if not disimpacted.
- Balanced buttress plate(s) are the mainstay of posterior wall fracture fixation (Fig. 11-6).
  - A seven- or eight-hole undercontoured 3.5 reconstruction plate is usually sufficient for this application, depending on the cranial extend of the fracture.

Figure 11-6. The posterior wall component of this associated transverse and posterior wall fracture is fixed with a balanced, slightly undercontoured buttress plate. This implant is usually a seven- or eight-hole reconstruction plate and is the mainstay for posterior wall acetabular fractures. This plate also functions to stabilize the posterior column portion of the transverse fracture.

- 0.062 inch K-wires accomplish provisional fixation and should be strategically located remote from the planned implant zone.
- A “spring plate” can be used for peripheral posterior wall fractures that are incompletely captured by the buttress reconstruction plate.

- This implant is fashioned from a three-hole one-third tubular plate and should be placed underneath the buttress plate.
- To make a hook plate, the end hole of the one-third tubular plate should be flattened and bent 90 degrees through the hole of the single-hole side of the plate.
- Once bent, a section of the bent hole should be cut out to fashion two prongs (Fig. 11-7).

Figure 11-7. A spring plate can be fabricated from a standard three-hole one-third tubular plate using two sets of pliers and a wire cutter. To begin, flatten the single hole end of the plate and bend it to 90 degrees as shown. The size and location of the fracture fragment will determine the depth of the tines, which can be varied based on how much of the residual plate is removed.

- The spring plate is applied with the prongs set in bone on the peripheral edge of the posterior wall fragment.
- Avoid placing the prongs in soft tissues or labrum, as this may result in erosion of the femoral head.

- With the leg prepped free, the universal distractor can be used to improve access to the joint for extraction of intra-articular fracture debris (Fig. 11-8).

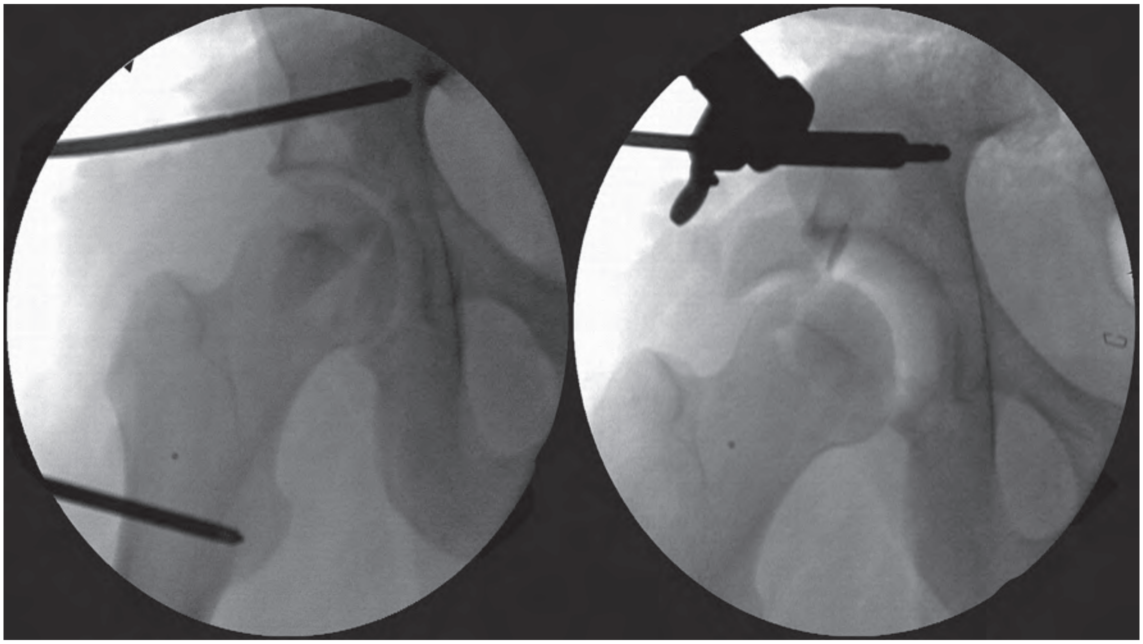


Figure 11-8. The universal distractor may be used to improve visualization of the hip joint while extracting fracture debris. Make sure the threaded bar is oriented to provide a lateral and caudal distraction vector that roughly parallels the femoral neck.

The Caudal Segment of a Transverse Fracture

- The transverse acetabular fracture pattern is an elementary acetabular fracture that occurs when a single fracture plane divides the acetabulum into cranial and caudal fragments (Fig. 11-9).

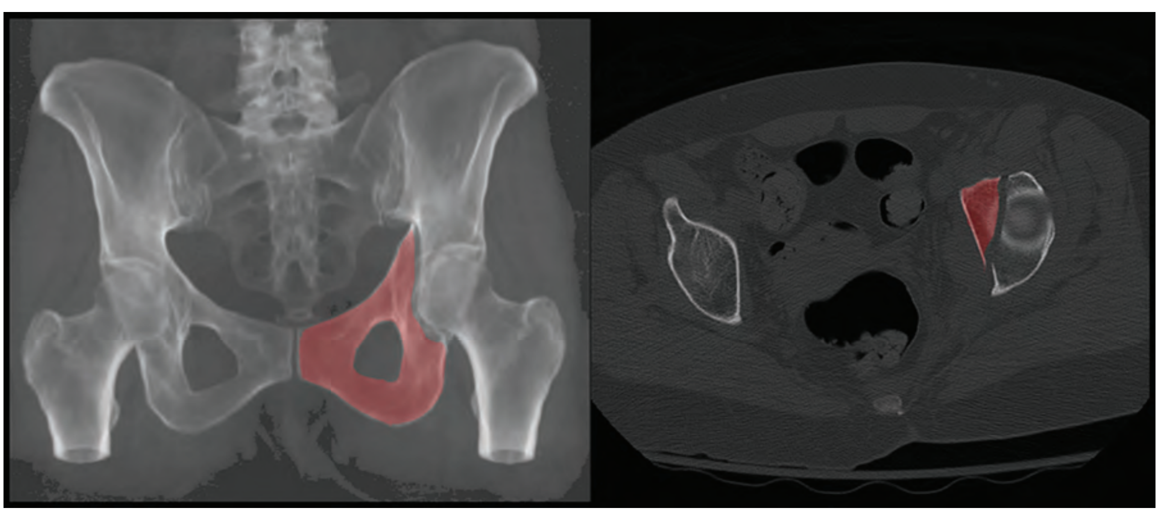


Figure 11-9. The caudal segment of this transtectal transverse acetabular fracture is shown in red. Note the disruption in both the iliopectineal and ilioischial lines on the AP radiograph.

- By definition, this fracture plane must traverse the anatomical areas of the anterior and posterior columns, as well as the areas of the anterior and posterior walls. This can be confusing since there are also fracture patterns named after these anatomical areas.
- The transverse acetabular fracture disrupts the pelvic ring and can occur in conjunction with sacral fractures, sacroiliac joint injuries, or disruptions to the pubic symphysis. Look carefully for these associated injuries.
- The caudal segment is usually the unstable component of the transverse acetabular fracture pattern and typically displaces medially.
  - Often, the caudal segment displacement has a rotational component and is "hinged" either anteriorly or posteriorly by intact soft tissues.
  - The location of maximal displacement usually determines the surgical approach required for reduction.
- The caudal segment of the transverse acetabular fracture should behave as a unit during reduction efforts and can often be accurately reduced with strategic clamp placement.
- It can be difficult to assess the reduction intraoperatively since direct visualization of both columns simultaneously is not possible without extensile or combined simultaneous approaches.
- The surgical approach is decided based on the anatomic column that needs to be visualized intraoperatively, which most often is determined by the region of maximal displacement but may occasionally be determined by the need to clean comminution from the primary fracture plane (Fig. 11-10).

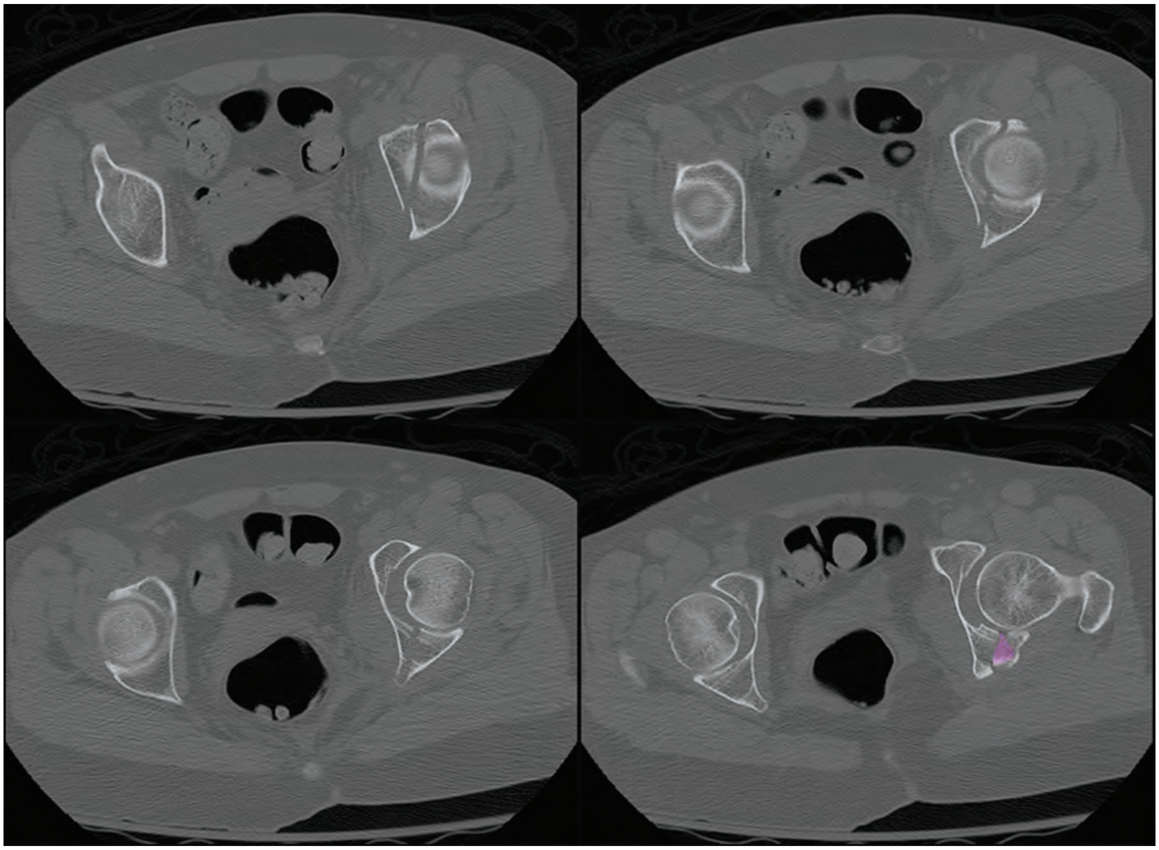


Figure 11-10. Use the CT to plan the surgical approach for transverse fractures. The column that requires direct visualization (usually the most displaced) determines the approach. While the displacement of this transtectal transverse fracture is fairly symmetric, there is comminution in the area of the posterior wall (magenta) that will prevent an anatomic articular reduction if it is not addressed. The ideal approach for this fracture is a prone Kocher-Langenbeck approach.

- The medullary superior ramus screw is a useful implant to stabilize displaced pubic root fractures whether they occur in the context of a pelvic ring injury or the anterior column component of an acetabular fracture (Fig. 11-11).

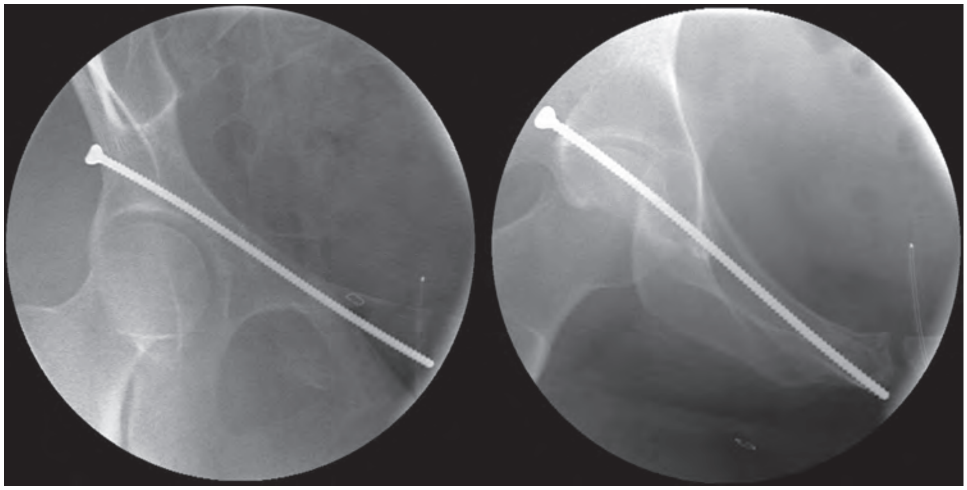


Figure 11-11. Medullary superior ramus screw. These screws can be inserted antegrade or retrograde using the obturator outlet **(left)** and inlet **(right)** fluoroscopic views. The superior ramus is a triangular tube of bone oriented roughly 45 degrees oblique to the coronal plane. To remain safe, the screw trajectory should course through the largest area of the medullary canal, which is cranial and posterior (shown). Use blunt rather than self-tapping screws, and overdrill the starting point to make screw insertion easier.

- This implant is applicable in patients who have sufficient anatomy in the anterior supra-acetabular area to accommodate the screw and can be inserted with the patient supine or prone, and in an antegrade or retrograde direction, depending on patient anatomy (Fig. 11-12).

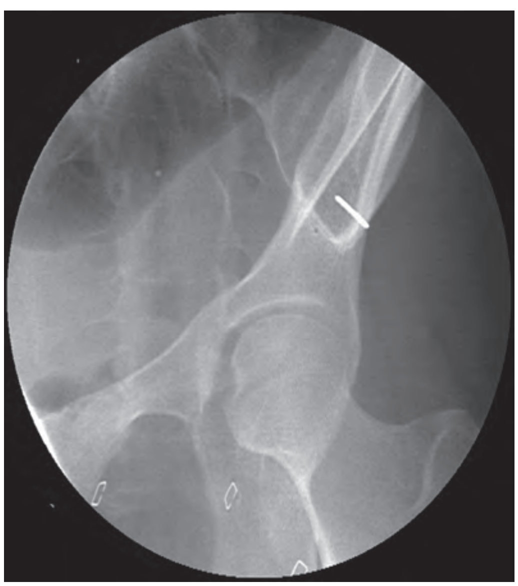


Figure 11-12. This patient's superior ramus is narrow and undulating, which makes antegrade medullary fixation difficult. However, this parasymphyseal ramus fracture would be appropriate for a shorter retrograde screw.

- The fluoroscopic views used during superior pubic ramus screw insertion are the obturator oblique and the inlet.
- The starting point for an antegrade screw is 1 to 2 cm cranial to the acetabulum on the gluteus medius pillar.

- The retrograde screw insertion point is medial and caudal to the pubic tubercle, on the anterior edge of the pubic symphysis.
- The near cortex is overdrilled to allow easier screw insertion.
- The ideal screw trajectory is central to high on the obturator oblique view and posterior on the inlet view.
- A 3.5-mm screw is most commonly used and is often sufficient; however, a 4.5-mm screw can be used when the surgeon desires and the patient's anatomy will accommodate the larger screw.

- Options for plate fixation of the anterior portion of the anterior column require an ilioinguinal approach and have been discussed in the section "The Anterior Column Fragment."
- Reduction of the displaced posterior portion of the caudal segment is accomplished most often with direct visualization through a prone Kocher-Langenbeck approach.
    - A modified Weber clamp (or two) placed through drill holes in the ilium and ischium is usually sufficient.
    - A 4- or 5-mm Shantz pin in the ischial tuberosity may be used to help correct rotational deformity but should be remotely placed from anticipated fixation sites.
    - The anterior portion of the caudal segment may be accessed for palpation or clamp application through the greater sciatic notch.
    - There is frequently not enough room to palpate the anterior reduction after application of a clamp through the greater sciatic notch (Fig. 11-13).

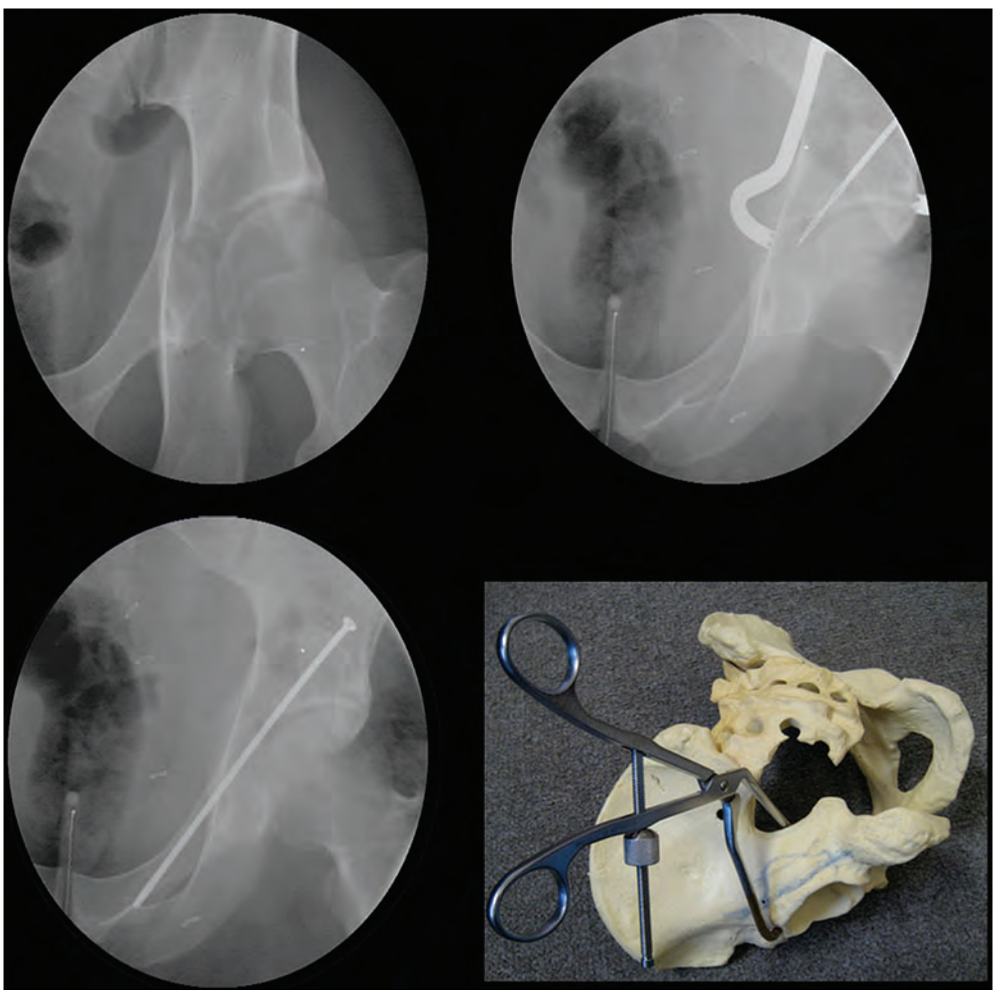


Figure 11-13. The transverse portion of the associated transverse and posterior wall fracture is cleaned and then clamped as shown. A portion of the obturator internus muscle origin must be elevated subperiosteally and the knee must be flexed to allow application of this clamp. A medullary superior ramus screw maintains the reduction of the anterior column portion after clamp removal.

- An associated posterior wall fracture allows an articular reduction read in addition to cortical and radiographic assessments.
  - When working from the posterior approach, clamp and reduce and fix the anterior column first.
- Plate fixation for the posterior portion of the caudal segment is similar to that of the posterior column fragment, which is described in the section "The Posterior Column Fragment."
  - If there is an associated posterior wall fracture, the caudal segment should be reduced and stabilized first with the posterior wall fragment displaced, as this allows visualization of the articular surface from which one can further assess the quality of the caudal segment reduction.
- Malreductions occur usually in the column opposite the surgical approach, and there are several reasons that may explain this issue.
  - First, the surgeon is unable to directly visualize the reduction of the opposite column and may incorrectly interpret intraoperative radiographs.
  - Second, insufficient cleaning of the unvisualized portion of the fracture can result in the inability to effect an accurate reduction.
  - Third, fixation options for the opposite column are limited, and inadequate fixation may result in early displacement.
  - Finally, undercontoured implants on the posterior column can displace the anterior column if it is unfixed and its periosteal hinge is insufficient.

The Posterior Column Fragment

- The posterior column fragment occurs in the elementary posterior column fracture pattern and also in several associated fracture patterns to include the anterior column plus posterior hemitransverse, associated both-column, and the T-shaped fracture patterns.
- The posterior column fragment is produced by a fracture that traverses the obturator ring, divides the acetabulum into anterior and posterior halves, and exits cranially and posteriorly into the greater sciatic notch.
  - The exit point in the greater notch is variable, as is the obturator ring exit point (Fig. 11-14).

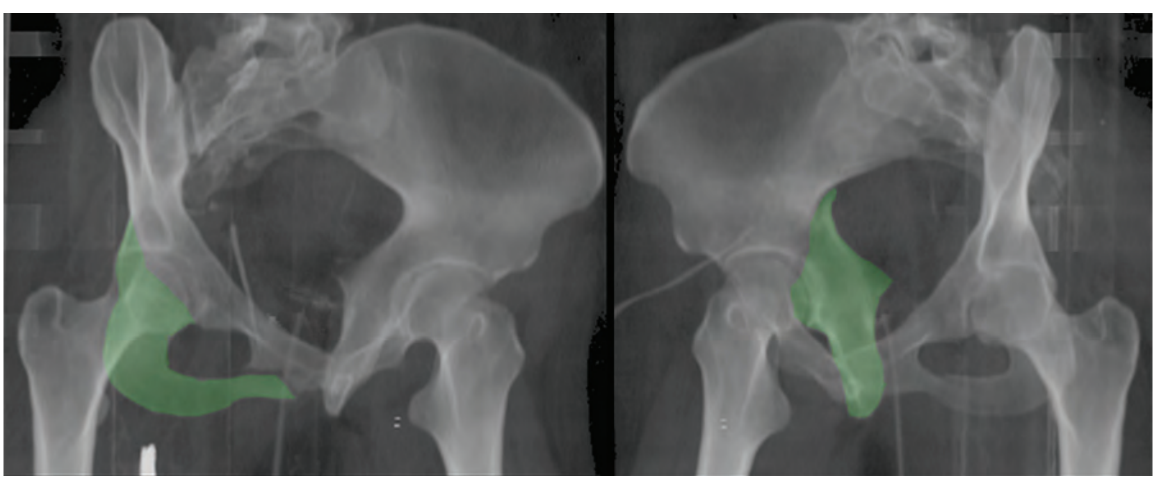


Figure 11-14. These Judet views define the posterior column fragment (green) in an elementary posterior column fracture. Note the posterior spike of bone created as the fracture enters the greater sciatic notch. Although the bone quality in this area is typically quite good, the spike tends to be plastically deformed and may not be reliable for assessing the articular reduction.

- Displacement of the posterior column fragment is maintained in part by deforming muscular forces, specifically the abductor group, hamstrings, and rectus femoris.
  - The posterior column thus assumes a medialized, flexed, and, occasionally, internally rotated position (Fig. 11-15).

Figure 11-15. This elementary posterior column fracture demonstrates flexion and internal rotation deformities. Note the asymmetry of the obturator foramina on the AP and the distraction at the greater sciatic notch on the iliac oblique. A Schantz pin applied in the ischial tuberosity may be useful to correct any residual malrotation that may be present after clamp application. Consider using a smaller 4.0-mm pin and make sure its location is compatible with both the reduction maneuver and the anticipated fixation strategy. When a large pin cavitates, it can negatively affect fixation options.

- The posterior capsule is usually in continuity between the femoral neck and the fractured posterior column fragment, resulting in the tendency for the femoral head to follow the displacement of this fragment.
- Fracture displacement in the region of the greater sciatic notch can result in an injury to the sciatic nerve and/or the superior gluteal neurovascular bundle.
- Fractures involving the posterior column frequently produce a "spike" of bone that remains on the posterior column fragment as the fracture plane exits the greater sciatic notch.
  - This "spike" is occasionally plastically deformed and may not be a reliable reduction read.
- Not all fractures involving the greater sciatic notch produce a posterior column fracture fragment.
  - For this fragment to occur, the fracture plane must divide the obturator ring.
- Long screws can be placed into the posterior column from the inner table of the ilium using the iliac window portion of an ilioinguinal exposure.
  - Typically, these screws are applied through or adjacent to a reconstruction plate, which acts as a washer to fortify the proximal screw purchase.

- The iliac oblique and outlet fluoroscopic views are used to guide the placement of these screws (Fig. 11-16).

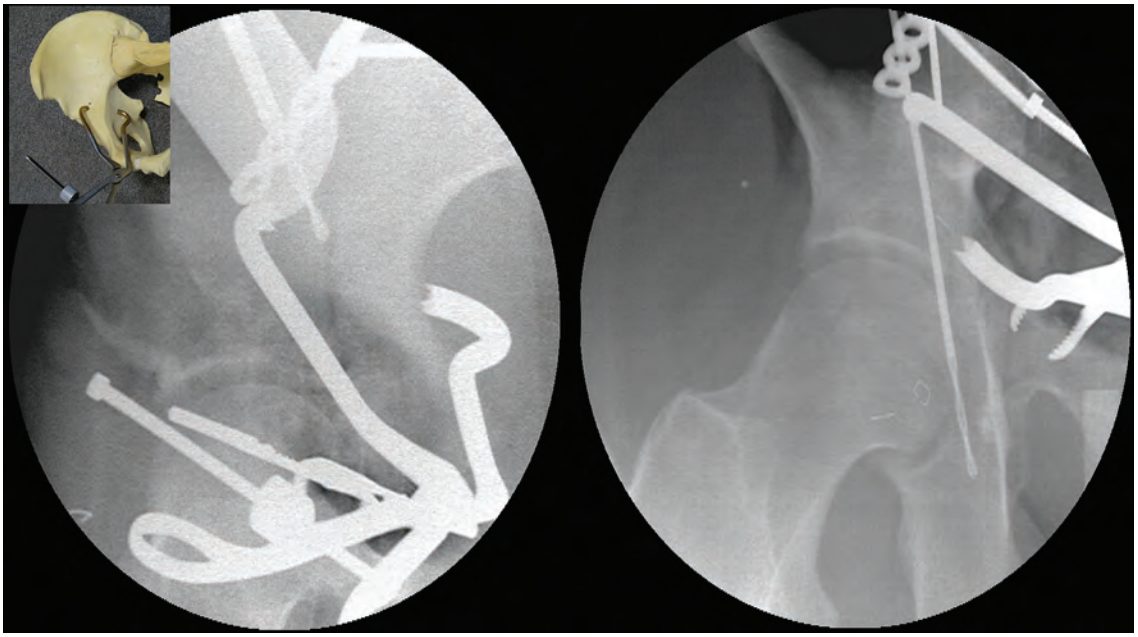


Figure 11-16. Working from the lateral window of an ilioinguinal approach, these posterior column screws are inserted through the distal end of an eight-hole reconstruction plate using the iliac oblique and outlet fluoroscopic views. The trajectory is just posterior to the acetabulum and just lateral to the quadrilateral surface toward the medial aspect of the ischial tuberosity. The plate is in effect a large washer, preventing the intrusion of the screw heads through the inner table of the ilium. The large clamp is applied through the Stoppa window, with one tine on the quadrilateral surface and the other over the pelvic brim near the psoas gutter. Axial CT images are used during preoperative planning to determine the appropriate vector for this clamp application.

- The screw path should course from its starting point lateral to the pelvic brim and anterior to the sacroiliac joint to the medial aspect of the ischial tuberosity for maximal length.
- Screws with a more lateral trajectory will exit on the dorsolateral surface of the ischium in the area of the posterior wall and will be shorter as a result.
- For longer screws, the ideal path is just posterior to the acetabulum on the iliac oblique and adjacent to the quadrilateral surface on the outlet.

- Fixation of the posterior column fragment using the Kocher-Langenbeck approach most often is accomplished with reconstruction plates. Depending on the fracture morphology, one or two plates may be used to obtain stability of the posterior column (Fig. 11-17).

Figure 11-17. This elementary posterior column fracture has been stabilized using a single appropriately contoured eight-hole reconstruction plate.

- Elementary posterior column fractures are usually associated with a labral tear that can obstruct the reduction.
  - If present, the torn labrum should be identified and its unstable portion repaired or debrided.

The Anterior Column Fragment

- Several variants of the anterior column fracture pattern have been described, differentiated by where the fracture plane exits the ilium.
  - The high fracture variant spans the iliac crest and inferior ischiopubic junction, traversing the iliac wing dorsal to the gluteus medius pillar, entering the acetabulum at its cranial margin.
  - The low fracture variant involves the area caudal to the anterior inferior iliac spine (AIIS) in the region of the psoas gutter or pubic root and traverses the acetabulum and obturator ring to exit the inferior ramus at the ischiopubic junction.
- Fractures involving the anterior column produce two common fracture fragments and can occur as an elementary anterior column fracture or as a component of associated fracture patterns (Fig. 11-18).

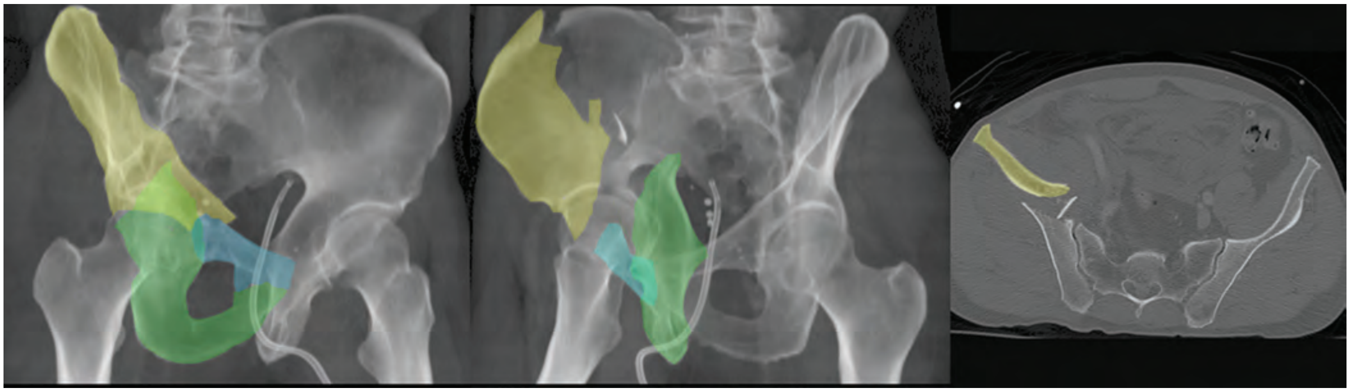


Figure 11-18. This associated both-column acetabular fracture produced three dominant fragments: the anterior iliac fragment (yellow), the pubic fragment (blue), and the posterior column fragment (green). Additionally, there is comminution at the pelvic brim, noted on the iliac oblique and the axial image.

- The anterior iliac fragment occurs in fractures that have a high anterior column component and usually includes the anterior half of the ilium including the medius pillar, as well as a larger portion of the acetabular dome.
  - When present, it usually demonstrates multiplanar displacement, with an extension in the sagittal plane and concurrent rotation and medial translation in the coronal plane.
  - Often, the fracture runs obliquely between the inner and outer tables of the ilium, exiting the pelvic brim near the anterior margin of the sacroiliac joint and the outer table just dorsal to the gluteus medius pillar.
  - Comminution of the dense bone at the pelvic brim complicates the reduction since the unicortical portion of the iliac fossa is often plastically deformed.
- The pubic fragment is formed when a fracture involving the psoas gutter divides the caudal portion of the anterior column from its iliac portion.
  - If displaced, its hinge point is usually the pubic symphysis.
- Plastic deformity in the unicortical portion of the anterior iliac fragment can complicate the articular reduction since reduction of the iliac crest and upper portions of the inner table may not effect an accurate reduction of the articular surface.

- Thus, the most accurate articular reduction is often obtained indirectly through extraarticular cortical reduction near the pelvic brim and quadralateral surface. The relative density of the bone in this area makes it resistant to plastic deformation.
- If this area is comminuted, reassembly of the comminuted fragments is often necessary to effect an accurate reconstruction of the joint surface.

- Occasionally, the iliac portion of the fracture will be incomplete at the crest and displacement at the joint will occur through plastic deformation along the iliac wing.
    - The incomplete fracture usually must be completed to achieve an accurate articular reduction, and residual plastic deformity in the iliac wing can be manifest as an imperfect reduction of the iliac crest despite anatomic reduction at the level of the pelvic brim (Fig. 11-19).

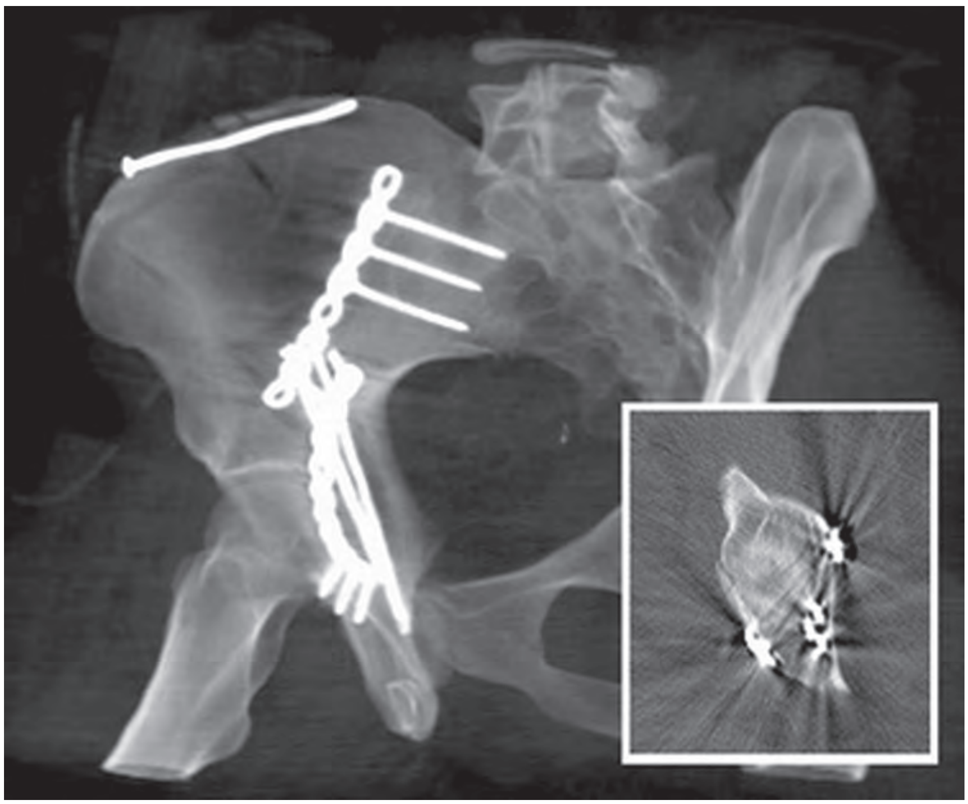


Figure 11-19. This is the postoperative radiograph of the associated both-column fracture in Figure 18. The incomplete fracture of the anterior column was completed with an osteotome and reduced using a cortical read at the pelvic brim. Note that plastic deformation through the unicortical portion of the ilium causes an imperfect reduction at the iliac crest despite accurate restoration of the articular surface.

- Secure fixation of the iliac fracture requires fixation both at the crest and at the brim.
- Reduction of the anterior iliac fragment requires traction, lateralization at the level of the pelvic brim, and rotation in the coronal plane.
    - Often, a clamp at the iliac crest is helpful in stabilizing a fragment cranially, allowing the fragment to be abducted, flexed, and internally rotated around this point.
- A buttress plate along the pelvic brim is very useful in stabilizing the caudal aspect of the iliac fracture.
    - A seven- or eight-hole plate is most often used.
    - The proximal and posterior screws gain purchase in the posterior iliac crest and angle medially paralleling the sacroiliac joint.

- Distal fixation is available with screws into the cortical bone of the greater sciatic notch (consider undersizing these screws as the density of the bone in this area tends to cause the screw head to strip before it is fully seated.) or with longer screws into the posterior column.
- If long posterior column screws are planned, do not twist the plate to match the contour of the iliac fossa, as doing so will interfere with the ability to aim longer screws along the quadrilateral surface into the ischium. (Posterior column screws are described in the section "The Posterior Column Fragment.")

- Alternatively, an opportunity for screw fixation at the pelvic brim exists in the "tube" of bone between the AIIS and the PSIS.
  - The fluoroscopic views used for insertion of this screw are the obturator outlet, the obturator inlet, and the iliac oblique.
  - The starting point is located on the obturator outlet view, while the screw trajectory is followed on the other views (Fig. 11-20).

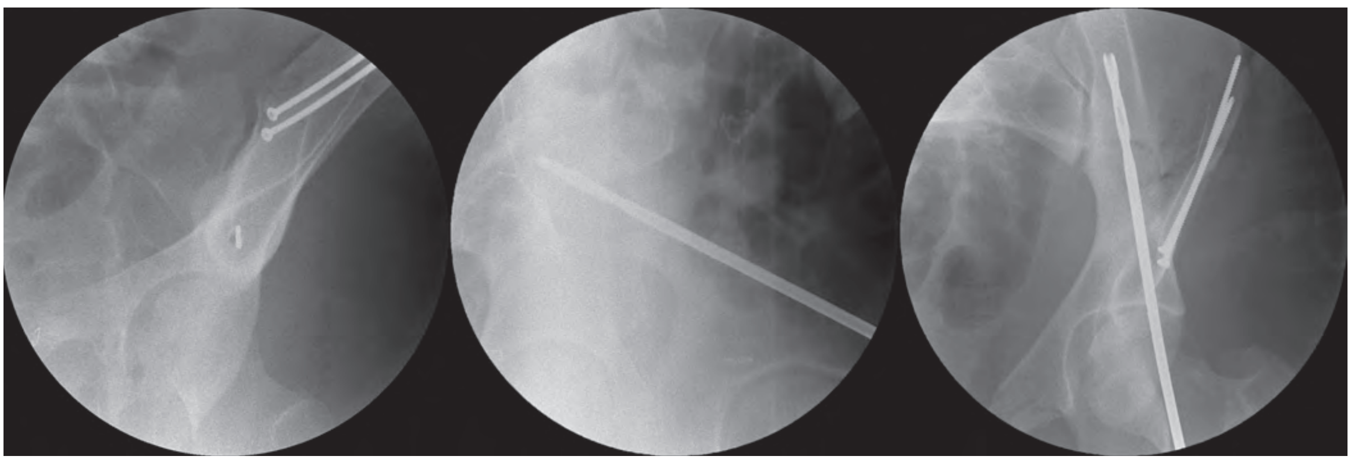


Figure 11-20. One opportunity for medullary fixation at the level of the pelvic brim is the conduit between AIIS and PSIS. The starting point is identified using an obturator outlet view **(left)**. Use the iliac oblique view **(center)** to aim cranial to the acetabulum and the greater sciatic notch and the obturator inlet view **(right)** to guide the trajectory between the inner and outer tables. It is important to consider the need for superior ramus screws and adjust the starting point appropriately. The screw shown will likely obstruct the path of an antegrade superior ramus screw (see left).

- The intrapelvic plate is applied through the Stoppa window and is useful for stabilizing low anterior column fractures but is most useful for buttressing the posterior column and quadrilateral surface in fractures involving both the anterior and posterior columns.
  - This is usually a ten-hole reconstruction plate.
  - It should have a slight undercontoured bend to accommodate the quadrilateral surface and should be twisted anteriorly through the anterior four holes to allow easier screw insertion into the superior ramus.
  - The posterior three holes should be overreamed with a 3.5-mm drill to allow increased angulation of the screw in the plate.

- If long posterior column screws are planned, make sure to evaluate the location of the plate relative to the posterior column screw trajectory which usually courses adjacent to the second and third holes.
- The obturator inlet is useful for checking the length of the posterior screws (Fig. 11-21).

Figure 11-21. Intrapelvic plate. This ten-hole reconstruction plate spans the posterior column and the superior ramus. Note the trajectory of the posterior column screws relative to the plate.

The Independent Dome Fragment

- Frequently, the acetabular dome is displaced as a separate fragment (Fig. 11-22).
- This fragment is commonly seen in the posterior wall, posterior column, transverse plus posterior wall, and T-shaped fractures.
- It is important to accurately reduce this fragment, not only because of its location within the weight-bearing surface of the acetabulum but also because malreduction of this fragment frequently prevents accurate reassembly of the remainder of the joint.
  - In effect, the malreduced dome fragment prevents an accurate reduction of the column or wall pieces.

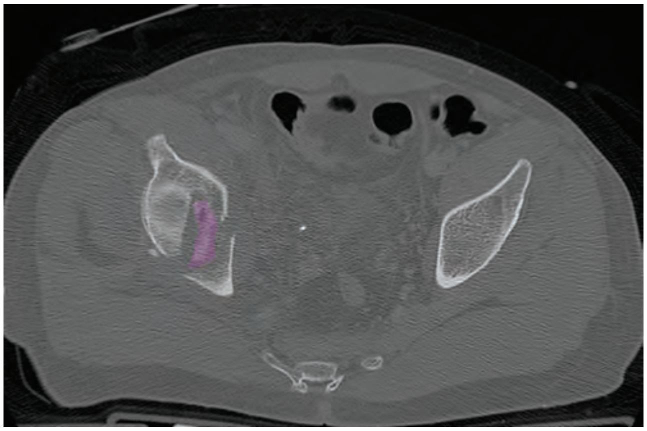


Figure 11-22. Dome fragment. This elementary posterior column fracture has comminution in the area of the acetabular dome. This fragment must be reduced anatomically or it will prevent reduction of the posterior column. These osteochondral fragments should be supported with bone graft if there is an adjacent cancellous impaction present.

- When displacement of this fragment occurs, it often occurs through impacted or compacted cancellous bone, and when the articular surface is realigned, a cancellous void remains.
  - The void should be assessed, and it should be filled with some form of structural bone graft if it renders the independent fragment unstable.

Reference

1. Rath EMS, Russell GV, Washington WJ, et al. Gluteus minimus necrotic muscle debridement diminishes heterotopic ossification after acetabular fracture fixation *Injury*. 2002;33:751–756.

Chapter 12

Femoral Head Fractures

Raymond D. Wright
Milton L. Chip Routt

Sterile Instruments/Equipment

- Deep retractors
- Large nonabsorbable suture for rectus femoris and capsular tagging
- Free needles for postfixation rectus femoris and capsular repair
- Dental picks
- Large and small pointed bone reduction clamps (“Weber clamps”)
- Implants:
  - 2.0- or 2.4-mm screws
- K-wires and wire driver/drill

Patient Positioning

- Supine on a radiolucent table.
- A padded bump, 3 inches thick and 12 inches wide, is placed in the midline of the patient, from the midlumbar spine caudal to the perineum.
- The entire ipsilateral lower extremity is circumferentially prepped and draped to allow manipulation of the operative limb.
- The C-arm is placed on the contralateral side of the operative extremity.

Surgical Approach

- The caudal limb of the Smith Petersen approach allows optimal exposure.
- The skin incision is from the palpable anterior superior iliac spine, distally approximately 15 to 20 cm, in line with the lateral border of the patella (Fig. 12-1).
- Use blunt dissection to avoid injury to the lateral femoral cutaneous nerve.

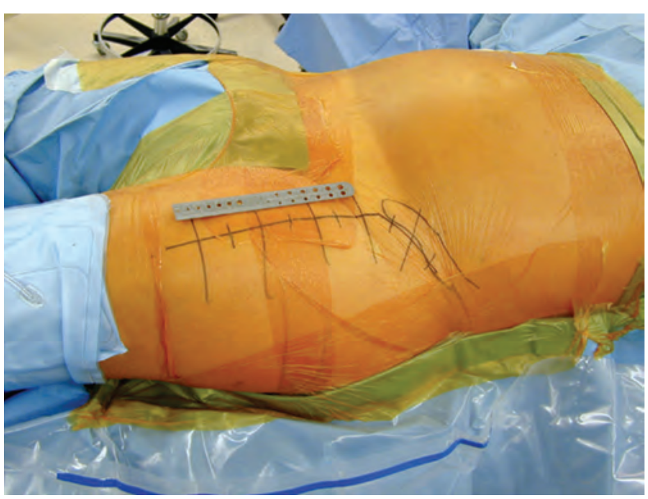


Figure 12-1. Skin incision for a femoral head fracture from the ASIS, in line with the lateral patellar border.

- After developing the superficial muscular interval between the sartorius and the tensor fascia lata, a tenotomy of the common tendon of the rectus femoris is performed (Figs. 12-2 and 12-3).

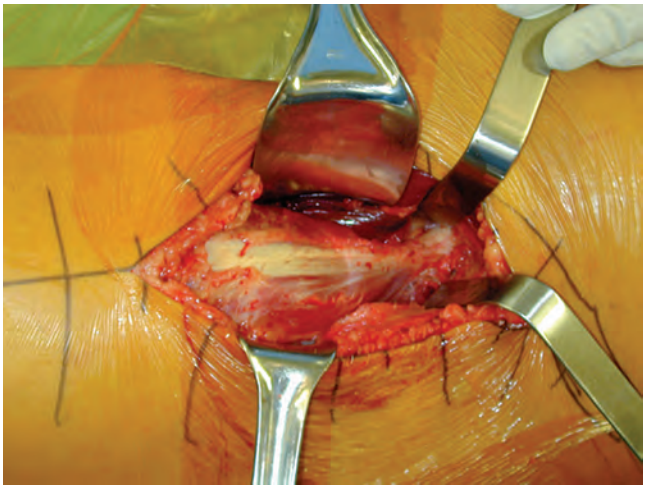


Figure 12-2. Deep to the tensor fascia lata/sartorius interval, the origin of the rectus femoris is exposed.

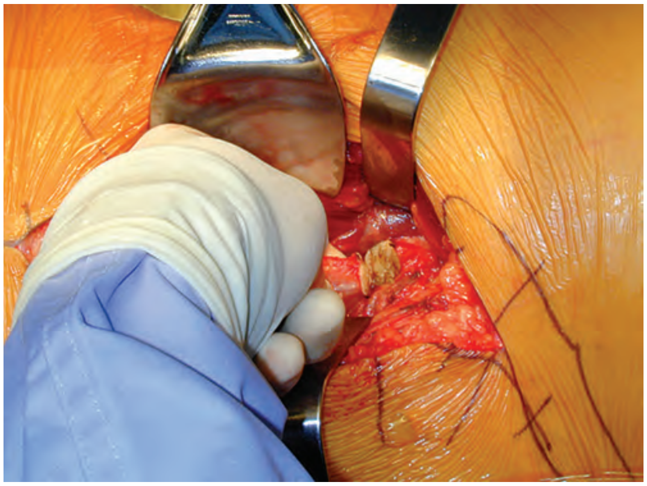


Figure 12-3. The rectus femoris origin is incised just distal to the anterior inferior iliac spine.

- Sutures are placed in the distal portion for caudal retraction of the tendon and later tendon repair (Fig. 12-4).

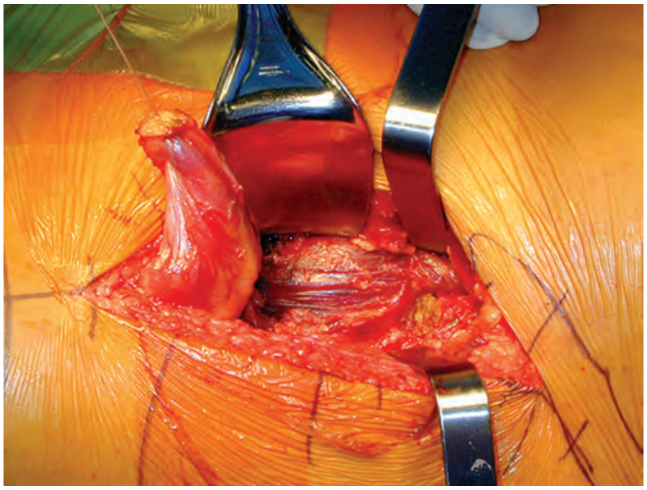


Figure 12-4. The rectus femoris tendon is tagged and retracted distally.

- Create a short proximal stump in order to keep it out of the surgical field.
- Debride the iliocapsularis muscle.
  - This is a lateral outcropping of the iliopsoas muscle that overlies the hip joint capsule.
  - It is of variable size and may be a nidus for the postoperative ectopic bone formation.
- Retract the iliopsoas medially.
- Create a T-shaped capsulotomy.
  - Transverse limb should be cranial and lateral (e.g. parallel) to the labrum to avoid injuring the capsular perforating blood vessels (Figs. 12-5 and 12-6).

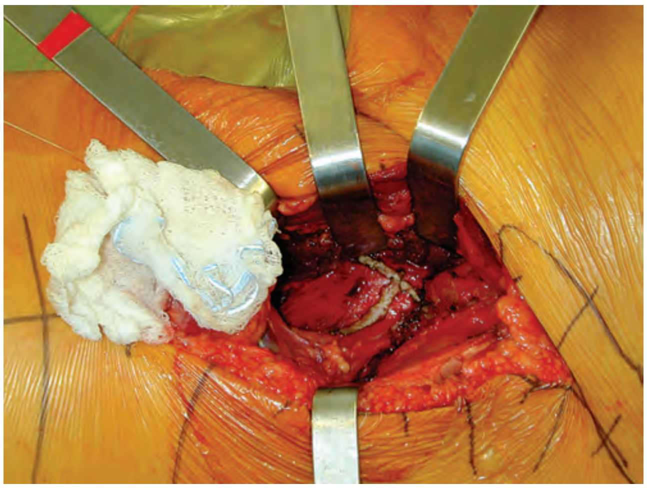


Figure 12-5. Retraction of the iliopsoas exposes the anterior hip capsule, and an oblique T-shaped capsulotomy is marked.

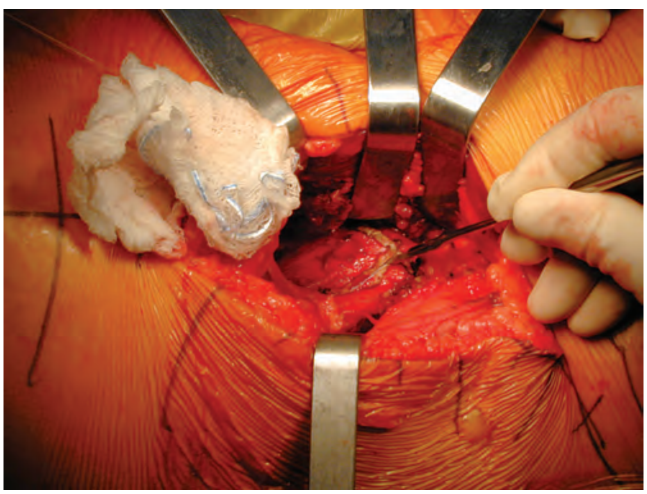


Figure 12-6. The capsulotomy is completed.

  - Avoid incising the labrum with the transverse limb of the capsulotomy.
- The femoral head is then gently dislocated anteriorly for complete visualization (Fig. 12-7).

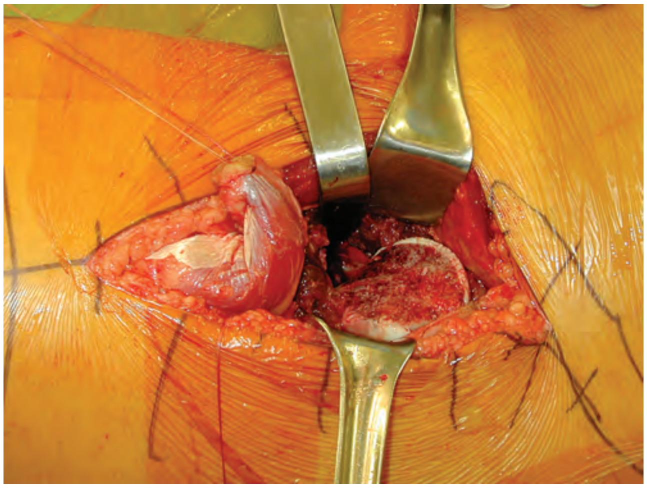


Figure 12-7. Anterior dislocation of the femoral head allows complete exposure of the fracture surfaces.

- Axial traction, adduction, and external rotation.
- Bone hook may be used very cautiously on the femoral neck to assist dislocation.
- Place leg in Figure 4 position.

Reduction and Fixation Techniques

- Reduction of the femoral head fragment must be performed using the chondral fracture margins to assess an anatomical fracture reduction.
- The free femoral head fragment(s) may be predrilled on the sterile back table prior to dislocation of the hip and fracture reduction (Fig. 12-8).

Figure 12-8. The fracture fragment is prepared on the back table, with strategically placed 2.0-mm glide holes.

- Reduction is maintained provisionally with K-wires (Fig. 12-9).

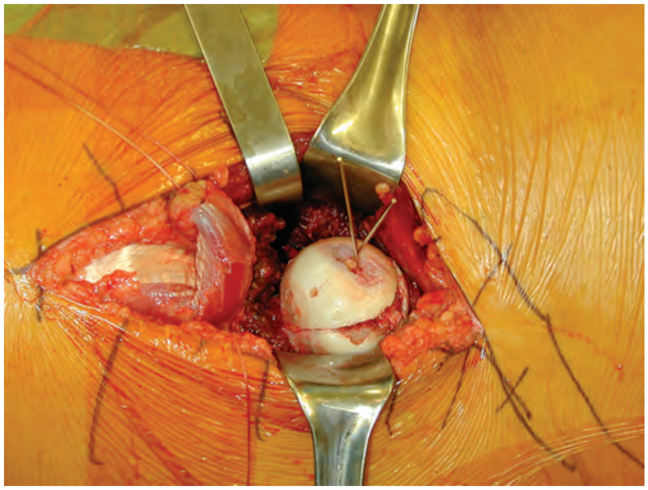


Figure 12-9. The fracture is reduced anatomically and stabilized provisionally.

- Two or three 2.0- or 2.4-mm countersunk lag screws are used for fixation for the major fragment(s).
- Examine the acetabulum critically for osseous and chondral debris.
- Reduce the hip expeditiously and check the range of motion and stability under fluoroscopy, especially when an ipsilateral posterior wall acetabular fracture is present (Fig. 12-10).

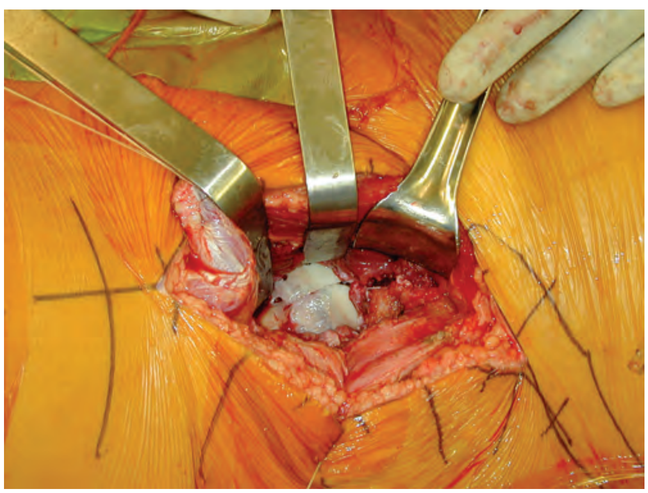


Figure 12-10. Following screw fixation, the femoral head is reduced into the acetabulum.

- Close the capsule completely (Fig. 12-11).
- Repair the rectus femoris tendon using the previously placed suture as a core suture.

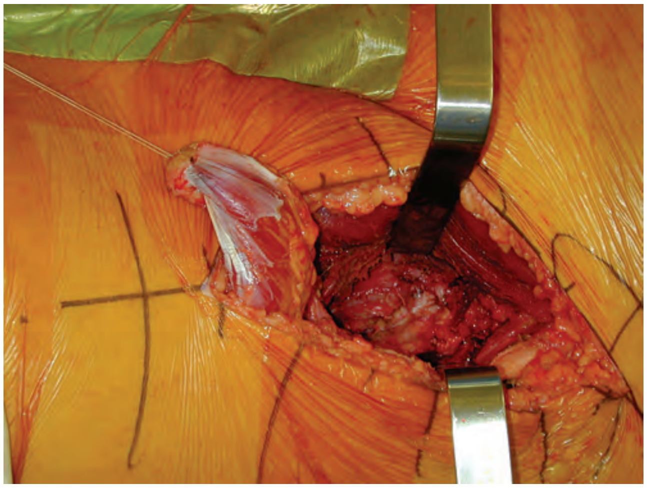


Figure 12-11. The capsulotomy is repaired.

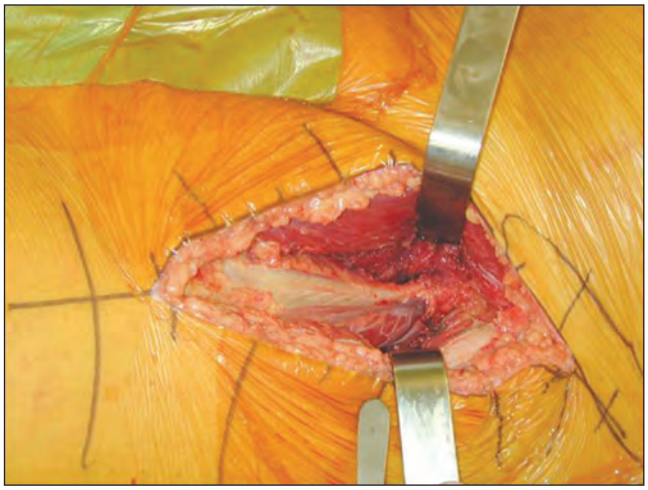


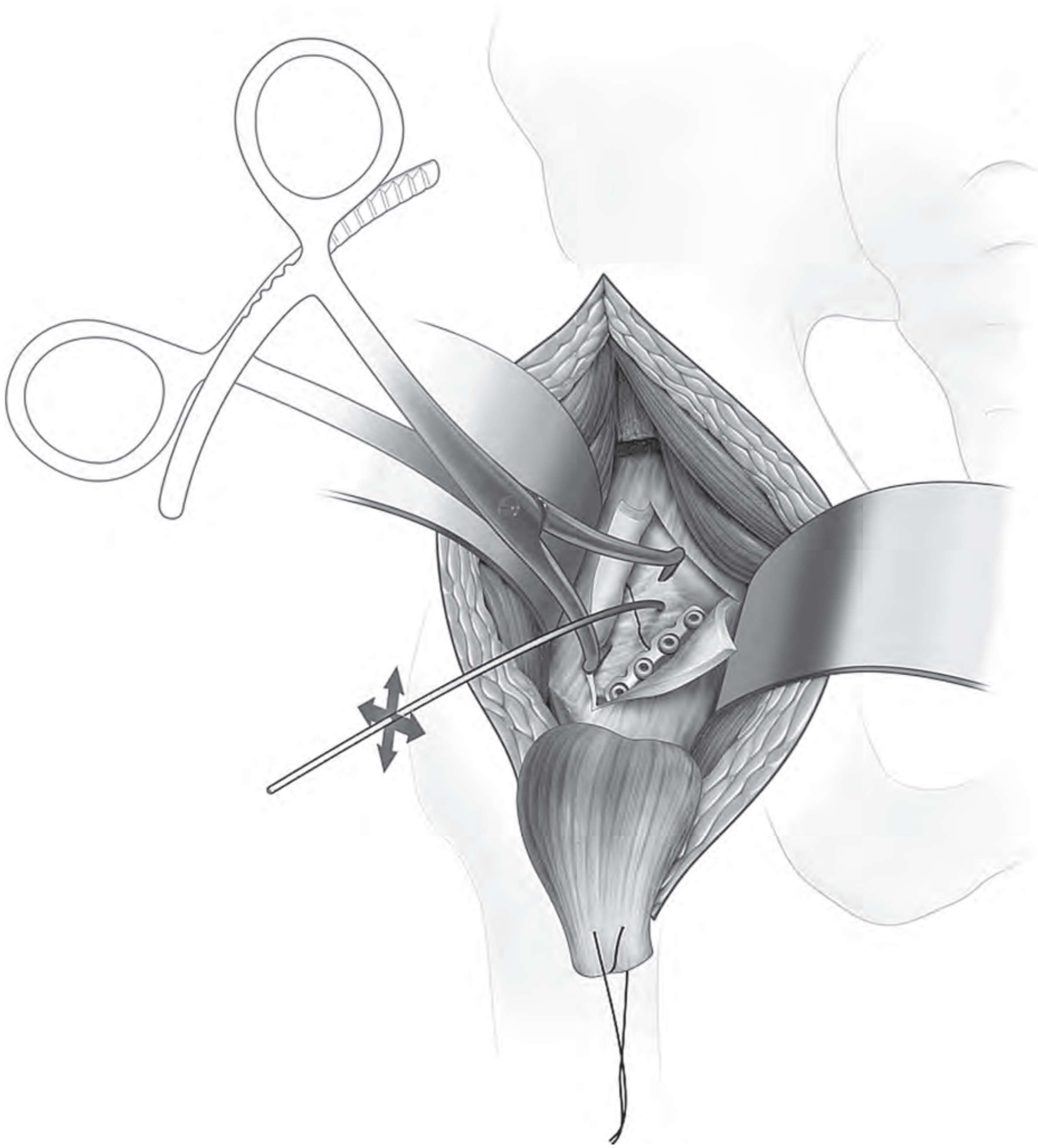
Figure 12-12. The rectus tendon is then repaired.

- Augment the repair with size 0 resorbable sutures in the paratenon (Fig. 12-12).

Section 5

Hip

Sean E. Nork



Femoral Neck Fractures

Jason M. Evans

Chapter 13

Sterile Instruments/Equipment

- 2.5- or 4.0-mm Schanz pins for use as joysticks in the femoral head/neck fragment.
- Large pointed reduction forceps.
  - Modified (straightened) tines for engagement in drill holes.
- Small pointed reduction forceps.
  - Modified (straightened) tines for engagement in drill holes.
- Small fragment drill to assess for the vascularity following reduction.
- 5.0-mm Schanz pins for rotational control of distal (shaft) fragment.
- 5/64 inch (2.0-mm) K-wire for use as a distal traction pin with a tensioned traction bow.
- Implants.
  - 6.5-, 7.0-, or 7.3-mm fully threaded and partially threaded screws for subcapital/transcervical fractures and hip screw for basicervical fractures.
  - Reconstruction and/or mini-fragment plates for provisional stabilization of anteromedial femoral neck in comminuted fractures.
  - Bone graft for comminution.

Positioning

- Supine on radiolucent table with C-arm from opposite side of the table.
- A small rolled towel bump under the injured hip allows for lateral imaging of hip.
  - A bump may not be necessary, as long as fluoroscopic visualization on a cross-table lateral is possible.
- Elevate the operative lower extremity on the leg ramp.
  - This relaxes the hip flexors and minimizes deforming forces.
  - To increase the hip flexion and offset muscular forces, a radiolucent tibial nailing triangle may be placed under the knee.
- Isolate the perineum from the operative site with an exclusionary drape.
- Sterilely prepare and drape the entire leg circumferentially for maximum control during reduction.
- Sterile skeletal traction using table attachment or dedicated fracture table may facilitate reduction.

Reduction and Fixation Techniques

- Closed reduction attempt by Ledbetter or other femoral neck fracture reduction maneuver.
    - Hip flexion, external rotation and abduction followed by gentle traction with hip in flexion.
    - Subsequent hip extension and internal rotation may result in an anatomic-appearing reduction on fluoroscopy.
    - However, this frequently underestimates the amount of residual displacement that is found upon direct visualization following capsulotomy.
- Closed reduction reserved for subcapital fractures primarily, especially in the geriatric population.
- If closed reduction is deemed acceptable (preferably anatomical on orthogonal and oblique views), consider percutaneous fixation with a decompressive capsulotomy to release the hematoma and to theoretically decrease intracapsular pressure, potentially decreasing the avascular necrosis risk.
    - An anterior capsulotomy can be performed utilizing a small laterally based skin incision, with a scalpel blade advanced proximally along the anterior femoral neck.
    - C-arm localization is helpful.
    - Consider using a disposable scalpel, with the blade integrated into the handle, to prevent disengagement of blade from knife handle, in the stout soft tissues.
- Either an anterolateral or an anterior approach can be useful for visualization and reduction of the femoral neck fracture.
    - If a Watson-Jones (anterolateral) approach is used, reduction and implant placement can proceed through the same incision.
        - However, visualization of the neck fracture and soft tissue retraction is more difficult.
- A modified Smith-Petersen (Heuter) approach allows excellent visualization of the anterior femoral neck for reduction and clamp placement (Fig. 13-1).
    - A second, small lateral approach is necessary for implant placement if an anterior approach is used.

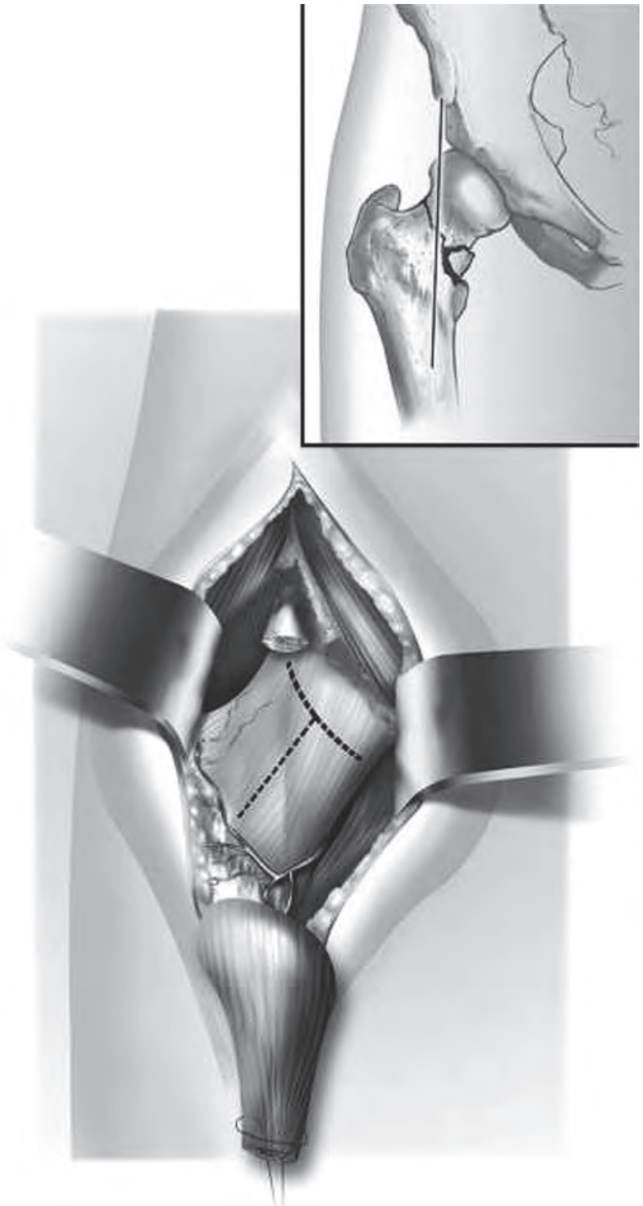


Figure 13-1. These illustrations of a right hip anterior exposure demonstrate the retraction of the sartorius and the iliopsoas muscles medially and the lateral retraction of the tensor fascia lata muscle. The rectus femoris tenotomy is shown, and the planned oblique T-shaped capsulotomy is indicated by the dotted lines. (Adapted from Molnar RB, Routt ML Chip. Open reduction of intracapsular hip fractures using a modified Smith-Petersen surgical exposure. *J Orthop Trauma*. 2007;21(7):490–494. With permission.)

- Additional exposure can be achieved by
  - Detaching the rectus femoris tendon origin.
  - Flexion of the hip by placing a triangle under the leg to relax the rectus, psoas, and sartorius muscles (Fig. 13-2).

Figure 13-2. The anterior hip capsulotomy has been made, preserving the local vascular anatomy and the anterior labrum. The manipulative reduction screws are shown. (Adapted from Molnar RB, Routt ML Chip. Open reduction of intracapsular hip fractures using a modified Smith-Petersen surgical exposure. *J Orthop Trauma*. 2007;21(7):490–494. With permission.)

- Sharp elevation of iliocapsularis may minimize development of heterotopic ossification rather than blunt removal with an elevator.
- Make a T-shaped capsulotomy, beginning initially distally on the femoral neck and incising proximally to the acetabular labrum to create the vertical limb.
    - The transverse (oblique) limb of the capsulotomy can be made either parallel to the intertrochanteric line (along the base of the femoral neck) or parallel to the labrum (while avoiding labral injury).
    - Care must be taken to avoid extension of the superior limb of a basilar capsulotomy as the main trunk of the blood supply is at risk in this location.
    - The location of the fracture and the associated comminution typically determines the type and location of the capsular extensions.
- Place heavy nonabsorbable sutures in each corner of the capsule to allow for retraction, and to facilitate reapproximation for repair later.

- Avoid placing Hohmann retractors around the superior (and inferior) portion(s) of the femoral neck after the capsulotomy has been made, as their tips lever against the posterior femoral neck.
    - This may interfere with the primary blood supply to the femoral head, which enters the capsule posterosuperiorly.
    - Instead use large Sofield or Hibbs-type retractors for exposure.
- A small (2.0- or 2.5-mm) drill hole can be made at the femoral head/neck junction for use as a docking site for clamp application and to assess for femoral head vascularity.
- A 2.5- or 4.0-mm Schanz pin placed in the femoral head as a joystick is also a helpful reduction aid for directly manipulating the proximal fragment, which is frequently rotationally displaced.

- Large pointed reduction forceps can be modified (one tine straightened) for more effective reduction control (Fig. 13-3).

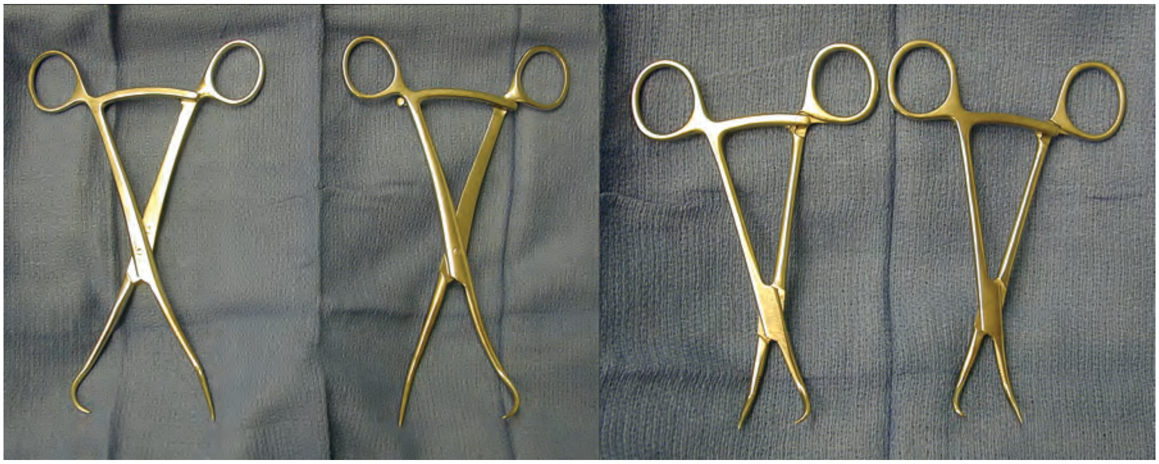


Figure 13-3. "Modified" large Weber **(left)** and small Weber **(right)** clamps, with one tine straightened, are useful for femoral neck clamp reductions using unicortical drill holes through an anterior approach.

- The most consistent cortical reduction assessment is both anteriorly and inferiorly (both should be visualized), with comminution most frequently found posteriorly.
  - Even when anterior and inferior neck fracture margins appear anatomic, an extension deformity may exist due to posterior comminution resulting in fracture extension (retroversion).
    - This is best assessed with a cross-table lateral radiograph with the X-ray beam orthogonal to the long axis of the femoral neck, and not the long axis of the femoral shaft.
- An extension deformity may be avoided by placement of an anterior bone clamp.
  - However, the bone available for clamp application is limited, and when clamps are placed anteriorly, the result may be an apex posterior angular malreduction (i.e., neck anteversion and flexion), particularly in patients with anterior or inferior comminution.
  - To avoid this, place the tines of the clamp as deeply into the femoral head or medial femoral neck as possible, so the tines are near the neutral axis/center of rotation.
  - Alternatively, a Farabuef clamp can be applied to screws strategically placed into the head and neck.
    - The longer lever arm of the screws may afford a more even distribution of the compression, especially if the screws are inserted slightly off an orthogonal axis.
    - The disadvantage is that the clamp is large and will obstruct further access to the reduction through the relatively surgical small window.
- A curved tine of a large Weber clamp can be placed laterally on the greater trochanter, cranial to the proposed insertion site of the definitive fixation construct, especially in Pauwels' Type III fracture patterns.
- Particular emphasis should be placed on obtaining an anatomic reduction of the inferior/medial spike in basicervical or vertical femoral neck fractures to improve the overall stability of the construct and diminish the likelihood of late translation/displacement.

- If comminution exists anterior and inferiorly, a 2.4-mm straight plate or 2.7-mm reconstruction plate can be contoured and placed anteroinferiorly for additional stability and maintenance of neck length prior to definitive fixation of the femoral neck (Figs. 13-4 and 13-5).

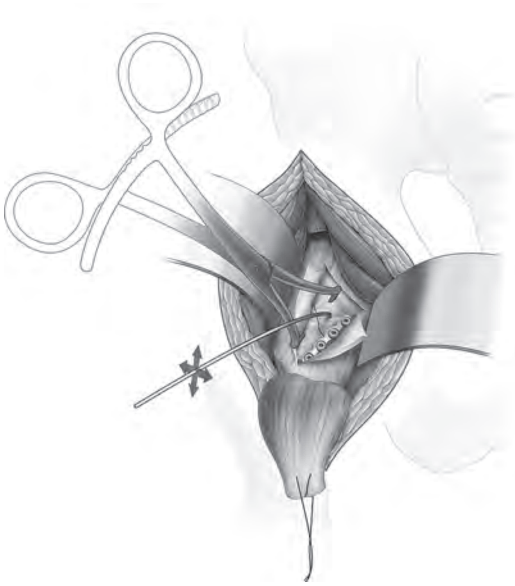


Figure 13-4. Effective femoral neck fracture reduction maneuvers through an anterior approach include manipulative Steinmann pin joysticks, clamp placement through unicortical drill holes, and provisional reconstruction plates.

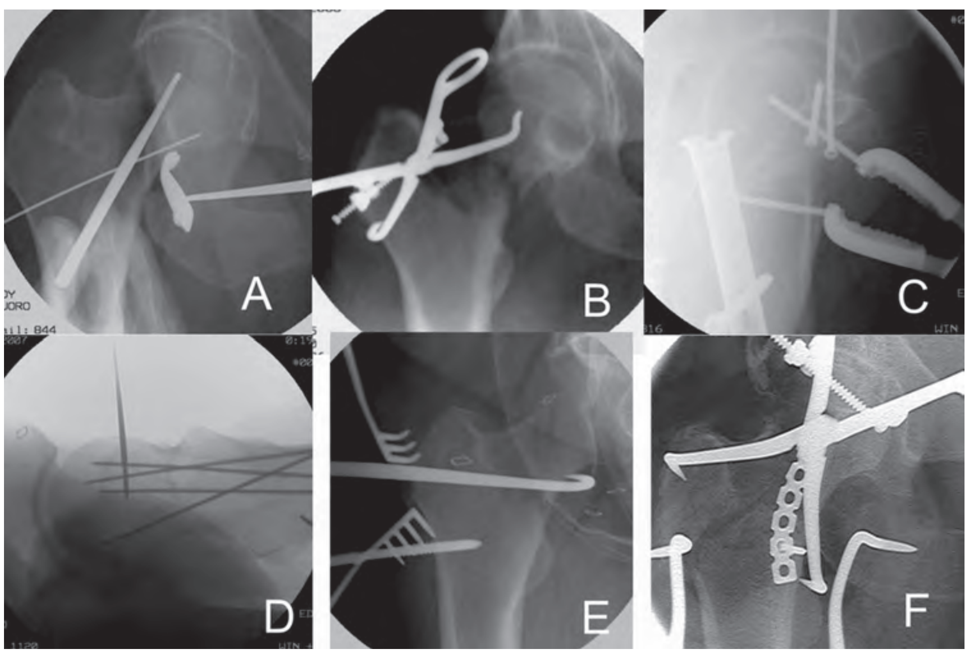


Figure 13-5. Reduction aids **A:** Shoulder hook in femoral head and an intracapsular small Hohmann retractor at inferior femoral neck spike **B:** Large modified large pointed bone reduction (i.e., Weber) clamp from femoral head to greater trochanter **C:** Farebeuf clamp with 3.5-mm screws **D:** 2.5-mm Schanz pin as anterior joystick in femoral head/neck; provisional K-wires stabilizing the neck fracture **E:** Shoulder hook around the inferior neck spike **F:** Provisional (or definitive) anterior/inferior 2.4- or 2.7-mm reconstruction plate and large pointed bone reduction clamp from inferior neck to greater trochanter.

- If the comminution is extensive and precludes direct cortical contact with an anatomic reduction, a tricortical graft can be fashioned to fill the defect.

- A varus malreduction should not be accepted, slight valgus may be preferable to a perfectly anatomic reduction, particularly if the patient is elderly, if bone quality is poor, or if superior comminution exists.

Fixation Constructs

- Most common fixation constructs consist of 6.5- to 7.3-mm cannulated screws (three, sometimes four) in various configurations (Fig. 13-6).
- Some manufacturers' screws have larger diameter screw cannulations, allowing for stiffer guide wires, which are easier to control.
  - This often facilitates accurate screw placement as the trajectories of these stiffer guide wires are better controlled than those of smaller and more flexible guide wires.
- The starting point for screws should be above the level of the lesser trochanter to minimize the possibility of iatrogenic subtrochanteric fracture due to a stress riser effect.
  - This region typically correlates with the metaphyseal flare, just distal to the vastus lateralis ridge.
  - If a triangular configuration is used, a single screw should form the inferior apex of the triangle to minimize the risk of secondary subtrochanteric fracture.
- Screws should be placed to optimize compression across the fracture site.
- Screw spread should be maximized, placed as peripherally as possible within the femoral neck, to allow for stable fixation.
  - Placement of the inferior screw within 3 mm of the medial cortical bone of the femoral neck may help to minimize inferior displacement of the femoral head.
  - Placement of a screw within 3 mm of the posterior cortex of the femoral neck may help to minimize posterior translation and retroversion of the femoral head.
  - For subcapital and transcervial fractures, the inferior screw should be supported both at the lateral cortex and at the most medial aspect of the portion of the femoral neck that is attached to the shaft component.

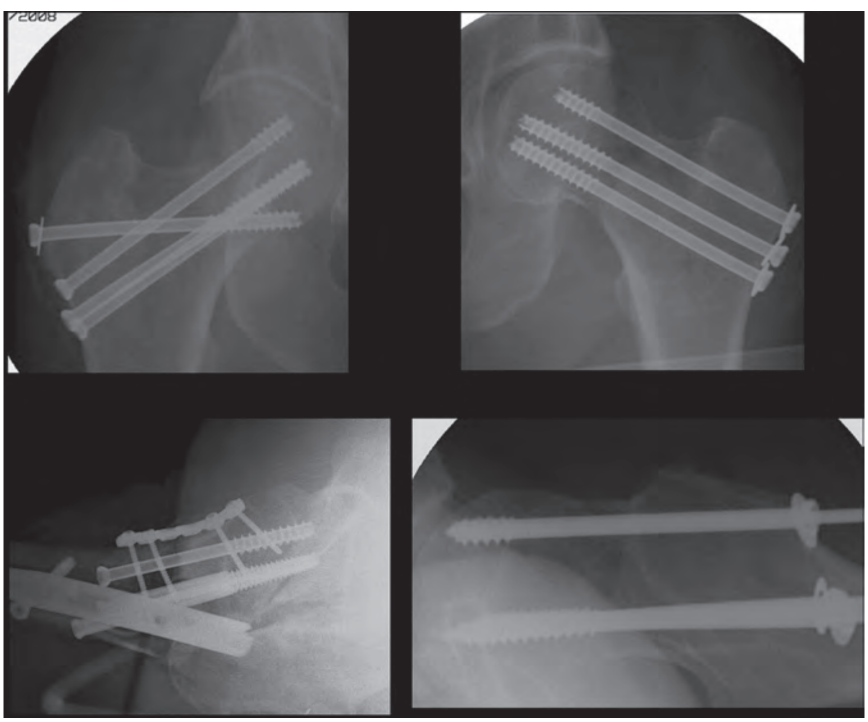


Figure 13-6. Typical implant constructs for femoral neck fractures. Attention should be paid to maximizing the spread of the screws within the femoral neck.

- This position effectively supports the screw along a large portion of its overall length and reduces cantilever "bending" failure of the construct.
- More cephalad screws do not achieve this mechanical benefit.

- Consideration should be given to avoidance of screw placement in the posterior-superior quadrant of the neck and head, as this is the primary area of vascular perfusion into the femoral head.
  - The posterior screw can be placed at the midcranial aspect or centrally (when viewed sagittally), or placed at the most cranial portion of the neck (Fig. 13-7).

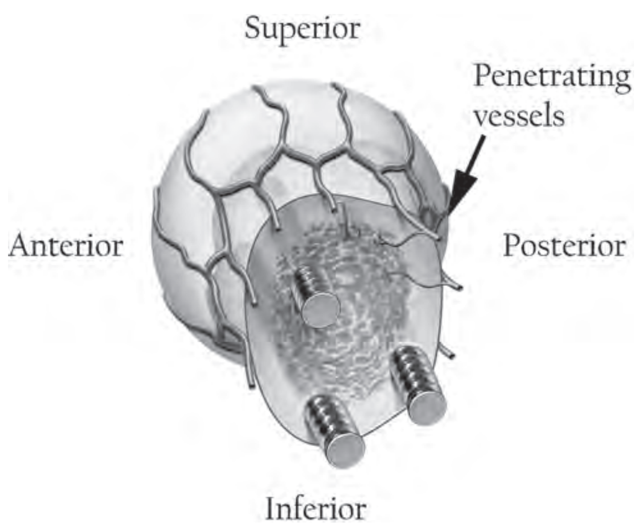


Figure 13-7. Avoidance of screw placement in the posterosuperior quadrant (upper right in figure) minimizes risk to the perforating vascular supply to the femoral head.

- When placing screws to obtain compression, insert the anterior/superior screw first, as it is least likely to create a deformity by compressing across a comminuted fracture zone.

Intertrochanteric Osteotomy (Fig. 13-8)

- All patients with femoral neck fractures should be informed of the risks of nonunion, malunion, and avascular necrosis, in addition to standard surgical risks.
- In the event of a nonunion, a valgus intertrochanteric osteotomy is a reliable procedure to obtain healing.
- Any rotational or sagittal plane deformity can be corrected by altering the plane of the intertrochanteric osteotomy.
- Using preoperative templating, the appropriately sized wedge can be determined that will allow for conversion of the vertical fracture line/nonunion to achieve an orientation roughly parallel to the joint reaction forces; for optimal healing, this angle is ideally about 25 degrees from the horizontal.
- Blade entry point must be at least 15 mm above the osteotomy site to avoid communication of the blade entry site with the osteotomy during reduction and compression, thereby losing fixation strength.
- Guide wires are placed above the planned blade entry point across base of piriformis fossa.
- First, osteotomy cut is made parallel to the planned blade entry path, usually perpendicular to the femoral shaft, at the top level of lesser trochanter.
  - Check flexion and extension as well as rotation (anteversion) on lateral fluoroscopic view.
  - Correct any rotation prior to second cut.
- Use K-wires to measure and determine the appropriate version change, if needed.
  - After chisel, seat blade 8 to 10 mm proud to allow lateralization of shaft.
  - After blade is seated, place unicortical screw distally.

- Use osteotomes to keep proximal plate 8 to 10 mm off of the femoral shaft distal to osteotomy. With the distal most aspect of the plate abutting the bone, create a triangular space between the lateral cortex and the plate.
  - Osteotomy site should be in increased valgus relative the final anticipated correction at this point.
  - Insert and tighten the most proximal screw in the distal fragment, removing the osteotomes.
  - This pulls the bone to the plate, hinging off of the distal unicortical screw, while correcting the tilt, and achieves strong compression across the osteotomy, by using the principle of bone length/plate length mismatch.

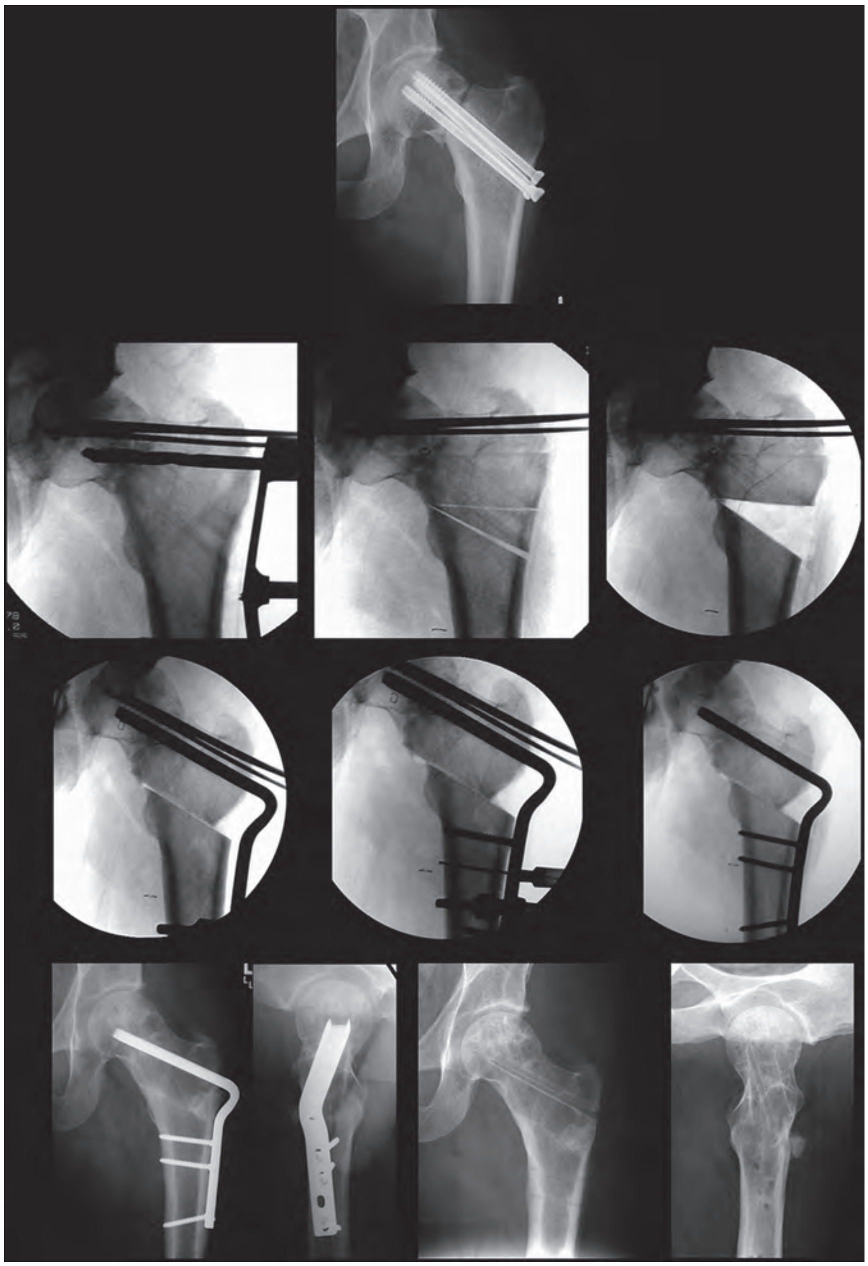


Figure 13-8. Stepwise technique for intertrochanteric osteotomy for femoral neck nonunion.

Chapter 14

Intertrochanteric Femur Fractures

Zachary V. Roberts

Sterile Instruments/Equipment

- Radiolucent OR table with traction device or fracture table
- 5.0-mm Schanz pins for manipulative joysticks
- Large pointed bone reduction clamps (Weber clamps)
- Ball-spike pushers
- Shoulder hook/bone hook
- K-wires and wire driver/drill
- Reamers
- Implants: depending on the fracture pattern and consistent with the preoperative plan
  - Intramedullary nail (trochanteric cephalomedullary nail)
  - Screw-side plate device (dynamic hip screw or similar)
  - Blade plate (95-degree angle)

Patient Positioning

- Supine on a radiolucent table with attachment for sterile traction (see Femur Fracture positioning), or supine on a fracture table.
- Positioning is largely a matter of the surgeon's preference, with each having advantages and disadvantages.
  - For some fractures and in some patients, the use of a fracture table offers predictable indirect reduction and intraoperative imaging and reduces the need for an assistant.
  - However, with unstable fracture patterns, the use of a fracture table tends to accentuate deformity in the sagittal plane (usually apex posterior angulation) and posterior translation of the distal fragment(s).
  - Some patients have contralateral hip arthrosis and contractures that prevent adequate abduction and flexion to allow quality lateral intraoperative imaging.
  - The use of a fracture table has also been implicated in a number of complications to include compartmental syndrome of the contralateral limb, pudendal nerve dysfunction, and perineal skin breakdown.
  - Finally, the use of a fracture table requires the presence of a skilled unscrubbed assistant to make intraoperative changes in limb position or traction.
  - Prepping the leg free on a flat radiolucent table allows the surgeon unencumbered access to limb position and eliminates complications caused by traction against a perineal post.
  - The use of a flat radiolucent table often avoids posterior displacement of the distal fracture fragment as is commonly seen with fracture tables, since the thigh is supported and can be elevated on rolled sterile towels (towel bump).
  - However, imaging the hip intraoperatively can be more challenging with intertrochanteric fractures than with other proximal femur fractures.

Imaging Tips

- When using the radiolucent flat top table, place a bolster under the ipsilateral sacrum and torso to roll the patient away from the surgeon about 10 to 15 degrees and flex the hip 10 to 15 degrees when the operative limb is placed on a leg ramp.
  - This allows for cross-table lateral hip imaging.
  - Avoid too large a hip/pelvic bolster so that the cross table lateral of the hip does not demonstrate "relative" neck-shaft retroversion.
- To adequately image the hip, the C-arm must mirror these positioning modifications.
  - The position of the C-arm should be individualized to obtain a true AP image of the hip, with a small crescent of lesser trochanter visible.
    - Often a straight vertical C-arm position with patient bumped up 10 to 15 degrees will offset the anteversion and will give a true AP of the hip (Fig. 14-1).

Figure 14-1. Patient positioning and fluoroscopic setup for AP view for intertrochanteric fracture treatment.

    - However, some C-arm roll-back may better simulate an AP image.
  - To obtain a lateral, roll the unit all the way back so that the beam is flat on the floor (Fig. 14-2).

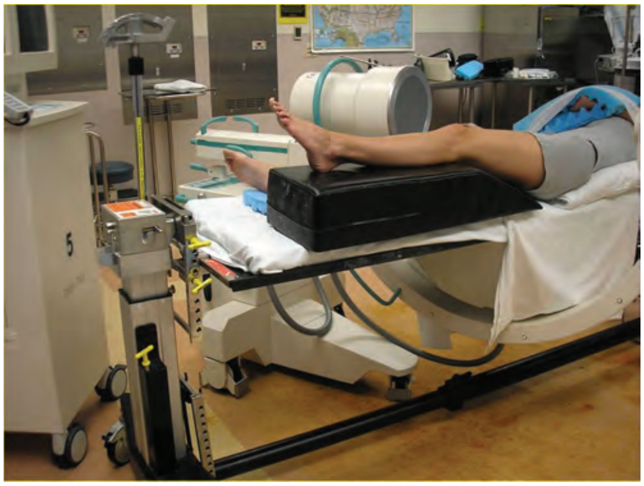


Figure 14-2. Fluoroscope position for obtaining a lateral view.

- This view should be perpendicular to the "long" axis of the femoral neck (i.e., ~45 degrees relative to the longitudinal axis of the OR table).
- There should be no significant "retroversion/anteversion" visible on the image if the fracture is reduced and the leg is internally rotated to match the normal anteversion.
  - Since the patient is on a bump, the contralateral hip should be out of the C-arm image as it is posterior to the imaged hip.
  - In obese individuals, a C-arm position just above the horizontal will prevent extremity and hip radiographic overlap.
- If the cross-table lateral shows the femoral neck in "retroversion," the patient's ipsilateral hemipelvis may be elevated too far and relatively "internally rotated."
- Excessive internal rotation of the pelvis and attached proximal femoral fragment will make the lateral radiograph difficult to obtain.
  - This may require the intraoperative placement of a clamp or Schanz pin to help control and externally rotate the proximal fragment(s).
  - Alternatively, a smaller bump/bolster can be used.

Implant and Reduction Techniques

- A sliding hip screw with a two- to four-hole side plate is one of the two implants of choice for most intertrochanteric hip fractures.
  - Two hole side plates are usually sufficient for basicervical femoral neck fractures and stable two part intertrochanteric fracture patterns.
  - This implant is less expensive than most intramedullary devices. It can be applied through a lateral approach to the proximal femur, by elevation of the proximal vastus lateralis.
  - Intertrochanteric fracture "stability" is a topic of debate, and depends on a number of factors, including the displacement, integrity of the lateral cortex, the presence of significant posteromedial comminution, involvement of the subtrochanteric area of the femur, and the fracture pattern, especially the orientation of the primary fracture plane (standard or reversed obliquity).
  - Intramedullary devices are indicated for unstable fracture patterns, reversed obliquity patterns, or pathological fractures, including severe osteoporosis.

Sliding Hip Screw Technique

- The proximal femur is exposed using a lateral approach.
- Localize the incision fluoroscopically with an extracutaneous guide pin running parallel with the center of the femoral neck to determine its "intersection point" over the lateral thigh.
  - The proximal extent of the incision is generally at the level of the lesser trochanter.
- If the femoral neck portion of the fracture is rotationally unstable, in addition to the guide pin used for screw placement, consider inserting one or two additional K-wires or pins to control torsional forces associated with reaming/tapping/screw insertion.
  - One pin may be replaced with an antirotational 5.0, 4.5, or 3.5 lag screw (Fig. 14-3).

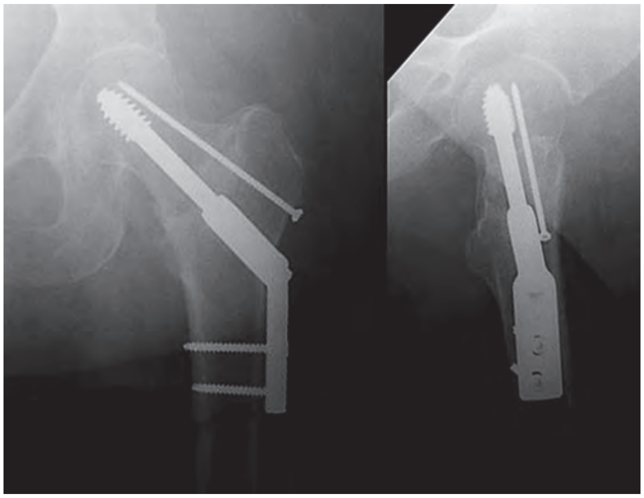


Figure 14-3. Placement of a screw-side plate device with an "antirotational" 3.5 cortical lag screw. A 3.5-mm gliding hole was created in the lateral femoral cortex/ greater trochanter with a 2.5-mm pilot hole for the femoral neck/head.

Intramedullary Devices

- Most intramedullary devices are designed to treat the intertrochanteric fractures common to a geriatric population.
- Thus, they have a relatively large proximal nail diameter to accommodate the cephalomedullary screw or blade.
- Obtain a reduction prior to reaming the canal, and maintain the reduction during reaming.
  - The starting point in the proximal segment should be collinear with the proximal geometry and anticipated path of the nail.
- In thinner individuals, a displaced fracture that cannot be reduced by closed manipulation may be reduced and clamped percutaneously.
  - Alternatively, larger patients will often require an open reduction (Figs. 14-4 and 14-5).

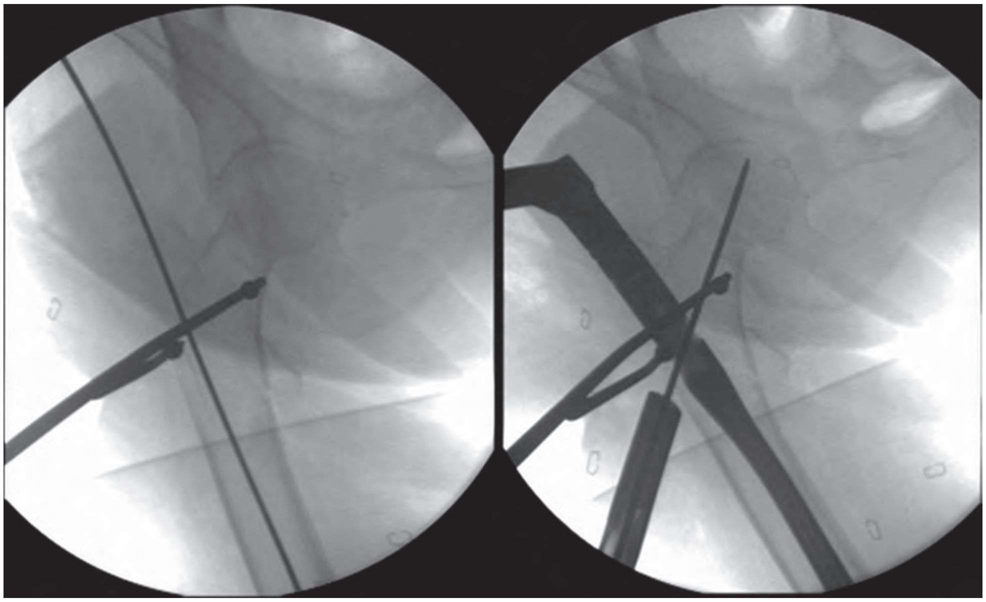


Figure 14-4. A long cephalomedullary nail was chosen to treat this three-part intertrochanteric femur fracture predominately because of the patient's marked osteoporosis. A percutaneous clamp was used to reduce the fracture prior to its fixation. Placement of the clamp should consider the path of the cephalomedullary screw/blade.

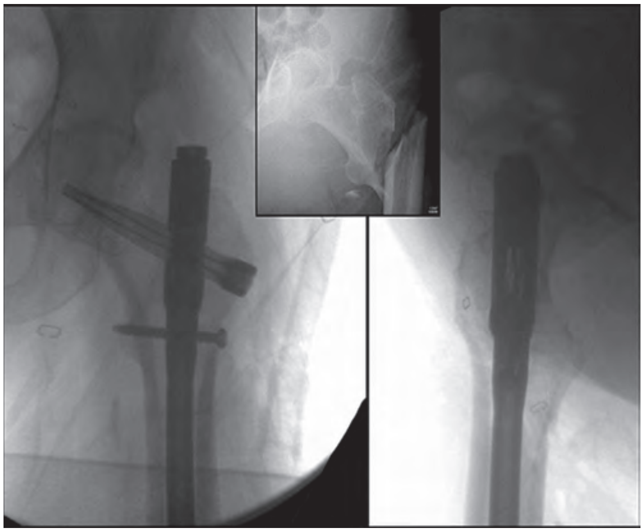


Figure 14-5. This cephalomedullary nail entry portal (piriformis) was chosen to spare the lateral cortex of the proximal segment, which allows the greater trochanter to resist varus displacement. This fracture required an open reduction prior to medullary nail insertion.

- Orient clamp to allow passage of the reamers and subsequent nail and femoral head element.
- Alternatively, depending on the fracture, place the clamp obliquely or more toward the coronal plane (Fig. 14-6).

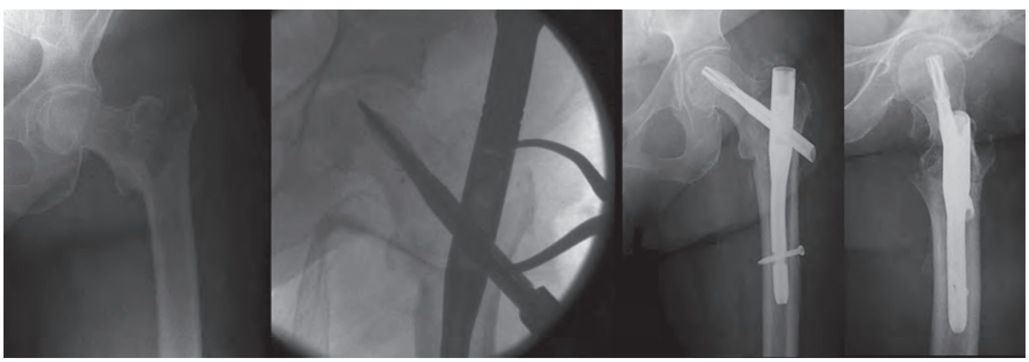


Figure 14-6. Careful placement of a clamp in the coronal plane may help resist/correct varus deformity, but should be positioned carefully so it does not interfere with cephalomedullary instrumentation.

- A percutaneously inserted bone hook placed anteriorly and around the medial femoral neck can be used to maintain the reduction during reaming and nail insertion (Fig. 14-7).

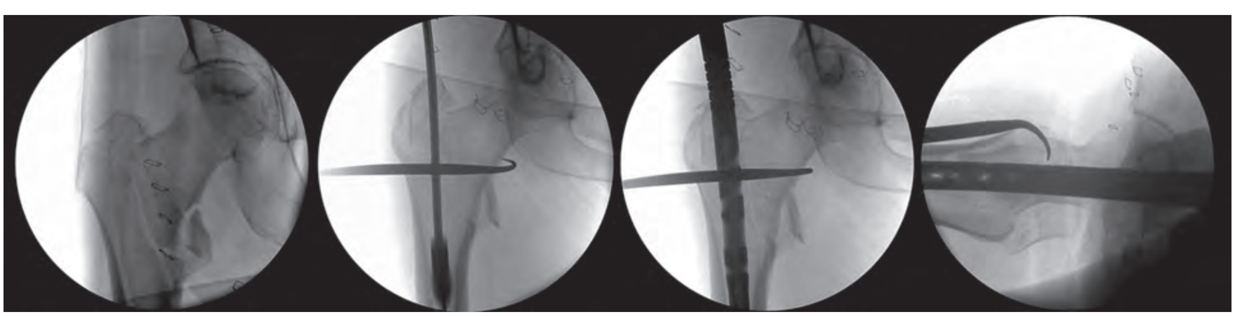


Figure 14-7. A bone hook can be used to reduce the proximal fragment prior to reaming.

- When reaming, avoid eccentric reamer passage, which may occur in comminuted and malreduced fractures.
  - Eccentric reaming often leads to thinning of the distal-posterior and proximal-lateral portions of the proximal fragment (due to its flexion/ abduction if unreduced).
  - A ring clamp (e.g., the handle of a large Kocher clamp) placed over the guide wire and reamer shaft can be used to guide the entry path of each reamer by applying an anteromedially directed force.
    - This can help control the entry position and path of each reamer as they enter and transit the proximal fragment.[1]
- The tip apex distance remains important for intramedullary devices.
  - The nail and the proximal targeting jig can obscure the trajectory of the cephalomedullary guide pin, making optimal placement difficult (Figs. 14-8 and 14-9).

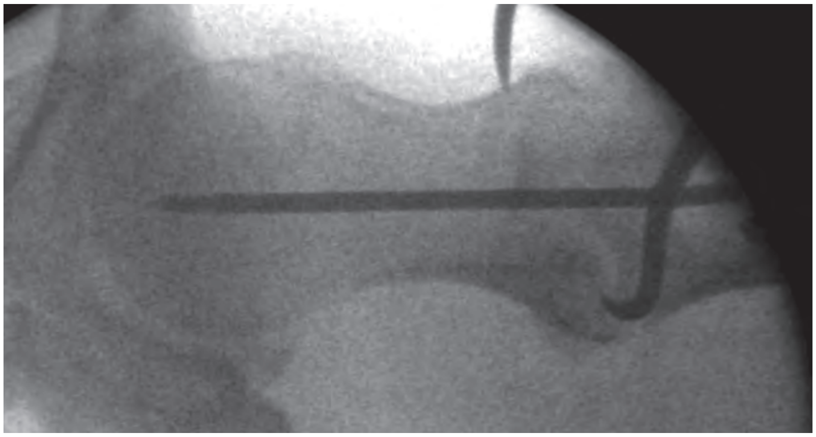


Figure 14-8. Positioning the base of the C-arm toward the patient's feet, so that it approximates 45 degrees to the long axis of the patient, will orient the beam perpendicularly to the femoral neck and will allow better imaging of the femoral head in the cross-table lateral view.

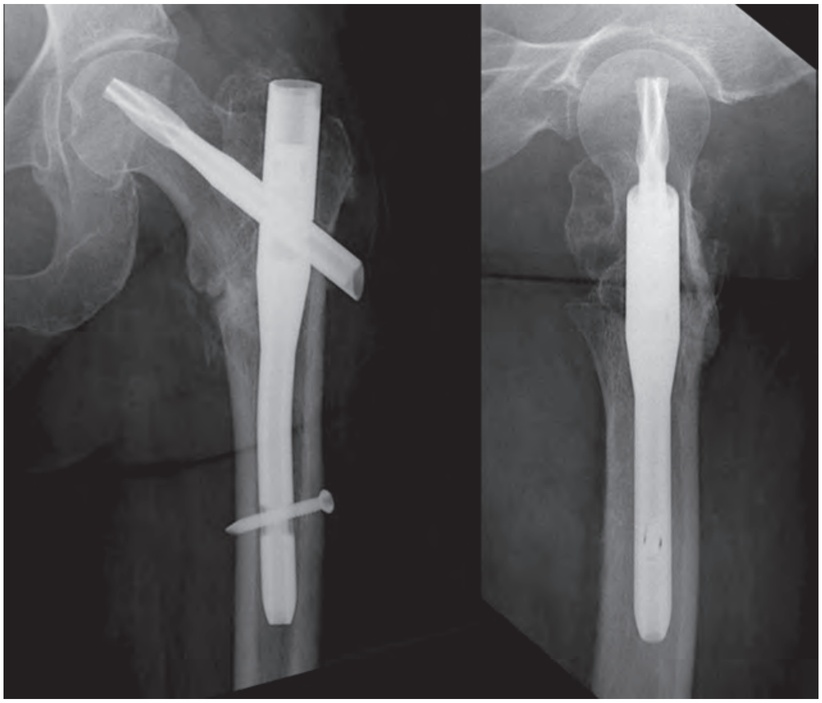


Figure 14-9. Final images demonstrating the optimal femoral head implant position.

- If a long intramedullary nail is used, the knee should be imaged on the lateral view as the nail is inserted.
    - Mismatch between the curvature of the nail and femur may occur in the elderly and can lead to either anterior cortical perforation or extrusion of the nail beyond the anterior cortex of the distal femur.
    - When recognized, this may be avoided by selecting an implant with a smaller radius of curvature or modifying the implant using a bending device to match its curvature to that of the patient's femur (Fig. 14-10).

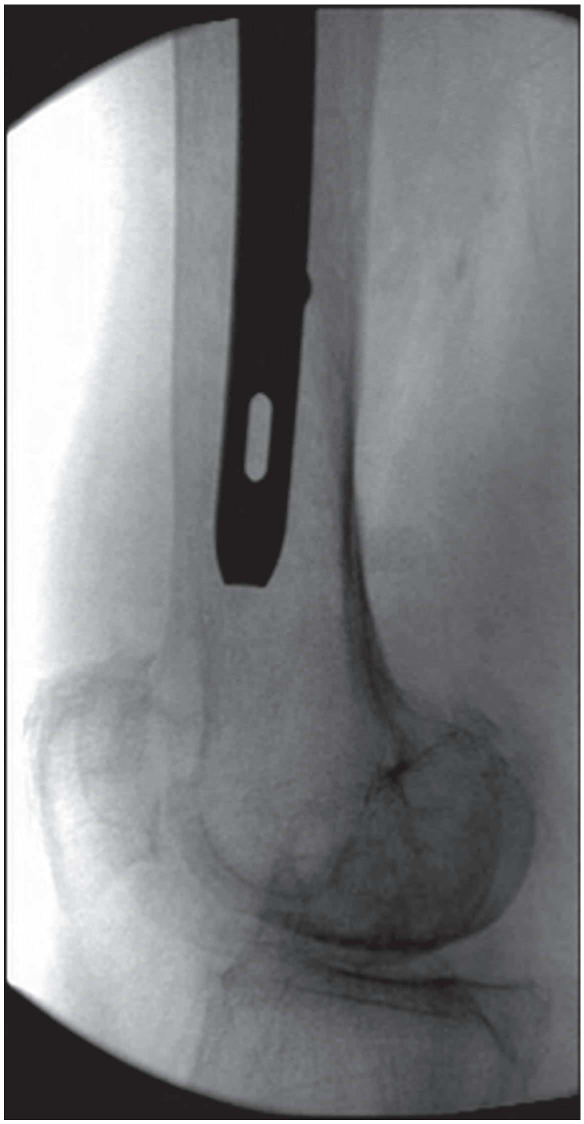


Figure 14-10. A lateral view of the knee should be assessed to ensure that the nail does not penetrate the anterior femoral cortex.

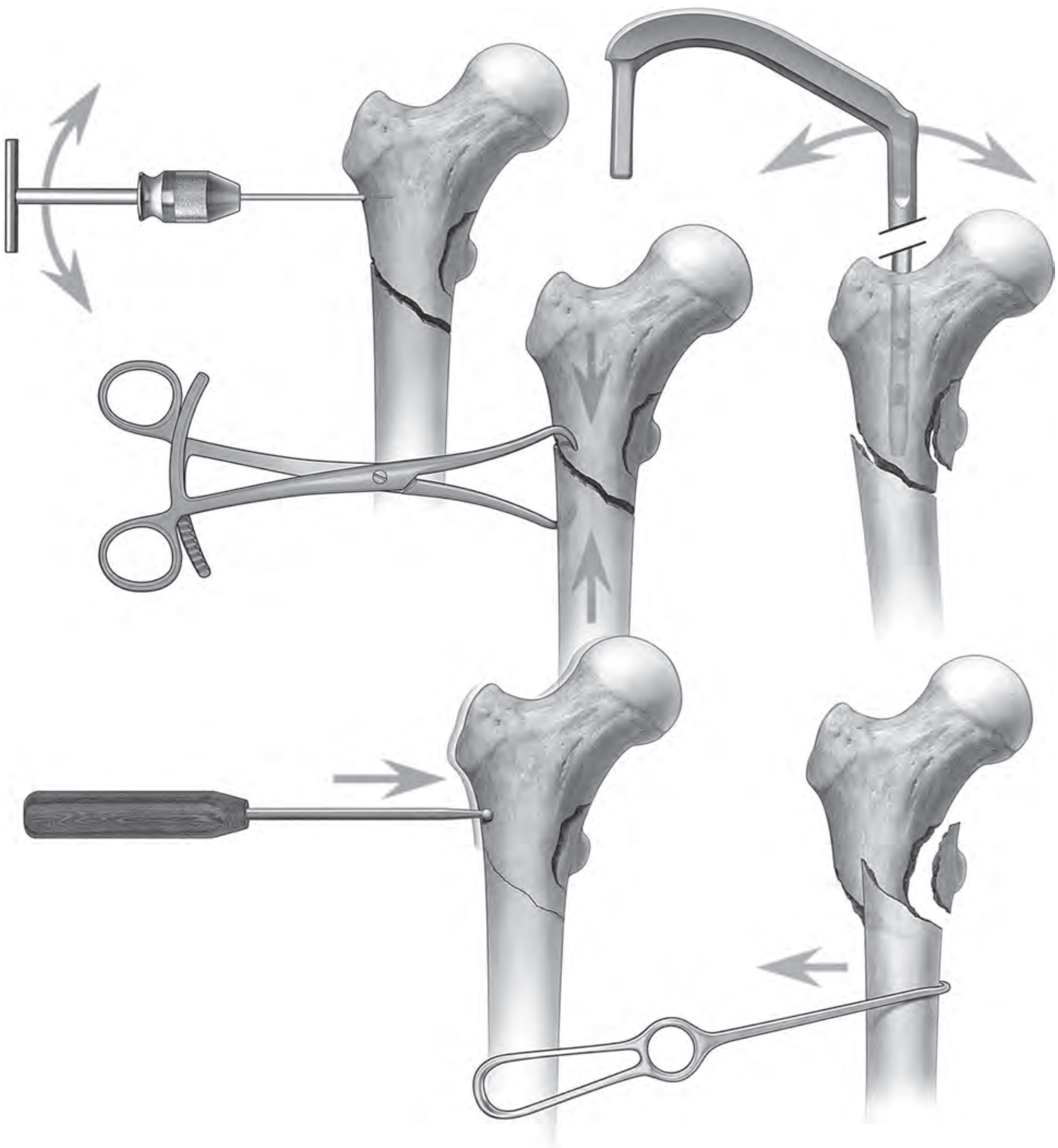
Reference

1. Palm H, Jacobsen S, Sonne-Holm S, et al. Integrity of the lateral femoral wall in intertrochanteric hip fractures: an important predictor of a reoperation. *J Bone Joint Surg Am.* 2007;89:470–475.

Section 6

Femur

Lisa A. Taitsman



Subtrochanteric Femur Fractures

Michael J. Gardner

Chapter 15

Sterile Instruments/Equipment

- On-table traction or fracture table
- 5.0-mm Schanz pins for manipulative joysticks
- Large pointed bone reduction clamps (Weber clamps)
- Serrated bone reduction clamps
- Femoral distractor
- Ball-spike pushers
- Shoulder hook/bone hook
- K-wires and wire driver/drill
- Reamers
- Implants
  - Intramedullary nail
    - Reconstruction (cephalomedullary) versus conventional (condylomedullary)
  - Proximal femoral locking plate
  - Blade plate

Positioning

- Supine on a radiolucent table.
- Bump under the ipsilateral hemipelvis and torso.
- Move patient as far as possible to the table's edge so that buttock is partially overhanging the edge of the table, particularly if a piriformis nail is being planned.
  - Improves access for nail insertion
  - Confirm ability to obtain adequate intraoperative AP and lateral images prior to prepping and draping.
- Skeletal traction through a distal femoral pin is useful in restoring the fracture length.
  - Limb elevated on radiolucent foam ramp or triangular wedge.
  - Assists in reducing fracture and matching flexion of distal fragment to proximal fragment's flexion deformity.

Surgical Approaches for Open Treatment

- Standard lateral approach to proximal femur.
- Incise iliotibial band.
- Elevate vastus lateralis origin from vastus ridge; identify perforating vessels.
- Selective approaches for clamp placements or joysticks.

Reduction and Implant Techniques

- The most common deforming forces are flexion, abduction, and external rotation of the proximal fragment due to tendon insertions and muscular forces (Fig. 15-1).

Figure 15-1. The primary forces that must be counteracted with reduction maneuvers in subtrochanteric fractures are flexion, abduction, and external rotation of the proximal fragment.

- Two main reduction methods can be used separately or in combination.
  - Reducing the distal fragment to the proximal fragment without manipulating the proximal fragment.
    - This requires matching the flexion, external rotation, and variable abduction with concomitant traction.
  - Reducing the proximal fragment to the distal fragment without manipulating the distal fragment.
    - This is accomplished by controlling the proximal fragment either directly (open technique) or percutaneously with joysticks, reduction clamps, or other devices.
    - In this scenario, the deforming forces on the proximal fragment are counteracted by adducting, extending, and internally rotating the proximal fragment.
    - This is difficult to correct with traction alone.
- Limb alignment and fracture reduction must be maintained during reaming and implant placement so as to assure a concentric nail position, while maintaining fracture reduction.
- When placing a trochanteric entry nail with cephomedullary fixation (i.e., reconstruction screws), the starting point should be slightly more anterior and medial than is typical for treating a shaft fracture.

- A properly placed starting point is critical for obtaining and maintaining an acceptable reduction. This starting point is variable and based on the specific implant used. Adequate AP and lateral intraoperative imaging is necessary to confirm perfect entry point placement.
  - Occasionally, attempts at translating the reamers medially will displace fracture fragments medially instead of reaming medial bone.
  - When reaming with the patient supine, after each reamer is removed, the guide wire will tend to rest in the posterolateral aspect of the reamer track due to guide wire's trajectory, gravity, and flexion/abduction of the proximal fragment.
    - This will cause each successive reamer pass in the proximal fragment to occur more and more laterally and posteriorly if this is not addressed and counteracted (Fig. 15-2).

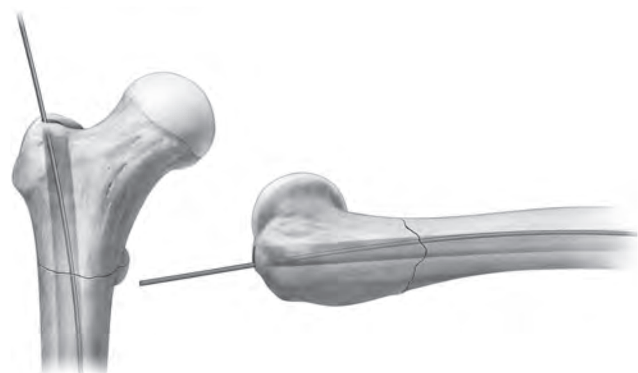
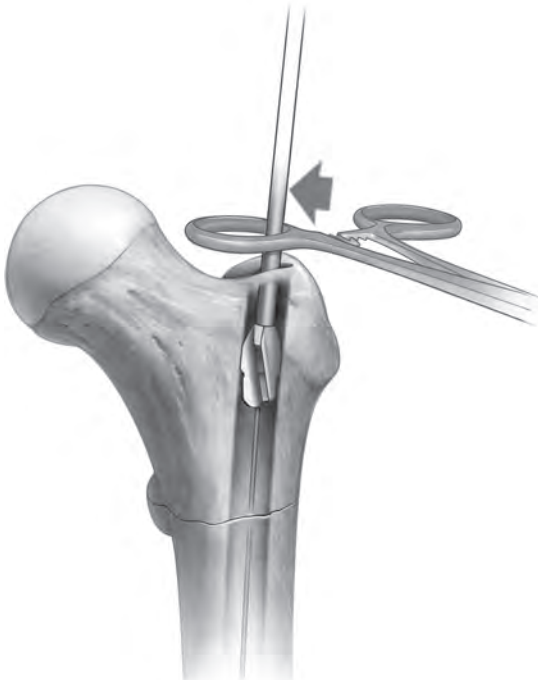


Figure 15-2. Gravity and soft tissue forces will tend to position the guide wire laterally (**left**) and posteriorly (**right**). If not corrected, this may cause eccentric reaming of the entry portal with each successive reamer pass.

- Use the ring of a clamp or other instrument to medialize wire during reaming, thus preventing eccentric reaming of the starting portal.
- Each reamer can be passed through the clamp ring without requiring its removal until guide wire exchange or nail placement (Fig. 15-3).



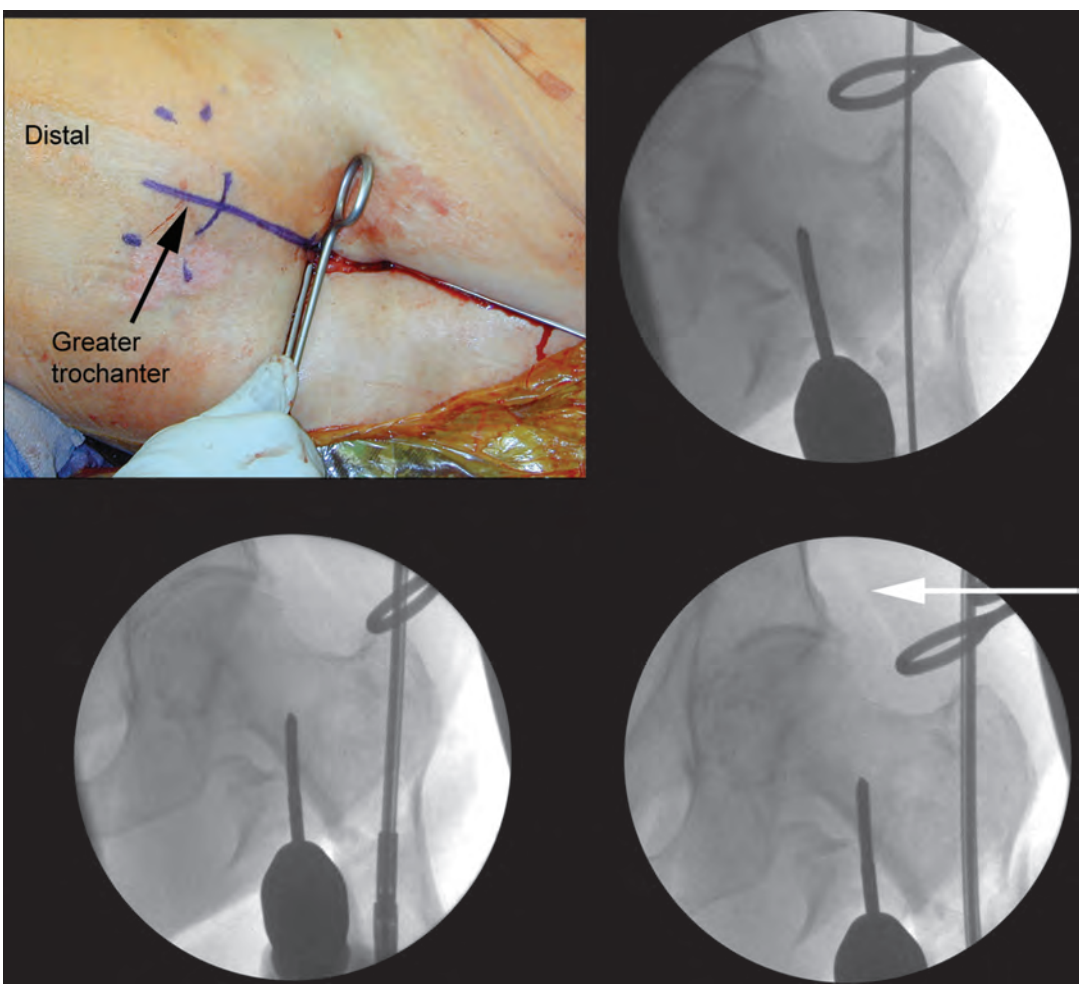


Figure 15-3. Placing the ring of a clamp over the guide wire and reamer shaft allows for medialization to avoid eccentric starting point reaming. The large amount of possible reamer shaft excursion is evident with medialization in this example (**lower right**).

- If varus malalignment results after a standard trochanteric starting point, a rongeur, awl, or other instrument may be used to remove additional bone medial to the initial starting portal.
  - This will prevent the nail from causing a varus fracture reduction by removing the contact point between the nail and the medial cortex of the reamer tract (Fig. 15-4).

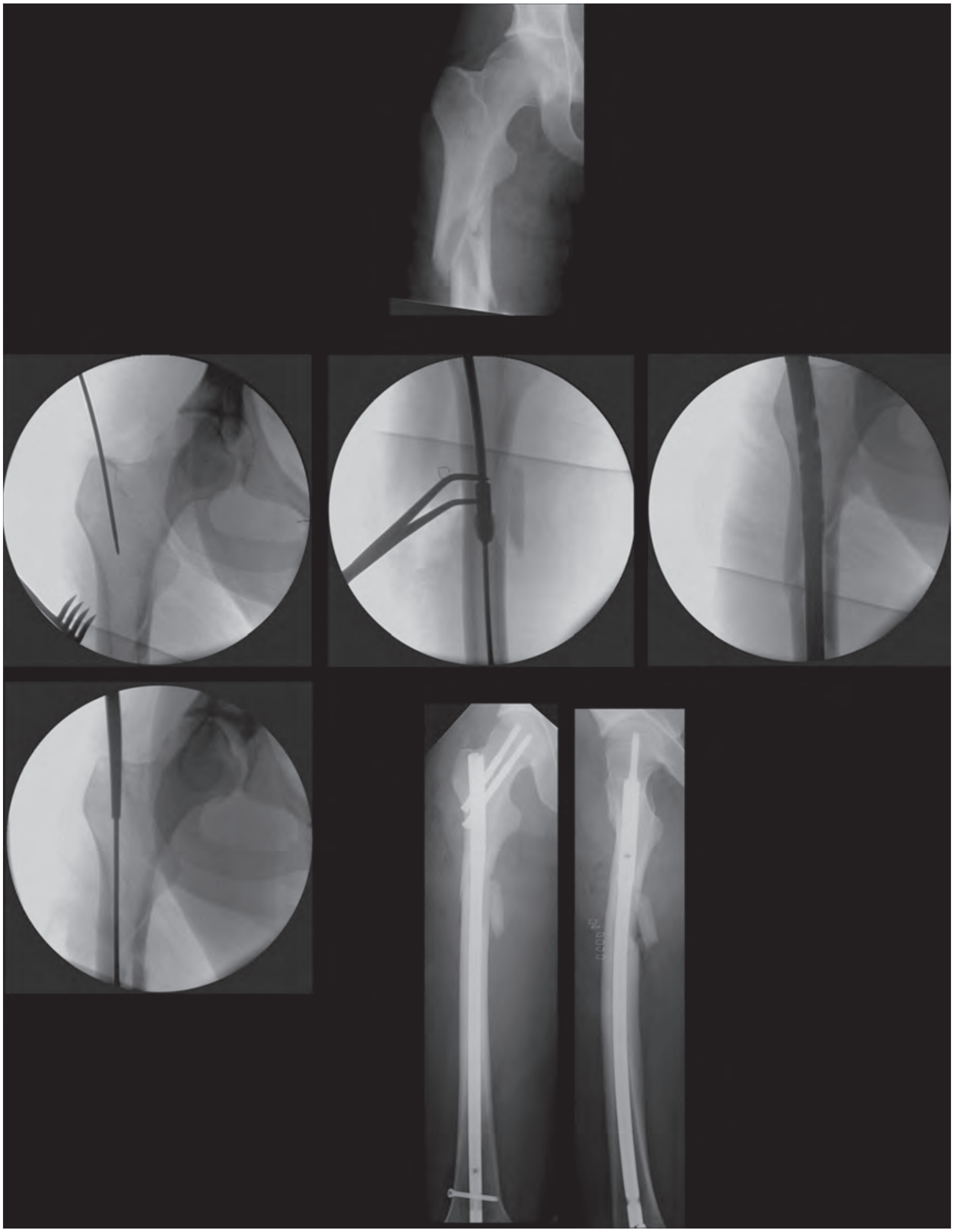


Figure 15-4. Clinical example of a subtrochanteric femur fracture treated with a trochanteric-entry nail. A small incision was made for clamp reduction, and the intramedullary canal was reamed with the fracture reduced anatomically. When the nail was seated, varus deformity was produced. The nail was removed, and additional cortical bone was removed from the medial edge of the starting portal. Deformity was subsequently improved.

- Alternatively, when an intact lateral cortex is present, a small plate may be placed laterally within the starting portal to force an improved and more medial reaming path as progressively larger reamers are used (Fig. 15-5).

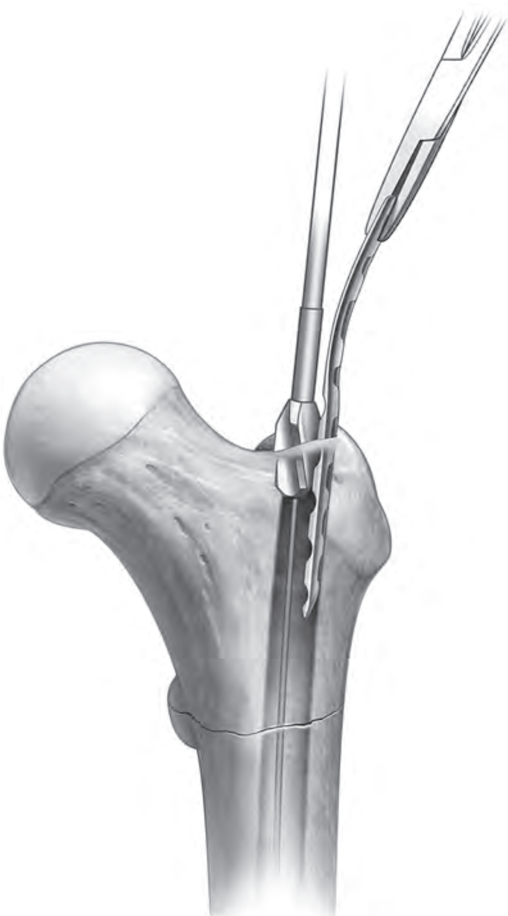


Figure 15-5. If varus deformity results after fully seating the nail, this may be due in part to an excessively lateralized reamer track in the proximal segment. This can be corrected by repeat reaming with a plate placed along the tract to preferentially ream the medial bone of the entry point.

- Place a bone reduction clamp open across fracture under direct visualization prior to reaming for nail placement (Fig. 15-6).

Figure 15-6. A small incision that allows for subtrochanteric clamp placement is effective in stabilizing the fracture reduction during the nailing procedure.

- If the fracture is more proximal, pointed reduction clamps can be placed from the greater trochanter to the shaft to obtain and maintain reduction during reaming and nail insertion (Fig. 15-7).

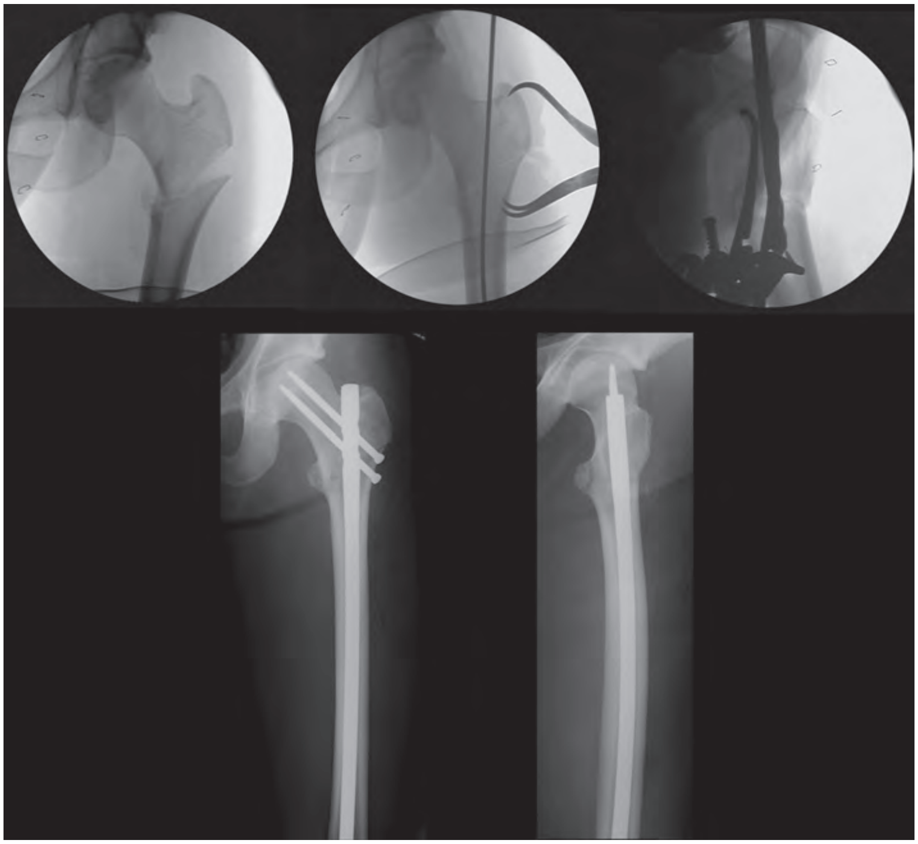


Figure 15-7. Clamps may be placed from the greater trochanter to the shaft to reduce the varus deformity. A unicortical hole in the lateral cortex of the distal fragment may be required for Weber clamp application.

- Alternatively, a Schanz pin may be placed from lateral to medial, posterior to the path of the nail, to joystick of the proximal fragment (Fig. 15-8).

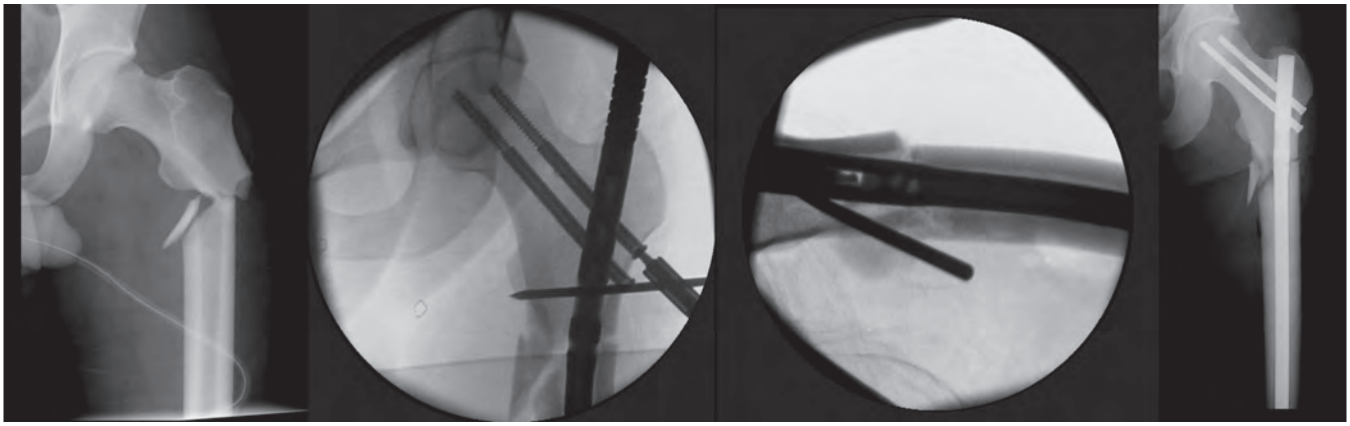


Figure 15-8. In this subtrochanteric fracture, a Steinmann pin was placed laterally, posterior to the path of the nail, for use as a manipulative joystick. Note that the starting portal was a bit more anterior than optimal, resulting in a reduction in slight extension.

- When the distal fracture orientation is more in the sagittal plane, a linear bone reduction clamp may achieve the correct fracture reducing force vectors (Fig. 15-9).

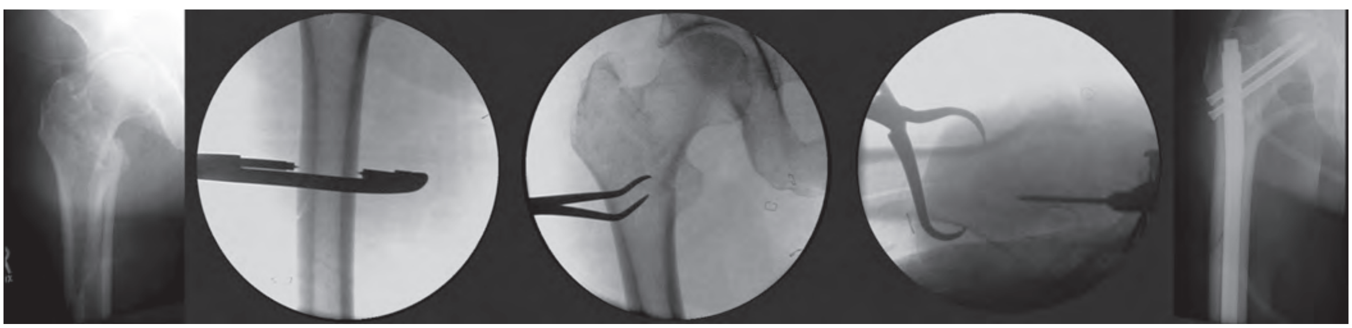


Figure 15-9. In this example, the fracture spiraled distally, and the distal fracture was more in the sagittal plane. A linear reduction clamp, with standard clamps proximally, allows for establishment of correct force vectors resulting in an anatomic reduction.

- It is critical to reduce and provisionally stabilize the flexion deformity of the proximal fragment.[1]
  - Place a Schanz pin percutaneously from anterior to posterior.
  - Place a towel or laparotomy sponge on the external part of the pin and use it to pull distally, reducing the flexion.
  - It is important to use the contralateral intact femur so as to match limb length and rotation.

- Clamp the sponge or towel distally to a fixed object or drapes to maintain the reduction and to avoid interference with fluoroscopy (Figs. 15-10 and 15-11).

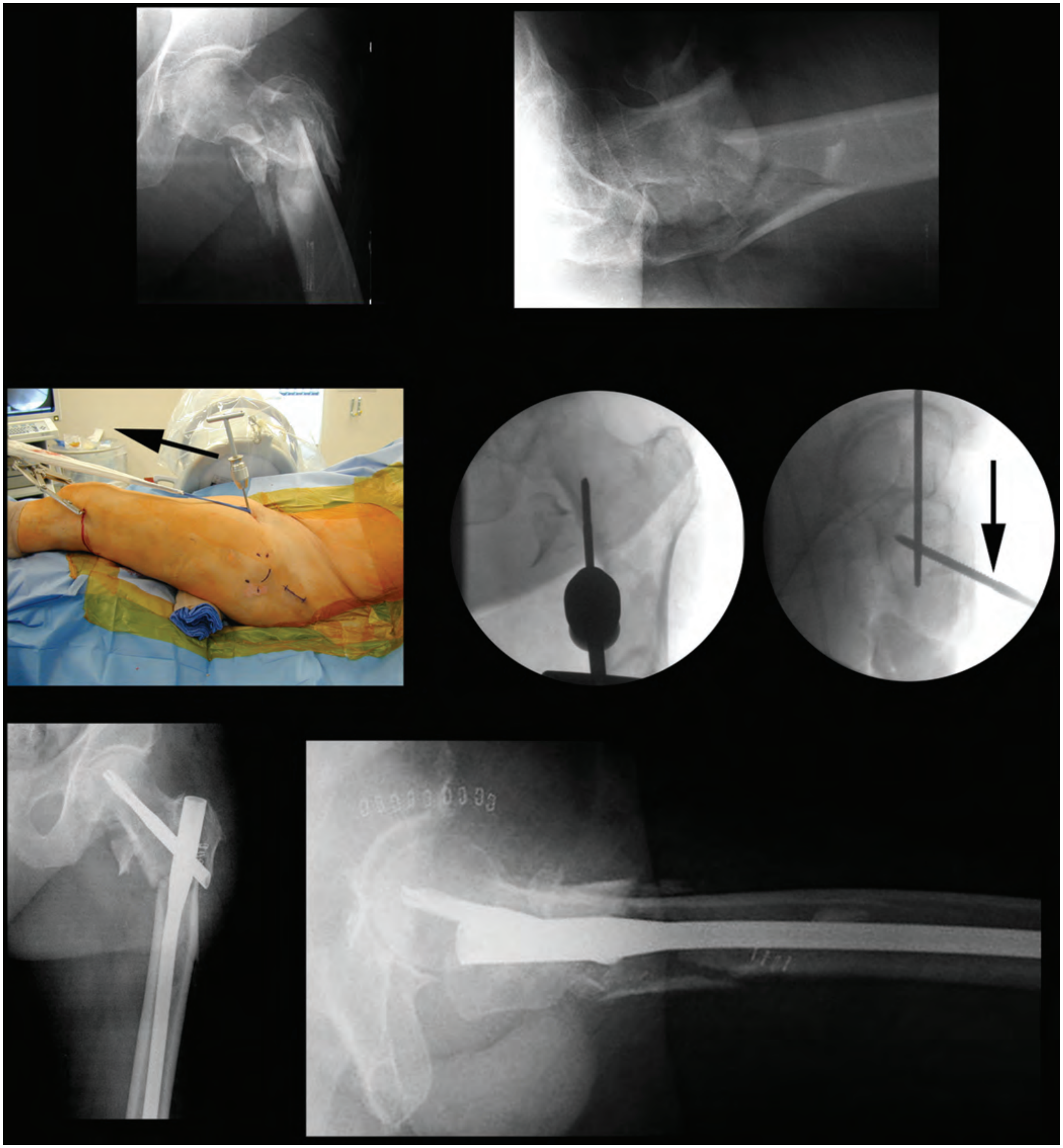


Figure 15-10. A Schanz pin placed anteriorly into the proximal fragment and pulled distally (*arrows*) can effectively reduce the flexion displacement.

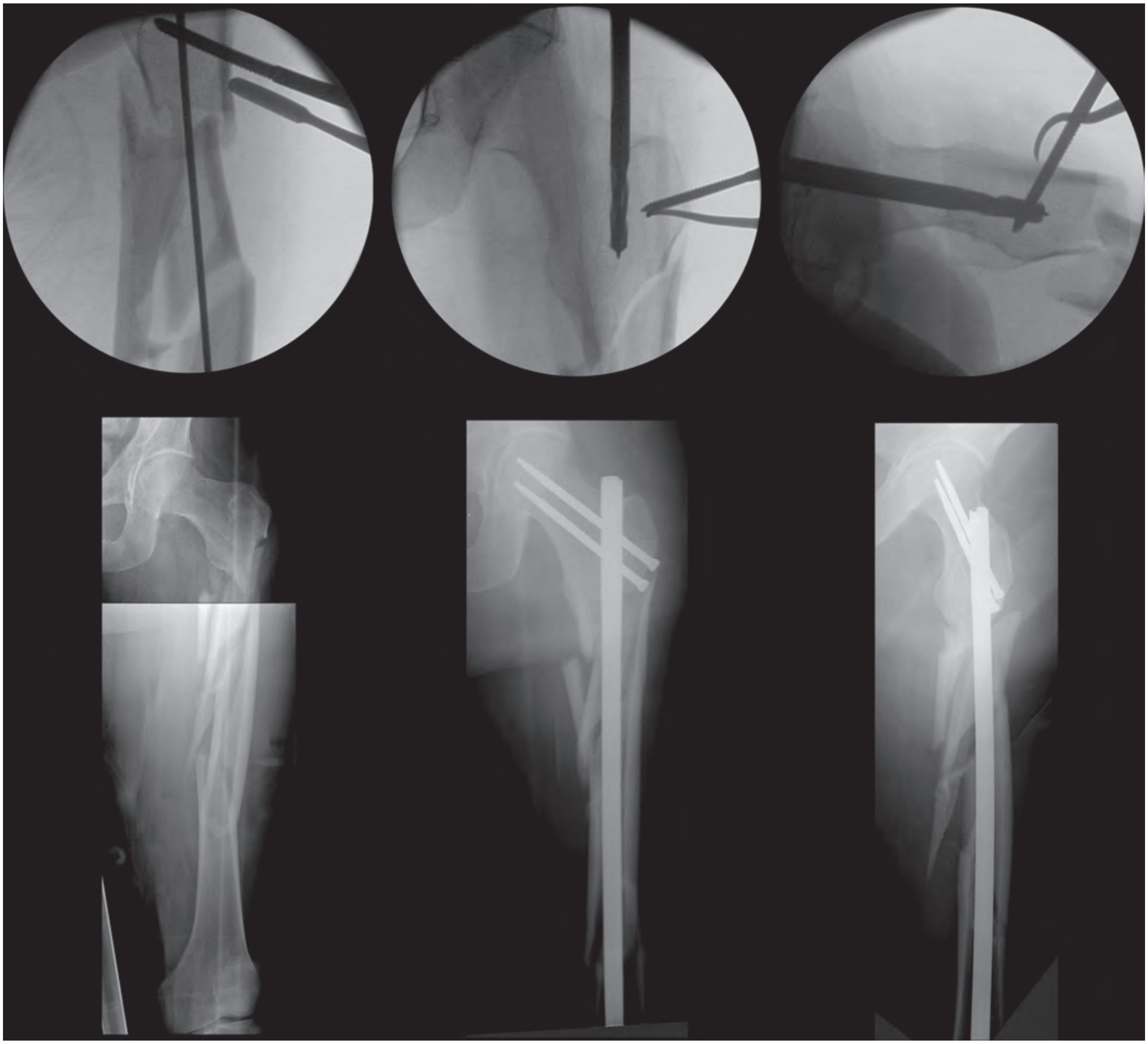


Figure 15-11. Another case example using an anterolateral Schanz pin for multiplanar control of the proximal fracture fragment.

- Eccentric reaming in the proximal medial cortex of the distal fragment (or the distal medial cortex of the proximal fragment) may also lead to varus alignment or translational deformity, especially in fractures with medial comminution.

- Following provisional reduction, a bone hook may be placed through the comminution to ensure reamers are appropriately lateralized in the distal fragment so that they maintain contact with the lateral endosteal cortex (Fig. 15-12).

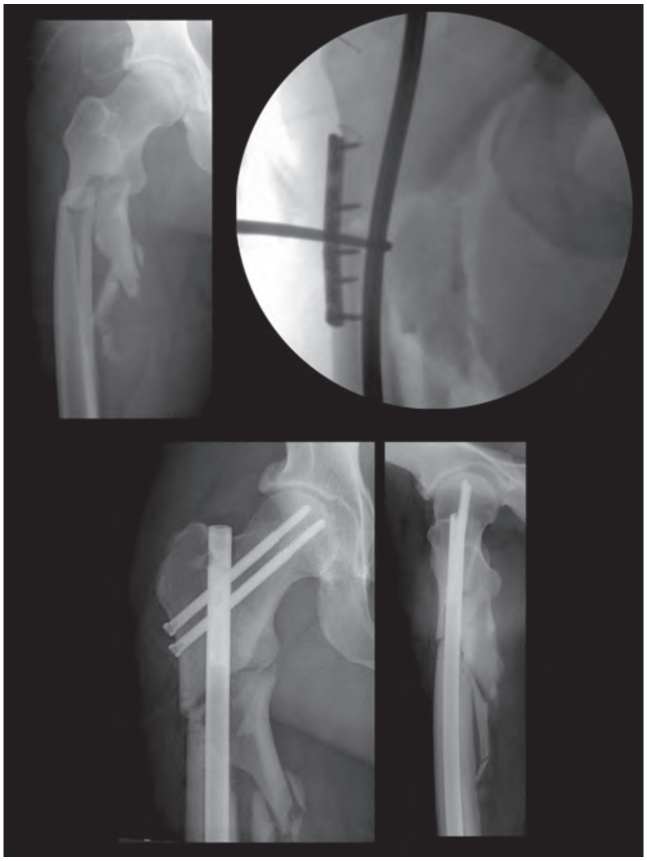


Figure 15-12. A bone hook can be placed in the comminution and used to manipulate laterally in the distal fragment to prevent eccentric reaming. A provisional plate was also used laterally in this case.

- Percutaneously inserted spiked pushers placed anteriorly and laterally (or a single one placed anterolaterally) can correct both coronal and sagittal plane malreductions (Fig. 15-13).

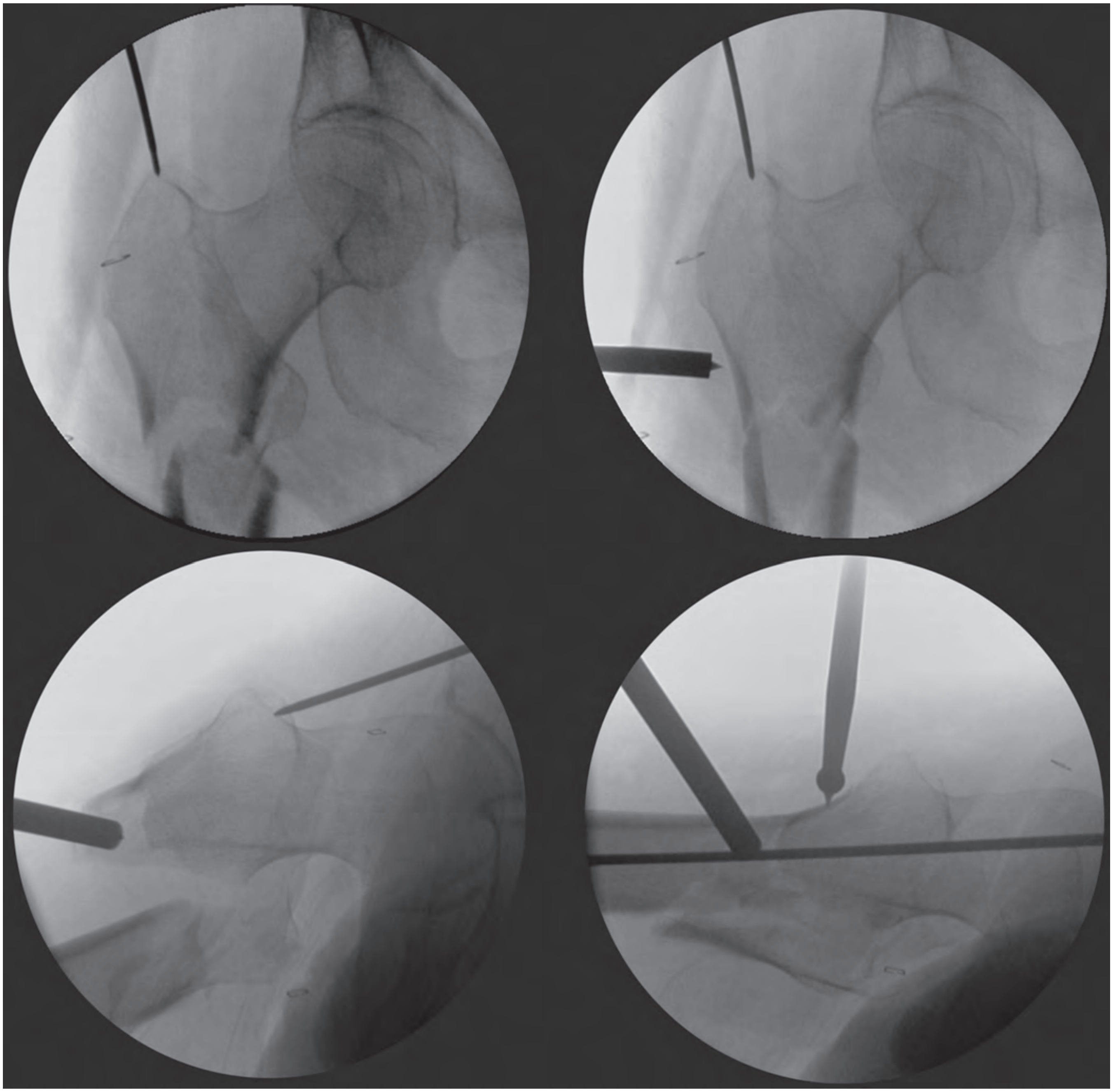


Figure 15-13. Spiked pushers can be inserted through small incisions to improve fracture reductions. It is important to consider multiple planes of deformity. In this case, the initial laterally placed spiked pusher reduced the coronal plane deformity (**upper right**), but the lateral view demonstrated that the fracture was unreduced in the sagittal plane (**lower left**). This was corrected with an additional spiked pusher inserted anteriorly (**lower right**).

- A bone hook placed around the distal fragment, in combination with a spiked pusher on the proximal fragment, can be used to reduce fractures with predominantly coronal plane translational deformities (Fig. 15-14).

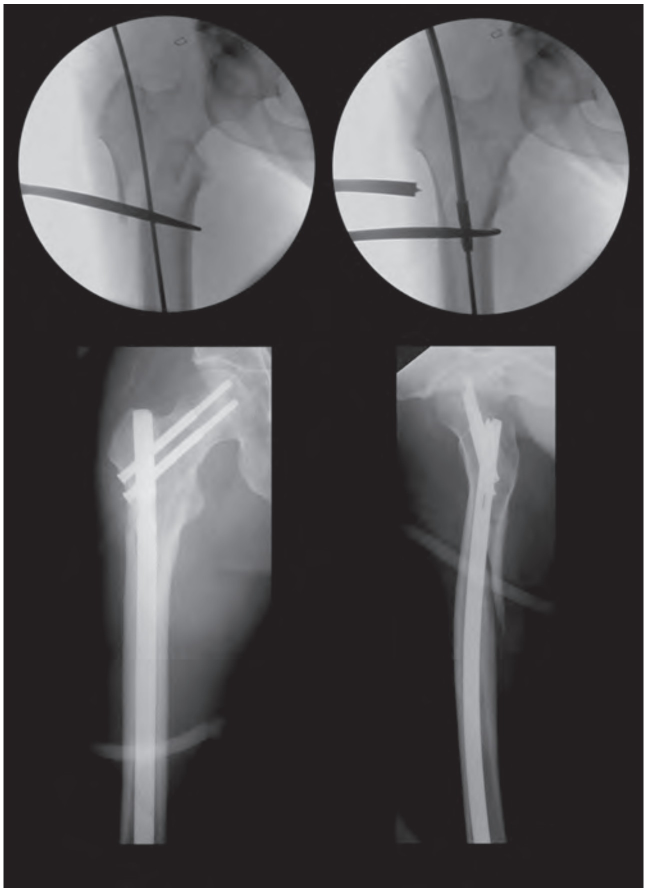


Figure 15-14. A hook may be placed through a small incision to lateralize the distal fragment. A spike pusher on the lateral cortex of the proximal fragment can assist in minimizing the eccentric endosteal reaming, coronal plane translation, and varus.

- With adequate radiographic views and attention to the correctly placed starting point, nails may be used to reduce fractures indirectly.
  - If the entry portal and nail path matches precisely the nail geometry, the subtrochanteric fracture will reduce indirectly.

- This technique should rarely be relied upon as the sole reduction maneuver (Figs. 15-15 and 15-16).

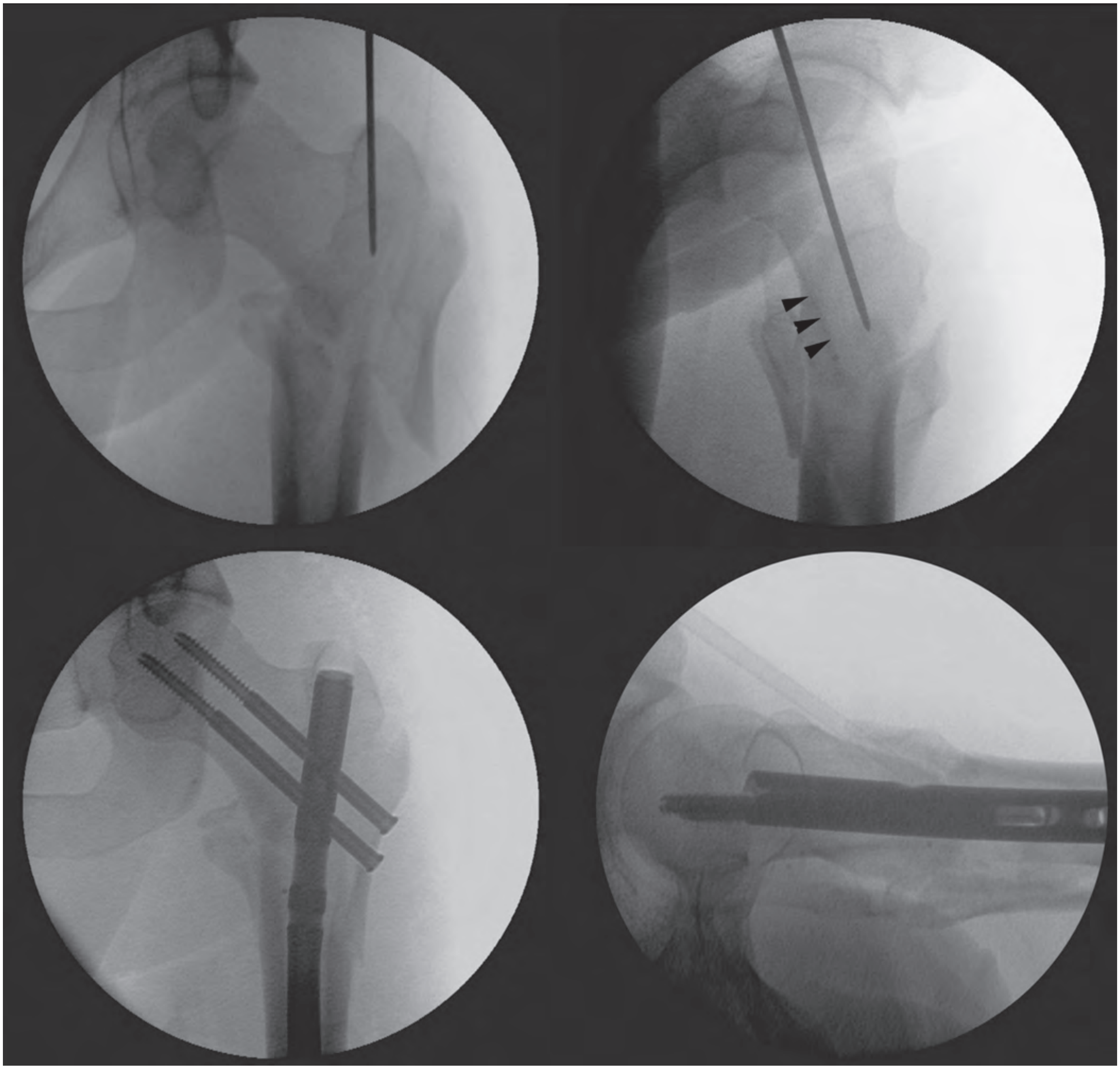


Figure 15-15. By understanding the deforming forces and the correct starting point, the nail can be used to reduce the fracture indirectly. On the lateral view, the guide wire should be collinear with the posterior corticated margin of the vastus ridge (*arrow heads* on **upper right** figure).

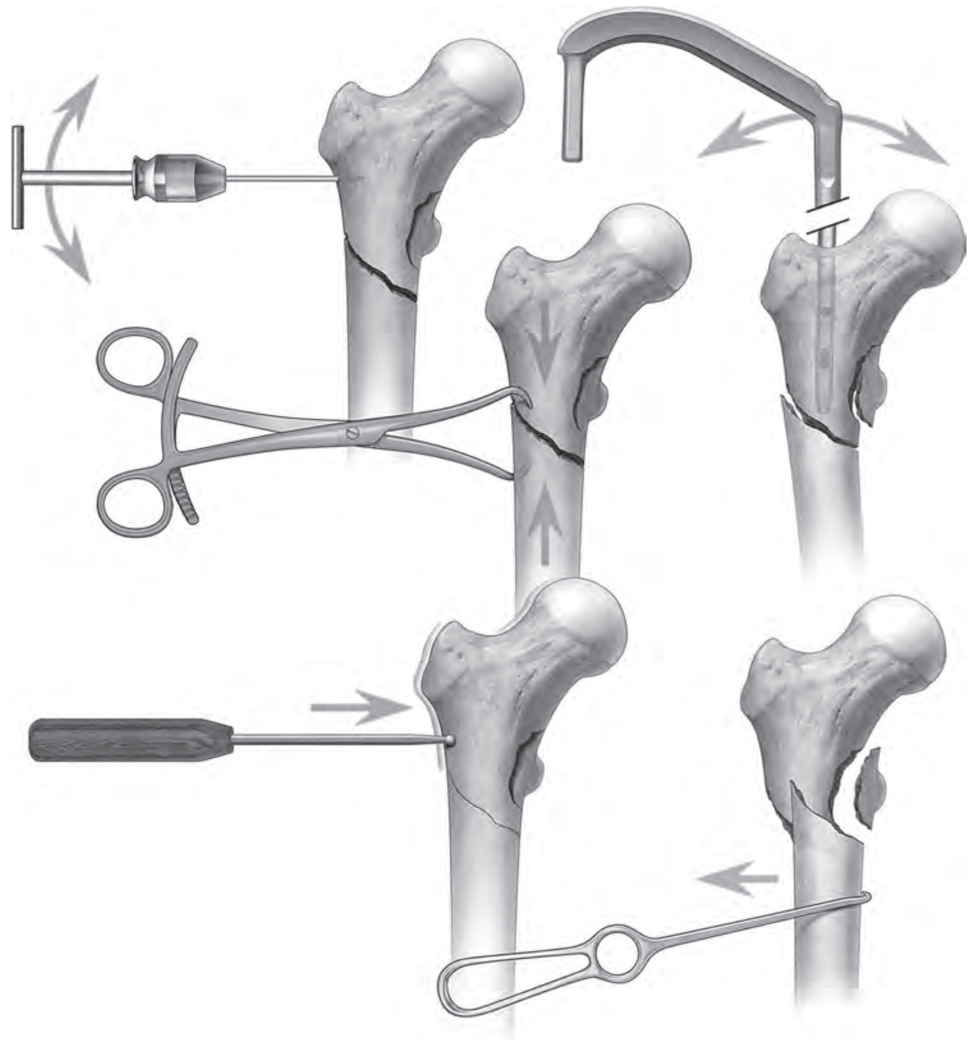


Figure 15-16. Summary of various reduction maneuvers for subtrochanteric femur fractures. Arrows indicate force vectors of the reduction instruments.

Reference

1. Browner BD. *Clin Orthop.* 1986;212:192–208.

Chapter 16

Femoral Shaft Fractures

Jason M. Evans

Sterile Instruments/Equipment

- On-table traction
- Towel bumps
- 5.0-mm Schanz pins for manipulative joysticks
- Femoral distractor
- Ball-spike pushers
- Shoulder hook/bone hook
- Steinmann pins
- K-wires and wire driver/drill
- Reamers
- Implants
  - Intramedullary nail
    - Reconstruction versus condylomedullary
  - Large fragment locking or nonlocking plate

Patient Positioning

- Supine on fully radiolucent table, with a folded towel bump or bolster under the ipsilateral hip and flank, acknowledging spine injuries and stabilizing appropriately.
  - Bump can be one or two rolled blankets, but one is typically adequate.
  - If bump is too big, lateral imaging can be difficult.
- Position patient in a slight "C" position with shoulders centered on table and the affected hip brought as far as possible to the side, preferably overhanging the edge of the table slightly to provide access to the starting point.
- A traction apparatus can be secured to the end of the table and draped into the sterile field (Fig.16-1).

Figure 16-1. A "traction post" fashioned from a pipe bender is applied to the end of the operating table to allow for an on-table axial lower extremity traction that is easily removable.

- A tensioned distal femoral traction pin (5/64-inch or 2.0-mm K-wire) is placed at the level of the superior pole of the patella as anteriorly as is possible to allow space to pass the guide wire/nail (Figs.16-2 and 16-3).

Figure 16-2. A 2.0-mm smooth Steinmann pin is placed at the level of the superior pole of the patella, just posterior to the anterior distal femoral cortex to allow for nail passage.

Figure 16-3. With the traction post mounted, and the distal femoral traction pin in place, a sterile traction bow and rope are used to achieve traction. Weights are placed to hang from the rope distally off the traction post.

- Alternatively, use a femoral distractor to restore length prior to nailing.[1]
- Place a radiolucent foam ramp under the leg to elevate and assist with lateral imaging.
- Nailing without use of traction table has several advantages:
  - Ease of positioning in polytrauma patients
  - Simplified imaging
  - Access to opposite leg for comparison of length and rotational alignment
  - Circumferential access to limb with unlimited ability to manipulate leg to archieve reduction or starting point
  - Avoids pressure complications from perineal post
- Prior to prepping, place ramp under the contralateral limb and obtain comparison images to assist with rotational reduction.[2]
  - With C-arm in full lateral position (beam parallel to the floor), rotate the leg to obtain a perfect lateral view of the knee (superimposed posterior femoral condyles) and save the image.
  - While holding this exact limb rotation, rotate the C-arm up 90 degrees (beam perpendicular to the floor) and shoot AP image of the hip.
  - Center on the lesser trochanter, and magnify the lesser trochanter. Save this image.
  - Alternatively, while holding the same limb rotation, obtain a cross table lateral image of the femoral neck (so that the neck's axis is co-linear with the proximal femoral diaphysis). This will correspond to the angle of femoral version (anteversion). Obtain the magnitude of this angular measurement from the C-arm's rotational orientation.
  - Use radiolucent ruler to accurately identify proper length (Fig. 16-4).

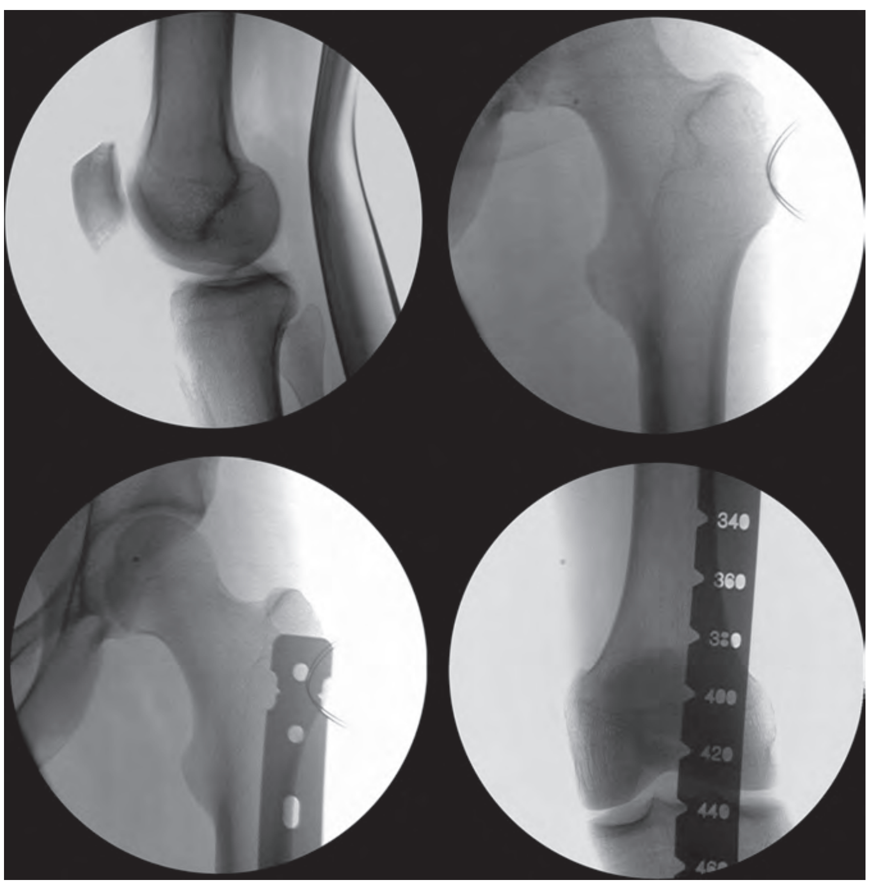


Figure 16-4. Contralateral fluoroscopic views are used to profile the lesser trochanter to ensure proper rotation of the fractured femur (**top row**). The uninjured limb is also used for length assessment (**bottom row**).

Implant and Reduction Techniques

- Percutaneous guides permit a small incision (3 to 4 cm) for nail insertion.
- Use a guide wire to locate piriformis fossa.
  - It is helpful to have the guide wire collinear with the femoral shaft on both views (Fig. 16-5).

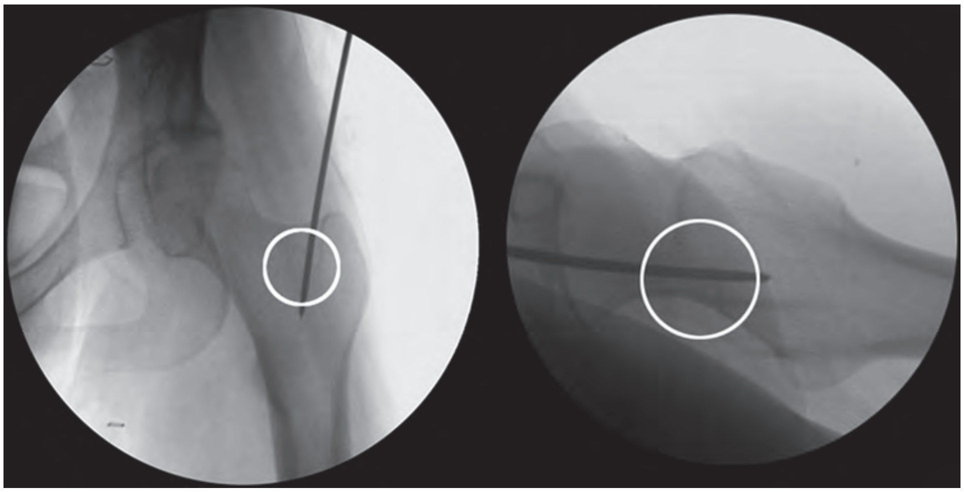


Figure 16-5. The piriformis fossa starting point is localized with a guide pin on the AP and lateral views.

  - If the starting point is correct on both the AP and lateral views, but the wire's insertion angle is not optimal, a smaller cannulated drill can be used to "swallow" the guide wire (such as from the hip screw instrument set) and then the drill can be used to correct the insertion angle since it is stiffer and can provide a more controlled correction of angulation.
- For proximal fractures, use the lateral view to assist with direction of drilling for the starting point.
  - The projection of the endosteal surface under the vastus tubercle on the C-arm can assist the surgeon in directing the guide wire. The drill/wire should be parallel to this endosteal surface (Fig. 16-6).

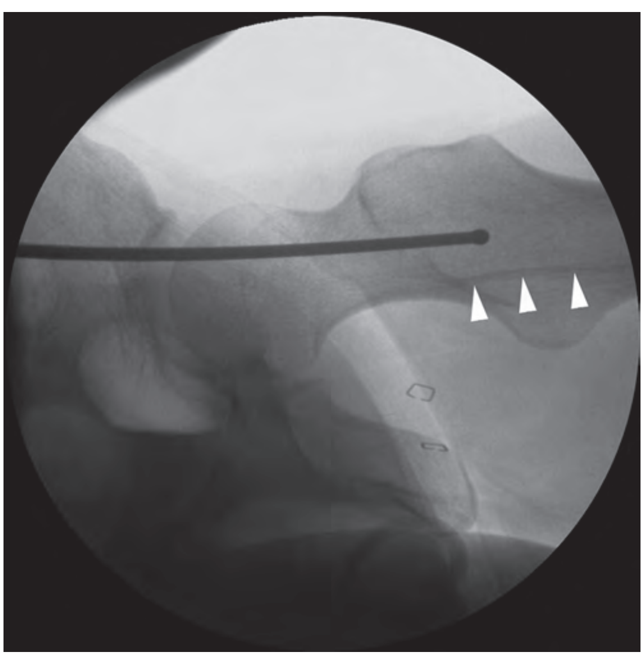


Figure 16-6. The posterior aspect of the vastus ridge (*arrow heads*) can be visualized on the lateral view and can be used to guide wire insertion vector.

- An accurate starting point minimizes the proximal femoral stresses during nail insertion, and can minimize iatrogenic fractures caused when the stiff nail is directed toward the medial, anterior or posterior cortex.
- Trochanteric entry nails are helpful in obese patients to reduce radiation exposure, although special attention to the proper starting point is necessary to avoid varus malreduction, particularly in proximal fractures.
  - The proper starting point takes into account the degree of lateral bend built into the proximal portion of the trochanteric nail, as well as the radius of curvature of the nail. This varies by manufacturer and nail design.
  - The starting point should be just lateral to the vertical cortical density at the lateral margin of the piriformis fossa in most cases.
  - The guide wire should be directed toward a point in the center of the canal at the level of the lesser trochanter (Fig. 16-7).

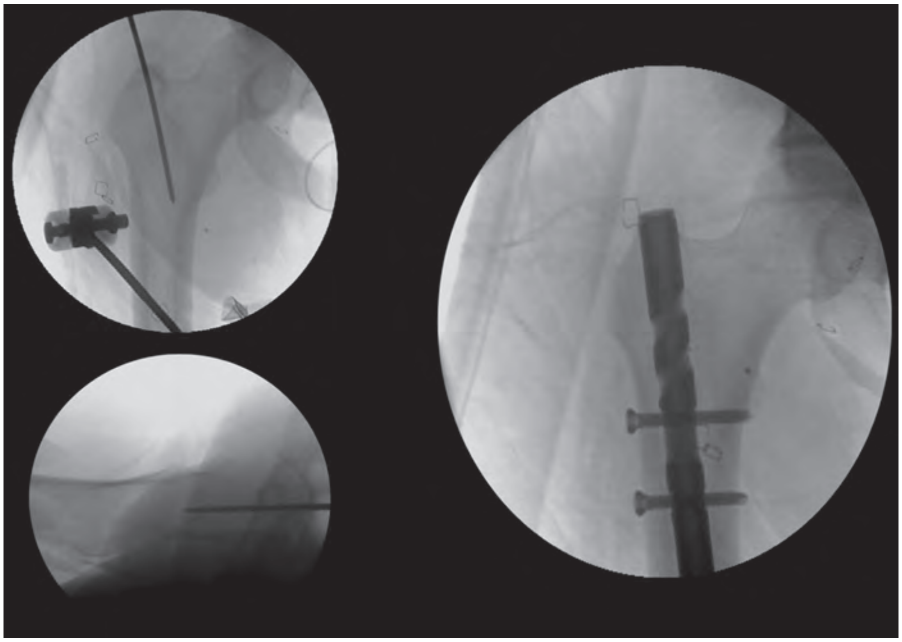


Figure 16-7. The trochanteric starting point is generally just lateral to the piriformis fossa (**upper left**), and slightly anterior to the midline on the lateral view.

- A femoral distractor or external fixator can be used to obtain and maintain provisional reduction.
  - Pins must be placed strategically out of the way of the nail path.
  - Proximally, the pin can be placed just medial to the nail.

- Distally, the pin can be placed from anterior to posterior (unicortically, or medial or lateral to the nail path) or from lateral to medial (typically posterior to the nail path in the linea aspera (Fig. 16-8)).

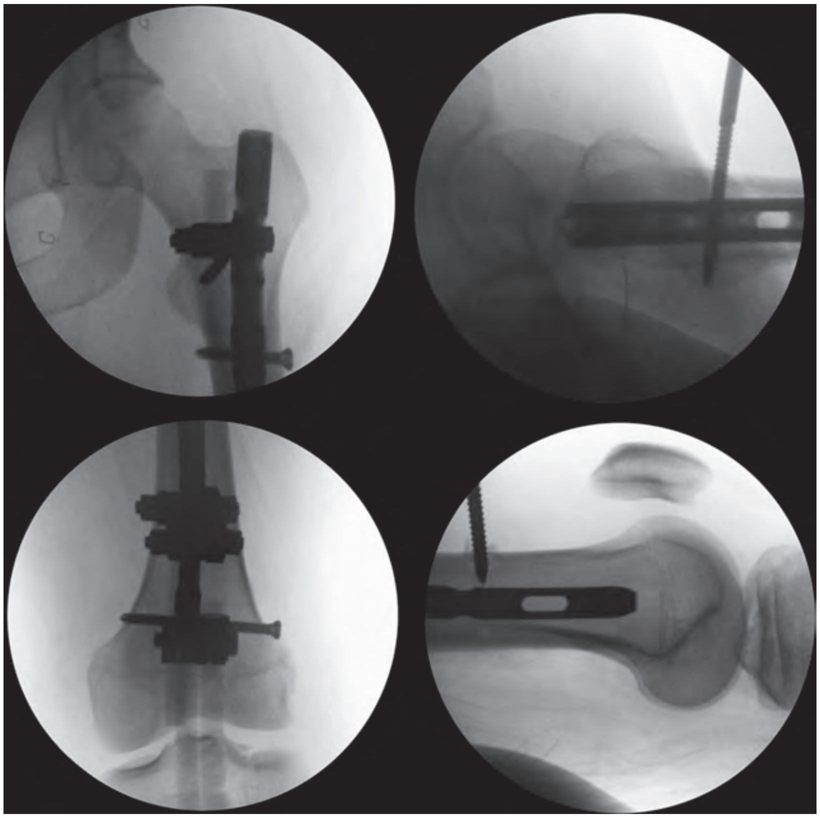


Figure 16-8. When using an external fixator or femoral distractor, Schanz pins should be planned to avoid the nail path.

- If necessary, use percutaneously placed unicortical 5.0-mm Schanz half pins in each fragment to assist with reduction.
  - These can be placed unicortically to allow simultaneous manipulation and avoid interference during reaming (Fig. 16-9).

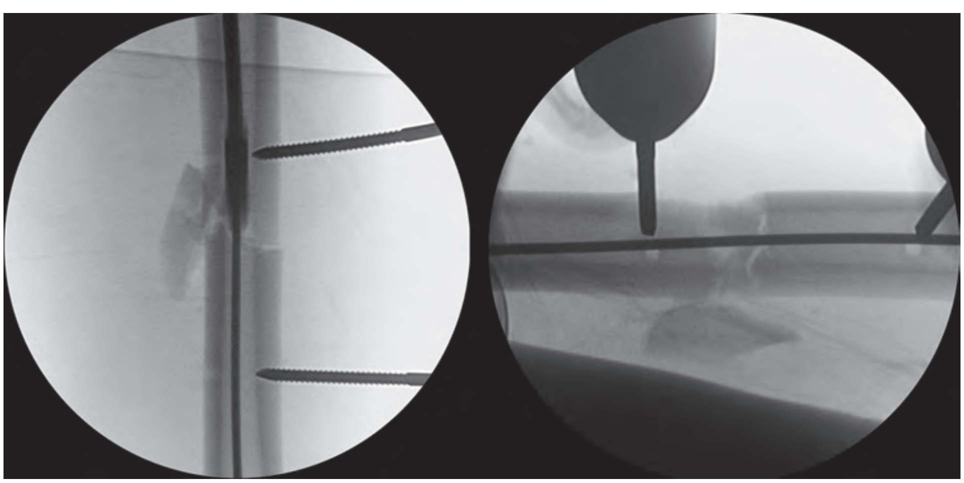


Figure 16-9. Unicortical Schanz pins can be effective for provisional fracture reduction during guide wire placement and reaming. Self-drilling pins have a drill bit on the tip and are generally ineffective.

- Alternatively, a spiked pusher and shoulder or bone hook can be inserted percutaneously to obtain and hold reduction while reaming and inserting the nail (Fig. 16-10).

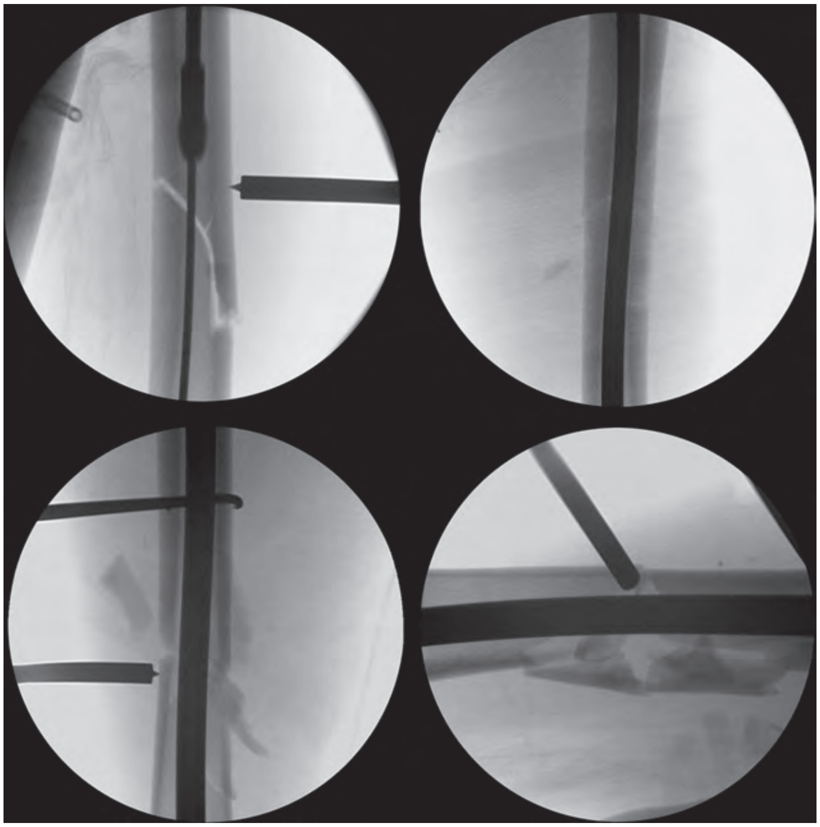


Figure 16-10. Two case examples using a ball spike pusher (**upper row**), and a ball spike pusher with a shoulder hook (**lower row**), both with an on-table skeletal traction, for femoral fracture reduction.

- For fractures with medial comminution, a provisional unicortical plate may be placed to realign the canal, and not violate the medial soft tissue.
  - Additionally, the reamer will tend to displace medially and not ream the lateral endosteum if there is no cortex to contain it medially.
  - A bone hook can be placed around the reamer shaft to draw it laterally to ream laterally, avoiding unintentional eccentric reaming and minimizing the risk of varus deformity upon seating of the nail (Fig. 16-11).

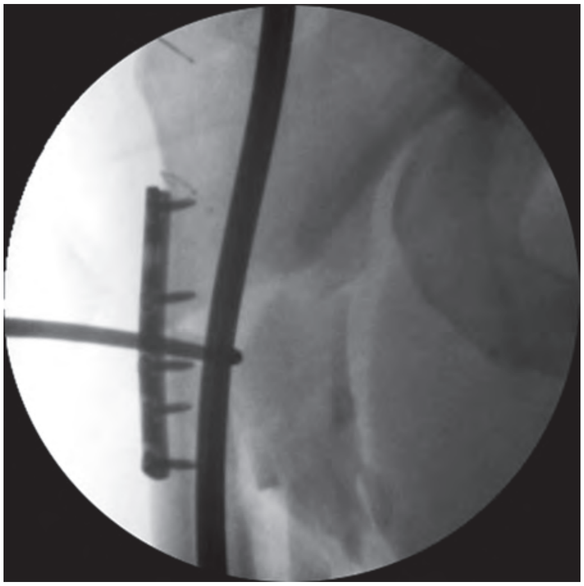


Figure 16-11. Using a provisional unicortical plate and a shoulder hook can assist in maintaining appropriate fracture reduction and reamer lateralization.

- Pass the guide wire so the ball tip is aimed at the medial tibial spine on an AP knee view.
  - A slight bend at the end of the wire prior to insertion facilitates its passage across the fracture.
    - This is also useful for making slight corrections in its distal placement by rotating the wire, then using slight mallet strikes to advance.
  - If the wire has been passed eccentrically in the distal segment, it can be difficult to redirect, as it tends to follow the previous path.
    - In this instance, a percutaneous K-wire can be strategically placed to "block" the incorrect path as it is withdrawn and reinserted (Fig. 16-12).

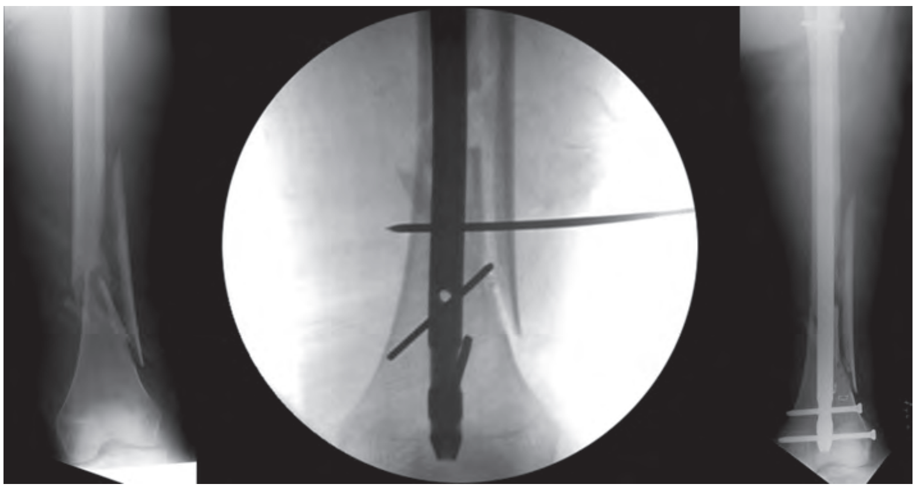


Figure 16-12. Blocking Steinmann pins were used to direct the guide wire centrally in the distal fragment to maintain anatomic alignment.

- Verify on the lateral projection that the guide wire is posterior to the distal femoral traction pin.
- Occasionally, the nail will be blocked from final seating in the distal fragment by the traction pin.
  - Rather than removing or exchanging the traction pin, it is possible to retain the pin and pass the nail by impacting the nail against the wire, placing an intraosseous bend in the wire.
  - The nail can then be withdrawn slightly, and the traction pin rotated 90 degrees so that the "V"-shaped bend is now more anterior, allowing the nail to pass posterior to it (Fig. 16-13).

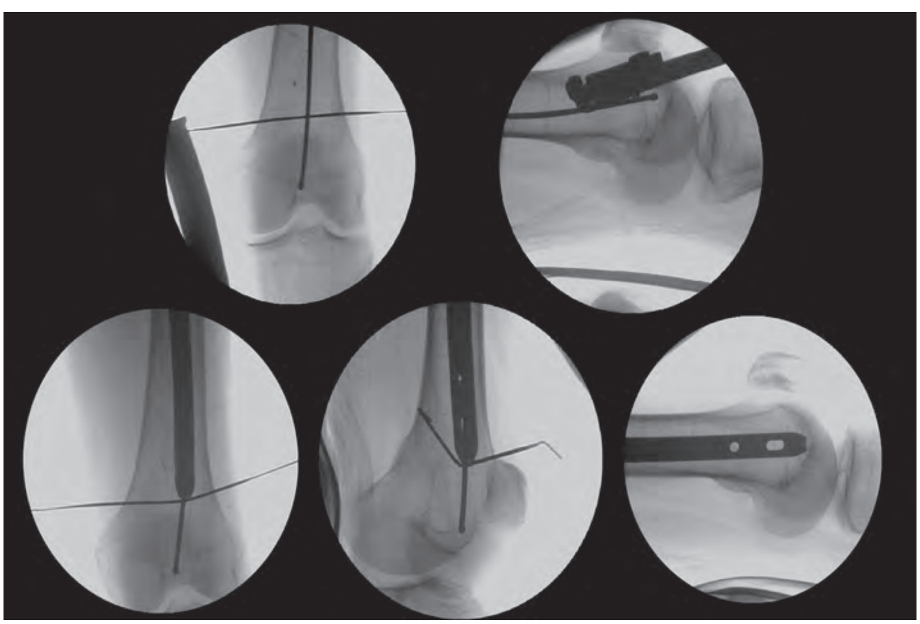


Figure 16-13. If the traction pin is too posterior and blocks the nail passage, the nail can be impacted into the pin to create a bend, and the pin then rotated to allow the nail to pass.

- Elderly patients frequently have an accentuated femoral bow relative to younger patients.
    - Most femoral nails on the market do not account for this increased bow and may extrude the anterior cortex whether placed antegrade or retrograde.
    - Plan for this by
        - Choosing a nail with a smaller radius of curvature (more bend)
        - Modifying the nail to increase the bend, or
        - Using a shorter straight nail
        - Using a starting point as anterior as feasible
- Check the lateral knee image prior to placing the distal interlocking screws.
    - The distal interlocking holes should be nearly perfect circles when the perfect knee lateral is seen, if the fracture has been reduced properly and the nail has been placed with neutral rotation.
    - When the perfect circles are not seen with a perfect lateral of the distal femur, the surgeon must determine if the fracture is malaligned or if the nail is malrotated.
- If the fracture was significantly comminuted, or in the presence of bilateral fractures, be critical of possible rotational malreductions.
    - Combining a lateral view of the knee (and nail) with the lateral view of the femoral neck will indicate the reconstructed anteversion, and will ensure that no retroversion is present.
    - At the completion of the procedure, with the patient supine and with a level pelvis, flex the hips and knees simultaneously and compare the hip rotation bilaterally.
        - The total ROM should be symmetric in the absence of preoperative pathology.
    - If malrotation is a concern preoperatively, such as in segmentally comminuted fractures without good cortical apposition potential, it may be advisable to use only single interlocking screws in the proximal and distal fracture fragments.
        - If the fracture is later determined to be malrotated, it can be more easily corrected acutely by removal of the single distal interlock, derotation of the nail or fracture, and insertion of two new interlocks.
        - This technique helps to avoid a "snowman," or "planter's peanut" configuration of interlock holes, in which the new locking bolt site may be contiguous with the old hole, compromising purchase.
        - Changing the distal interlocking screw will more often allow for a native screw path, as the femoral condyles have a larger diameter compared to the proximal segment.
    - For objective data regarding rotation, a postoperative CT scan with several cuts through both knees and hips can provide precise data regarding the fracture rotation and nail rotation by comparing anteversion to the uninjured side.
        - This information is useful in determining which segment to rotate (proximal or distal) and the exact magnitude (Fig. 16-14).

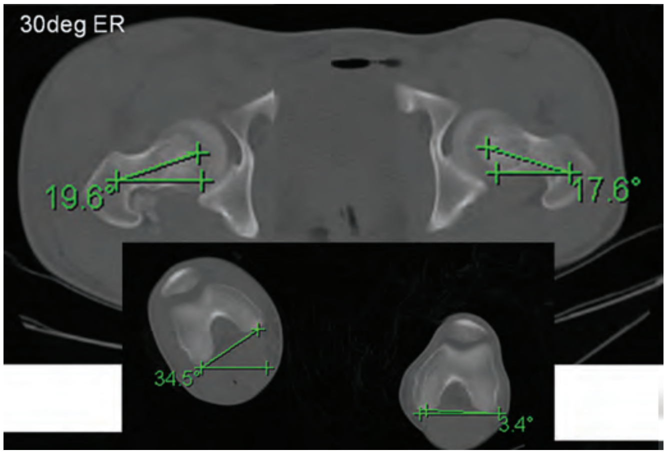


Figure 16-14. CT version studies can identify rotational deformities.

- For correction of rotational malreduction, use Schanz pins in each segment as rotational guides.
  - An external fixator can also be used to maintain length during rotation and may give more precise control.
  - The Schanz pins should be strategically placed around the nail so as not to interfere with subsequent rotation (Fig. 16-15).

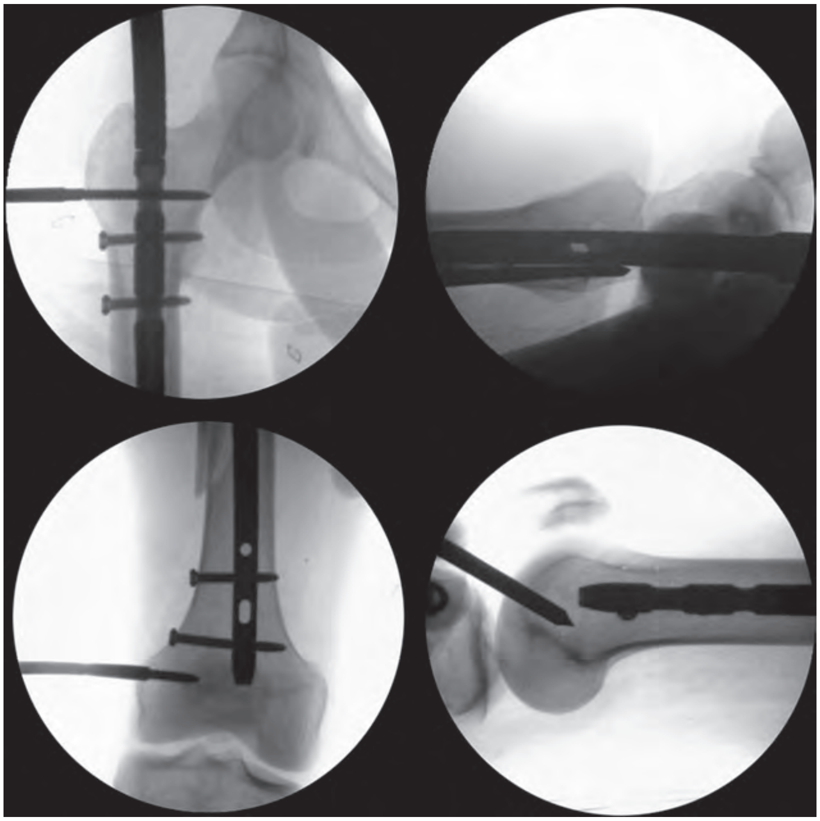


Figure 16-15. To derotate a rotationally malaligned femur, Schanz pins should be placed strategically around the nail prior to removing interlocking screws, to allow for a controlled derotation maneuver.

- For an overlengthened, yet rotationally correct, limb segment which needs an axial correction less than the total longitudinal length of the slotted hole, a screw can be placed in the distal portion of the slotted hole, and then the proximal screw removed permitting the fracture to be compressed until the locking screw is seated at the proximal extent of the slot.
  - Similarly, the reverse is also possible for a fracture previously stabilized too short.
  - In this situation, an additional locking screw can be placed in the proximal extent of the slot and the fracture distracted by the length of the slot.
- For proximal fractures, the proximal segment is typically flexed, externally rotated, and abducted.
  - A spiked pusher placed through a stab incision can counter this displacement with a force directed posteromedially while reaming and seating the nail.[3]
- Use as long a nail as possible.
  - The bending stress experienced by the most proximal distal interlock is inversely proportional to the distance of the bolt from the fracture site.

- For fractures with significant segmental comminution and wide displacement, stopping the reamer and manually pushing through the comminuted segment can prevent possible damage to soft tissue structures that may be displaced in the comminuted segment.
- For segmental fractures, a limited open approach to the proximal fracture allows for accurate reduction and temporary clamp placement.
  - This can remain in place while reaming.
  - This effectively converts the fracture into a simple pattern, while addressing the segment most likely to be malreduced.
  - This can simplify treatment and expedite the procedure.
- Blocking screws, wires, or Steinman pins can be used to effectively narrow the canal near the metaphyseal flares, providing improved ability to obtain and maintain reductions when intramedullary fixation is chosen for fractures in these areas (Figs. 16-16 and 16-17).

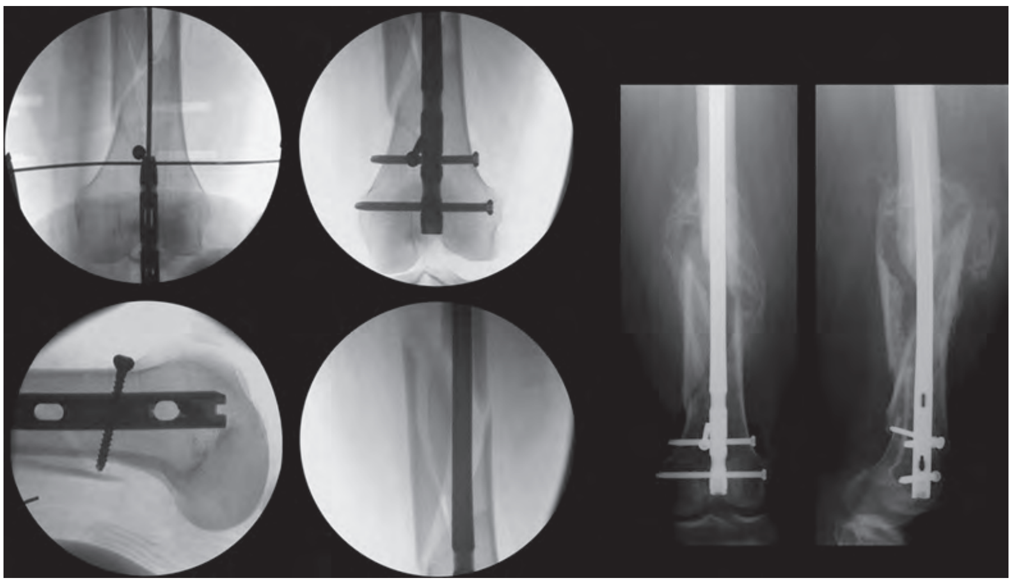


Figure 16-16. In this distal femoral shaft fracture, a blocking screw was used at the convexity of the deformity to obtain and maintain the reduction.

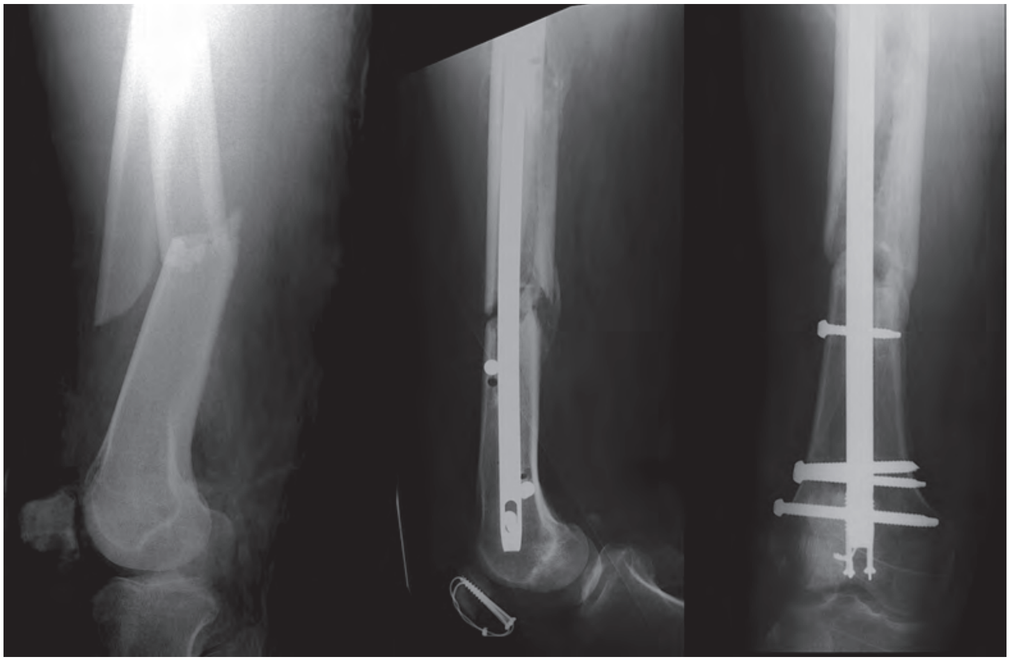


Figure 16-17. In this distal femoral shaft fracture with an apex posterior deformity, blocking screws were used with an antegrade nail to achieve an anatomic alignment.

- Postnailing, check four things before waking the patient up.
  - The femoral neck for an occult neck fracture.
    - This requires a good AP or internal rotation fluoroscopic view.
  - Symmetry of lower limb lengths and limb segment lengths.
  - Symmetry of lower extremity rotation.
    - Confirm by observing the passive limb rotation with the patient's pelvis level and actively confirm the clinical symmetry of hip rotation.
  - Examine the knee ligaments for the presence or absence of concomitant injury.
  - Palpate the thigh and calf to ensure all compartments are soft
- For an antibiotic-impregnated cement nail, use a 40 French Argyle chest tube (Kendall) to create an approximately 10-mm nail.
  - Use humeral nail guide wire (2.5 mm with ball tip) in the center of the cement-filled chest tube.
  - Alternatively, a 6-mm threaded Ilizarov rod with a female eyebolt attached proximally will improve the strength and stiffness of the cement nail construct; the eyebolt will facilitate removal[4].
  - Mix two bags of PMMA cement with 2 g of vancomycin and 2.4 g of tobramycin.

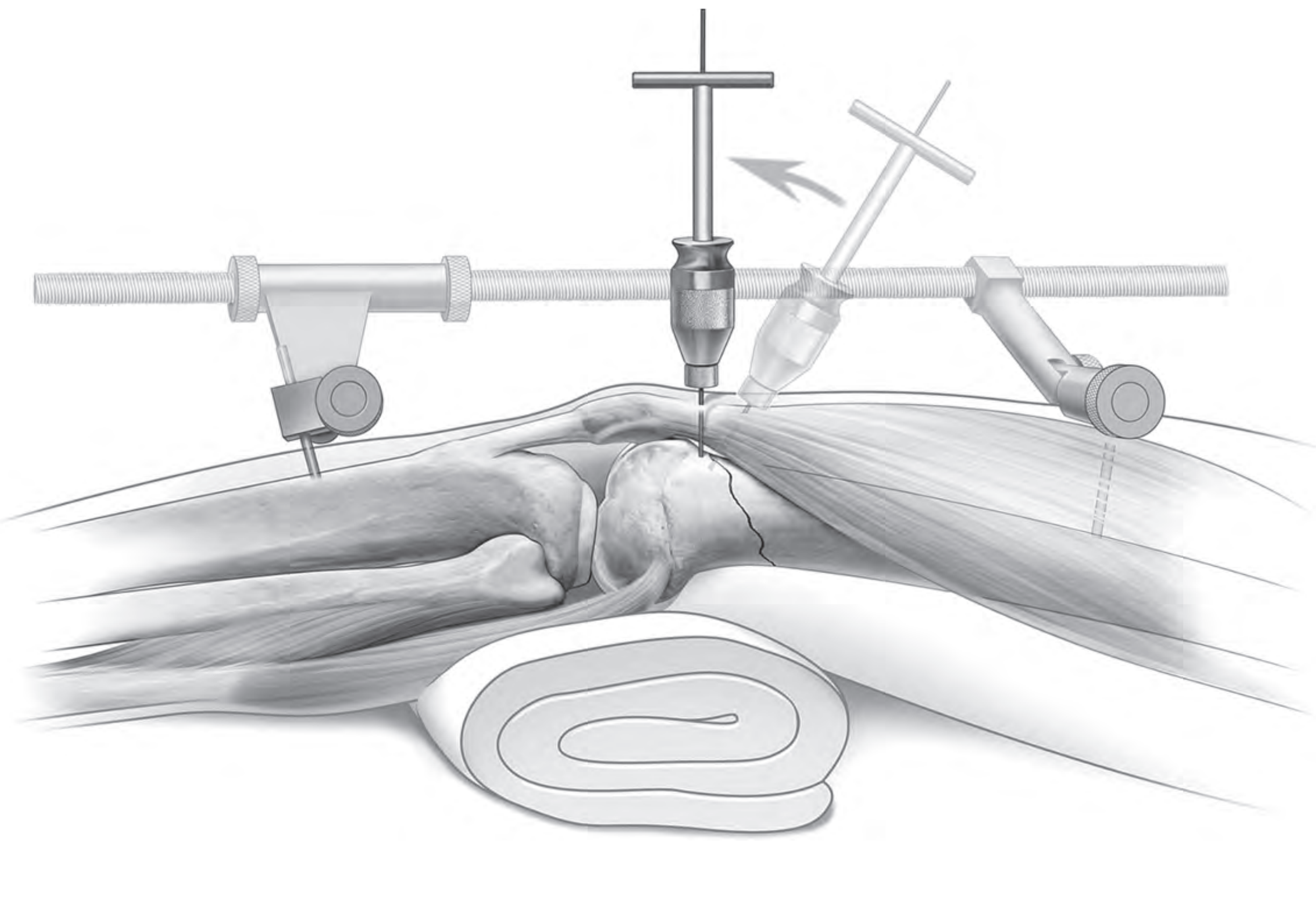
References

1. McFerran MA, Johnson KD. Intramedullary nailing of acute femoral shaft fractures without a fracture table: technique of using a femoral distractor. *J Orthop Trauma.* 1992;6:271–278.
2. Krettek C, Miclau T, Grun O, et al. Intraoperative control of axes, rotation and length in femoral and tibial fractures. Technical note. *Injury.* 1998;29 (Suppl 3):C29–C39.
3. Browner BD. Pitfalls, errors, and complications in the use of locking Kuntscher nails. *Clin Orthop Relat Res.* 1986:192–208.
4. Michael Sirkin, MD. *Personal communication*, 2008.

Section 7

Knee

David P. Barei



Distal Femur Fractures

Chapter 17

Raymond D. Wright
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M. Bradford Henley

Sterile Instruments/Equipment

- Large external fixator
- 2.5 mm, 4.0 mm, or 5.0 mm Schanz pins, or large K-wires or Steinmann pins for manipulative joysticks
- Large pointed bone reduction clamps (Weber clamps)
- Large quadrangular ball-spike clamp
- Femoral distractor
- Ball-spike pushers
- Shoulder hook/bone hook
- K-wires and wire driver/drill
- Smilie knee retractors and "Z-retractors"
- Implants
  - Nonlocking condylar buttress plate
  - Locking plate
  - Retrograde nail, if desired
  - Blade plate

Patient Positioning

- The patient is usually placed in a supine position on a radiolucent table.
  - A padded bump is placed under the ipsilateral hip to neutralize hip rotation.
  - The lower extremity is elevated on a soft ramp cushion or other padded bolster to facilitate lateral radiographic imaging.
- Alternatively, lateral positioning can be used for a lateral approach for direct ORIF.
  - This is useful for ORIF of supracondylar distal femur fractures for periprosthetic injuries where the entire femur is to be plated.
  - This is also useful for supracondylar nonunions.
- The C-arm is positioned on the contralateral side of the OR table, opposite the operative extremity.

Surgical Approaches

- Surgical approach is determined by the fracture pattern.

- The *direct lateral approach* may be utilized for the majority of supracondylar and intercondylar femur fractures (Fig. 17-1).

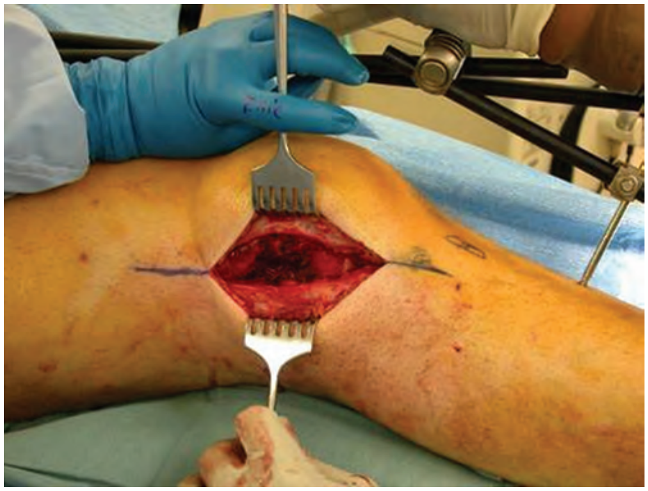


Figure 17-1. The direct lateral approach can be used effectively for most Type C1 and C2 distal femur fractures. The incision is made along the shaft of the femur, and often needs to be extended distally to the level of Gerdy's tubercle.

- This approach avoids incision of the quadriceps tendon.
- The distal portion of the vastus lateralis is elevated off of the lateral intermuscular septum.
- It is preferred for its soft tissue sparing benefits.
- If visualization of the distal articular surface is necessary, split and retract the iliotibial band anterior to Gerdy's tubercle and dissect towards the lateral border of the patellar tendon, then curving distally towards its insertion.
  - Avoid an incision crossing the patellar tendon.
  - The distal limb of the incision may be extended distally to the tibial tuberosity lateral to the tendon, to allow for an increased mobilization of the anteromedial soft tissues.
- Allowing temporary limb shortening at the supracondylar level by bayonet apposition of the shaft and metaphyseal portions of the fracture removes the tension from the extensor mechanism, allowing improved medial soft tissue retraction of the extensor mechanism and visualization of the distal articular surface, femoral trochlea, intercondylar notch, and medial femoral condyle, if required (Fig. 17-2).
- Hyperextending the knee with a bump under the heel can also relax the extensor mechanism to improve visualization.

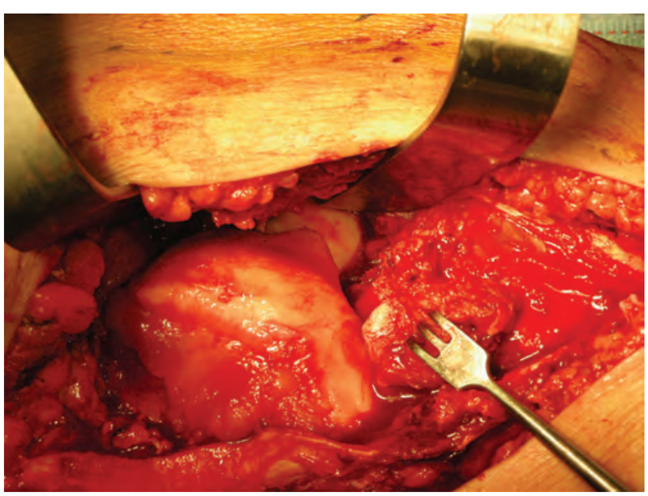


Figure 17-2. By extending the incision into the lateral part of the fat pad (to the patellar tendon), the distal articular surface of both femoral condyles can be visualized.

- Placing two "Z" retractors, one superior and one inferior to the patella, facilitates retraction of the extensor mechanism.

- Alternatively, a *lateral parapatellar approach* may be used in cases with significant intercondylar comminution, and/or for associated coronal plane fractures (Fig. 17-3).

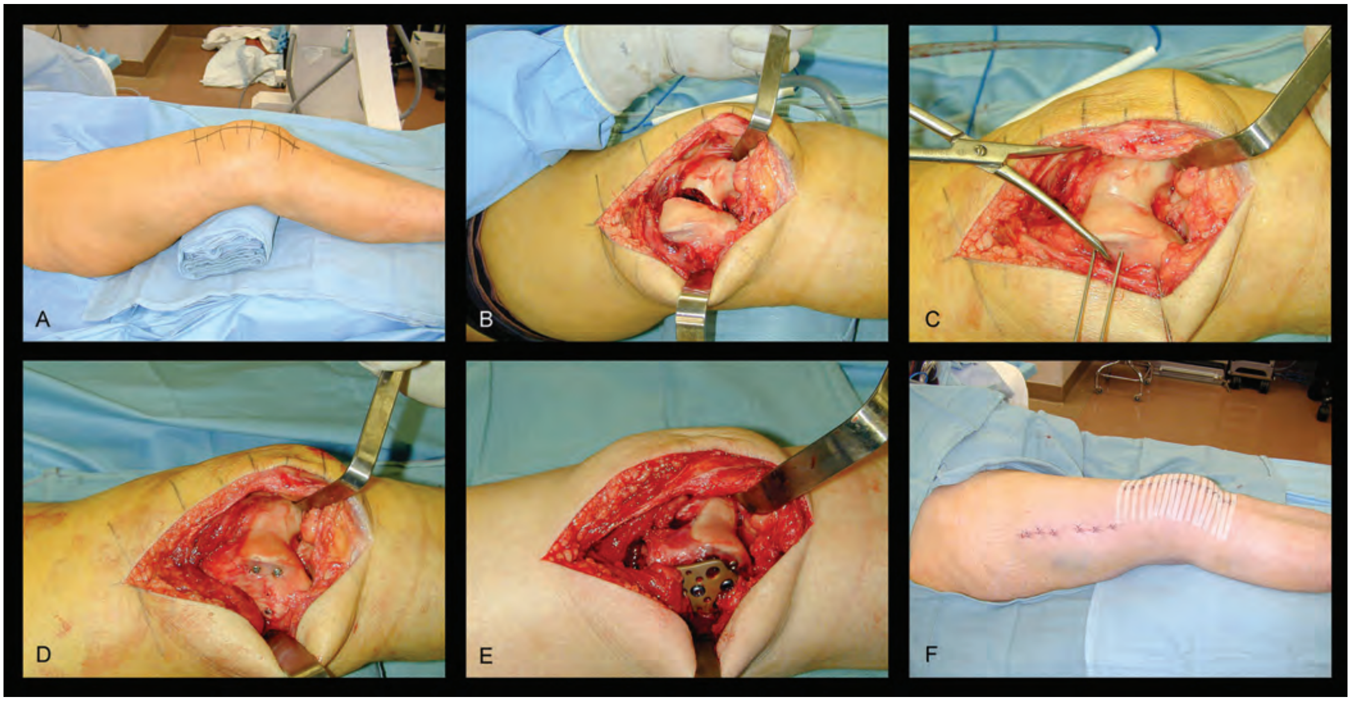


Figure 17-3. Using a lateral parapatellar approach through a midline or paramedian incision, the articular surface is visualized, and sagittal plane fracture reduction is facilitated **(A,B)**. This approach is anterolateral and thus permits coronal plane fracture fixation (Hoffa fractures) with anterior-to-posterior screws, especially if these involve the medial condyle. The intercondylar articular displacement is then reduced under direct vision, and transcondylar K-wires are placed **(C)**, followed by peripheral screws **(D)**. This allows room for a locking plate to be placed unobstructed **(E)**. The proximal screws may still be inserted percutaneously with this approach **(F)**. (From Nork SE. Supracondylar femur fractures: open reduction and internal fixation. In: *Master Techniques in Orthopaedic Surgery: Fractures*. Philadelphia: Lippincott Williams Wilkins, 2006. With permission.)

- This approach sacrifices the superolateral geniculate artery to the patella and incises the quadriceps tendon.

- Rarely, a *medial approach* may be used in conjunction with a lateral approach, if necessary, for additional medial condyle access, or for placement of anterior to posterior screws for coronal plane Hoffa fractures.
  - The most proximal of the screws should be placed proximally enough so that it is posterior in the femoral condyle, ensuring adequate fixation.
  - This proximal screw can usually be inserted medial (and superior) to the femoral trochlea's articular cartilage.

- This position is typically proximal to the articular surface (Fig. 17-4).

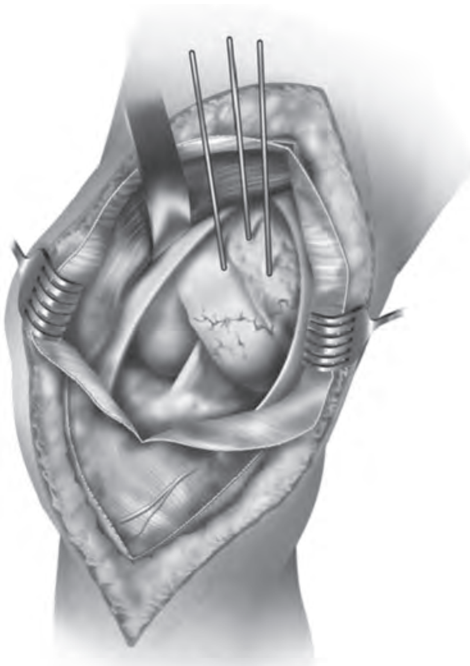


Figure 17-4. K-wire and screw placement for medial Hoffa fracture. These may be placed percutaneously as cannulated screws, or through a small medial parapatellar arthrotomy.

Reduction and Fixation Techniques

- Articular reduction should be performed first.
- Typically, coronal plane (Hoffa) fractures are reduced and provisionally stabilized prior to sagittal plane fractures in the intercondylar region.
  - This sequence may be reversed depending upon the complexity of each fracture.
  - Coronal plane fractures of the lateral and medial condyles can be reduced and compressed with a large pointed reduction clamp.
  - Medial condyle coronal plane fractures may be clamped through the lateral incision.
    - One tine is placed just deep to the extensor mechanism on the anterior aspect of the medial femoral condyle, and the other tine is placed through the intercondylar notch on the posterior medial femoral condyle (Fig. 17-5).

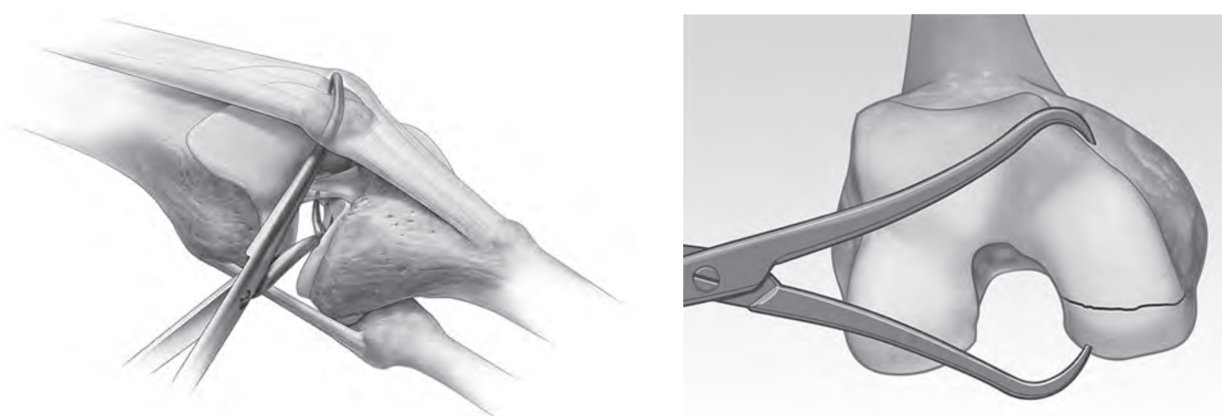


Figure 17-5. **A,B:** A large Weber clamp may be placed through the intercondylar notch through the lateral incision to access some medial femoral condyle coronal plane fracture patterns.

- Multiple anterior to posterior K-wires may be necessary to provisionally secure these fractures during screw placement.
- When using nonlocking lateral plates or polyaxial locking plates, Hoffa fractures should ideally be stabilized definitively with interfragmentary lag screws prior to plate placement.
  - However, when using non-polyaxial locking plate implants, Hoffa fractures may require definitive stabilization after plate placement to avoid interference between the lateral-to-medial plate screws and the anterior-to-posterior Hoffa/condylar screws.

- Fracture location and obliquity in the lateral condyle determines the screw orientation, which should be perpendicular to the fracture plane.
- These are usually 2.7- or 3.5-mm cortical screws (countersunk, if placed through articular cartilage) or headless compression screws placed from anterior to posterior (Fig. 17-6).

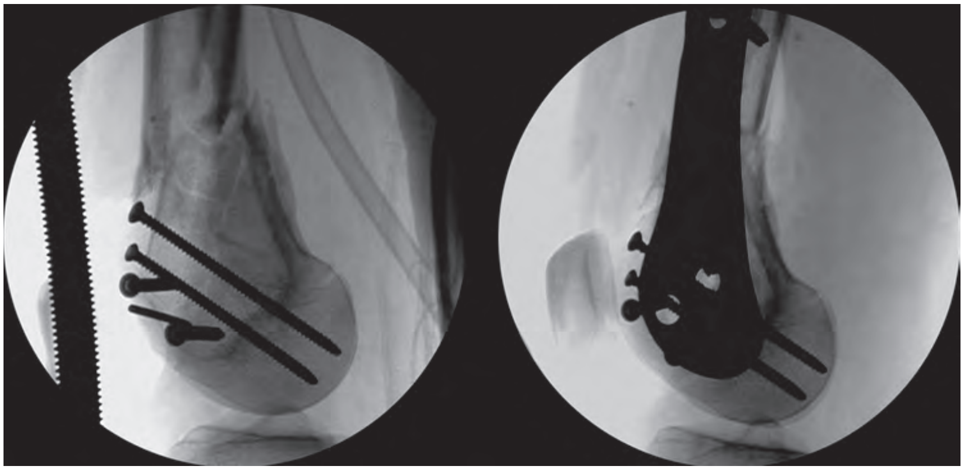


Figure 17-6. Anterior-to-posterior lag screws for a coronal plane fracture. Note the potential interference with lateral-to-medial locking screws applied through the plate.

- The screws should be angulated approximately 10 degrees from medial to lateral to parallel slope of lateral condyle in sagittal plane, and approximately 25 degrees for medial screws (Figs. 17-7 and 17-8).

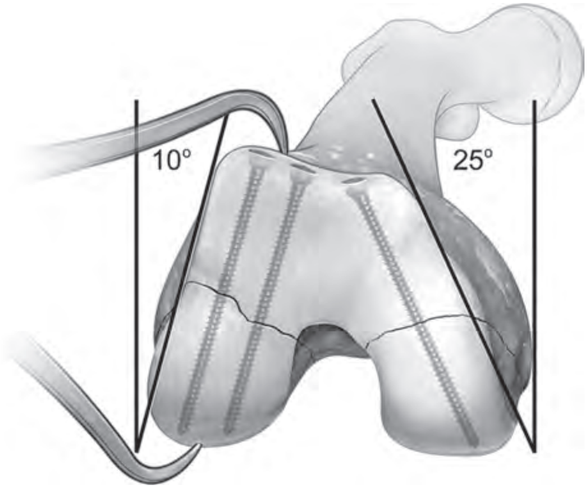


Figure 17-7. The distal femoral anatomy must be considered with planning and inserting implants for coronal plane fractures. The medial screw starting point may be more medial when inserted through an arthrotomy.

Figure 17-8. Screws for lateral condyle coronal plane fractures are often placed obliquely for containment within the condyle and parallel to the fracture.

- The screws should be placed in lag fashion and the heads countersunk below the articular surface.
  - These are often inserted through a second small anteromedial incision and medial parapatellar arthrotomy.
- Once the coronal fractures have been stabilized, the intercondylar fracture may be reduced and provisionally stabilized. Loose osseous fragments, soft tissue, and hematoma must be completely removed prior to reduction of the fracture, especially in young patients with dense bone.
- When the fracture configuration allows, a large pointed reduction clamp placed at the level of Blumensaat's line on both the medial and lateral epicondyles will provide balanced compression across intercondylar sagittal plane fractures (Fig. 17-9).

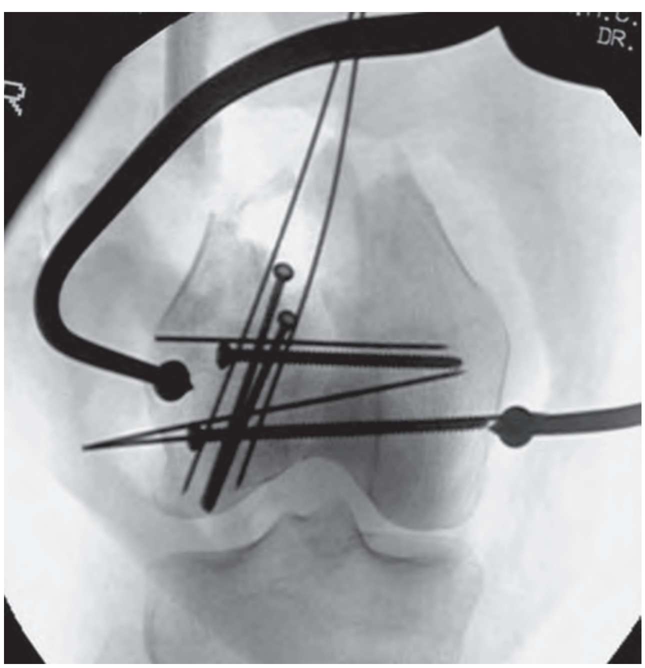


Figure 17-9. A reduction clamp is placed in the center of each condyle to concentrically compress the intercondylar fracture.

- The clamp tines should be placed near the center of rotation on each condyle, as anterior placement may preferentially compress the intercondylar fracture anteriorly and distract it posteriorly (Fig. 17-10).

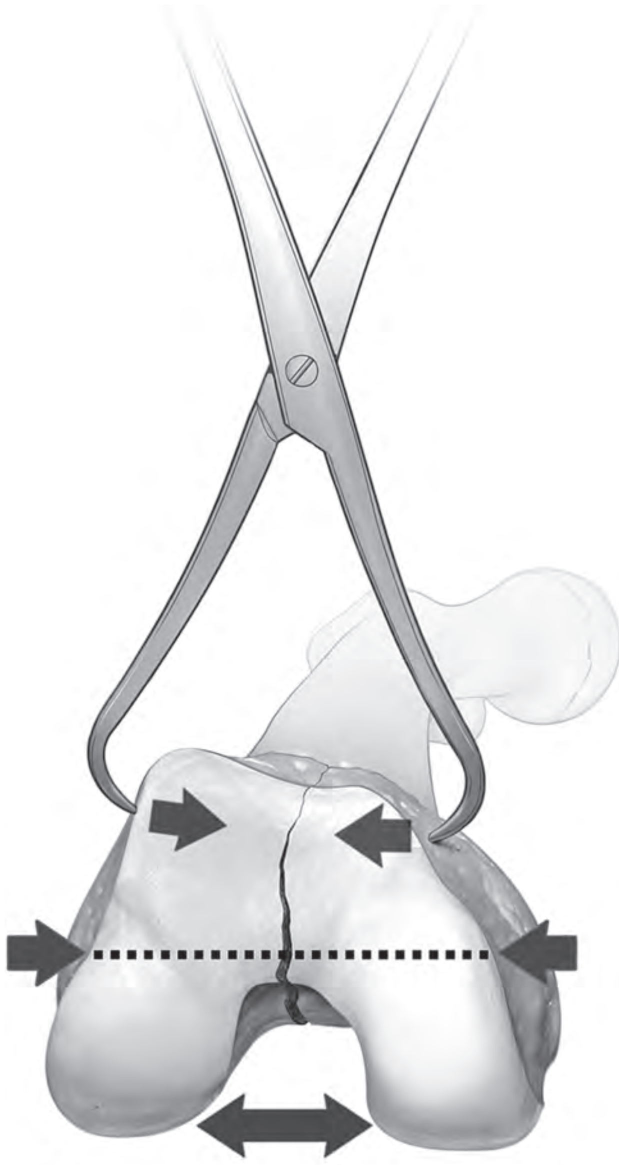


Figure 17-10. If the intercondylar clamp is placed too anteriorly, the posterior condyles risk becoming distracted (*bottom double arrow*). The ideal clamp placement for balanced fracture compression is relatively posterior on the condyles (*middle arrows and dashed line*) at the level of Blumensaat's line.

- Alternatively, in some fracture patterns, placing one time in the intercondylar notch and the other time on the epicondyle can achieve the appropriate fracture reduction vector (Fig. 17-11).

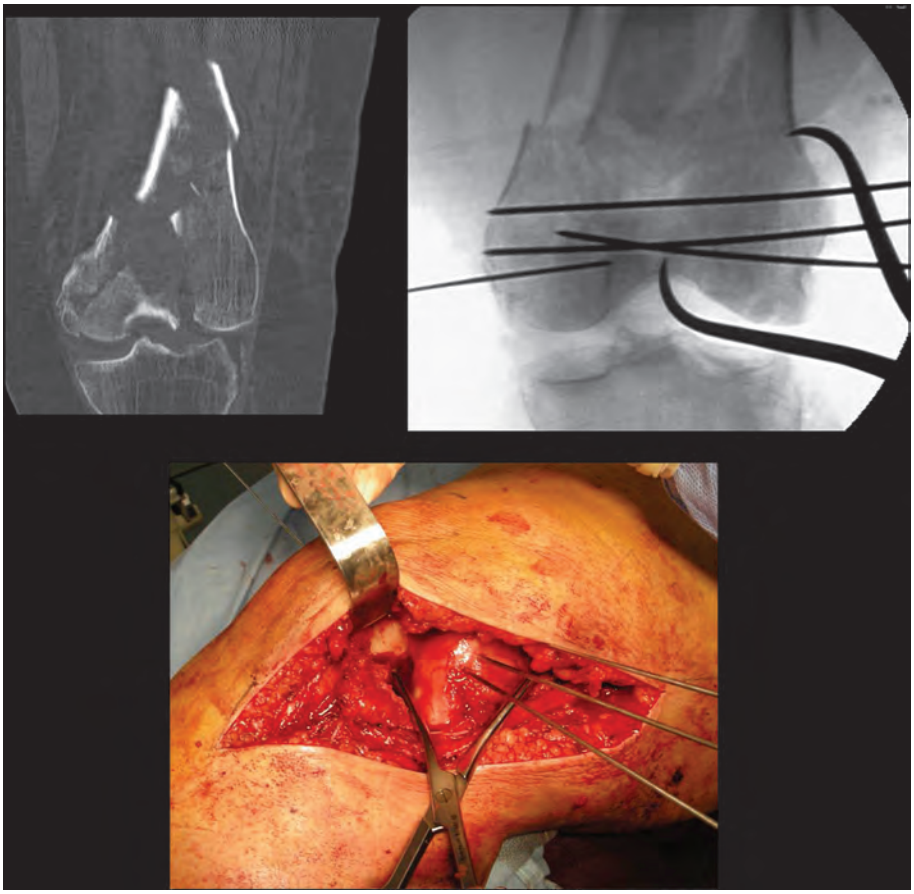


Figure 17-11. When a separate intercondylar or notch fracture fragment has a lateral spike involving the lateral femoral condyle, a reduction clamp placed in the intercondylar notch from the fragment to the lateral epicondyle allows for the appropriate reduction vector.

  - This works well if the intercondylar notch is a separate fracture fragment.
- When placed in an epicondyle or condyle, large (2.0- or 2.4-mm) K-wires may be used as joysticks to facilitate reduction of the flexion-extension displacement between the condyles (Figs. 17-12 and 17-13).

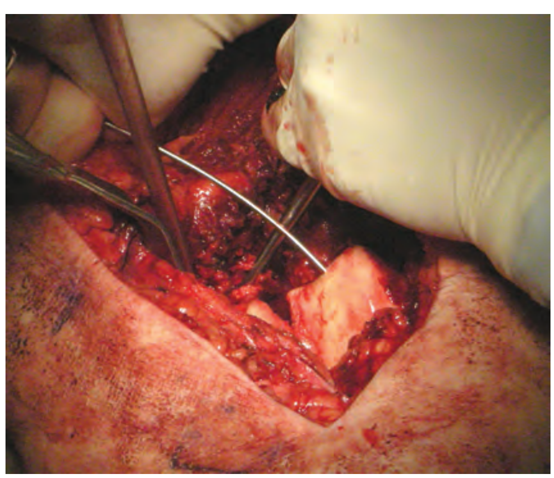


Figure 17-12. The lateral femoral condyle may be angulated/translated/rotated in multiple planes using a K-wire joystick.

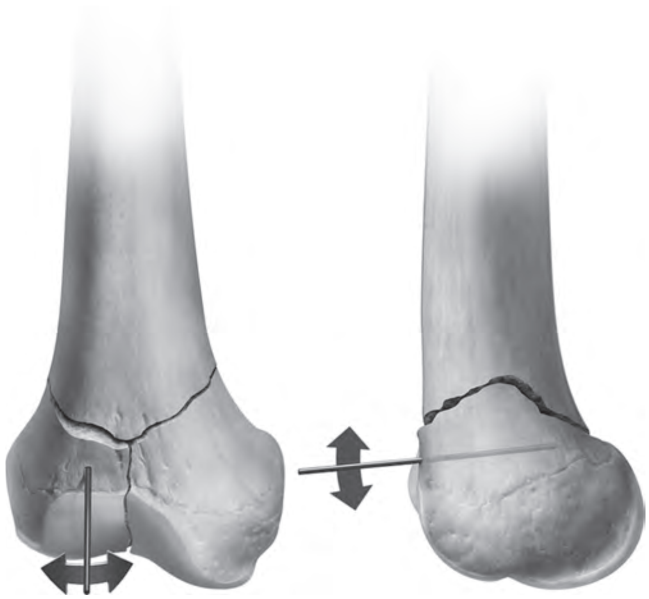


Figure 17-13. Small Steinmann pins can be inserted anteriorly into the fractured condyle just proximal to the articular surface. These can be particularly effective for internal/external rotation and flexion/extension reduction maneuvers.

- Multiple K-wires are placed across the fracture as provisional reduction stabilization.
  - Wires should be kept peripherally, just outside the border of the articular cartilage and the epicondyle (vermillion border) to avoid obstructing plate placement (Fig. 17-14).

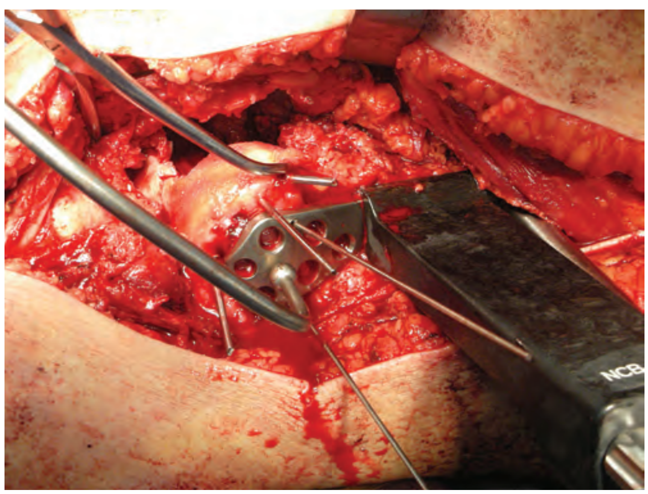


Figure 17-14. K-wires placed from lateral to medial across the condyles must be kept just below the vermillion border of the distal femur to avoid interference with the plate.

  - Wires can also be placed from lateral to medial and then advanced through the medial aspect of the distal femur, out through the medial skin if they may interfere with ideal plate placement, and are critical to fracture reduction.
    - The wires can then be "withdrawn" from the medial side until their blunt ends are flush with the lateral femoral cortex.
    - This removes any K-wire obstruction of the lateral epicondyle for plate application.
  - Alternatively, wires can simply be placed percutaneously from medial to lateral to achieve the same effect, but may be a little less accurate than when they are inserted from the lateral side.

- For definitive stabilization, strategically placed screws (usually 3.5 mm) may be placed perpendicular to the fracture anterior or distal to the eventual plate margin. These can be placed so that they are nearly flush with the lateral cortex (Fig. 17-15).

Figure 17-15. Intercondylar lag screws are placed for articular compression, in a position that will not interfere with the lateral plate placement.

- Intercondylar screws should be placed with the anatomy of the trochlea in mind.
  - Screws placed anteriorly should be placed with a slight (~10 degrees) declination.
  - Additionally, due to the trapezoidal profile of the femoral condyles, bicortical intercondylar screws should not protrude beyond the medial cortex on the "AP" view tangential to the slope of the medial epicondyle.
  - Screw protrusion risks the development of localized synovitis and/or knee pain.
  - To adequately assess the screw tips relative to the medial cortex, internally rotate the femur (or externally rotate the C-arm) 25 degrees (Fig. 17-16).

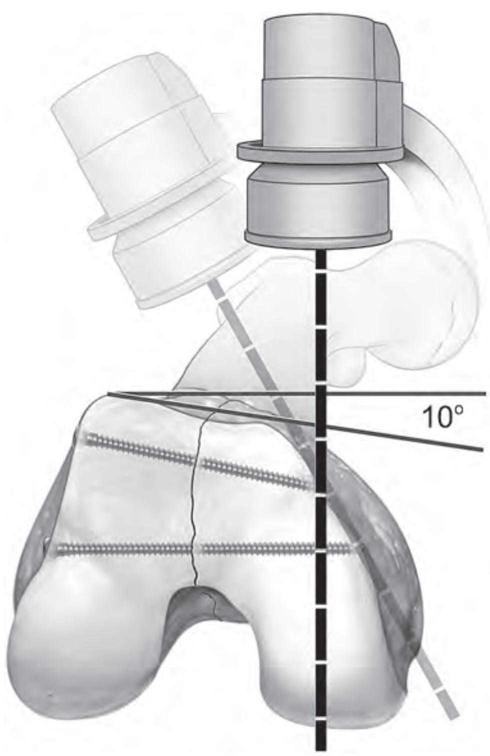


Figure 17-16. Schematic showing appropriate intercondylar screw angles with respect to the condylar anatomy and fracture plane. Additionally, bicortical screws should not appear to cross the medial epicondyle's cortical border on the AP view due to the trapezoidal shape of the medial condyle. A view tangential to the medial epicondyle may be obtained by rotating the femur internally or the C-arm externally (shadowed C-arm). This allows a more accurate determination of the screw length.

- In cases of more articular comminution, smaller screws (2.0 or 2.4 mm) may be used for stabilization of coronal and intercondylar fracture fragments (Fig. 17-17).

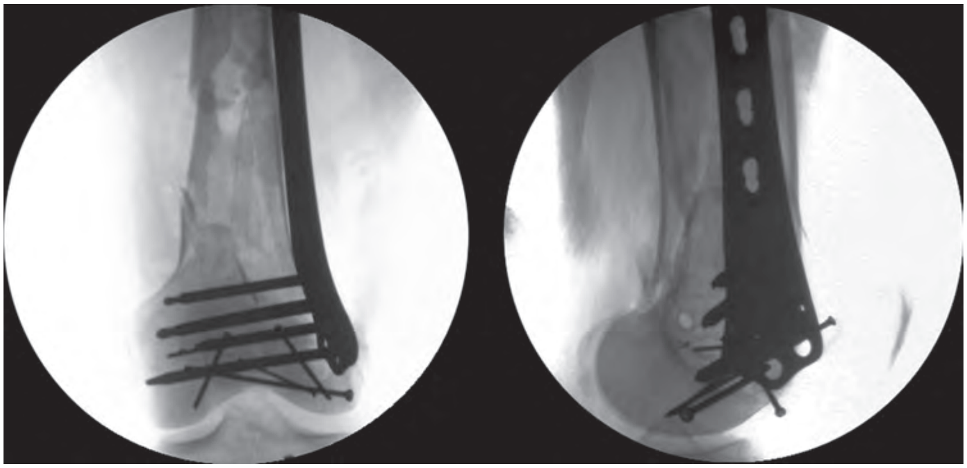


Figure 17-17. In cases of articular comminution, multiple small screws are placed and countersunk for osteochondral fixation.

- Once the articular segment is reduced anatomically and stabilized, limb length and alignment are restored.
  - Occasionally, there is a cortical interdigitation (i.e., a "direct read") in the supracondylar area immediately proximal to the lateral femoral condyle.
    - Take advantage of this opportunity, provided minimal additional soft tissue dissection is required, by elevating the distal muscle fibers of the vastus lateralis.
  - More often, comminution exists in the metaphysis, and indirect reduction maneuvers are preferable.
- The articular segment is frequently in an extended position relative to the diaphysis due to the attachment of the gastrocnemius and the force of the extensor mechanism (Fig. 17-18).

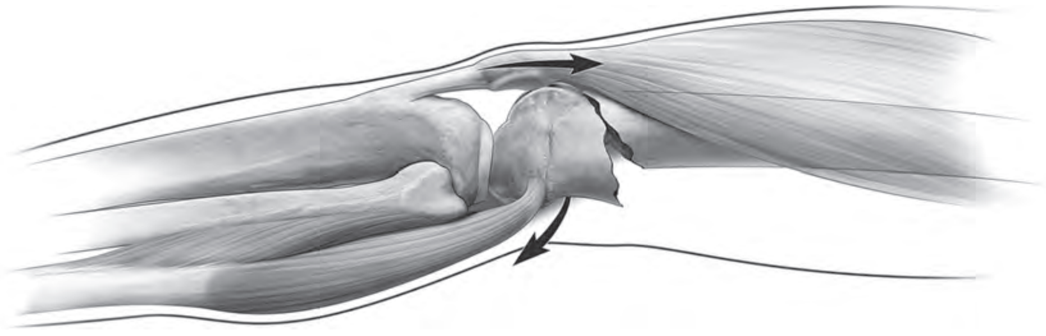


Figure 17-18. Typical deformity of the distal femoral metaphyseal fracture includes shortening and apex posterior. These are due in large part to the pull of the gastrocnemius and the extensor mechanism.

- A femoral distractor can be placed anteriorly to reestablish limb length.
  - Varus and valgus can be manipulated using independent Schanz pins or the plate as a reduction aid (Fig. 17-19).

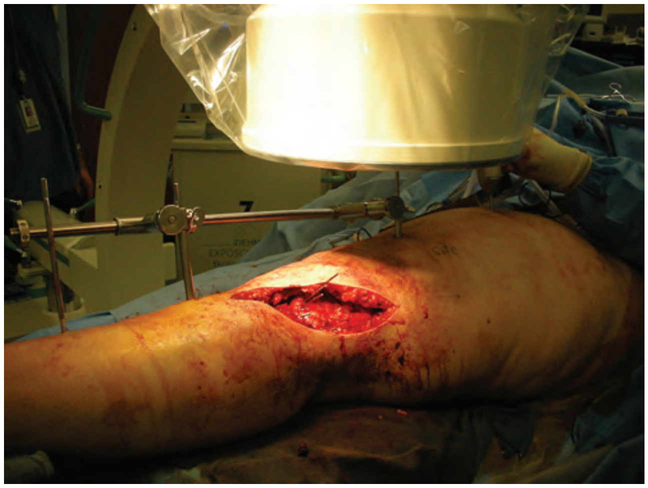


Figure 17-19. An anterior femoral distractor can facilitate an indirect reduction. Take care to accurately assess the sagittal plane deformity, as this can be accentuated with over distraction.

- An external fixator placed anteriorly may also be applied to achieve reduction, similar to a provisional spanning frame.
  - Anterior placement in the sagittal plane facilitates locking plate placement as it does not interfere with a lateral operative exposure or application of the plate.
- An anterior Schanz pin may be placed into the distal metaphyseal-articular segment.
  - The pin may be used to manipulate the flexion and extension of the articular segment directly.
  - This pin may be secured to an external fixator, or the previously reduced distal femoral articular fracture segment may be K-wired provisionally after Schanz pin manipulation (Fig. 17-20).

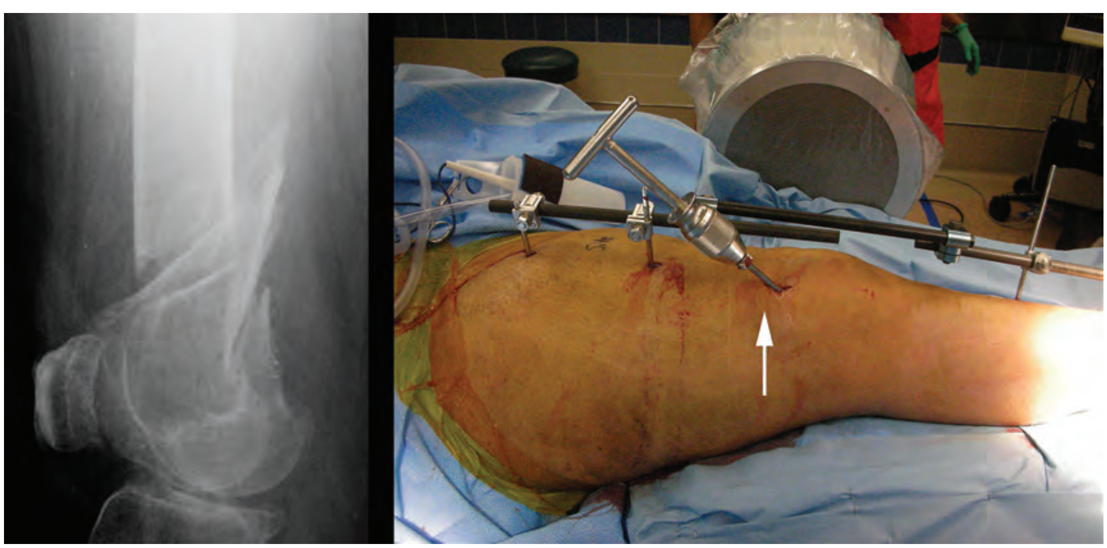


Figure 17-20. An anterior, percutaneously placed Schanz pin (*arrow*) in the femoral condylar fracture segment can be used to correct a flexion, or more commonly, an extension deformity at the fracture site, as in this case.

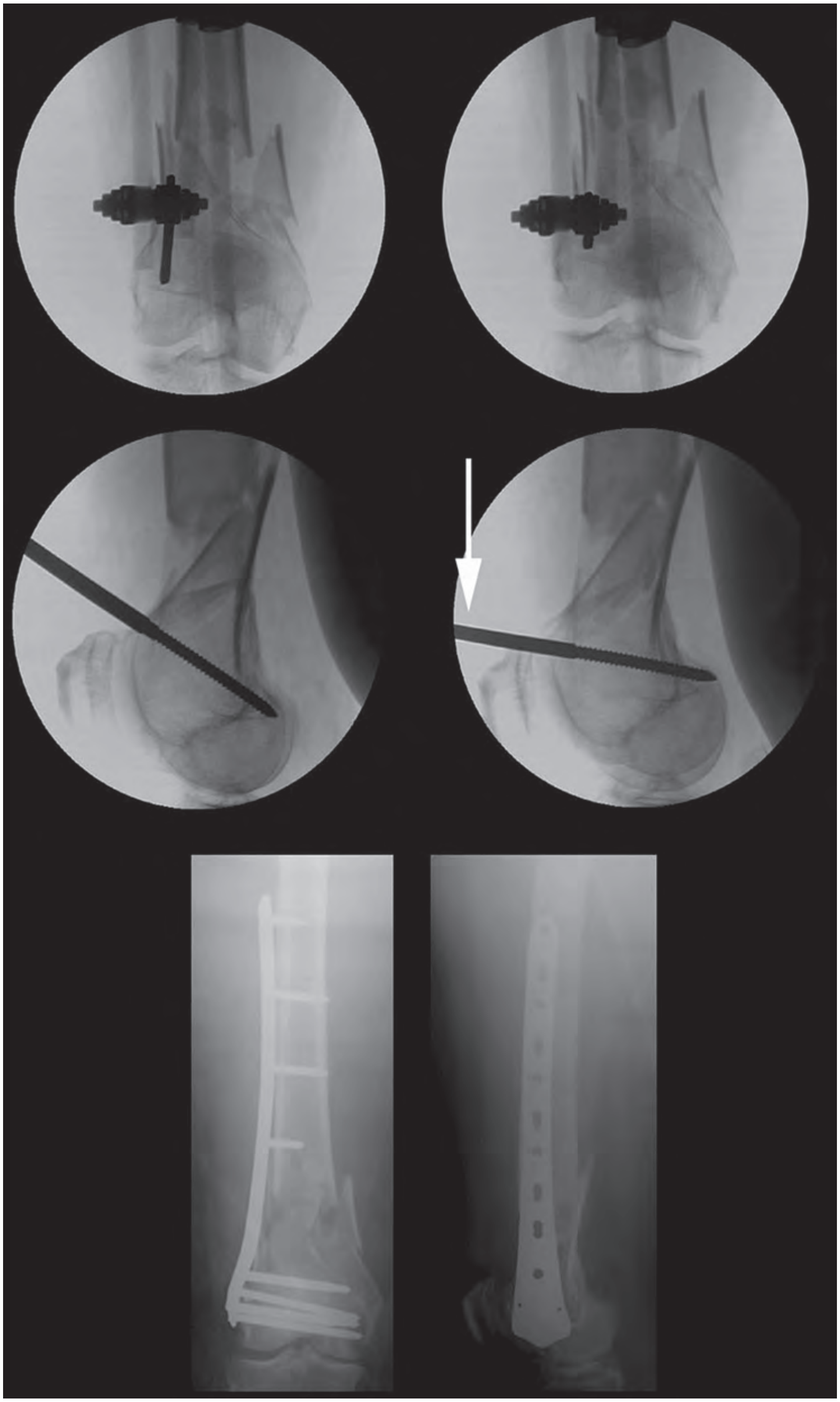


Figure 17-20. continued.

- A bump placed posteriorly, behind the patient's knee, will also aid in reduction of extension deformity at the fracture site (Fig. 17-21).

Figure 17-21. A useful reduction aid is a towel bolster under the apex of the metaphyseal fracture to counteract the forces of the gastrocnemius.

- Some reduction of lateral metaphyseal comminution may be necessary to establish length, alignment, and rotation of the distal articular fracture segment relative to the diaphysis.
  - In cases with significant metaphyseal comminution, alignment should be confirmed with an intraoperative radiograph (long cassette) and/or Bovie cord from the center of the femoral head to the center of the ankle joint.
  - In this case, these small fragments may be secured with 2.0-mm straight plates and 2.4-mm screws.
  - The medial metaphyseal comminution should not be manipulated directly, so as to avoid devascularization or soft tissue stripping.
    - If required to gauge reduction, medial comminution should be approximated by pushing or pulling through the fracture's cancellous surfaces via the lateral incision.
- For reduction of the major supracondylar fracture components, multiple simultaneous reduction maneuvers are often necessary (Fig. 17-22).

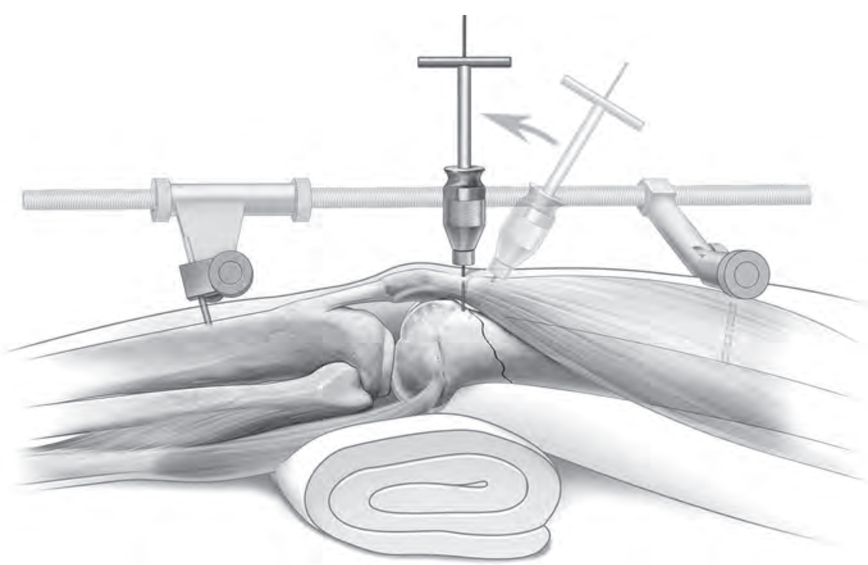


Figure 17-22. Typical reduction maneuvers for metaphyseal reduction include manual limb traction and manipulation, Schanz pin joysticks, a femoral distractor/external fixator, and strategically placed bumps.

- Once the articular fracture segment has been reduced to the diaphysis, a lateral locked implant is usually used for fixation in fractures with metaphyseal comminution.
  - The plate is inserted submuscularly, deep to the vastus lateralis and extraperiosteally along the lateral cortex of the femur.
  - Once positioned correctly, K-wires are inserted at its proximal and distal ends to secure it provisionally.
  - Its position is confirmed again clinically and radiographically.
  - Next screws are used to secure (or lag) the plate provisionally to the distal articular fracture segment and diaphysis.
  - Length, rotation, flexion, extension, and alignment of the entire femur are then confirmed using intraoperative planar radiographs.
  - Definitive fixation is then inserted sequentially (Fig. 17-23).

Figure 17-23. A laterally based locked plate can be slid submuscularly, with percutaneous diaphyseal screws.

  - All remaining metaphyseal comminution may be displaced into the medial and/or posterior portion of the metaphysis.

- This theoretically provides a scaffold for bony healing medially and leaves an anterior lateral window for delayed bone grafting, if needed (Fig. 17-24).

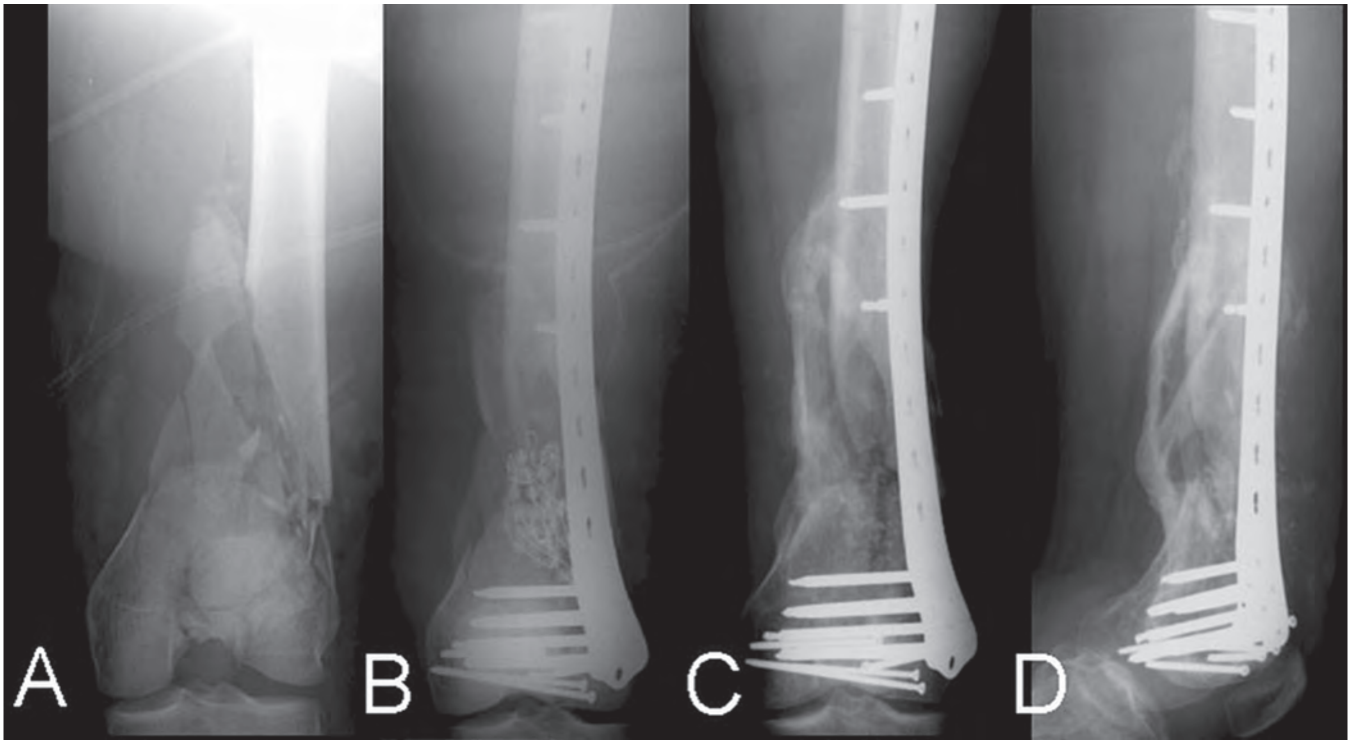


Figure 17-24. An example of a comminuted distal femur fracture **(A)**, with a metaphyseal bone defect remaining after ORIF. The comminution was pushed medially and antibiotic beads were placed empirically **(B)**. This facilitated the planned anterolateral bone grafting procedure. The fracture healed uneventfully with posteromedial bridging bone **(C,D)**.

- For isolated medial or lateral femoral condyle fractures with separate trochlear fracture fragment(s), or complex medial Hoffa fractures, a contoured reconstruction plate is a good option and achieves excellent fixation.
  - Plate contour follows articular condylar margin and is placed "extra-cartilagenously" along the rim of the medial (or lateral) femoral condyle in the anterior portion of the medial "gutter."
  - Allows transverse lag screws through plate, if necessary.

- If proximal extension of a medial plate is necessary, or if this fixation is being used without a lateral plate, it allows anterior-to-posterior plate screws in the shaft to avoid dissection in Hunter's canal and femoral vessel exposure (Figs. 17-25–17-27).

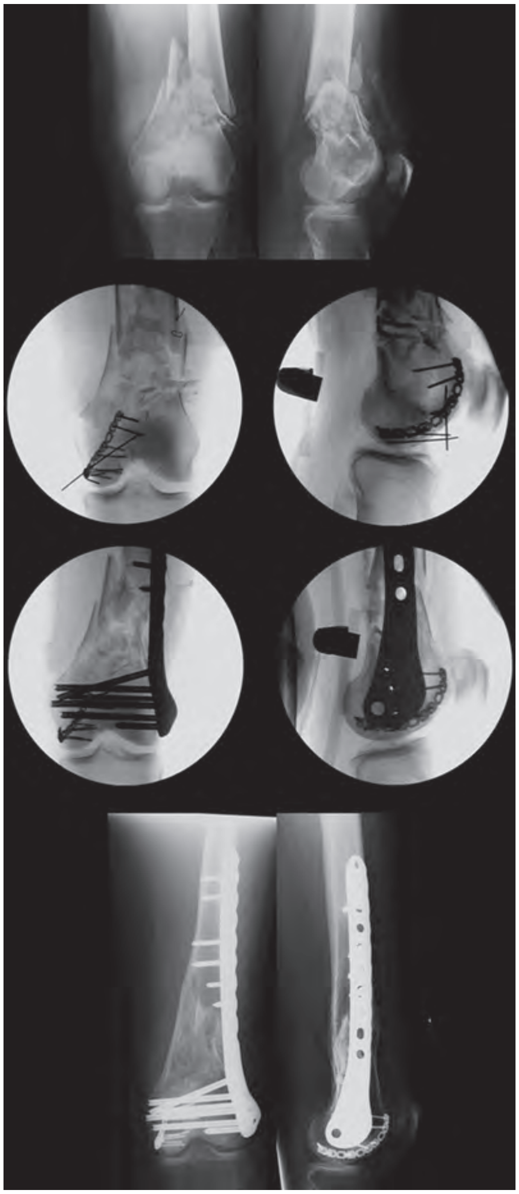


Figure 17-25. Example using a contoured reconstruction plate along the articular margin for fixation of a medial femoral condyle fracture.

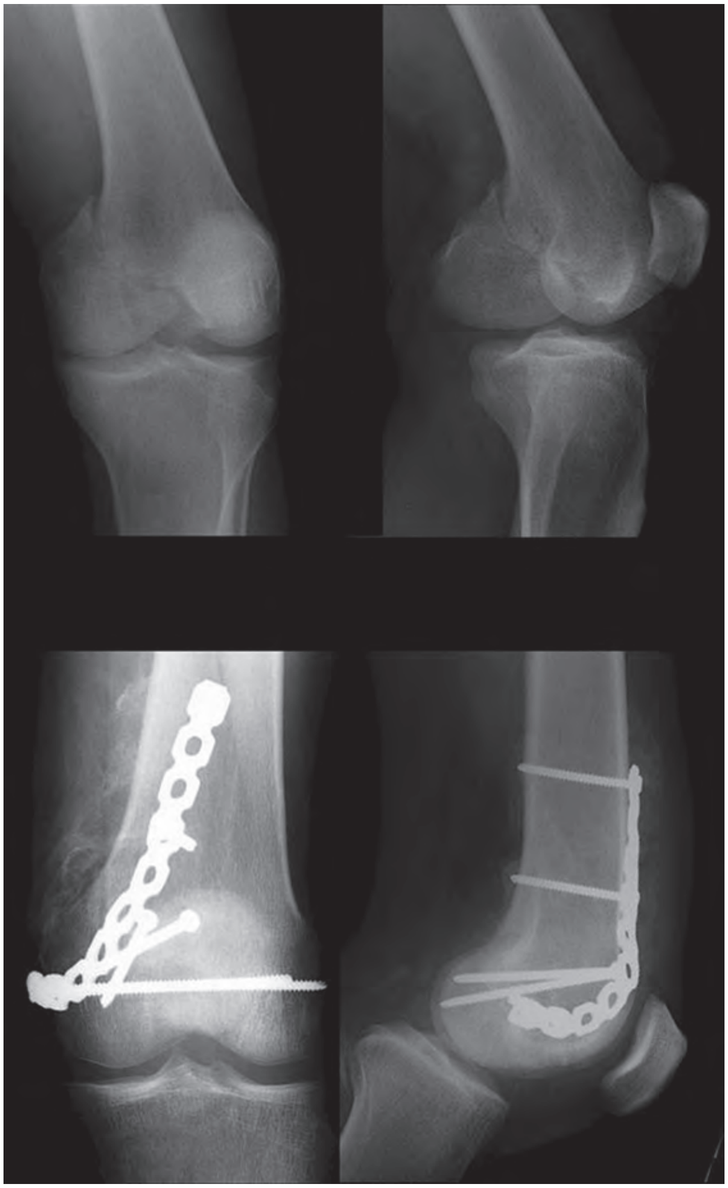


Figure 17-26. Another plate configuration for an isolated medial femoral condyle fracture.

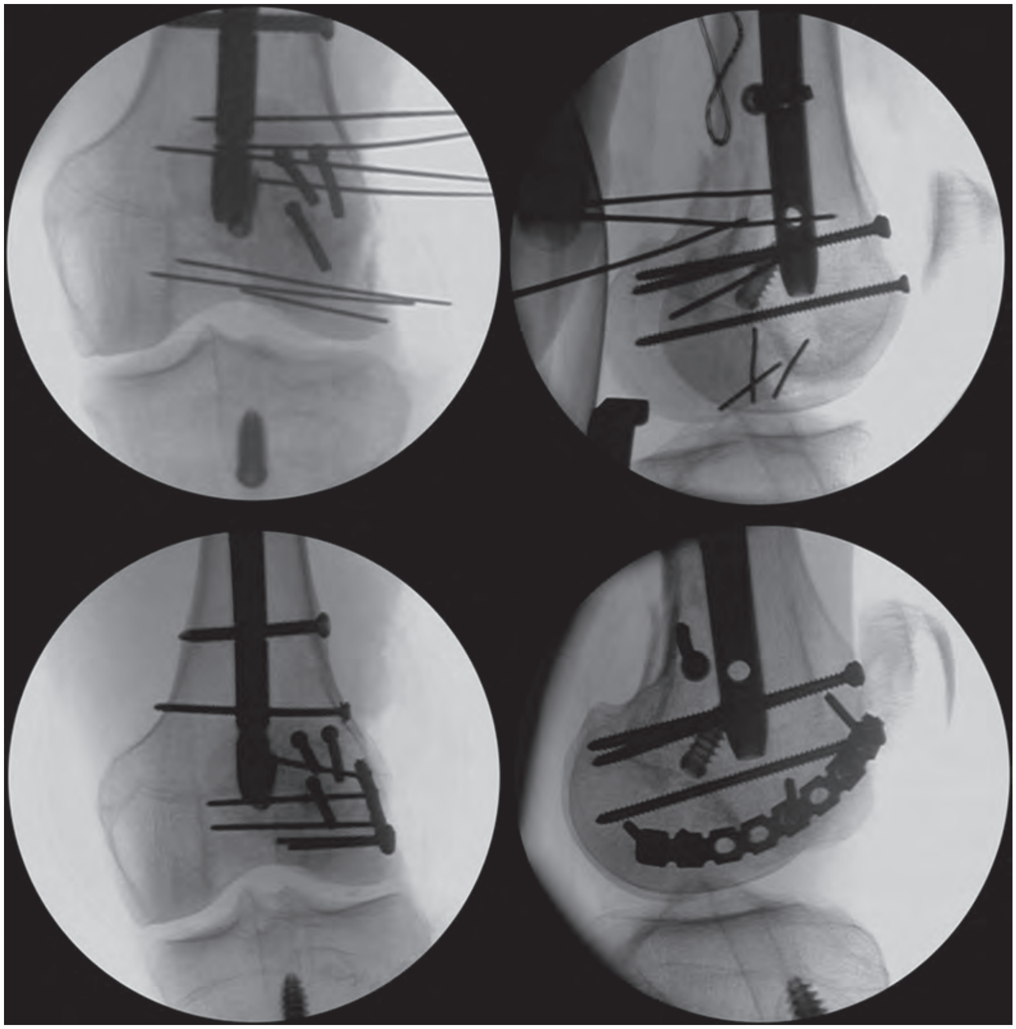


Figure 17-27. A similar periarticular curved reconstruction plate can be used to buttress multifragmentary lateral condylar and/or trochlear fractures.

Patellar Fractures

Chapter 18

Raymond D. Wright
M. Bradford Henley

Sterile Instruments/Equipment

- Large and small pointed bone reduction clamps (Weber clamps)
- Specialized patellar bone clamps
- Implants
  - Cannulated 3.5- or 4.0-mm screws
  - 1.0-mm cable or 18-gauge wire
  - Mini-fragment screws for free fragments
  - Mini-fragment plates (2.0/2.4 mm) for associated coronal plane fracture lines
  - Strong nonabsorbable suture with good handling characteristics, such as no. 2 Fiberwire, Ticron or Tevdek.
- K-wires and wire driver/drill
- Beath pins or Hewson wire passer
- Sterile, removable bump for alternate placement behind knee/heel to obtain knee flexion/full knee extension

Patient Positioning

- Supine on a radiolucent cantilever table.
- Padded ramp under affected extremity to facilitate lateral imaging.
- Bump placed under the ipsilateral hip to limit external rotation of extremity.
- Padded tourniquet placed on the thigh if desired.

Surgical Approach

- Midline longitudinal incision to deep fascia.
  - A horizontal “smile” incision may be used for improved cosmesis in simple fracture patterns.
    - The medial and lateral ends of the transverse incision should be slightly curved proximally.
- Fracture is identified and cleansed of clot and fracture debris.
- Flex the knee over the sterile bump to identify and document associated intra-articular pathology, such as chondral injury to the trochlea or femoral condyle.
- Work through lacerations in medial and lateral retinaculae to view and/or palpate articular reduction.
  - These can be extended, if needed.

Reduction and Implant Techniques

- Modified tension band.
  - Reduction often facilitated with knee in full extension, to relax extensor mechanism especially when there has been retraction of fracture fragments/extensor mechanism.
    - Place a sterile bump behind the heel/distal leg.
  - Grasp major fragments with small pointed reduction forceps for direct manipulation while an assistant clamps major fragments into place with large pointed reduction clamps or a patellar clamp.
    - Specially designed clamps are available with dual prongs on each tine to grasp the bone though quadriceps and patellar tendons (Fig. 18-1).

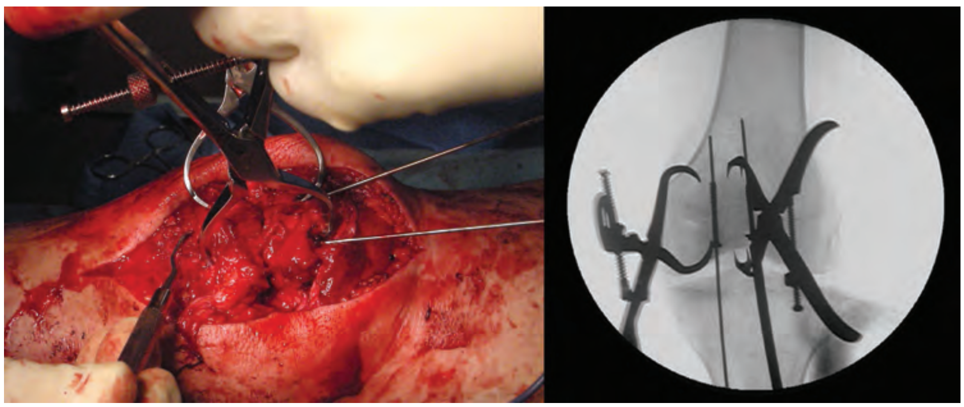


Figure 18-1. Specialized clamps with two prongs on each tine (large Weber clamp is to the left [medial] and patellar clamp is to the right [lateral] on the C-arm view) facilitate grasping the edge of the patella through tendon(s) for manipulation and stabilization.

  - Fine-tune reduction with dental picks.
  - Place multiple K-wires in patella for provisional fixation.
  - Lag screws may be placed through additional fragments to reconstruct the patella so as to convert a multifragmentary fracture into a simpler two part fracture with two remaining large fracture fragments and a transverse or short oblique fracture line (Fig. 18-2).

Figure 18-2. Screws placed perpendicular to the fracture lines of additional fragments should be used to sequentially reconstruct the patella into a main proximal and distal fragment.

- A surgical tactic should account for the location of screws in the patella (e.g., screws placed horizontally are placed more anteriorly while longitudinally oriented fixation will be placed closer to the articular surface).
  - This will avoid the frustration of screw collisions/deflections that compromise fixation and/or quality of reduction.
  - Horizontally placed screws are best placed from lateral to medial as the lateral patellar facet(s) are narrower than the medial facet(s).
- With transverse fracture line reduced and stabilized with clamps and/or additional K-wires, insert smooth guide wires for 3.5- or 4.0-mm cannulated screws from distal (usually the smaller fragment) to proximal (larger fragment), through patella.
  - Insert to the level of the proximal cortex but not protruding through the cortex (best viewed on the AP image), and measure indirectly (Fig. 18-3).

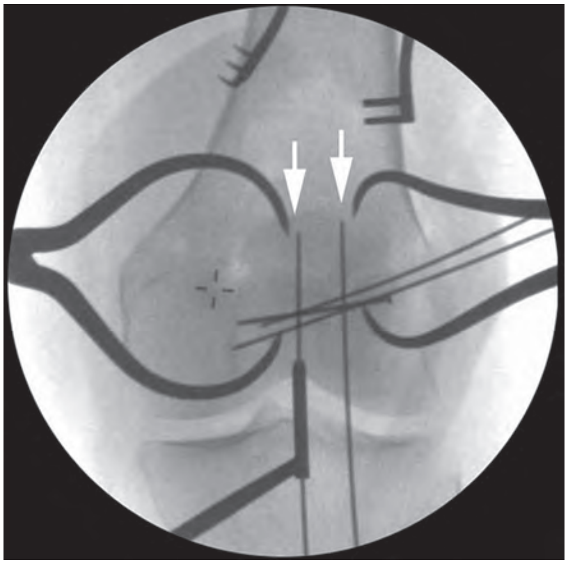


Figure 18-3. The guide wires are inserted to abut the proximal cortex, and indirect measurement is performed.

  - Subtract 2 to 3 mm from measurement, to ensure screw tips do not penetrate proximal cortex when head is flush with near cortex.
  - This ensures that the tension band wire does not develop a stress riser as it is tensioned and bends over the sharp screw edge; additionally, it ensures that the compressive effect of the tensioned wire is transferred to the fracture, rather than to the screw.
- After measurement, advance guide wire through proximal patellar cortex, 1 to 3 cm into quadriceps tendon.
  - Use fluoroscopy or palpation to locate wire.

- Separate the tendon's fibers longitudinally to locate the tip of the wire and clamp with a hemostat or Kocher clamp (Fig. 18-4).

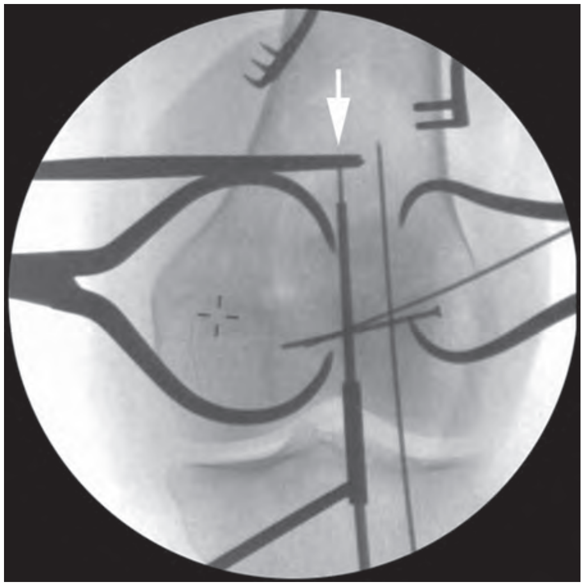


Figure 18-4. After measuring the screw length, the guide wire is inserted through the opposite cortex, and grasped with a clamp through a split in the quadriceps tendon. The wire is then overdrilled while the wire is held with a clamp.

  - Overdrill the wire with cannulated drill while maintaining the grasp on the proximal portion of the wire.
    - This prevents incarceration of the drill on the guide wire and loss of the drill path.
  - Overdrill only one wire at a time and then insert a screw.
    - Overdrilling both wires simultaneously risks loss of fracture reduction, if no other K-wires have been used for provisional fixation.
- Screws should be partially threaded, or drilled as lag screws if using fully threaded screws.
- Insert 18- or 20-gauge wire, or a 1.0-mm cable, through one of the cannulated screws from distal to proximal.
  - Bring wire limb that exits from proximal screw distally and insert from distal to proximal through the other cannulated screw.
  - Bring same limb back across patella to meet the other limb, tension the wire (i.e., compress the fracture) and secure.
- To decrease prepatellar symptoms and prepatellar bursitis, place the wire crimp or knot within the quadriceps tendon. If this is not possible, consider drilling a unicortical 2- to 3-mm hole in the anterior patella in which to bury the wire knot or cable crimp (Fig. 18-5).

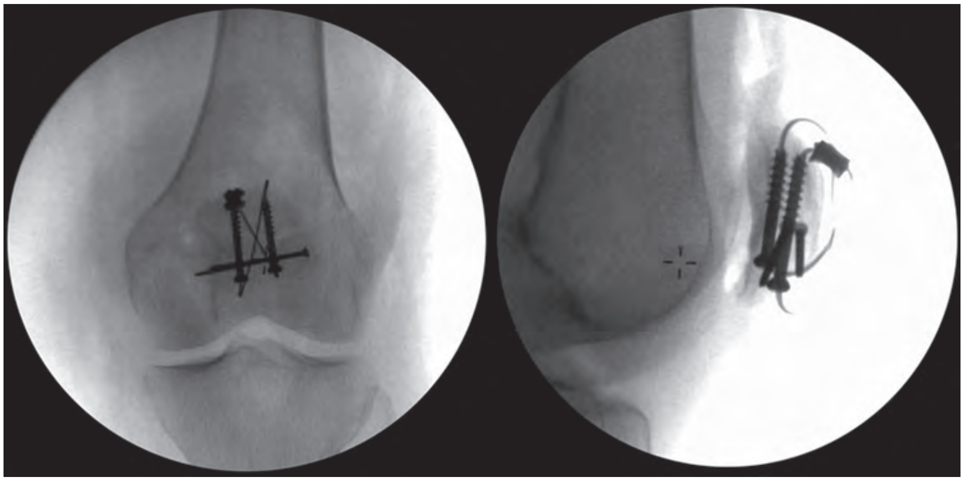


Figure 18-5. Ensuring that the cannulated screw length is short of the proximal cortex prevents crimping the tension band wire at the screw aperture as it exits.

- Dorsal patellar tension plating
  - Clean the fracture, reduce the patella, and stabilize with K-wires.
  - After reduction and provisional fixation, a 2.0-mm straight plate is measured, cut, and contoured to the caudal border of the patella.
  - The distal most hole is then secured to the caudal-anterior patella surface with a 2.4-mm screw.
  - The plate is then gradually contoured and tensioned on the anterior surface of the patella by using strategically placed screws (Figs. 18-6–18-8).

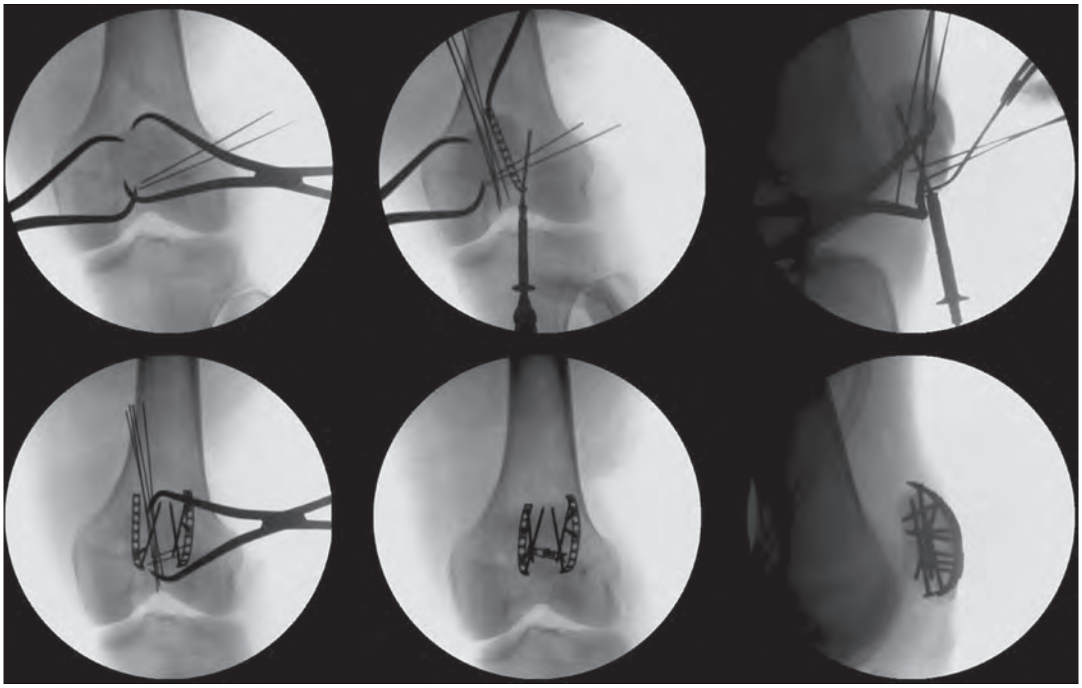


Figure 18-6. Sequence of reduction and fixation for dorsal patellar tension plating.

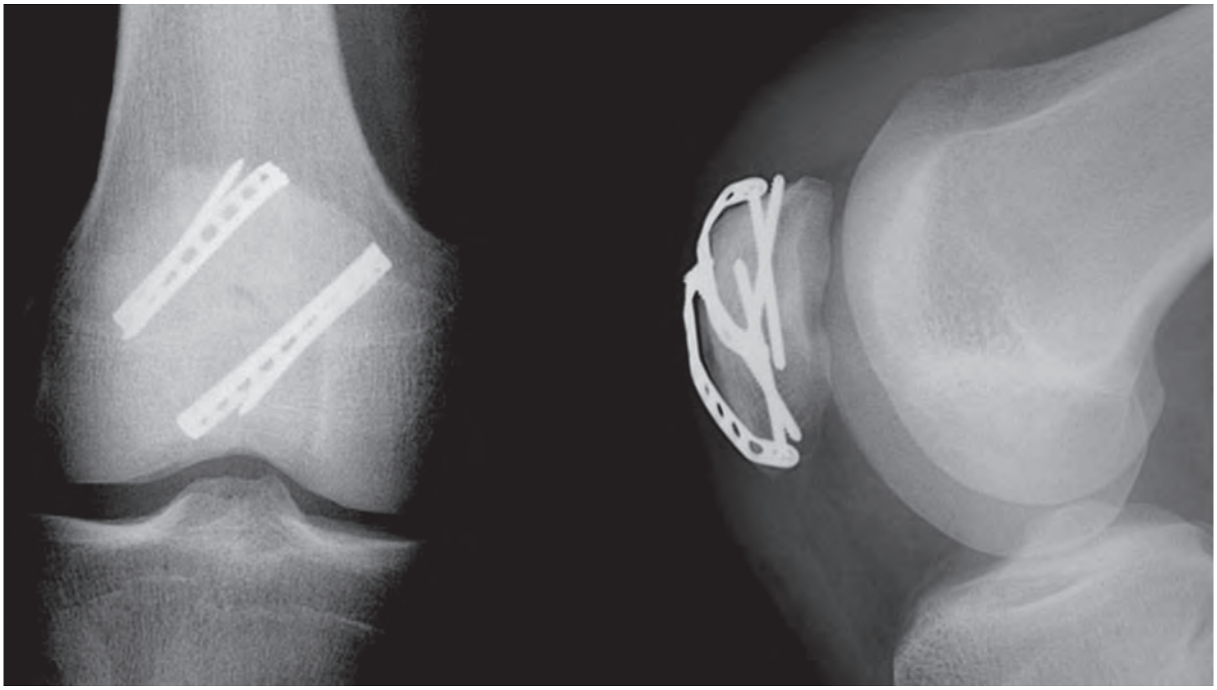


Figure 18-7. Another case example of patellar tension plating.

Figure 18-8. Intraoperative clinical photograph of tension band plates applied to the anterior surface of the patella.

- For complex or revision situations, specialty plates designed for the cuboid and navicular can provide multiple and customizable points of fixation (Fig. 18-9).

Figure 18-9. Small fragment specialty foot plates can be used in complex fractures to obtain multiple points of fixation.

- Partial patellectomy
  - Usually necessary for comminuted fractures involving the patella's inferior pole.
    - Leave some bone fragments attached to the patellar tendon to allow for bone apposition and osseous healing following repair (Fig. 18-10).

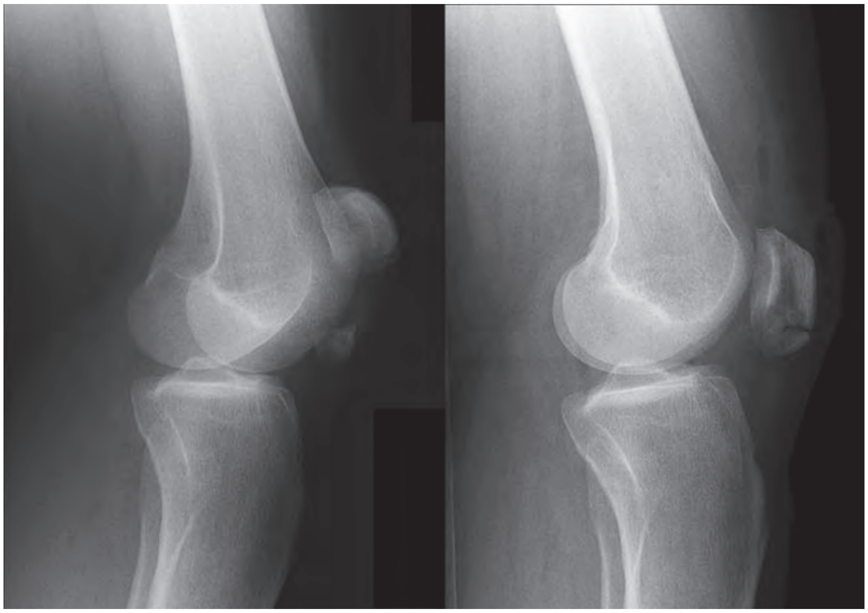


Figure 18-10. Example of a patient with an inferior pole patellar avulsion fracture, treated with patellar tendon repair. Retention of the comminuted inferior pole allows for bony healing.

- Depending on the patient's size, drill approximately four longitudinal parallel holes at the junction of the anterior and middle thirds of the patella to avoid extension deformity of the residual patella.
  - The most medial and lateral holes should be drilled with a 2.0-mm drill to accommodate one suture strand of nonabsorbable suture.
  - The two inner holes should be drilled with a 2.5-mm drill to accommodate two suture strands (if using no. 5 suture).
- Pass three suture strands (no. 2 Fiberwire or no. 5 Ethibond) as locking Krackow stitches in the patellar tendon—medial, central, and lateral.
  - This results in six suture ends at the edge of the patellar tendon.
- Pass the six sutures through the four drill holes from distal to proximal so that the two central holes carry two sutures, and the medial and lateral holes carry only one suture each.
  - Beath pins facilitate suture passage.
    - Oscillate Beath pin partially through the predrilled hole (Fig. 18-11).

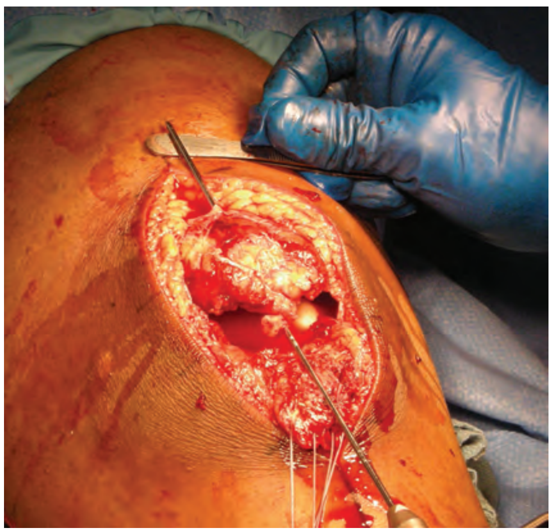


Figure 18-11. A Beath pin is advanced from distal to proximal through a predrilled longitudinal hole in the patella.

- Place suture strand from patellar tendon through the eyelet in the pin (Fig. 18-12).

Figure 18-12. A suture strand from the patellar tendon stitch is placed through the eyelet of the Beath pin (*arrow*).

- The Beath pin is then pulled retrograde from the proximal end, pulling the sutures through (Fig. 18-13).

Figure 18-13. The pin is then pulled retrograde, pulling the suture strand with it through the hole.

- Tie each suture strand to its mate strand over the bone bridge between the longitudinal parallel holes.
- Tie the sutures with the knee in extension to achieve apposition (Fig. 18-14).

Figure 18-14. Each suture is sequentially tied proximally to its mate strand, completing the repair.

- Once repair is complete, the knee is placed through a range of motion to assure fracture stability and to help guide postoperative rehabilitation.
- The medial and lateral retinaculae are closed with robust suture.
- Occasionally, the knots of no. 2 Fiberwire may be prominent.
  - This prominence can be minimized by imbricating local soft tissue (usually fibers of quadriceps tendon) over the Fiberwire knot with an absorbable 2-0 Dexon suture, thereby burying them.

Tibial Plateau Fractures

Chapter 19

Michael J. Gardner
M. Bradford Henley

Sterile Instruments/Equipment

- Headlight.
- Tourniquet if desired.
- Femoral distractor.
- Langenbeck and/or Smilie retractors.
- Large and small pointed bone reduction clamps (Weber clamps).
- Large periarticular quadrangular bone clamps.
- Number 2 Ethibond suture for retraction of meniscus after submeniscal arthrotomy and repair of peripheral meniscal detachment (if required); choose a needle with a short radius of curvature (e.g., a GU needle).
- Dental picks and Freer elevators.
- Bone tamps, curved and straight.
- Lambotte osteotomes for metaphyseal cortical window.
  - Alternatively, 2.5- to 4.5-mm drill bits
- Implants: anatomically contoured lateral proximal tibial periarticular plates, standard buttress plate(s) and/or locking plate(s).
  - Long 3.5-mm cortical screws with 2.7-mm low-profile heads
  - Periarticular plate, one-third tubular, or 3.5-mm compression plate for medial or posteromedial buttress (Schatzker Type IV)
  - Distal radius 3.5-mm T-plate (old style); also useful for posteromedial side
  - Mini-fragment screws and mini-fragment plates (2.0/2.4 mm) depending on fracture comminution and fracture repair requirements
  - Cancellous allograft, osteobiologic bone void filler (e.g., $CaPO_4$), cancellous allograft, or other product for subchondral support
- K-wires and wire driver/drill.

Surgical Approaches

- *Posteromedial approach*
  - Positioning
    - Supine on a radiolucent table.
    - Elevate the extremity on a radiolucent foam ramp.
    - Bump under the contralateral hip, unless sufficient hip external rotation is possible or simultaneous posteromedial and anterolateral approaches are planned.
    - Can place inflatable IV bag bladders under each buttock, which can be inflated and deflated sequentially during the case when switching from one approach to the other.

- Incision is approximately 1 to 2 cm posterior to posteromedial tibial border, but may be more posterior if a posterior plate (rather than posteromedial plate) is needed or more anterior if a medial or anteromedial plate is required (Fig. 19-1).

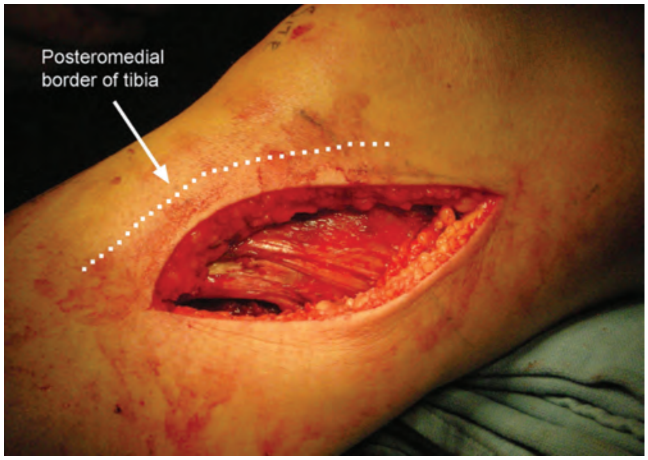


Figure 19-1. The posteromedial incision is made approximately 2 cm posterior to the tibial border, but may be made more anteriorly or posteriorly according to the fracture pattern and anticipated plate placement.

- Find saphenous vein and nerve.
- Palpate pes tendons through fascia.
- Incise fascia over medial gastrocnemius and follow this fascial incision along the posterior aspect of pes anserinus tendons (Fig. 19-2).

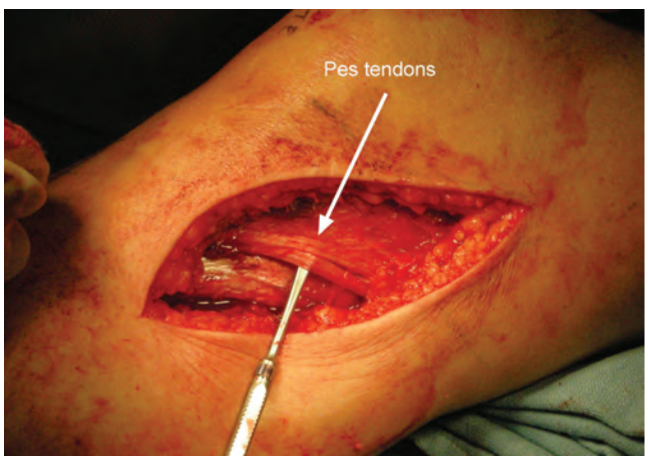


Figure 19-2. After incision of the deep fascia, the pes tendons are identified and protected, and usually retracted anteriorly.

- Work proximal to tendons, if necessary for exposure.
- Elevate the popliteus origin off the posteromedial proximal tibia, distally elevate a portion of the soleus' origin off the posteromedial tibia.
  - Placing towel bolsters under the knee and ankle lets the gastrocnemius-soleus hang freely for better fracture exposure during the posteromedial approach.
  - Increased mobilization of the pes anserinus is obtained by releasing fascial bands that extend from the semitendinosus and the gracilus to the medial head of the gastrocnemius.
  - Anterior retraction of the pes anserinus tendons away from the proximal medial tibia will reveal the broad tibial insertion of the superficial medial collateral ligament.
  - For more anterior exposure, work in "windows" between tendons of pes anserinus.
- The posteromedial plate is positioned ideally deep to the pes tendons and posterior to the posterior border and insertion of the medial collateral ligament (Fig. 19-3).

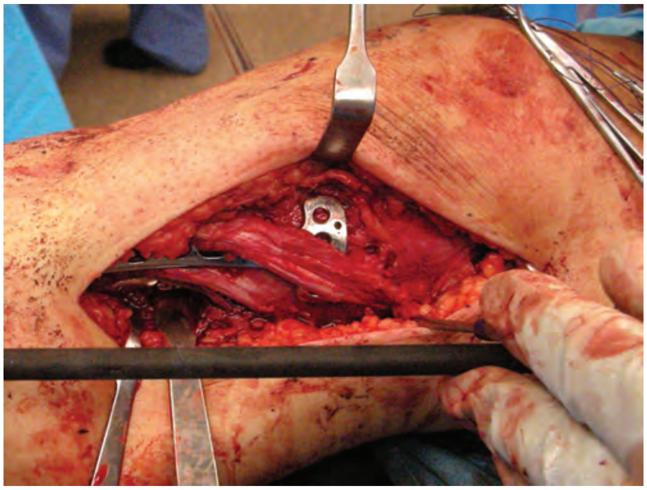


Figure 19-3. This T-plate is positioned on the posteromedial tibial surface, deep to the soleus and the pes tendons, and posterior to the insertion of the medial collateral ligament.

- The interval between the popliteus and the medial head of the gastrocnemius will lead to the popliteal artery.
- Alternatively, a plate can placed more posteriorly, rather than posteromedially, depending on the position of the fracture fragment's apex (Fig. 19-4).

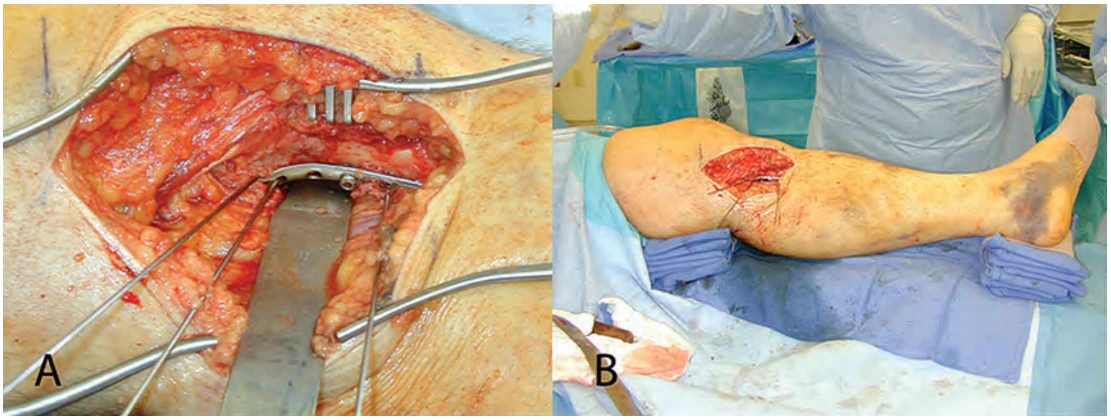


Figure 19-4. In this example, the plate is placed more on the posterior tibial surface, posterior to the hamstring tendons and the medial collateral ligament (**A**). Bumps under the knee and the ankle allow the gastrocsoleus to hang free to improve fracture site access (**B**).

- A medial arthrotomy can be performed if required for articular visualization.
- This is typically performed by following the coronal plane fracture proximally to its entry into the chondral surface of the medial plateau.
- Visualization of the articular surface is not as extensive as it is on the lateral side, as the meniscus and medial collateral ligament impede exposure.

- *Anterolateral approach*
  - Positioning
    - Supine on a radiolucent table, foam ramp under the injured extremity.
    - Bump under the ipsilateral hip to internally rotate limb for true AP image of knee (so patella is pointing anteriorly).
    - Can place inflatable IV bag bladders under each buttock, which can be inflated and deflated sequentially during the case when switching from one approach to the other.

- Distally, skin incision is 1 to 2 cm lateral to the tibial crest, crosses the center of Gerdy's tubercle, and is extended proximally approximately 8 cm proximal to joint line along the midaxial lateral femur at the level of the lateral epicondyle, splitting the IT band in line with its fibers.
- Incise anterior compartment fascia 5 to 10 mm lateral to tibial crest to allow for closure, elevate anterior tibialis muscle off the periosteum of the proximal tibial metaphysis, starting distally and working proximally, exposing the lateral tibial fracture line.
- Elevate the IT band anteriorly and posteriorly from Gerdy's tubercle, working from distally towards the knee joint.
  - Stop approximately 5 to 10 mm below the knee joint so as to avoid an inadvertent arthrotomy with its bulging lipohemarthrosis.
- Split the fibers of the IT band longitudinally (in line with its fibers), starting proximally (approximately at the level of the lateral femoral epicondyle).
  - Working caudally, elevate the IT band off of the knee capsule both anteriorly and posteriorly.
  - A Smilie retractor placed deep to the IT band can be used to pull its fibers away from the knee capsule as it bulges from hemarthrosis to prevent an unnecessary arthrotomy.
- Work distally towards the knee joint continuing to Gerdy's tubercle.
  - Place the Smilie retractor at the level of the knee joint and retract laterally and posteriorly (protecting the LCL) while releasing the posterior attachment of the IT band to Gerdy's tubercle.
- Continue a posterior release on the proximal tibia, working posterior to the LCL (medial to the LCL and lateral to the tibial plateau and joint capsule), until the anterior capsule of the proximal tibia-fibular joint is encountered.
  - The LCL is easily identified if it is placed under tension with a femoral distractor (see below).
- Next elevate the anterior IT band, again from proximal to distal, off the knee capsule and anterior tibia, continuing towards Gerdy's tubercle.
- Below Gerdy's tubercle, elevate the IT band and anterior compartment fascia towards the lateral border of the patellar tendon until the retropatellar fat pad is accessible.
- Lighten up on knife just proximal to Gerdy's to avoid entering joint capsule.
- Placing a femoral distractor at this point facilitates distraction of the knee joint and permits palpation of the lateral collateral ligament, lateral joint space, tibial plateau, and meniscal rim (if present) to allow for an accurate submeniscal arthrotomy incision.
  - Distraction places the knee capsule tension.
  - Additionally, the LCL is placed on tension, clarifying the posterior limit of the submeniscal arthrotomy.
- Submeniscal arthrotomy, multiple sutures for retraction (Fig. 19-5).

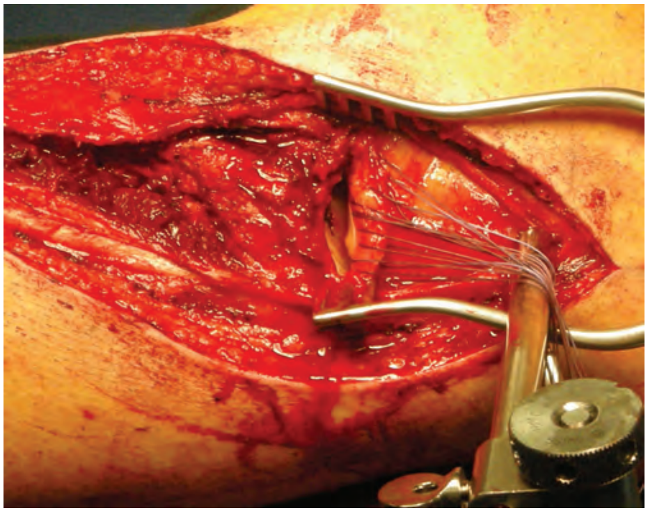


Figure 19-5. A submeniscal arthrotomy with retraction sutures in peripheral lateral meniscus and a femoral distractor (proximal pin in lateral femoral epicondyle) provide excellent visualization of the lateral tibial plateau.

- Arthrotomy should leave sufficient inferior capsule (tibial coronary ligament) attached to tibia to allow capsular repair.
- Passing capsular and meniscal sutures through plate has the disadvantage of pulling the meniscus inferiorly and away from it anatomic origin.
  - Additionally, capsular disruption and meniscal injury may occur if subsequent hardware removal is necessary.
- Arthrotomy can extend anterior/medial as far as infrapatellar fat pad and patellar tendon.
- Arthrotomy can extend posterior/lateral until LCL and proximal tibiofibular joint are palpable or visible.
  - Typically, the capsulotomy limit is 5 to 10 mm anterior to the popliteal hiatus.
- Occasionally, the joint will be entered and the lateral meniscus cannot be identified.
  - Invariably, this is due to meniscal detachment from the lateral capsule at the meniscal "red zone."
  - The meniscus may be displaced medial to the split in the lateral tibial fracture and usually rests on the cartilage of the depressed articular segment.
  - Often the meniscus is not so much displaced medially; rather the lateral split fracture component has been displaced laterally.
  - Accurately narrowing the width of the tibial plateau is critical to restoring the lateral meniscal-plateau-femoral condyle relationships.
- A displaced meniscus can often be retrieved with a nerve hook or other curved instrument.
  - A suture is placed into the peripheral margin of the meniscus and is used to continue "delivering" the meniscus laterally to accept additional peripherally placed sutures for repair to its capsular origin.

Reduction and Implant Techniques

- If a knee spanning external fixator was placed previously, prep the spanning external fixator into the surgical field to facilitate the sterile limb preparation and draping, and to minimize the risk of iatrogenic neurovascular injury.
  - The pin-bar clamps can be removed from the pins and replaced with a femoral distractor if necessary, but the pins should be cleansed with tincture of iodine or similar antiseptic following clamp removal.
  - Ideally, the pins should be left in situ, until the wound is closed and dressed at the end of the case to minimize egress of contaminated fluid and debris on to the surgical field from the pin tracts.
  - After definitive fracture stabilization, it is important to take the knee through a range of motions, but only after the pins are removed, to free any quadriceps adhesions and confirm final ROM and knee joint stability.
    - This is especially important if several weeks have elapsed between injury/fixator application and ORIF.

Use of Femoral Distractor

- Place the proximal distractor pin at the shoulder of the lateral femoral epicondyle.
  - This can be done either percutaneously or at the proximal extent of lateral incision, through the split fibers of the IT band.

- Distal pin should be placed percutaneously, a bit beyond the anticipated distal end of the plate (Fig. 19-6).

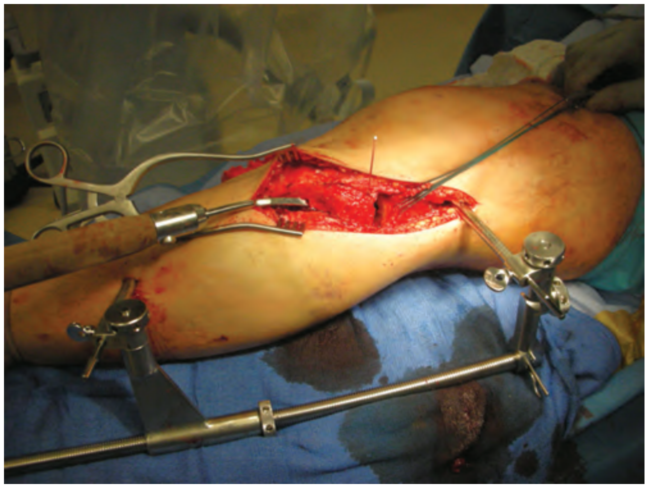


Figure 19-6. The femoral distractor placed laterally within the lateral incision proximally.

- With a lateral distractor, the limb should be placed initially in relative valgus, as distraction creates a varus bending moment when applied.
- A distractor placed anteriorly can be used to adjust rotation and sagittal plane alignment.
  - With an anteriorly placed distractor, position the limb in extension initially, because the distraction force tends to flex the fracture site.
- A second distractor can also be placed medially to restore the medial column length if a preoperative varus deformity exists (Fig. 19-7).

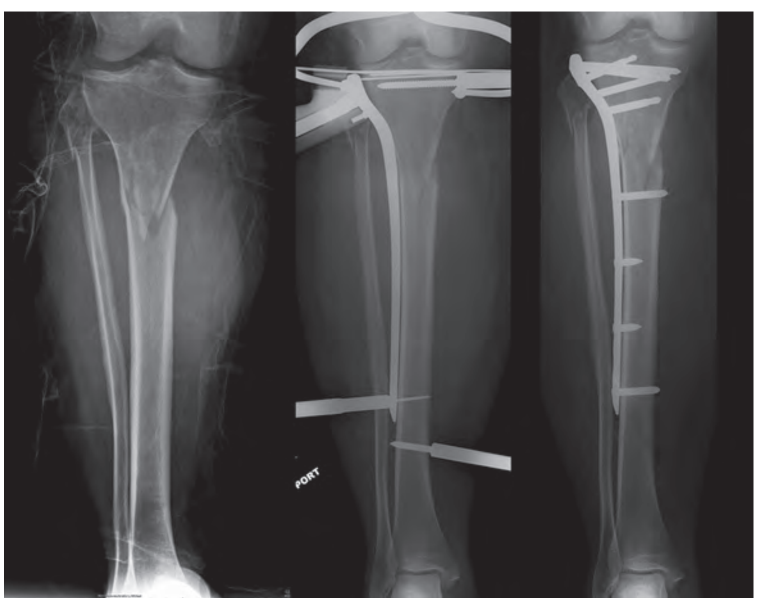


Figure 19-7. The femoral distractor can be placed medially if a varus deformity exists preoperatively.

- This may be placed in conjunction with a clamp and K-wires for articular surface reduction.
- After provisional reduction and fixation of the medial plateau, a medial femoral distractor can be left in place to “protect” the medial reduction/fixation from inadvertent or purposeful varus forces applied to the lateral plateau and metaphysis during reduction.

  - In a metaphyseal fracture, the distractor can be used to manipulate the proximal segment to achieve anatomic alignment and coronal plane rotation.
  - Intraoperative planar radiographs after provisional fixation are crucial to determine accurate limb alignment before finalizing fixation (Fig. 19-8).

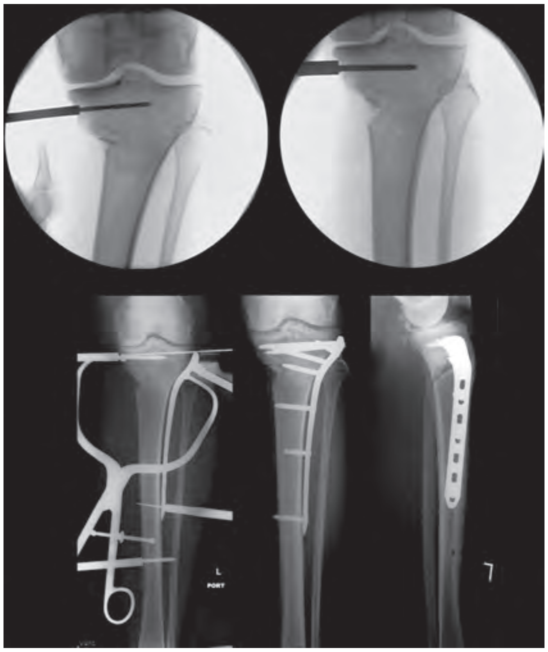


Figure 19-8. A metaphyseal fracture in varus was reduced indirectly with a medial femoral distractor.

- If femoral distractor sleeves are positioned so that they interfere with visualization of the joint surface or another fracture line on fluoroscopy, changing to the other set of sleeves (e.g., longer to shorter, or vice versa) flips the elbow of the sleeve in the opposite direction to avoid radiographic obstruction.
  - Alternatively, an external fixator may be constructed to be unobtrusive to C-arm visualization and implant placement.

Specific Fracture Patterns

- For lateral split-depression patterns, the cortical displacement of the split fragment with an intact rim may be reduced first and provisionally stabilized with clamps and K-wires placed peripherally.
  - If this is chosen, ensure that laterally based K-wires are placed anterior and/or posterior to the articular depression to avoid blocking its subsequent elevation.
- A metaphyseal corticotomy may be created with a large drill bit.
  - Alternatively, 4-mm or more small 2.5-mm drill holes can be created to perforate the metaphyseal cortex in a square of rectangular shape (1 cm × 1.5 cm).
    - These are connected with an osteotome and the cortical “window” is removed (and saved) for introduction of bone tamps or elevators.
  - Bone tamps are used to elevate the articular surface with the underlying subchondral bone.
  - As it is elevated, the level of the depressed segment is monitored by direct vision through the submeniscal arthrotomy and after reduction its relationship to the surrounding articular surface is palpated with a Freer elevator to assess congruity.

- Avoiding "opening the book" to diminish fragment devitalization, allow the fragments to remain in the correct orientation near their native position(s) and avoid reconstructing free osteochondral fragments outside of the metaphysis (Fig. 19-9).

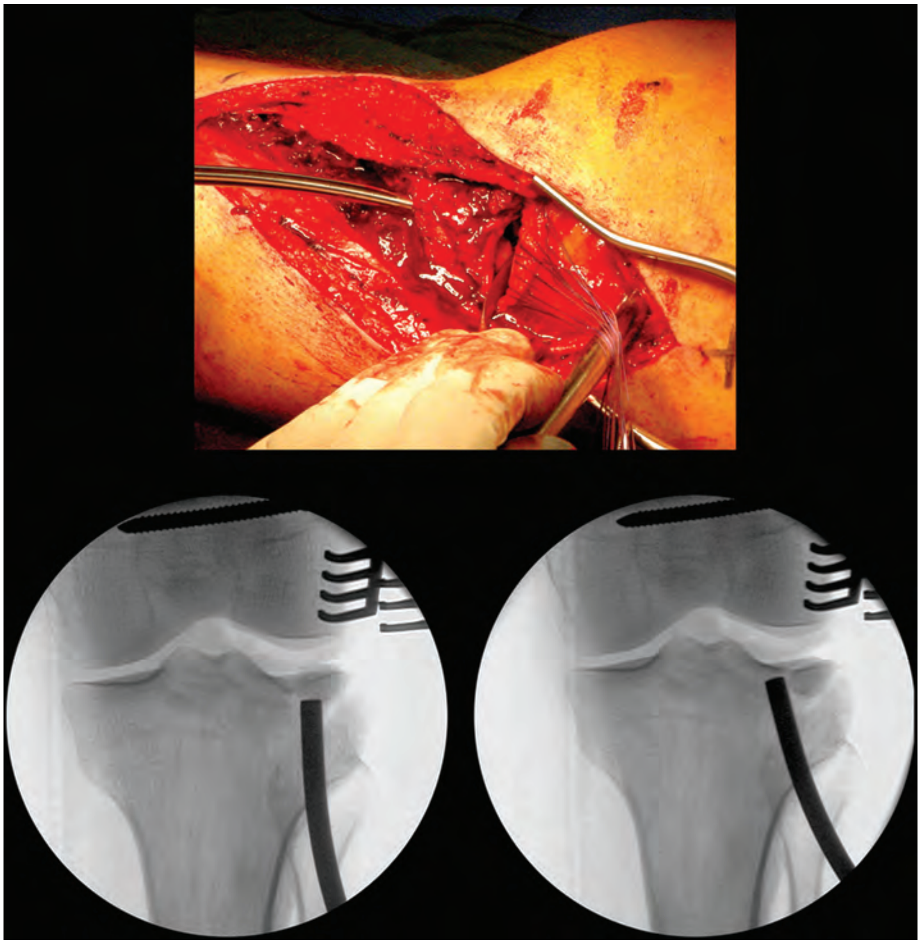


Figure 19-9. A drill hole or small cortical window, made at the osseous reflection of the lateral plateau, allows access for a bone tamp. Direct articular visualization and palpation with a Freer are used to guide the reduction.

- Multiple areas of articular depression can be elevated en masse with multiple taps of the tamp along multiple points below the depressed fragment(s).
- If the articular fragment to be elevated is not readily accessible due to the location of the corticotomy and the tamp shape, a Steinmann pin can be bent to achieve the desired vector for fragment elevation.
- A K-wire may also be used to drill just below the depressed osteoarticular fragment, its location confirmed with C-arm in orthogonal planes, and subsequently overdrilled with a cannulated drill to create a direct path for an instrument to access the fragment.
- Occasionally, a medial corticotomy allows the best tamp vector for elevation of lateral plateau depressed articular fragments.

- Following elevation, a large quadrangular clamp (e.g., with ball spikes) can be used to reduce residual lateral condylar displacement (joint widening) and to compress the articular surface transversely (Fig. 19-10).

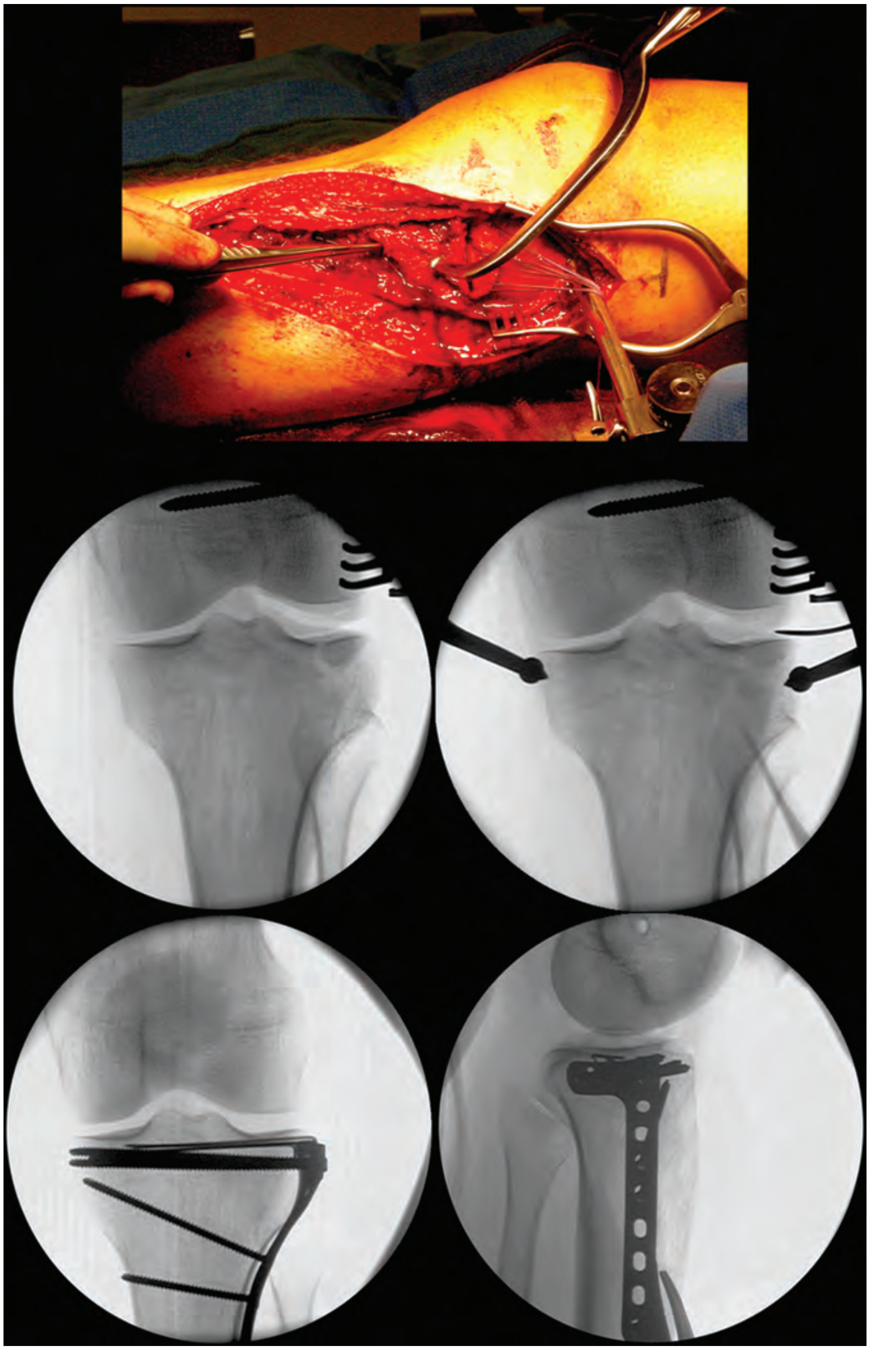


Figure 19-10. After elevation of the articular surface, the lateral wall can be clamped with the tines placed anterolaterally and posteromedially to compress the articular surface and restore the condylar width.

- When one or both metaphyseal cortices are comminuted or osteoporotic, use a ball spike clamp over a small plate (e.g., one-fourth tubular plate) or in a hole of the lateral buttress plate.

- This will distribute the compression forces over a larger surface area and apply more uniform compression of the condyles so as not to penetrate the metaphysis (Figs. 19-11 and 19-12).

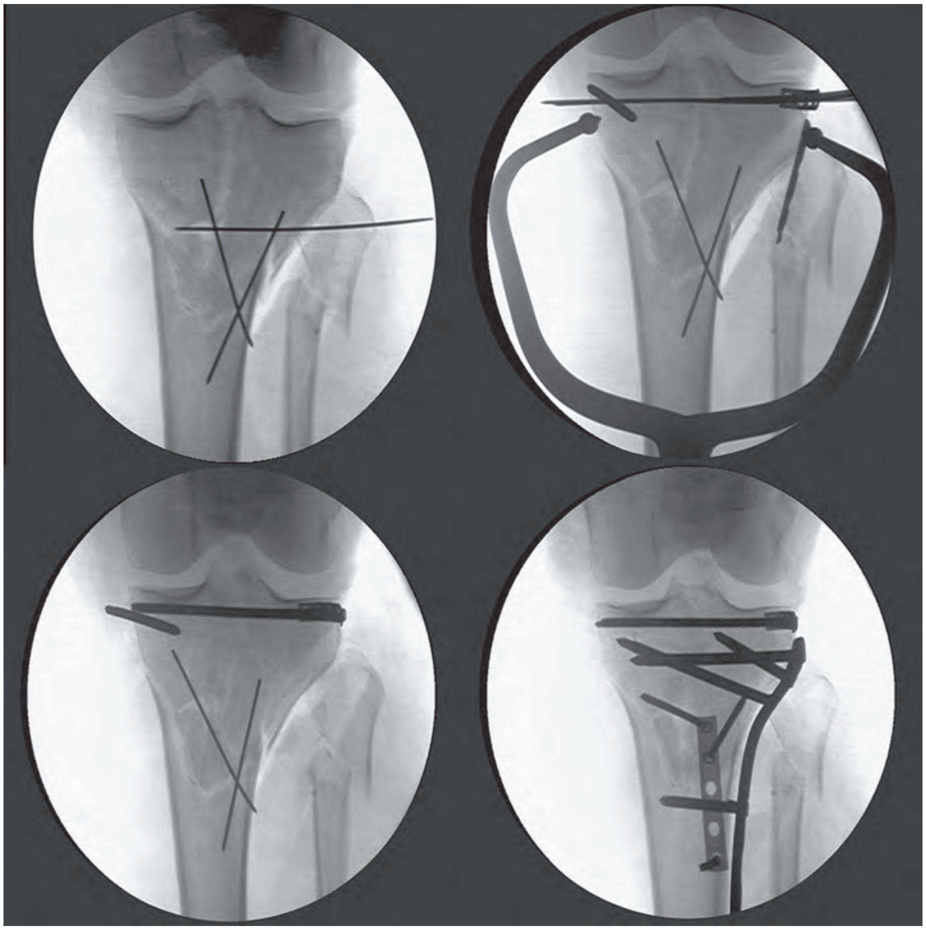


Figure 19-11. A small malleable plate may be used under the spike of a clamp to distribute the forces in areas of comminution. Note the sagittally placed Schanz pin in the medial tibial condyle, permitting rotational control of this fracture fragment.

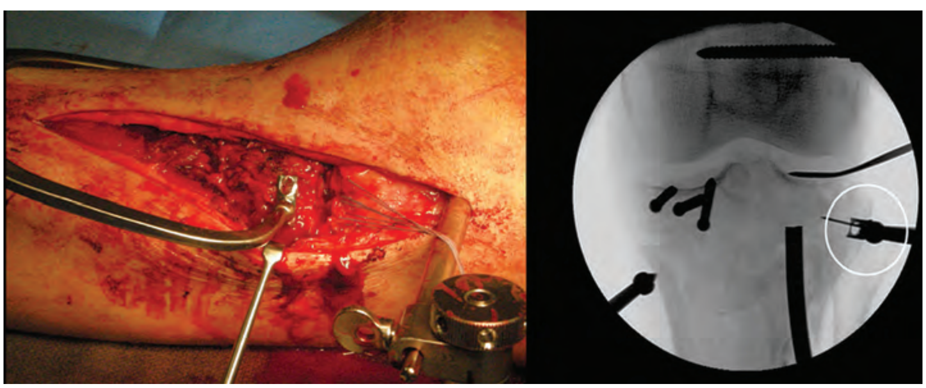


Figure 19-12. Another example of a quarter tubular plate used as a washer to clamp the lateral plateau to reduce the condylar width in this patient with osteoporosis.

- Intraoperatively, assess the congruity of the radiographic subchondral reduction (line[s]) of both the medial and lateral plateaus with an appropriate C-arm plateau tilt.
  - If one line is clear while on the same image, the other is not, there is likely a sagittal plane malrotation of one of the tibial plateaus.
  - Sagittal plane malrotations may be corrected with bone clamps and Schanz pin(s) placed anteriorly for fracture segment control prior to compression of the articular surface (Fig. 19-13).

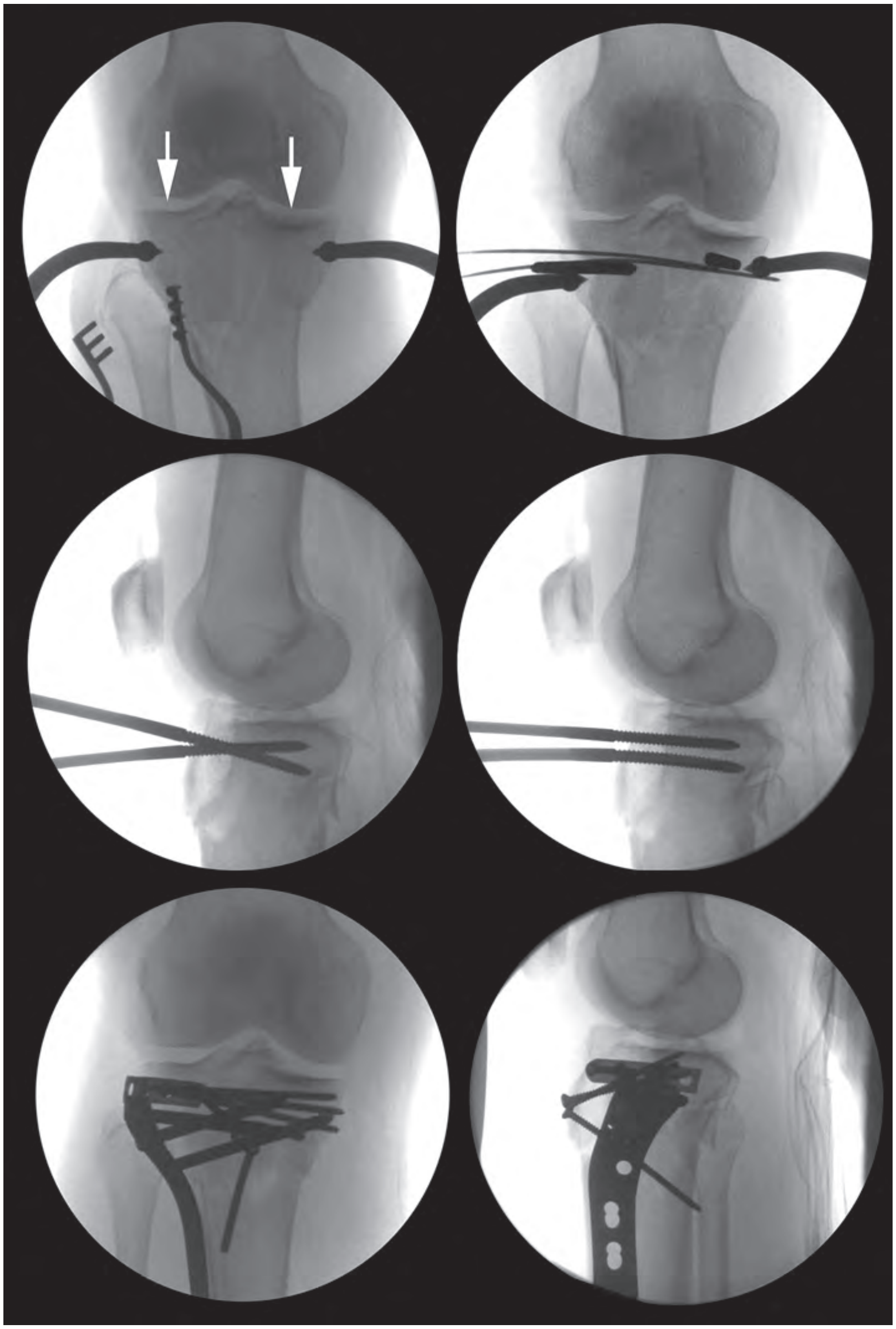


Figure 19-13. In this case, sagittal plane malalignment (in addition to varus and relative subsidence of the medial plateau) was noted on the AP (**upper left**) and lateral views (**middle left**). Schanz pins were inserted to derotate both plateaus (**upper right and middle right**). This restored the posterior tibial inclination in both plateaus (**middle and lower row**).

- Reduction and fixation of the posteromedial fragment
  - Large pointed reduction clamps from anterior to posterior; an old-style pelvic clamp or new-style "goose" neck pelvic clamp helps to avoid excessive pressure on the anteromedial soft tissue.
  - 2.5-mm Schanz pin to joystick.
  - 3.5-mm LC-DCP contoured with plate bending press
    - Stouter plate may be preferable if fracture involves the shaft or is unstable.
    - If an antiglide function is needed, a one-third tubular plate; 2.7 LC-DC plate; or 3.5-mm distal radius T-plate is sufficient.

- Femoral distractor or external fixator.
- Proximal screw to lateral fragment, after reduction of lateral plateau.
  - Assistant holds leg up from the lateral side, palpate elbow of lateral plate and triangulate drill bit (Fig. 19-14).

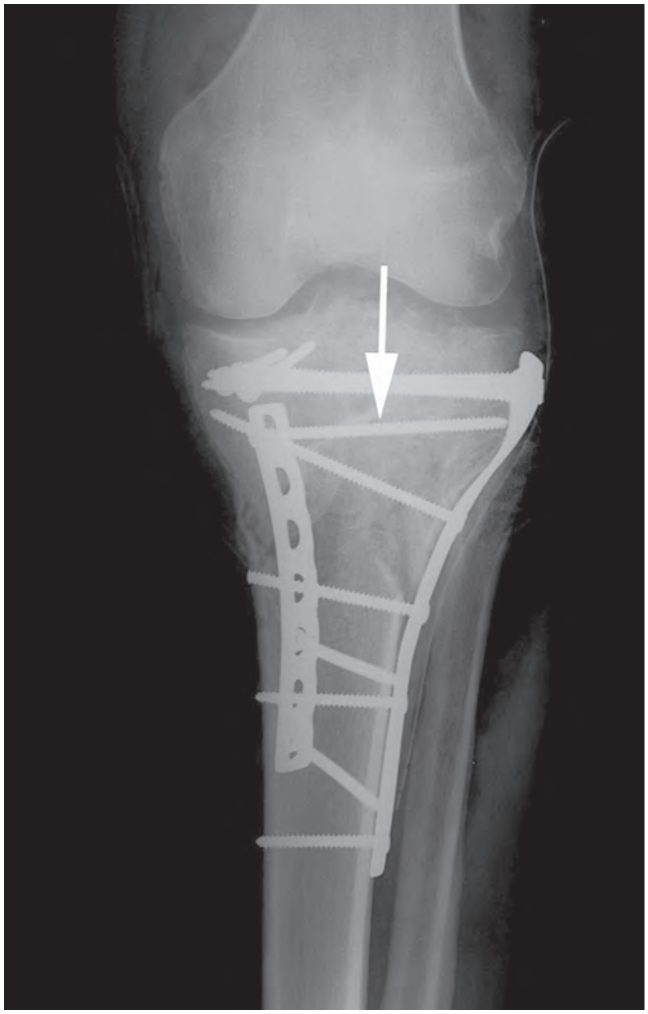


Figure 19-14. The most proximal of the medial to lateral screws (*arrow*) can be placed bicortically by palpating the anterolateral tibial cortex at the elbow of the plate and triangulating to avoid plate contact.

- In Schatzker Type IV and VI patterns, the unstable segment is most frequently the distal segment (i.e., the tibial [meta-]diaphysis), and the posteromedial fragment is the stable segment.
  - Thus, to reduce the shaft and leg to the intact medial plateau, typically axial traction, with valgus, extension, and internal rotation forces on the leg are necessary.
  - Note that this maneuver will tend to place the obstructing structures, such as the gastrocnemius-soleus and hamstrings, under tension.

- If the tibial tubercle is involved as a separate fragment, it should be reduced and stabilized separately.
  - This can be done as the first step if desired, and can be accessed through the lateral approach by mobilizing the tissues medial to the incision with or without a distal extension of the incision (Fig. 19-15).

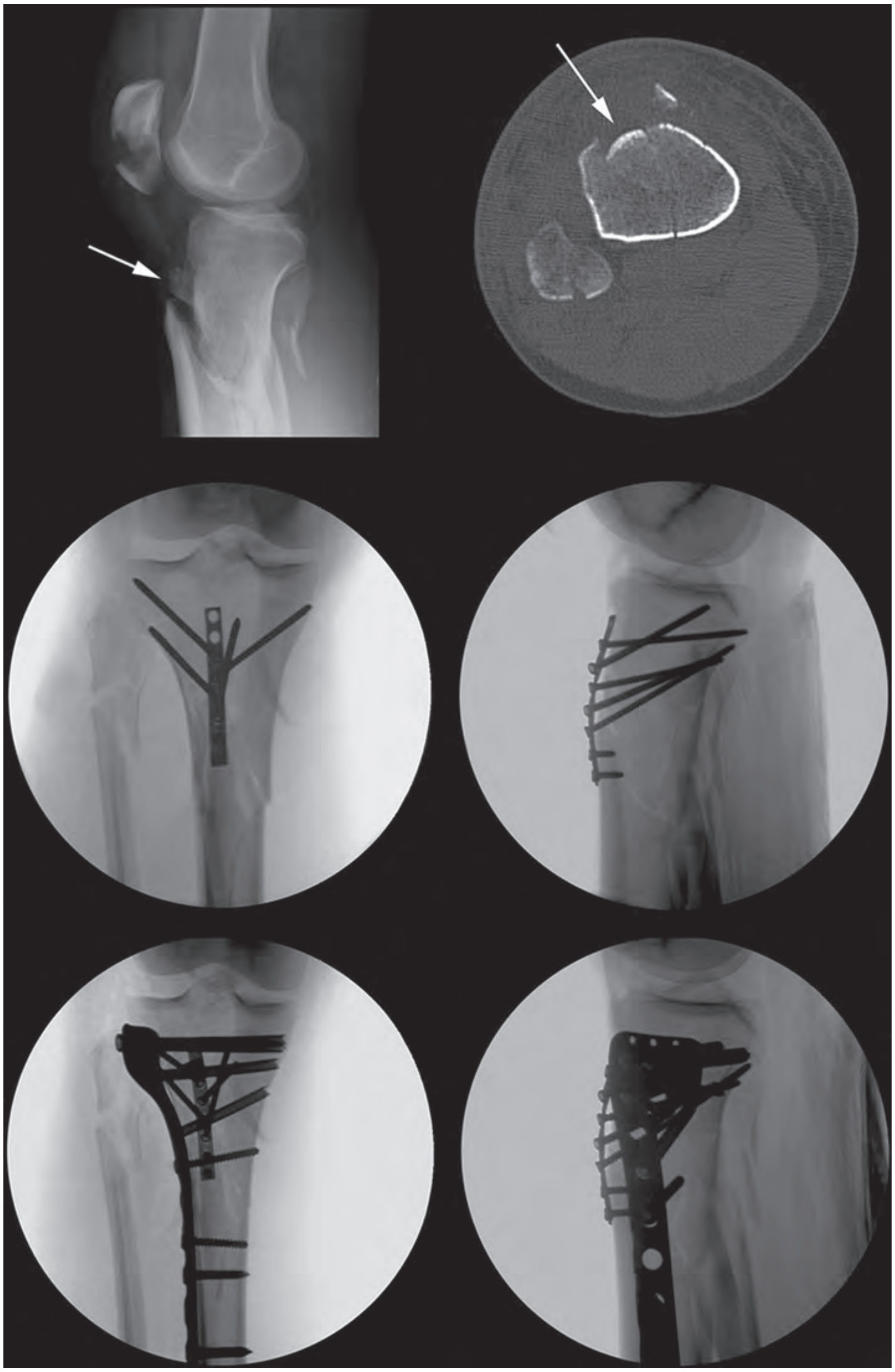


Figure 19-15. The tibial tubercle is a separate fragment in this case. It was reduced and stabilized using a small fragment plate. This also indirectly reduced a portion of the segmentally comminuted metadiaphyseal fracture.

- If more than a few screws are needed, unicortical screws may be preferable in the anterior plate initially avoiding interference with subsequent reductions and application of screws through other plates (either a lateral plate or a posteromedial plate) (Fig. 19-16).

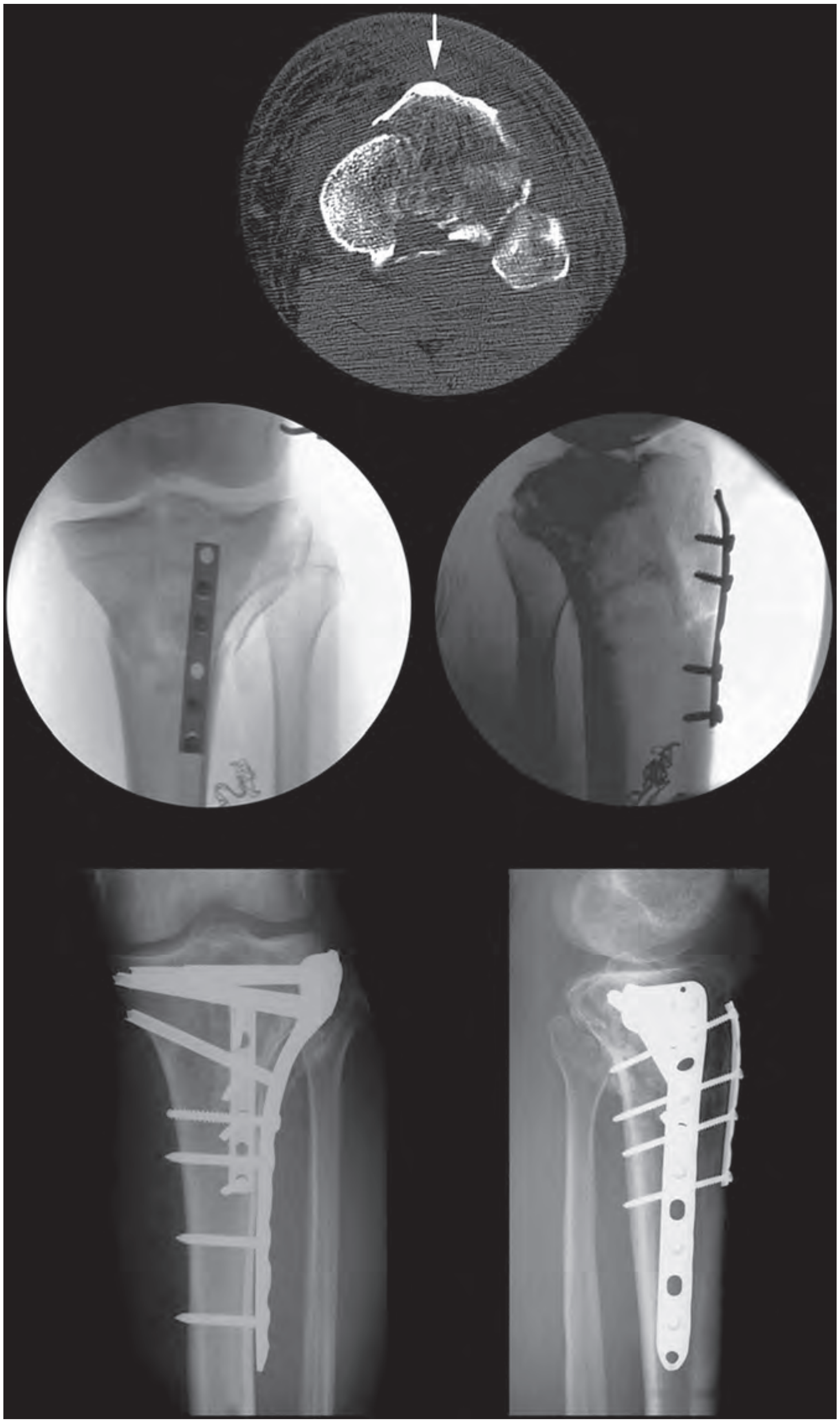


Figure 19-16. When stabilizing a tibial tubercle fracture associated with a tibial plateau fracture initially, unicortical screws allow unimpeded reduction and implant placement into the other fragments.

- Alternatively, if the tubercle is a large fragment, oblique anterior to posterior screws can be used (Fig. 19-17).

Figure 19-17. Lag screws may be used for a large separate tibial tubercle fragment.

- Associated fractures of the tibial spines/eminence rarely involve the weight-bearing surface. However, reduction can assist in cortical and articular "reads," and can restore integrity of the cruciate ligaments and meniscal crus.
  - A dental pick or small Freer elevator can be used through a lateral arthrotomy to reduce the central fragment.
  - Stabilization may proceed with K-wires followed by screws (Fig. 19-18).

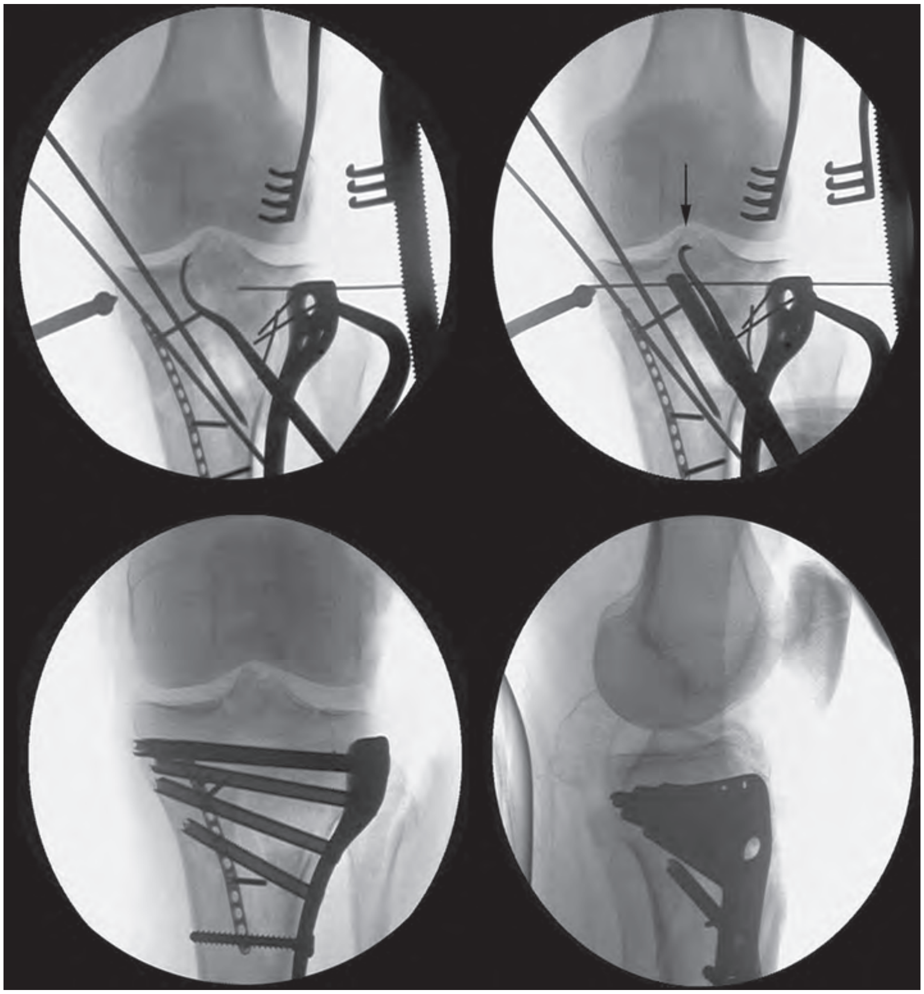


Figure 19-18. The tibial eminence can be reduced using a small hook through the lateral incision underneath the patellar tendon (*arrow*, **upper right**).

- K-wires can be placed into the main fragment, and advanced through the skin on the contralateral side.
  - These can then be pulled retrograde until they are flush to allow for plate placement (Fig. 19-19).

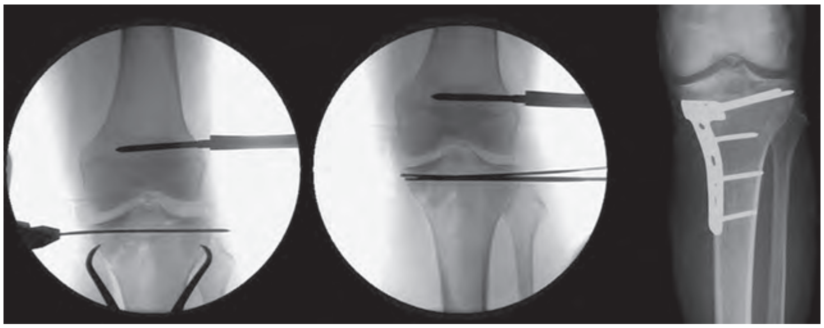


Figure 19-19. K-wires placed into the main fragment, advanced through the contralateral plateau, and pulled retrograde until flush allows for easier and unencumbered lateral plate placement.

- For an isolated fracture of the posteromedial tibial plateau, the fracture can be reduced under direct vision based on cortical interdigitation.
  - An antiglide plate can be placed on the posterior aspect of the tibia through a posteromedial approach when the patient is supine (Fig. 19-20).

Figure 19-20. Posterior tibial plateau plating through the posteromedial approach.

- The use of a 2.0-mm buttressing “rim plate” can be effective in applying support or compression to the subchondral and metaphyseal bone as it distributes forces over a larger surface area than screws alone, especially in soft bone. It functions as a large washer.
  - Using 2.0- or 2.4-mm screws also allows for multiple points of fixation of articular fragments near the subchondral bone.
  - Depending on the anatomic region of comminution, the plate may be placed selectively, anteriorly, anterolaterally, laterally, or medially (Figs. 19-21 and 19-22).

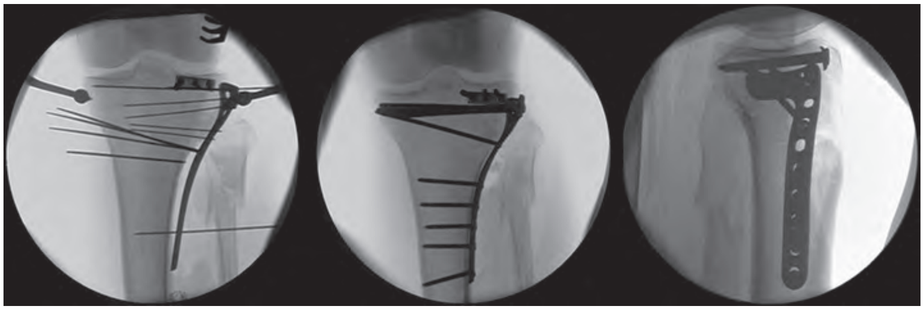


Figure 19-21. A one-quarter tubular plate with 2.7-mm screws applied as a rim plate placed on the anterior margin of the lateral tibial plateau. This allows compression across a coronal fracture plane and acts as a large washer supporting the screws and elevated articular surface.

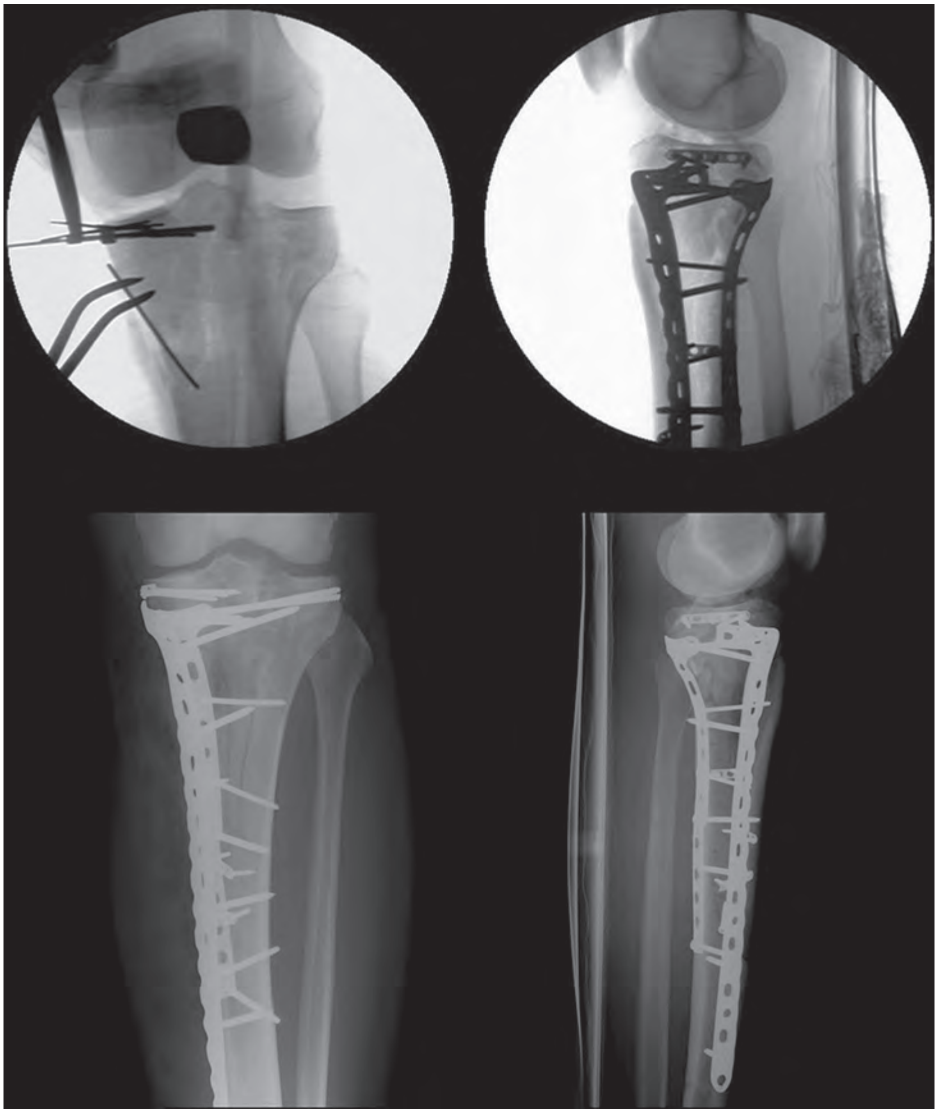


Figure 19-22. A rim plate can also be placed on the medial plateau to buttress articular segments.

- If comminution of both plateaus is present, a rim plate may be placed along the entire juxtaarticular anterior cortical surface.
  - This is helpful in coronal fractures that extend across both tibial plateaus.
  - The plate may be inserted from lateral to medial, under the patellar tendon/infrapatellar fat pad and over the distal insertion of anterior tibial capsule.
  - A small anteromedial incision, placed medial to the patella tendon facilitates medial screw insertion (Fig. 19-23).

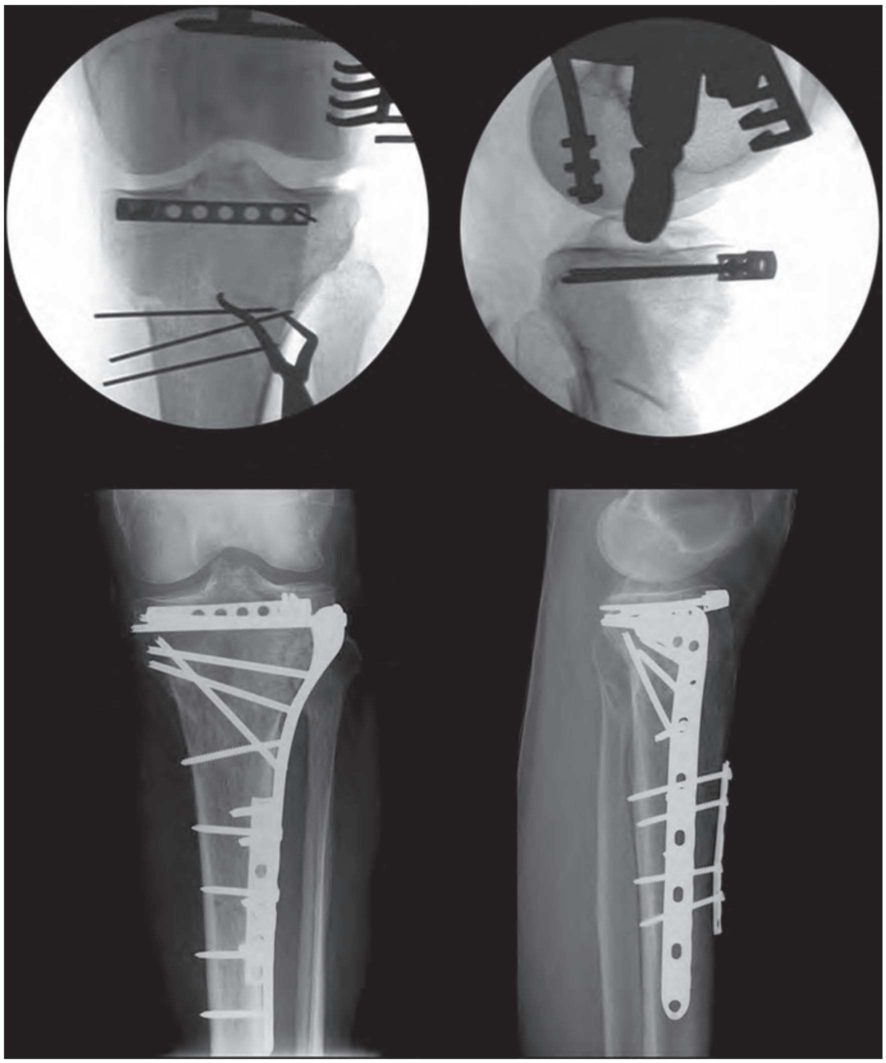


Figure 19-23. A one-quarter tubular anterior rim plate applied across the entire anterior extraarticular metaphysis of the proximal tibia.

- The anterior to posterior screws in these rim plates should be placed proximal to the lateral to medial screws inserted through periarticular plates.

- When sequentially reconstructing small fragments, small 2.0-mm plates can also be used to stabilize individual cortical fracture lines (Fig. 19-24).

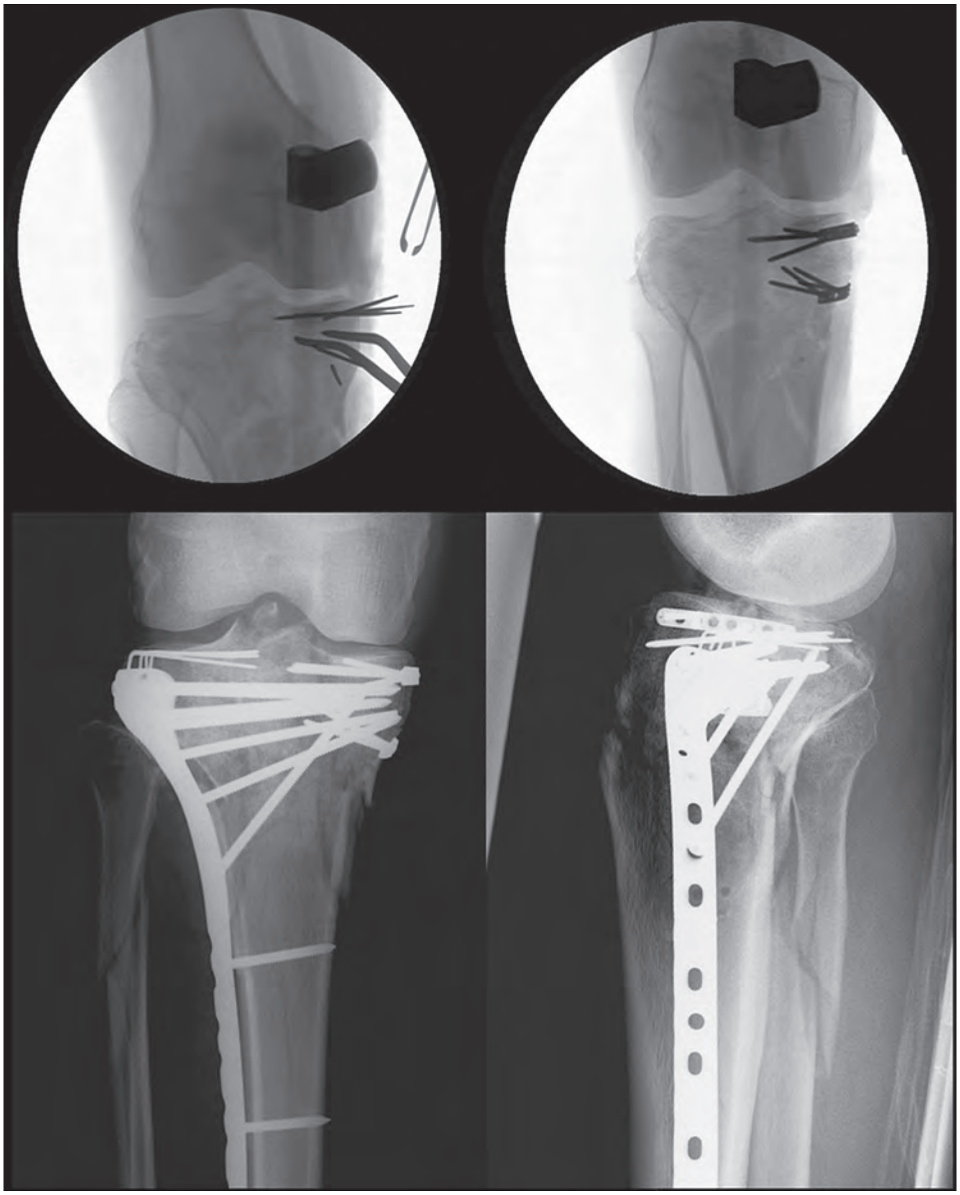


Figure 19-24. Mini-fragment plates can be used to stabilize individual fracture lines of small periarticular fragments.

- Similarly, small 2.0-mm plates can be used to segmentally stabilize long spiral fracture lines prior to buttress plate placement (Fig. 19-25).

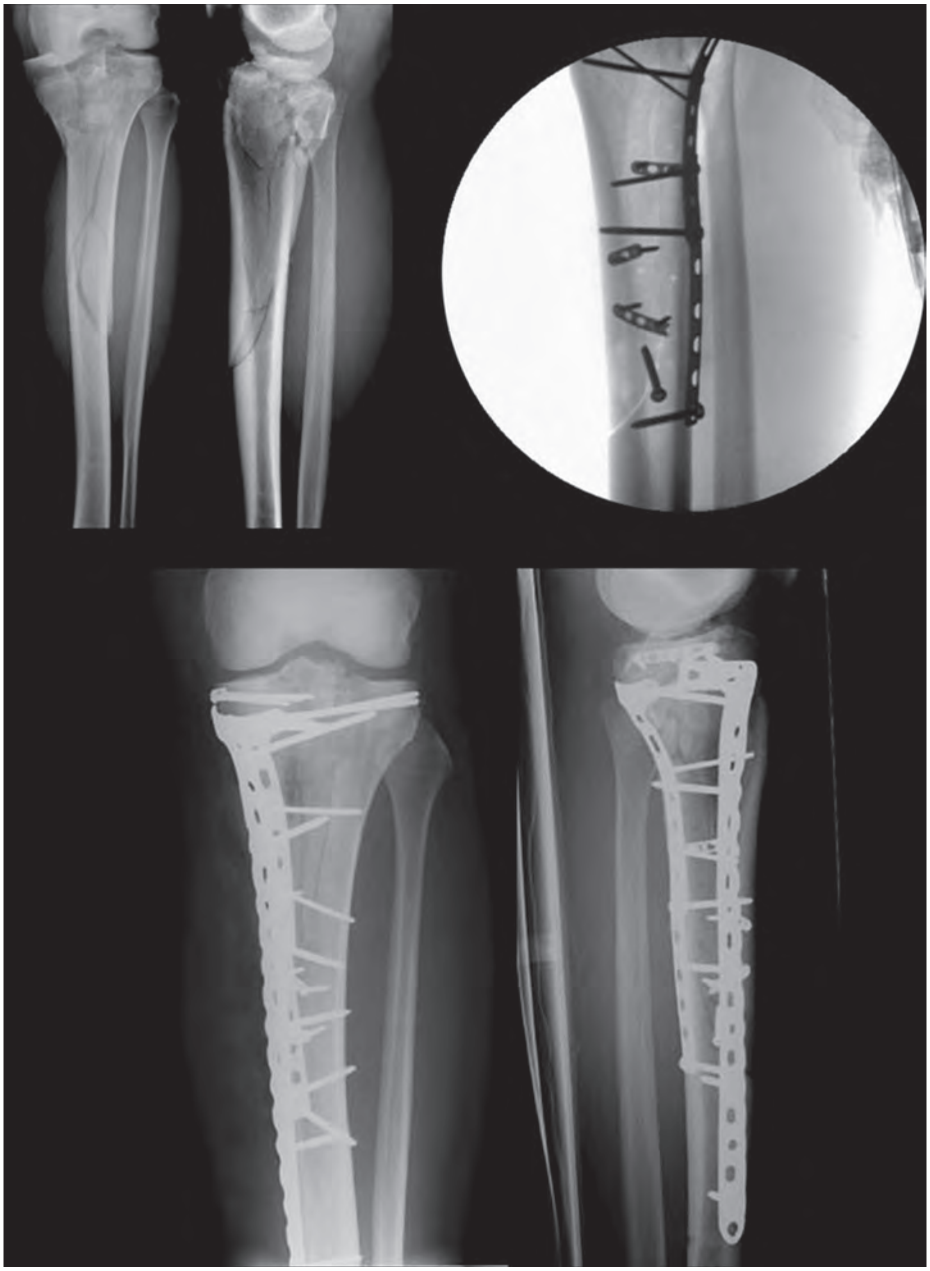


Figure 19-25. Long fracture lines can be stabilized with 2.0-mm plates and unicortical screws. These provide more stable fixation than K-wires and do not obstruct subsequent implants. These small plates must be supported by stronger neutralization/buttress plates.

- During the application of a temporizing external fixator, if one of the fracture lines of an articular fragment exits distally in the shaft, it can be reduced and stabilized concomitantly.
    - This converts an AO/OTA Type C fracture to a Type B pattern, simplifying the definitive reconstructive procedure. The stability of the initial reduction is improved too.
    - The soft tissues must be evaluated carefully to ensure they are amenable to surgical dissection (Fig. 19-26).

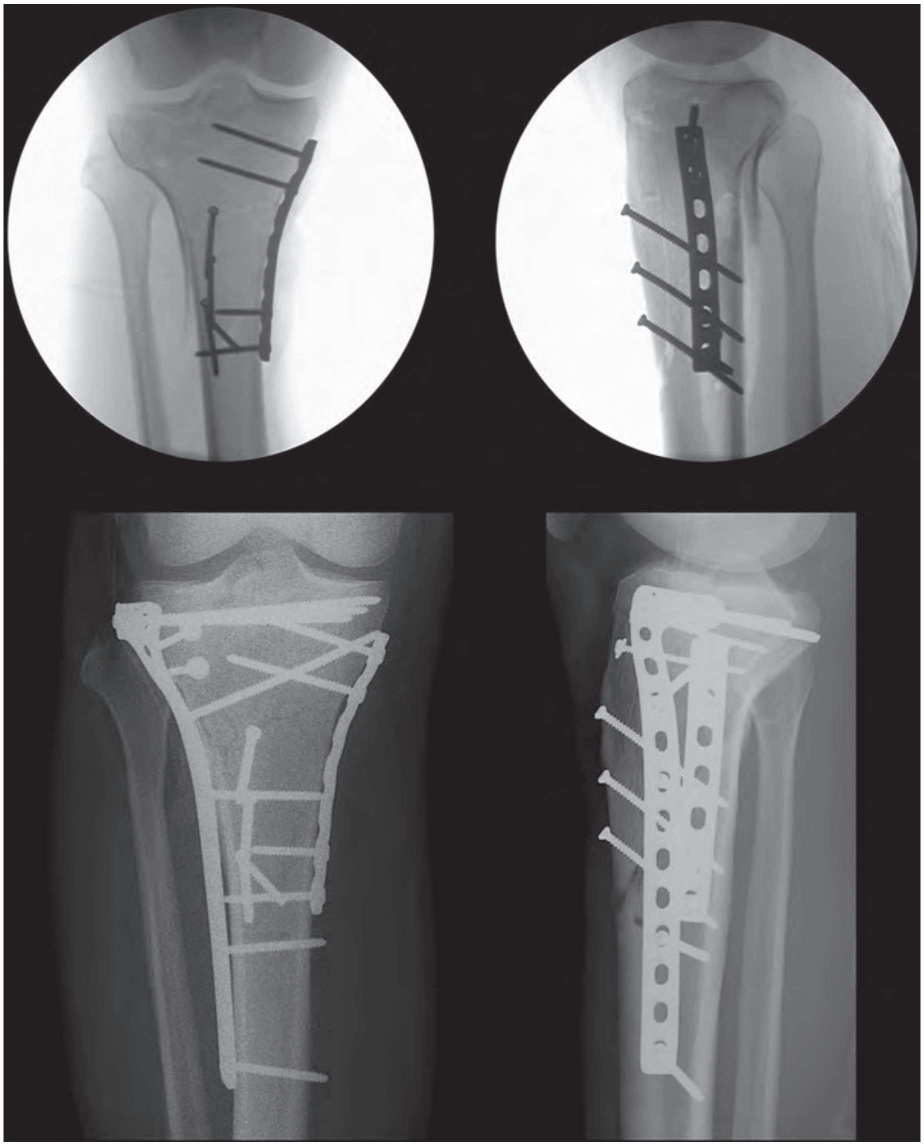


Figure 19-26. In this case, a medial plate was placed through a posteromedial approach distal to the articular surface at the time of spanning fixator application (external fixator pins are proximal and distal to the C-arm image fields). Several weeks later, when swelling had diminished, final articular repair was simplified.

- An effective reduction strategy for severely comminuted fractures includes reassembling the fracture fragments that have the clearest fracture lines.
  - This creates a progressively more stable fracture.

- The reduction of subsequent fracture fragments is facilitated, much like "doing a jigsaw puzzle."
- Sequential reductions and fragment stabilization then proceeds (Fig. 19-27).

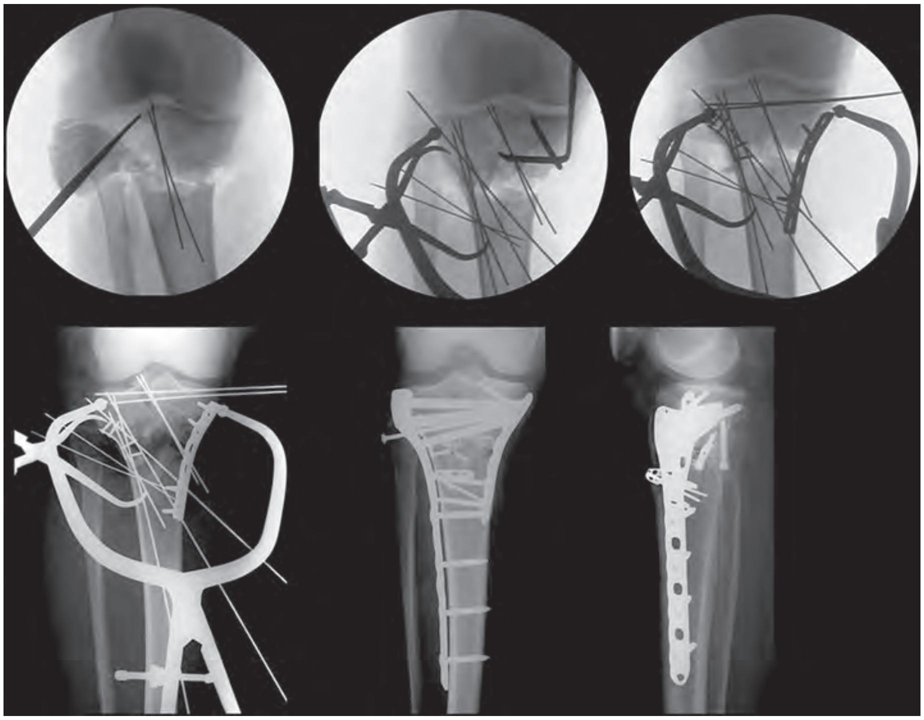


Figure 19-27. In this severely comminuted tibial plateau fracture, reliable cortical interdigitations (i.e., "cortical reads") are addressed first, and the remainder of the plateau is reduced sequentially to restore alignment.

- When osteochondral articular fragments are stabilized provisionally with K-wires and are too small for definitive screw fixation, these same K-wires can be used as adjunctive definitive fixation.
    - They can be cut short, bent, and then be impacted flush with the metaphyseal cortex.
    - These function as a subarticular support, buttressing reinforcement (similar to concrete "rebar" or joists).
    - Threaded K-wires likely migrate less often than smooth K-wires, but migration of these periarticular K-wires when associated with stable fixation is rare (Fig. 19-28).

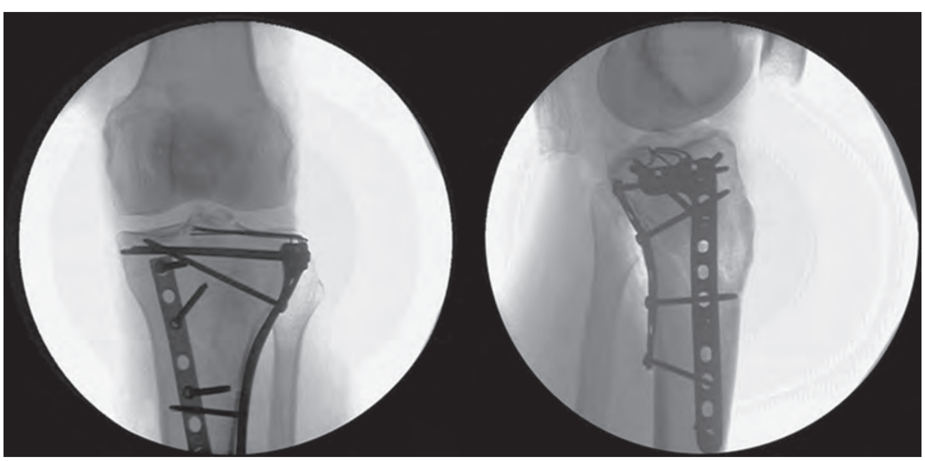


Figure 19-28. In this case, definitive subarticular K-wires were used for supporting small articular fragments.

- Another technique to capture small fragments is to cut through the two outer holes of a small malleable three- or four-hole plate (e.g., one-third tubular, one-fourth tubular, 2.4 mm, 2.0 mm), leaving one or more intact center hole(s).
  - Each end can be contoured into hooks to create a large linear spiked washer with a larger surface area, similar to a spring plate used for posterior wall acetabular fractures (Fig. 19-29).

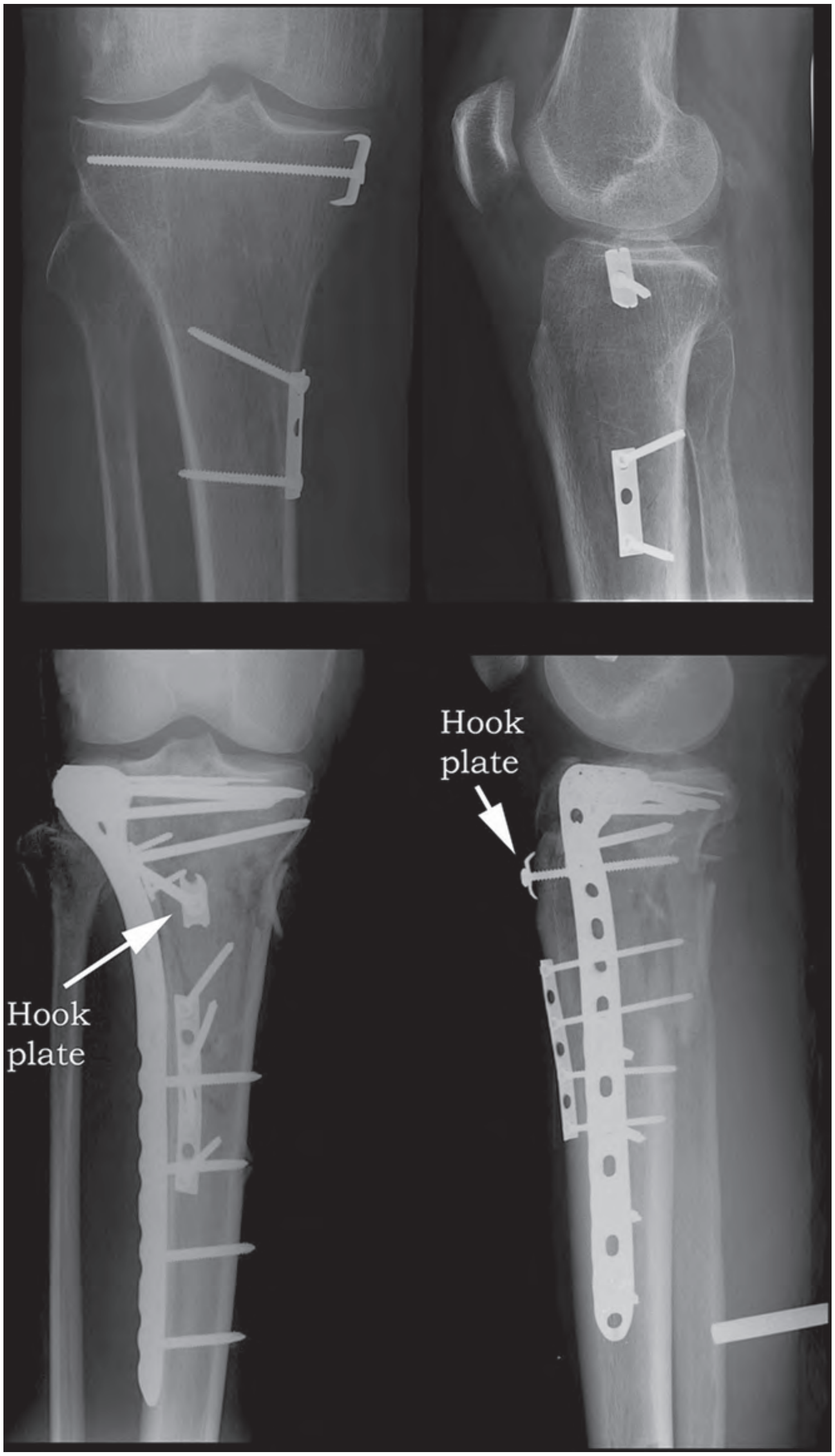


Figure 19-29. Two examples of hook plates fashioned by cutting a one-third tubular plate to act as a large washer on the tibial plateau.

- If a long medial plate is needed for tibial diaphyseal extension, an anterolateral distal tibial plate from the contralateral side often fits well.
  - This may be applied through a posteromedial approach (Fig. 19-30).

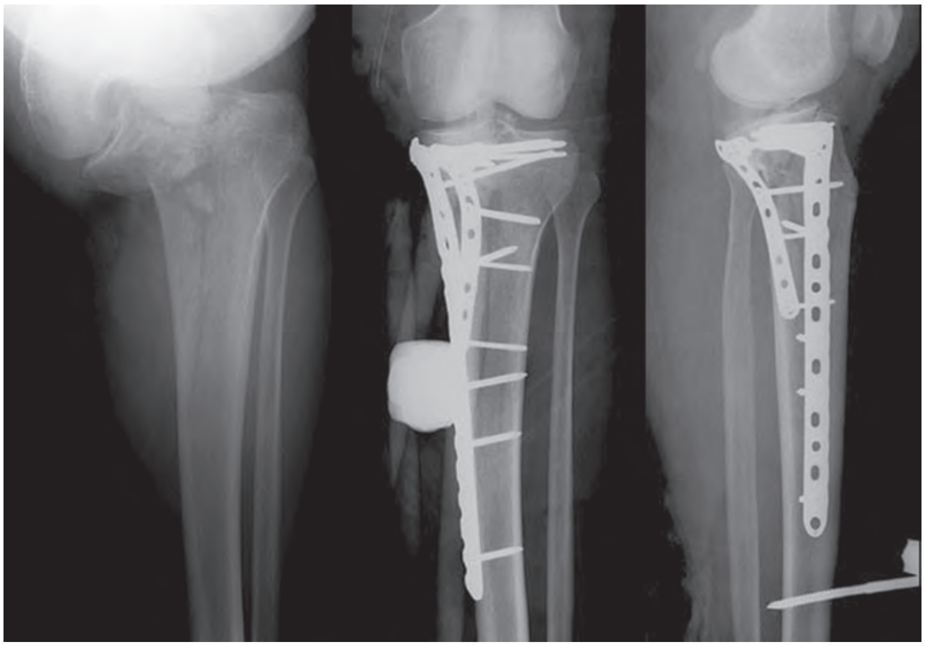


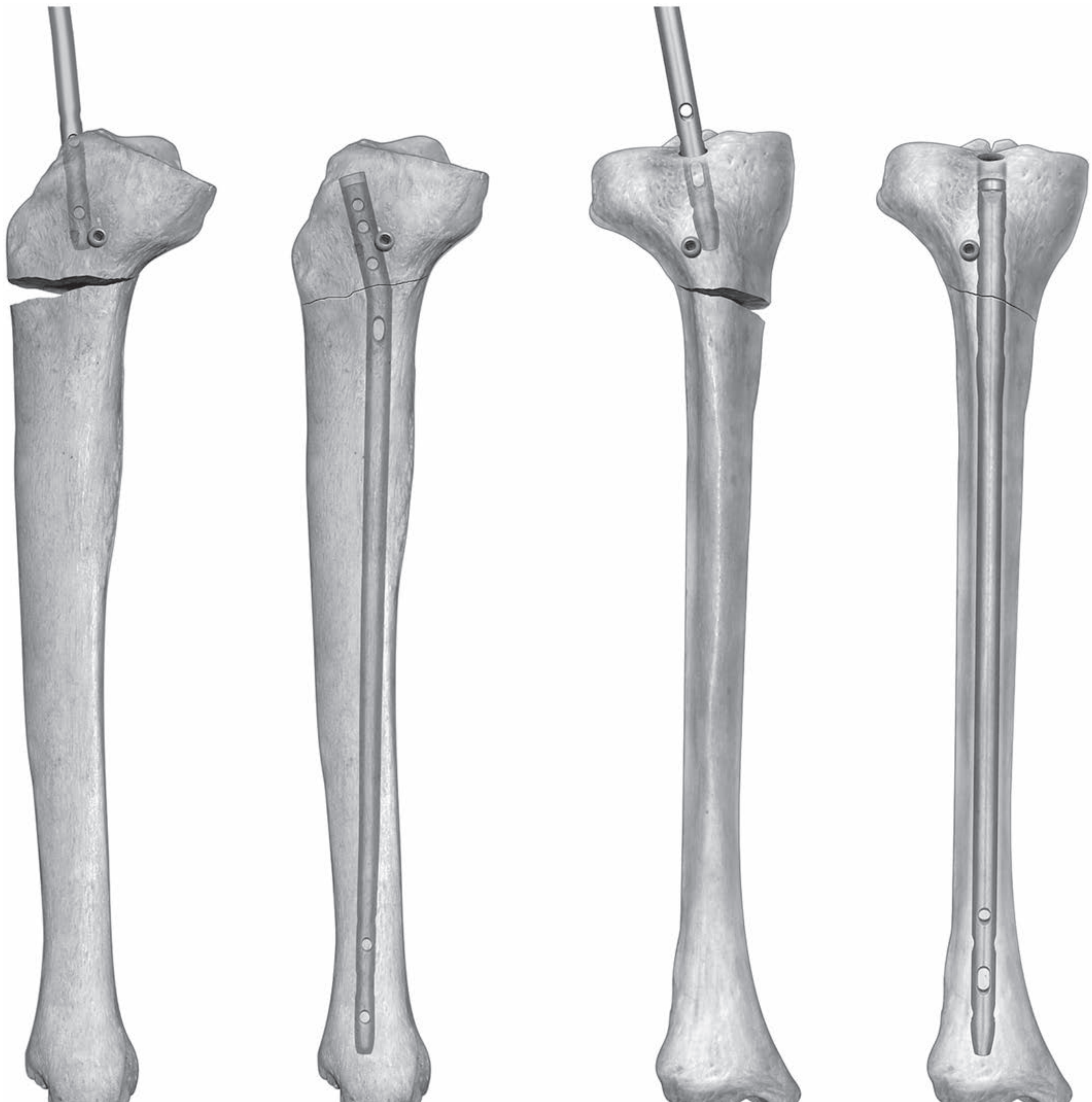
Figure 19-30. A contralateral anterolateral distal tibial plate may be used on the medial tibial plateau when distal extension is needed.

- If a coronal split exists in a reduced medial articular fragment, anterior to posterior subchondral lag screws can be placed below the medial tibial plateau, followed by lateral to medial locking screws through a laterally based locking plate.
  - The most proximal locking screws should be placed just distal to the medial subchondral screws to provide them with additional support.

Section 8

Tibia

Robert P. Dunbar



Chapter 20

Tibial Shaft Fractures

Andrew R. Evans
M. Bradford Henley

Sterile Instruments/Equipment

Irrigation and Debridement of Open Tibial Fractures

- Cystoscopy tubing or pulsatile lavage system
- ≥6 L of sterile saline
- Multiple small and large retractors, typically "L" shaped, such as Sofield, Langenbeck, or Army-Navy
- Large curettes (straight and curved)
- Small curettes (straight and curved)
- Dental picks
- Shoulder hooks, bone hooks
- Rongeurs (pituitary, etc.)
- Occasionally or available: motorized burr

Intramedullary Nailing of Tibial Shaft Fractures

- Multiple small and large retractors
- Gelpi retractor
- Medium or large radiolucent triangle for limb positioning
- Large and small pointed "Weber" bone reduction clamps
- Pigtailed awl or 2.8- to 3.2-mm guide pin and cannulated 8- to 10-mm drill bit
- Implants: small fragment plates and screws (for provisional stabilization of open fractures)
  - Tibial nailing or plating system of choice

Patient Positioning

- Supine
- Cantilever-type OR table with radiolucent extension (diving board) so that the C-arm is unencumbered for imaging in the AP and lateral planes.
- Place a small bump (rolled towel or blanket) beneath the ipsilateral buttock and flank to neutralize the lower limb external rotation (patella pointed superiorly).
- Consider positioning the ipsilateral upper extremity across the body to avoid shoulder hyperextension and brachioplexopathy.
- Exclude the groin and perineum from the operative field with an impervious U-shaped drape.
- Prep and drape the affected lower extremity to the ipsilateral groin.

- Wrap the toes with an impervious drape (e.g., Ioban, Coban, Viadrape) to minimize toe/toenail-related contamination.
- Position the lower extremity over an appropriately sized radiolucent triangular pillow or metal frame.
  - Puts patella tendon on slight stretch, which may facilitate incision placement.

Surgical Approaches

Anterior Approach to the Proximal Tibia (For Tibial Intramedullary Nailing)

- With the knee flexed over the radiolucent triangle, make an incision longitudinally over the midline of the patellar tendon, or medial (or lateral) to the tendon, depending on the fracture pattern and surgeon's preference.
  - This approach portion may also be performed with knee in extension to 30 degrees of flexion.
- Dissect sharply down to the paratenon of patellar tendon.
  - Avoid the occasional infrapatellar branch of the saphenous nerve inferiorly within the subcutaneous tissue.
  - Patellar tendon splitting approach
    - Incise the paratenon as a distinct tissue layer, separating its edges from the patellar tendon to facilitate closure.
    - Assess the medial and lateral borders of the patellar tendon through visualization or palpation.
    - Incise the patellar tendon longitudinally in its midline.
      - Use a Debakey forceps to retract tendon split, to allow maintenance of single plane in tendon fibers (Fig. 20-1).

Figure 20-1. A Debakey forceps placed in the tendon split allows for retraction, and extension of the split within the same tendon fiber plane (parallel to and between tendon fibers rather than crossing fibers).

    - Retract the medial and lateral portions of the tendon to visualize the retropatellar fat pad.
    - Atraumatically elevate the fat pad from its distal position, superiorly to visualize proximal tibia.
      - If the insertion point is not approached by elevation of the fat pad and periosteum, beware of injury to menisci or intermeniscal and coronary ligaments.

        - Consider Gelpi or two "L" shaped retractors (e.g., Langenbecks) to provide visualization and to protect the patellar tendon from reamers.
            - If Gelpi is used, it may be angulated when knee is placed in flexion by tension on the patellar ligament; this may be avoided by securing the retractor to the leg.
            - A laparotomy sponge placed through finger holes and placed posteriorly around proximal leg will maintain position of Gelpi retractor.
    - Paratendinous approach
        - May be performed medially (or rarely laterally) to the tendon.
            - Tibial tubercle is lateral to the intramedullary tibial axis.
            - Skin incision may be chosen to correspond more closely to the planned paratendinous approach.
        - Dissect sharply to the desired edge of the patellar tendon paratenon, and retract it.
- Separate the posterior aspect of the tendon from the retropatellar fat pad bluntly, and sweep the fat pad and anterior periosteum superiorly and posteriorly with a blunt elevator.
- Bovie cautery may be used to assist in elevating the fat pad with the anterior tibial periosteum.
    - Avoid penetration of the joint capsule or injury to the anterior intermeniscal ligament.
- The fat pad should be retracted just far enough to visualize the starting point for the tibial guide pin or awl/nail entry site.[1]
- To facilitate fracture reduction, heel should be elevated slightly off of the table by choosing a triangle of sufficient height.
    - This will permit gravity to assist in restoration of limb length for reduction.
- To correct procurvatum angulation, place bolster or towels posterior to heel or under distal metatarsals, distal to fracture (dorsiflexing foot and increasing apex posterior angulation).
- For recurvatum deformities, place bolster or towels proximal to fracture, allowing distal tibia and foot to sag posteriorly.

Anterolateral Approach to the Tibial Shaft

- Make skin incision longitudinally 1 to 2 cm lateral to the anterolateral tibial crest.
- Dissect sharply through skin and subcutaneous tissue to the anterior compartment fascia.
- Incise the fascia sharply, approximately 5 mm lateral to the tibial crest, leaving a small fascial flap attached to the tibial crest to facilitate closure of the anterior compartment once fracture fixation has been achieved, if indicated.
- The lateral aspect of the tibial shaft can be exposed by elevating the anterior compartment from the lateral tibial periosteum, leaving the periosteum and periosteal vessels intact.
    - Elevate the muscle from distal to proximal using the natural plane of muscle fiber insertion.
    - This will minimize muscle injury, bleeding, and devascularization.

Posteromedial Approach to the Tibial Shaft

- Most often used for
    - Stabilizing the tibial shaft component of a pilon or tibial plateau fracture.
    - Nonunions/malunions.
- Make an incision longitudinally 1 to 2 cm posterior to the posteromedial tibial border, being careful not to place incision on the poor and traumatized soft tissues on the medial face of the tibia.
- Dissect sharply through skin and subcutaneous tissue.
    - Dissect to the superficial and deep posterior compartment fascia of the tibia.
- Avoid injury to the saphenous nerve and branch of the saphenous vein.
- Incise the fascia sharply, leaving a 3- to 5-mm flap of fascia attached to the posteromedial tibial border to facilitate later fascial closure if indicated in atraumatic conditions.

- Superficial and deep posterior compartment musculature may be opened or elevated from the posterior aspect of the tibia.
- In the distal third of the tibia, the deep posterior compartment fascia is incised, and the musculature may be elevated off of the posterior tibial periosteum.
  - Posterior soft tissue attachments represent the most robust blood supply to the tibia during fracture healing.
  - Posterior submuscular and periosteal dissection should be limited to prevent further devascularization.

Management of Traumatic Wounds Associated with Open Tibial Shaft Fracture

- Elongate transverse lacerations that do not cross the tibial border in a Z-shaped fashion to maximize skin viability.
  - T-shaped or cruciform wounds may be contraindicated in compromised tissues.
    - Tendency to break down at the corners, and with ≥2 corners, can leave a sizeable defect that may not close or granulate sufficiently.
  - Try to make transverse wounds or oblique wounds longitudinal, as these will be less likely to gap when fracture is brought back out to length.
- For a Type I or II open wound over the medial tibial border, it may be reasonable to consider leaving this wound alone and instead using a separate anterolateral or posteromedial surgical approach for excisional debridement and irrigation of the open fracture.
  - It is best not to reconcile these "pre-tibial" open wounds into an extensile exposure over the medial aspect of the tibia, instead, only debride/excise the dermis, epidermis, and subcutaneous tissue (from outside-in).
  - Debride the open fracture and deeper tissues via a separate surgical approach—from the inside-out (Fig. 20-2).

Figure 20-2. In this patient with an anteromedial transverse traumatic laceration associated with an open tibial fracture, an anterolateral counter incision was used for the fracture debridement. This avoided extension of the medial traumatic wound, which has a more tenuous soft tissue envelope.

  - Rationale: if edema precludes primary closure, anterolateral wound over the anterior compartment musculature will be amenable to skin graft, whereas a wound on the medial face may require rotational or free soft tissue flap for coverage.
  - Do not use this technique if it is already clear that a free flap will be necessary.
    - Consider a discussion with a plastic surgeon to avoid compromising options for soft tissue repair.

- Expose the proximal and distal bone ends for débridement.
  - Be mindful that the zone of injury may extend in any direction further than the fracture and skin wounds themselves.
  - Evaluate all sheared tissue planes for the presence of dirt and other foreign debris.
  - Aggressively debride all foreign material and contamination.
  - Excise necrotic skin, avascular or loose subcutaneous tissue and fascia, noncontractile muscle, and cortical bone fragments lacking soft-tissue attachments.
  - As skin may be an important resource in patients who are not flap candidates, consider being somewhat conservative in the debridement of skin, removing only what is ischemic/nonviable.
  - Marginally viable skin may serve at least temporarily as a biologic dressing if sufficiently cleaned.
  - Remove, but do not discard, large, devitalized bone fragments that may be used to facilitate an anatomical reduction.
  - Irrigate all wounds and bone ends after debridement with multiple liters of sterile saline to decontaminate.
- Sizeable soft tissue and or osseous defects can be managed with creation of a bead pouch or application of a wound VAC (KCI Inc., San Antonio, TX) over a bone defect containing antibiotic beads.
- The risk of compartmental syndrome must be considered prior to, during, and following the stabilization of tibial shaft fractures (Fig. 20-3).

Figure 20-3. In this patient with a high energy proximal tibial fracture and a significant soft tissue injury, suspicion for acute compartment syndrome should be high.

Single Incision Fasciotomy[2]

- Supine position.
- Long, straight, longitudinal incision along the posterolateral aspect of the leg in line with the fibula, from 4 to 7 cm distal to the proximal aspect of the fibular head to approximately 5 cm proximal to the distal tip of the fibula (Fig. 20-4).

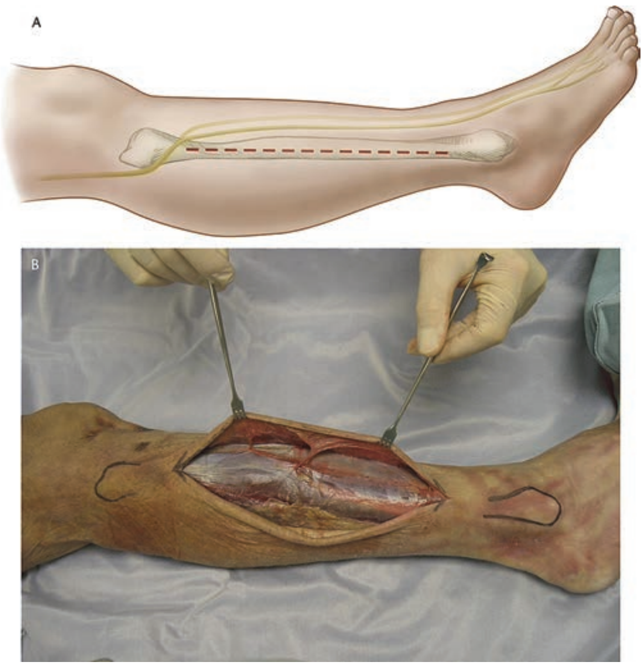


Figure 20-4. **A:** Schematic representation of the right leg and the incision location relative to the fibula. **B:** Cadaveric dissection of the right leg demonstrating elevation of full-thickness anterior and posterior skin flaps. The anterior, lateral, and superficial posterior compartments can be identified at this point in the dissection. Note the presence of fascial perforating vessels. (From Maheshwari R, Taitsman LA, Barei DP. Single-incision fasciotomy for compartmental syndrome of the leg in patients with diaphyseal tibial fractures. *J Orthop Trauma.* 2008;22:723–730. With permission.)

- Full-thickness anterior and posterior skin flaps are elevated.
  - Elevation of these flaps is facilitated with the use of a sponge to separate the skin and subcutaneous layer from the underlying fascia.
  - Perforating arterial vessels are encountered, often located adjacent to the intermuscular septa, and are preserved.
  - During distal elevation of the anterior skin flap, the fascial perforation of the superficial peroneal nerve from the lateral compartment is identified and the nerve is protected.
  - Skin flap elevation is continued until the anterior, lateral, and superficial posterior compartments are identified definitively.
    - Identification of these compartments is aided by the direct palpation of the anterior and lateral intermuscular septae.
  - A long longitudinally oriented incision is then made in the fascia overlying the superficial posterior compartment followed by the lateral compartment, and finally the anterior compartment. Proceeding in this order will limit the amount of blood obscuring posterior (lower) operative sites.
  - Transfascial entrance into each of the superficial posterior, lateral, and anterior compartments is verified by direct inspection of their muscular contents during ankle dorsiflexion, hind foot inversion, and ankle and metatarsophalangeal plantarflexion, respectively (Fig. 20-5).

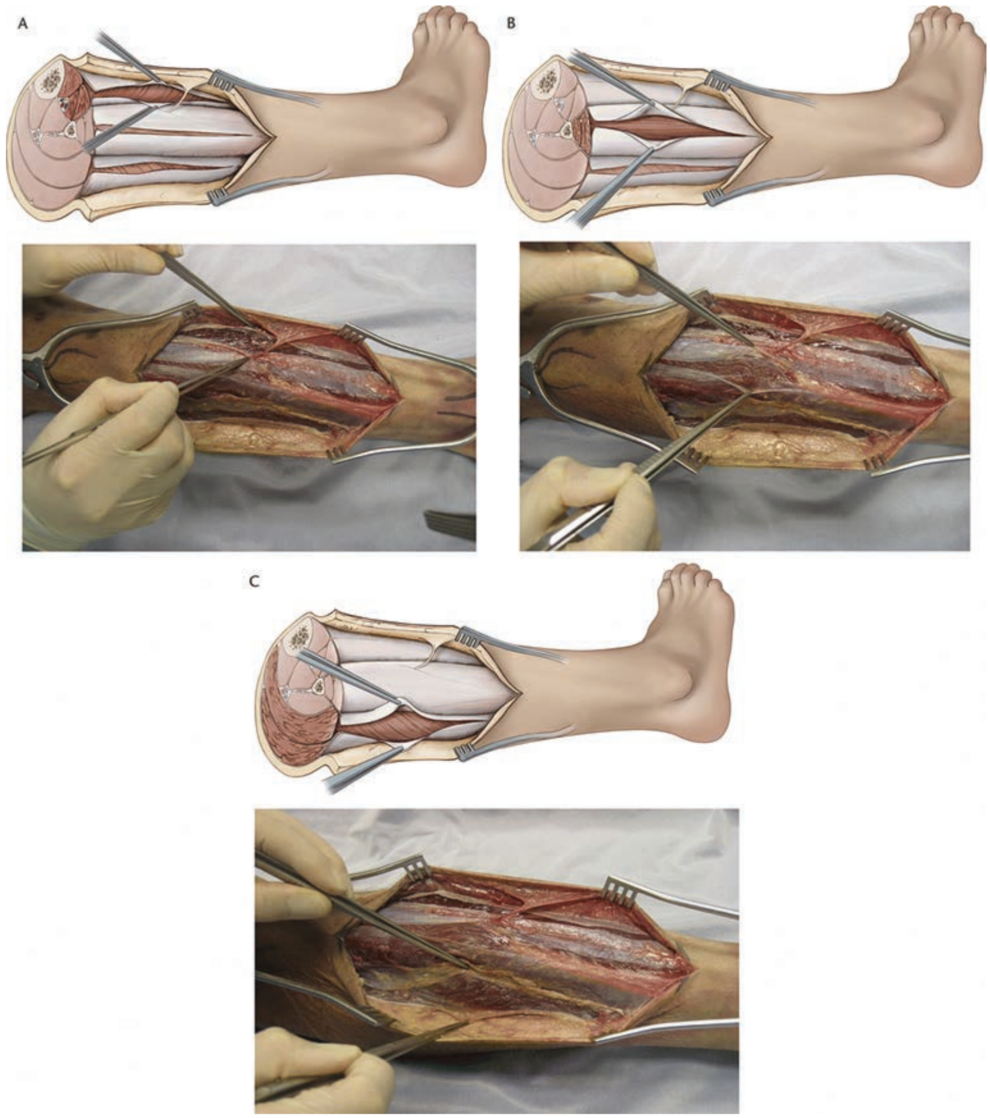


Figure 20-5. Schematic and cadaveric representations of the right leg demonstrating fasciotomy of the anterior compartment **(A)**, lateral compartment **(B)**, and superficial posterior compartment **(C)**. (In this example, self-retaining retractors are used for illustrative purposes only and are typically not required during the actual procedure.) (From Maheshwari R, Taitsman LA, Barei DP. Single-incision fasciotomy for compartmental syndrome of the leg in patients with diaphyseal tibial fractures. *J Orthop Trauma*. 2008;22:723–730. With permission.)

- The posterior portion of the incised lateral compartment fascia is grasped with an Allis clamp, and the lateral intermuscular septum is placed under tension by sustained gentle traction toward the surgeon.
- The posterior aspect of the peroneal musculature is then bluntly elevated from the anterior aspect of the lateral intermuscular septum until the insertion of the lateral intermuscular septum into the posterolateral aspect of the fibula is fully identified along the length of the surgical incision.
- The deep posterior compartment of the leg is entered by incising the posterolateral fibular insertion of the lateral intermuscular septum sharply or with electrocautery.
  - Fascia is incised immediately adjacent to the posterolateral fibula.

- The posterolateral fibular insertion of the lateral intermuscular septum is incised along the entire length of the fibula until the distal limit of the surgical wound is encountered, exposing the deep posterior compartment.
  - This dissection is facilitated by maintaining hemostasis, by lateral tension on the lateral intermuscular septum and with anterior retraction of the peroneal musculature (lateral compartment).
  - Adequate entrance into the deep posterior compartment is verified by identification of the FHL musculature noted with dorsiflexion and plantarflexion of the metatarsophalangeal and interphalangeal joints of the hallux (Figs. 20-6 and 20-7).

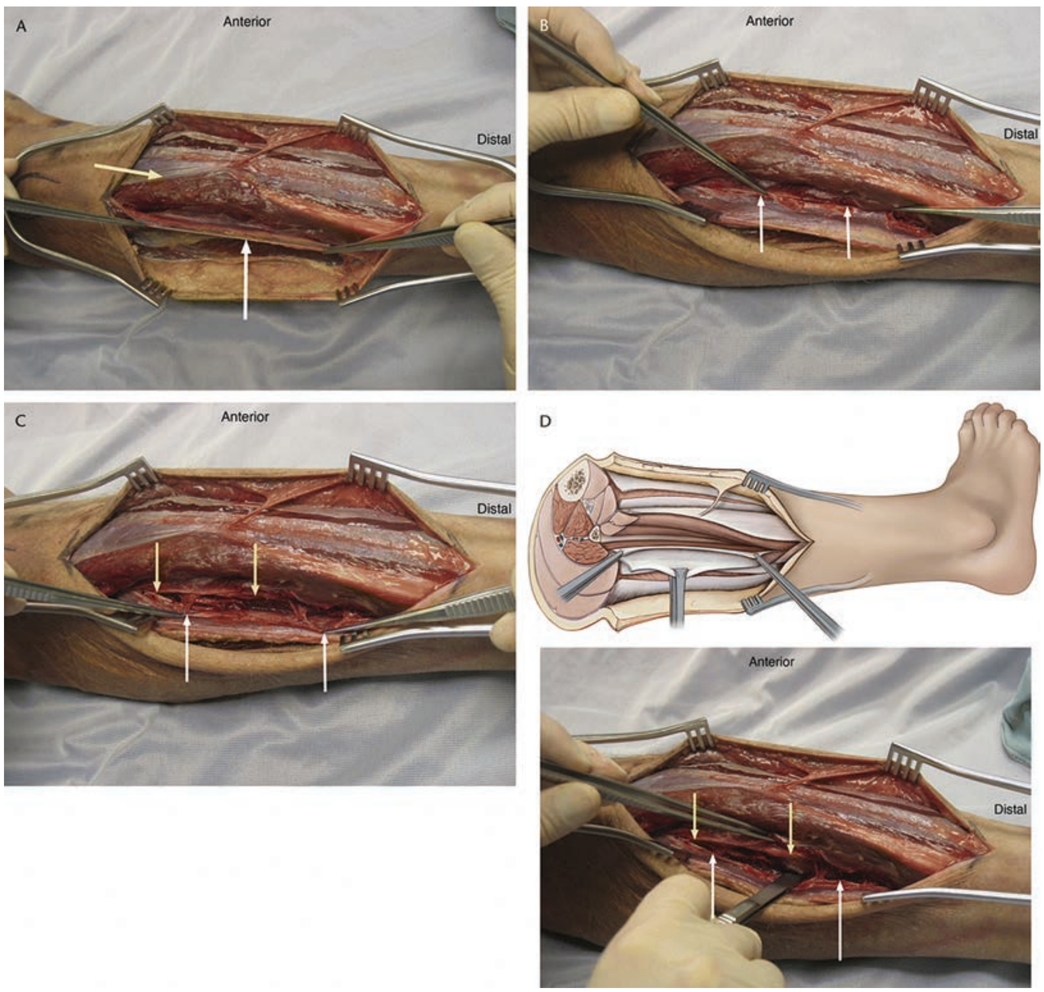


Figure 20-6. Cadaveric and schematic representations of the right leg demonstrating fasciotomy of the deep posterior compartment. **A:** The lateral compartment fascia has been incised. The posterior aspect of the incised fascia has been grasped with two forceps (*white arrow*) and has been retracted toward the surgeon. The *yellow arrow* demonstrates the lateral compartment musculature (peroneal) that has been elevated from the deep surface of the lateral compartment fascia and the anterior aspect of the lateral intermuscular septum. **B:** The insertion of the lateral intermuscular septum on the posterolateral aspect of the fibula is indicated by the *white arrows*. **C:** The insertion of the lateral intermuscular septum (*white arrows*) has been incised and retracted posteriorly from the posterolateral aspect of the fibula (*yellow arrows*). The deep posterior compartment has now been opened. **D:** An instrument has been placed beneath the posterolateral aspect of the fibula (*yellow arrows*) into the deep posterior compartment. The incised insertion of the lateral intermuscular septum is marked by the *white arrows*. (In this example, self-retaining retractors are used for illustrative purposes only and are typically not required during the actual procedure.) (From Maheshwari R, Taitsman LA, Barei DP. Single-incision fasciotomy for compartmental syndrome of the leg in patients with diaphyseal tibial fractures. *J Orthop Trauma*. 2008;22:723–730. With permission.)

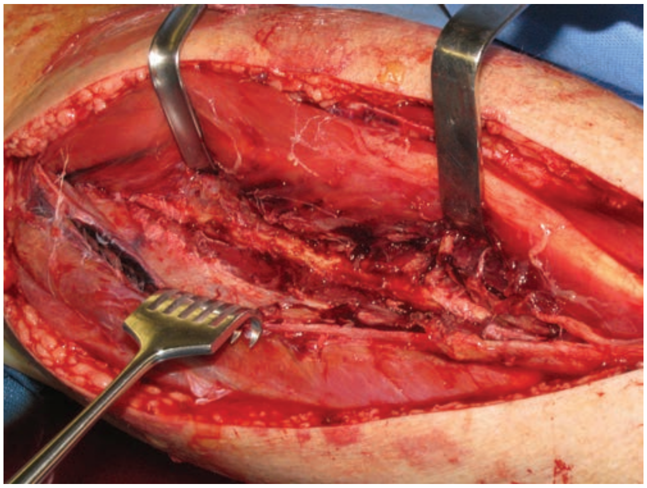


Figure 20-7. Clinical example of complete release of all four leg compartments through a single lateral incision.

- Fasciotomy incisions require sterile management after internal fixation.

Reduction and Implant Techniques

External Fixation

- Currently, uniplanar external fixation has a limited role in the definitive management of tibial shaft fractures, but can serve as a temporizing technique.
  - May be applied as provisional stabilization to restore limb length, alignment, and rotation in physiologically unstable patients (Fig. 20-8).

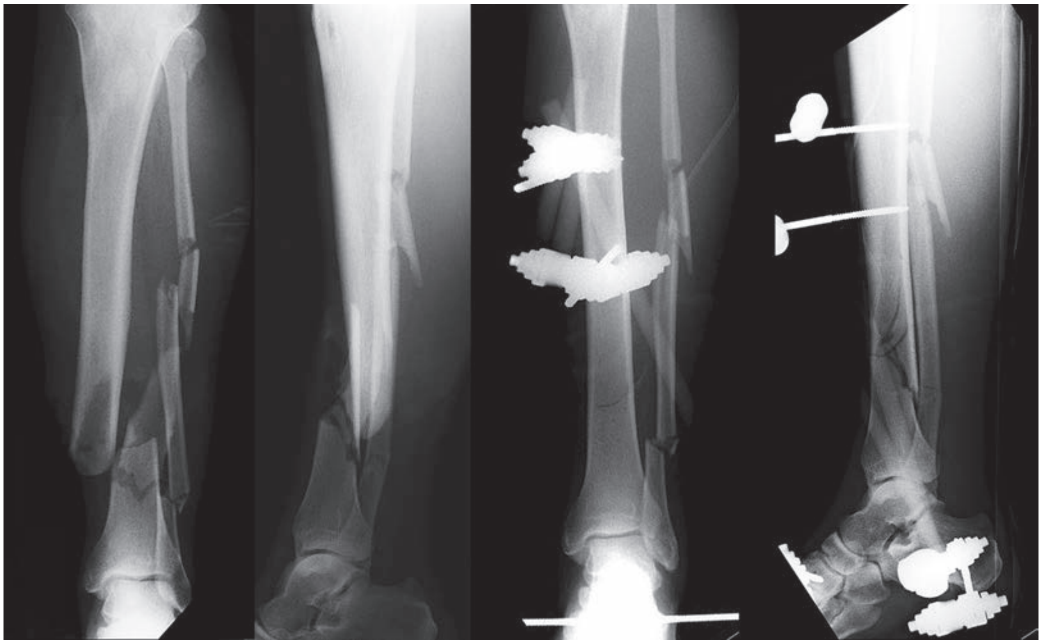


Figure 20-8. Example of a multiply injured patient with a comminuted open tibial fracture. A damage control approach was used, with tibial external fixation initially. Conversion to intramedullary nailing was performed in 6 days when the patient's hemodynamic profile improved.

- Conversion to internal fixation may be performed without significant increase in infection risk if performed within 5 to 14 days.[3]
- May serve as supplemental fixation to an internal fixation construct, but should avoid contact with the internal fixation devices to prevent contamination via pin tracts.

- Circular tensioned wire (e.g., Ilizarov) external fixation is a particularly useful technique for the management of open tibial fractures with sizeable segmental bone defects (>4 to 6 cm) and is a useful tool in the treatment of deformities and nonunions.
  - Provides the option for management of bone defects with bone transport (controlled mechanical distraction osteogenesis) techniques.

Tibial Nailing

- Provisional reduction may be obtained with a medially based femoral distractor.[4]
  - 5.0 mm × 170 mm Schanz pins
  - Proximal Schanz pin placement medial to lateral, in proximal tibial metaphysis, posterior to nail insertion point.
    - Pin placed posterior to the midpoint of the anterior-posterior dimension will avoid nail path if at the level distal of the physeal scar.
    - Pin typically placed approximately 1 to 2 cm distal to the articular surface.
  - Distal pin placement medial to lateral in the region of posterior metaphyhsis/malleolus, near the physeal scar (Fig. 20-9).

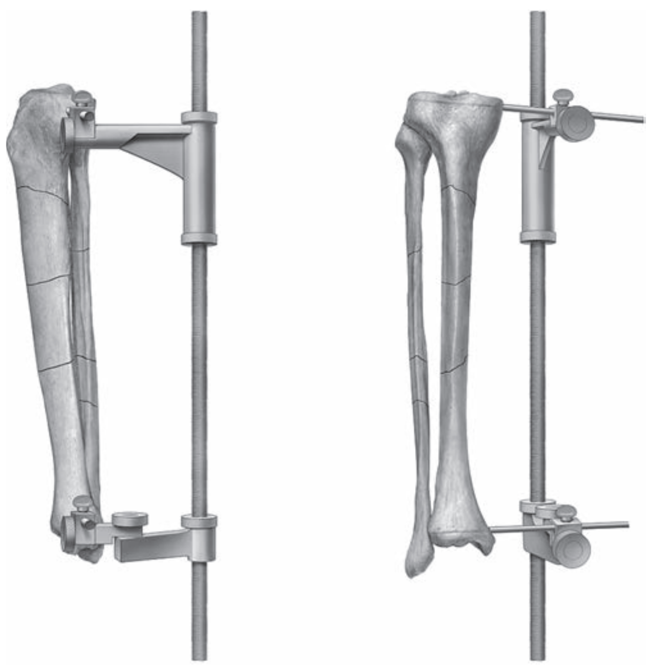


Figure 20-9. Pin placement for a medial tibial distractor should not interfere with reamer and nail insertion.

- Alternatively, distal distractor pin may be placed into the talar body (in line with tibial axis).
  - Localize starting point medially using fluoroscopy, just distal to anterior colliculus or intercollicular groove of medial malleolus (Figs. 20-10–20-12).

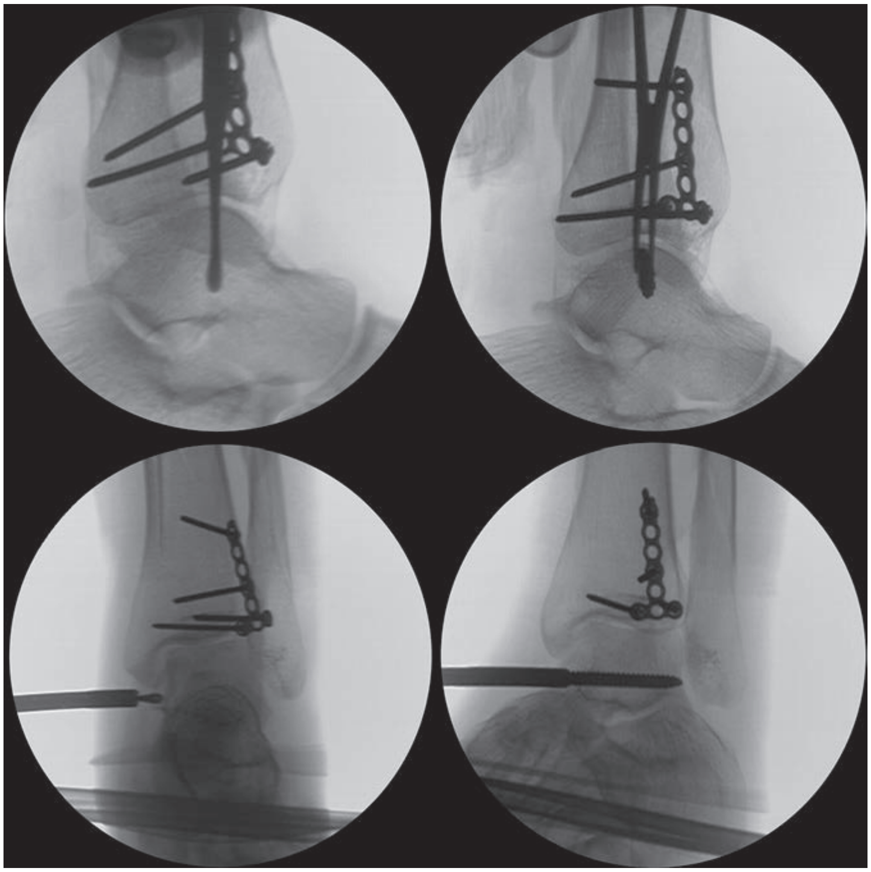


Figure 20-10. In this patient, the distal distractor pin was placed into the talar body, just distal to the intercollicular medial malleolar groove.

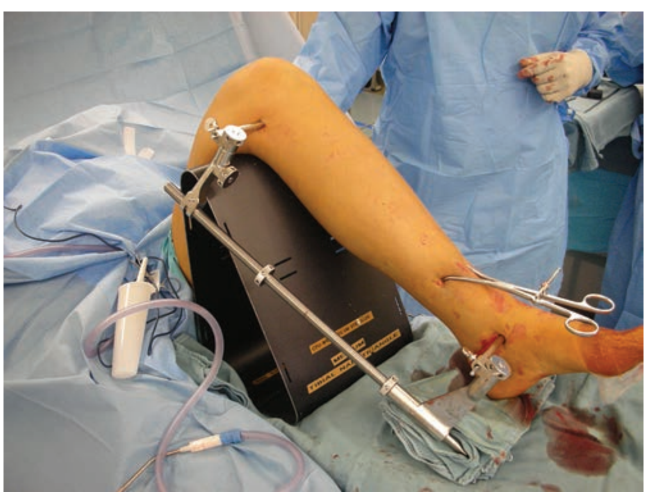


Figure 20-11. Medial femoral distractor used for reduction of a displaced spiral fracture of the distal third tibial fracture. The proximal Schanz pin is placed into the posteromedial tibial metaphysis in the coronal plane. The distal pin is placed into the talar body. A large Weber bone reduction clamp has been placed percutaneously to anatomically reduce and stabilize the spiral fracture.

Figure 20-12. Clinical example of Schanz pin placement, medially into the talar body for distractor application. The pin is placed into the central talar body using a small incision at the inferior apex of the anterior colliculus of the medial malleolus.

- Percutaneously placed point-to-point clamp applications are excellent for reduction and compression of closed (e.g., oblique or spiral) tibial shaft fractures (Fig. 20-13).

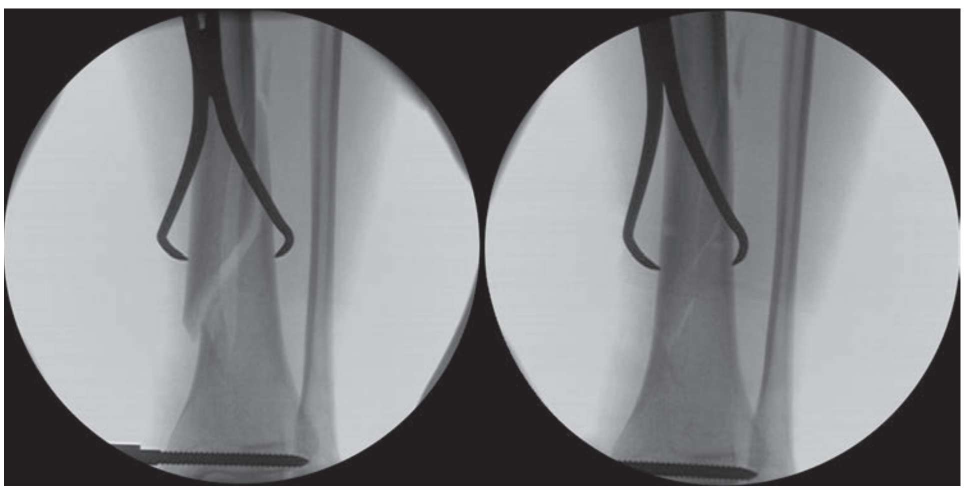


Figure 20-13. In many fracture patterns, a pointed Weber clamp placed through 0.5- to 1-cm (percutaneous) "stab" incisions can be very effective for fracture reduction.

  - Avoid crushing of the skin during clamp application.
  - Percutaneous technique minimizes soft tissue injury.
  - Incisions for clamp should be based on fluoroscopy, to allow for one tine on each fragment along the ideal vector for interfragmentary compression.
  - Large or medium pointed bone reduction clamps (Weber) are ideal for most limbs and fractures.
  - Spiral or oblique fractures are most amenable to clamp placement.
  - Retain clamps until interlocking screws are placed.
- Provisional unicortical plating for maintenance of reduction in open fractures is helpful as long as it does not require additional dissection or wound extension beyond that required for adequate debridement (Figs. 20-14–20-17).[5]

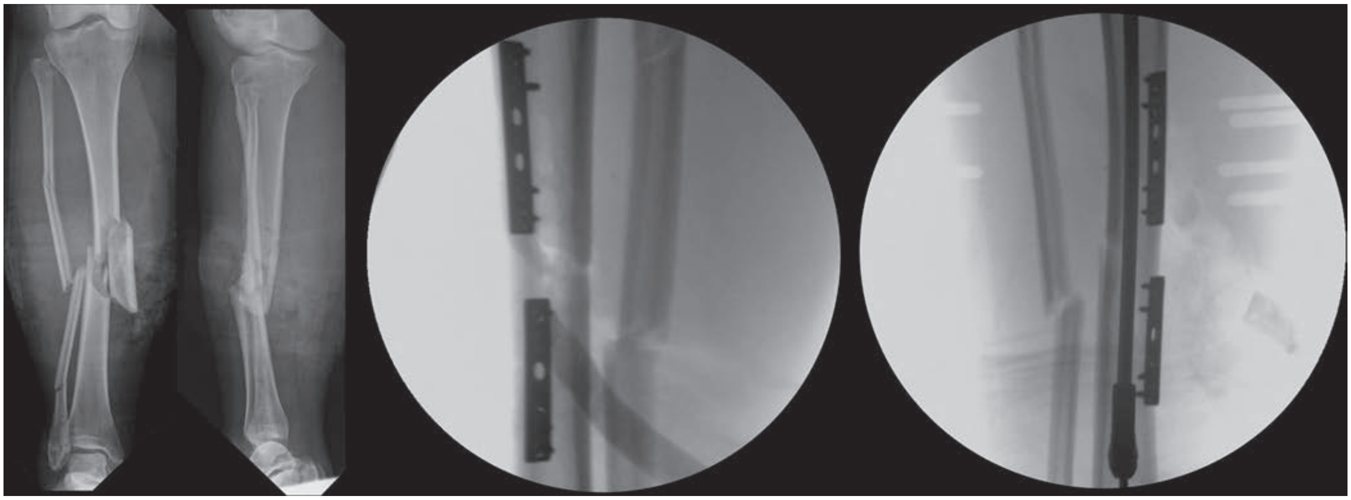


Figure 20-14. Open segmental tibial shaft fracture. **Left**, initial radiographs; **Center**, provisional unicortical plate fixation; **Right**, preparation of intramedullary canal for nailing.

Figure 20-15. Soft tissue injury of open Type 3A segmental tibial shaft fracture at presentation.

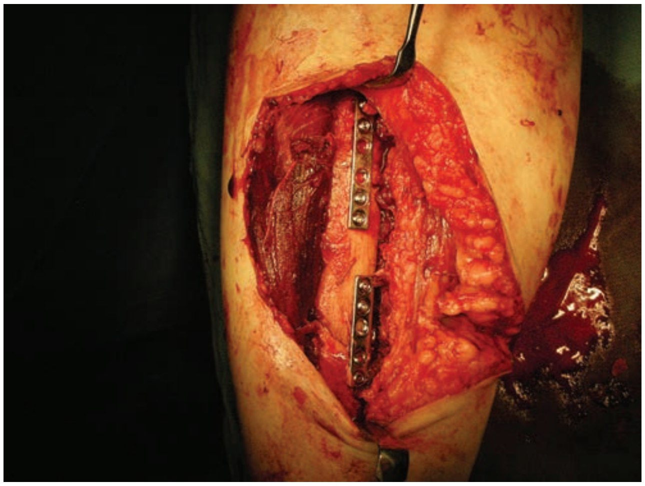


Figure 20-16. Example of a Type 3A segmental open tibial fracture associated with substantial periosteal stripping. After debridement, plates and unicortical screws were used for reduction maintenance during reaming and nail placement.

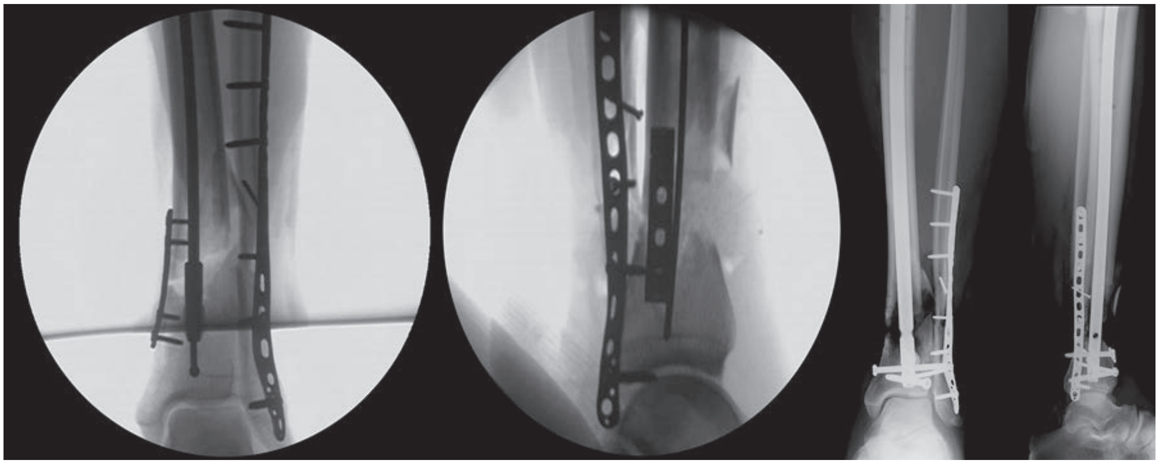


Figure 20-17. Another example of provisional plating of an open distal tibial fracture, prior to intramedullary nailing. Temporary antibiotic cement beads were placed in this defect prior to closure.

- Blocking (or "Poller") screws or temporary blocking pins/wires can be placed prior to reaming and nail insertion to "recreate" deficient cortices and narrow the effective medullary canal available for the nail (Fig. 20-18).[6]

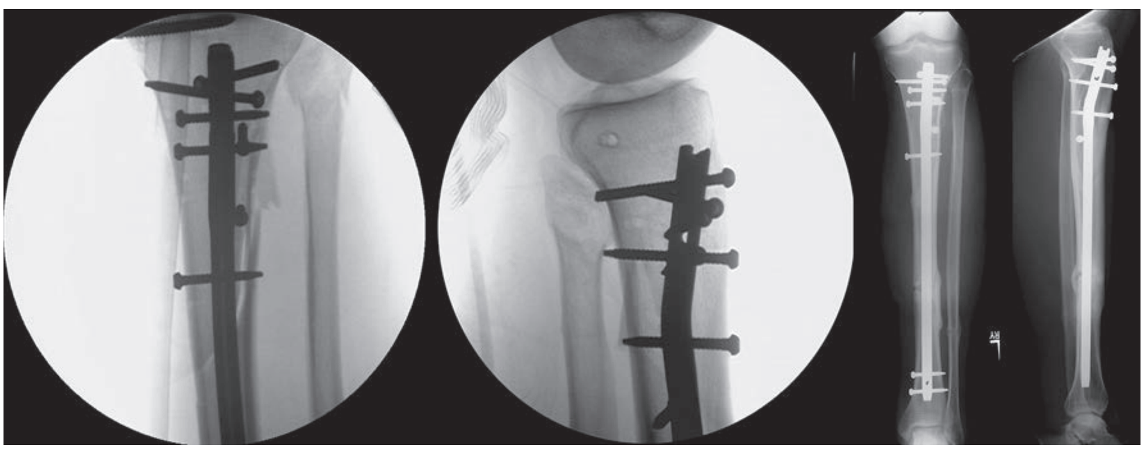


Figure 20-18. Multiple blocking screws can be used to narrow the effective endosteal pathway, thereby preventing translational and angular deformities. These also add to the construct stability.

- In the setting of oblique or comminuted metaphyseal fractures with a mismatch between the outer nail diameter and the inner diameter of the intramedullary canal (typically, in the metaphyseal or metadiaphyseal region), the nail tends to "seek" the deficient cortex leading to translational/angular deformities.
- These blocking screws are typically placed adjacent to the desired nail path on the concave side of the deformity (Fig. 20-19).

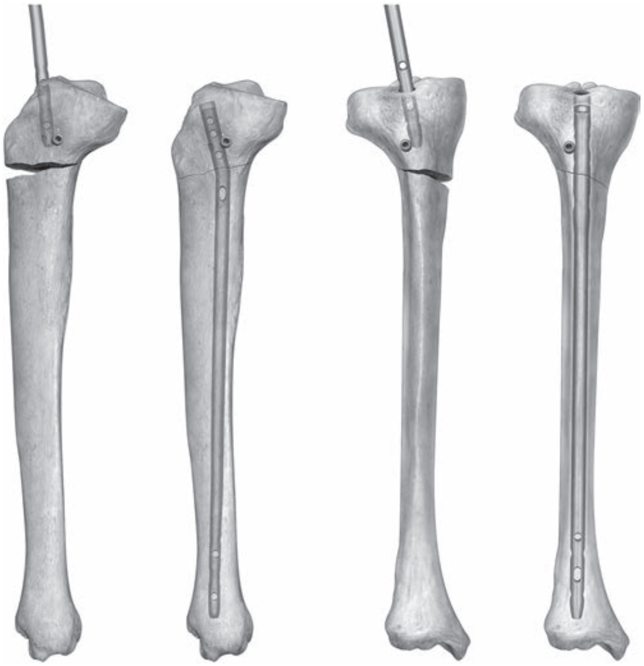


Figure 20-19. As a general principle, blocking screws are placed adjacent to the nail path, on the concave side of the deformity. This is applicable for both sagittal (**left**) and coronal (**right**) plane deformities.

- Alternatively, Steinmann pins can be used as blocking pins (Fig. 20-20).

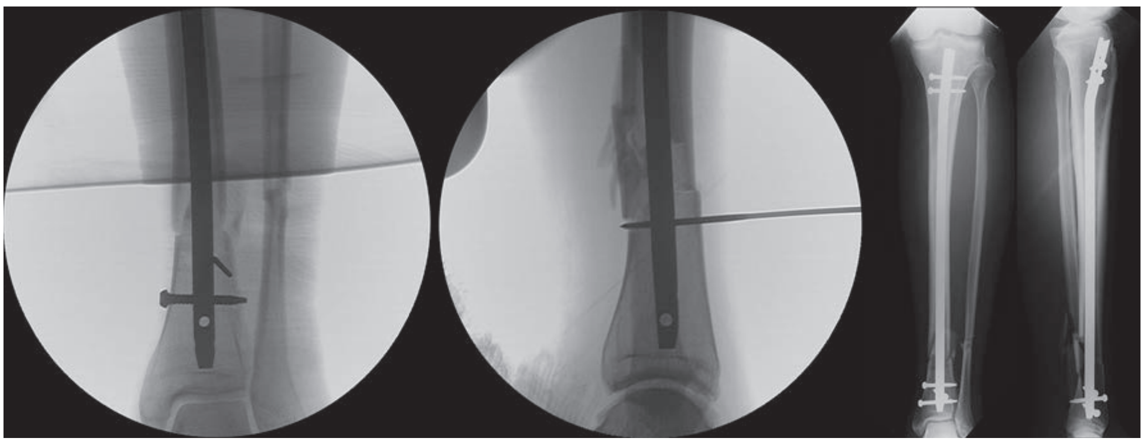


Figure 20-20. As an alternative to blocking screws, Steinmann pins may be placed to guide the wire and nail along the desired path.

- Pins should be of sufficient diameter so that they are not weakened by adjacent reaming nor deformed by nail insertion.
- Typically, 2.4- to 3.2-mm pins are adequate size depending on the intended application.
- If 3.2-mm pins are used, they may be replaced with 4.5-mm screws.
- If pins are to be removed without replacement by screws, interlocking fixation should be completed prior to pin removal

- Nailing of a tibial shaft fracture that involves a concomitant fracture of the tibial plateau or tibial plafond requires provisional and/or definitive articular stabilization prior to reaming and nail insertion (Figs. 20-21–20-23).

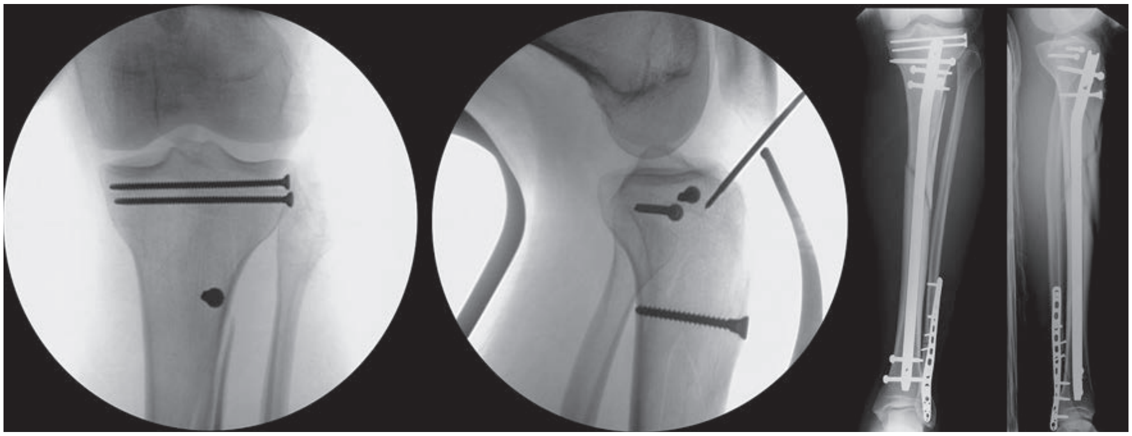


Figure 20-21. In this fracture pattern with proximal intra-articular extension, percutaneous reduction and fixation of the proximal intra-articular component was placed initially. These implants did not interfere with nail placement.

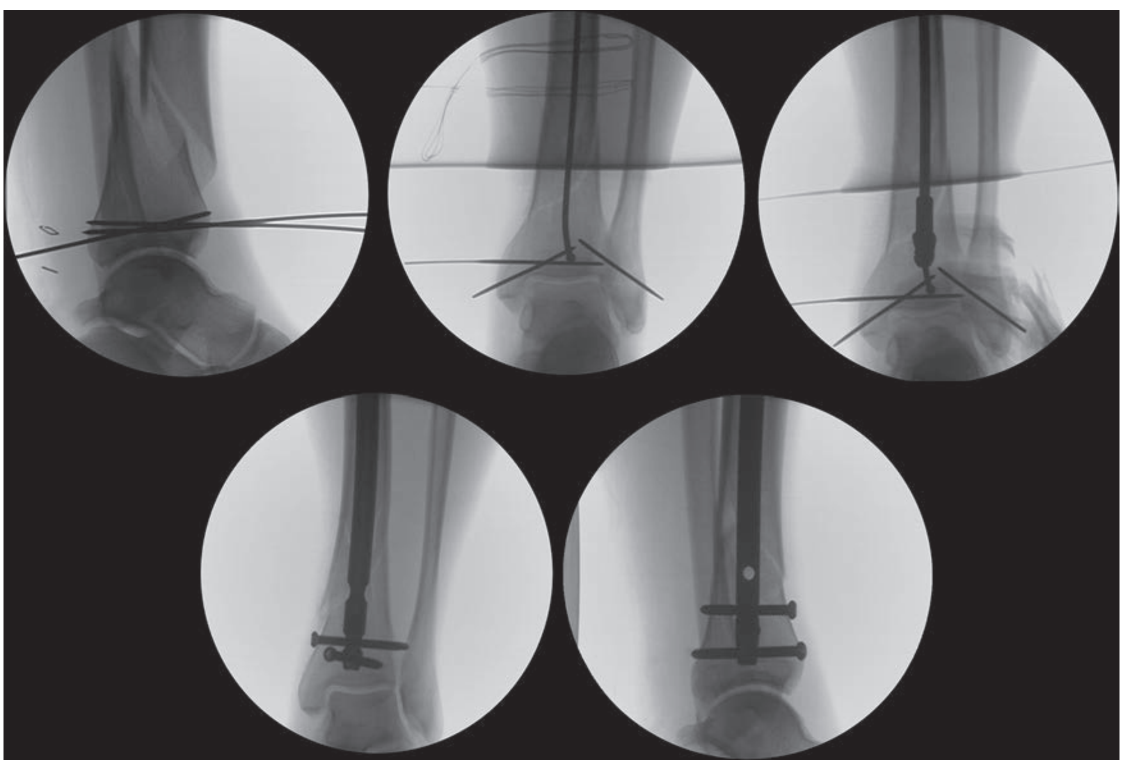


Figure 20-22. Example of using small Steinmann pins to prevent displacement of distal nondisplaced fractures during nail insertion.

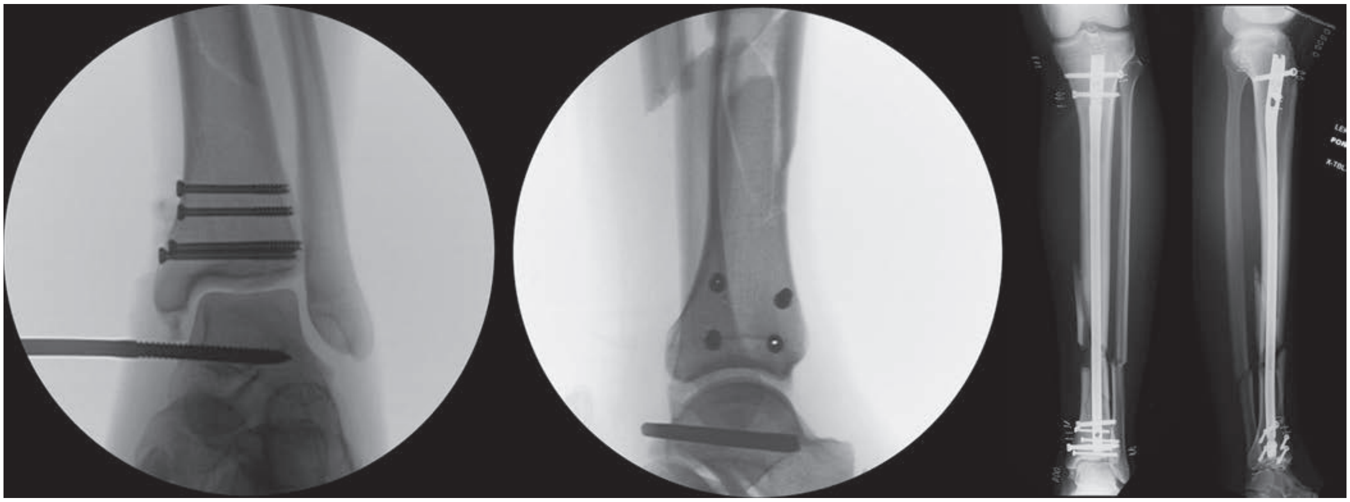


Figure 20-23. Another example using cannulated screws for ankle fracture fixation, while allowing room for distal nail placement.

- CT scanning should be considered for oblique fractures of the distal tibia, as a high incidence of concomitant, often noncontiguous, posterior malleolar and tibial plafond fractures have been described.[7]

- For segmental tibial shaft fractures, if the proximal fracture line is in the proximal third of the tibia, even if minimally displaced, stabilization of this prior to guide wire placement may prevent fracture displacement.
  - Adjuncts to reduction and maintenance of reduction include pointed clamp application, strategically placed lag screws, or plate/screws.
- Nail insertion point: locate the starting point for the tibial guide wire.[8]
  - Directly over the medial edge of the lateral tibial spine on an AP fluoroscopic view.
  - Ensure proper rotation by noting patella shadow centrally over femoral condyles, and a “normal” relationship of proximal tibiofibular joint.
  - At the anterior edge of the tibial plateau on a lateral fluoroscopic radiograph (Fig. 20-24).

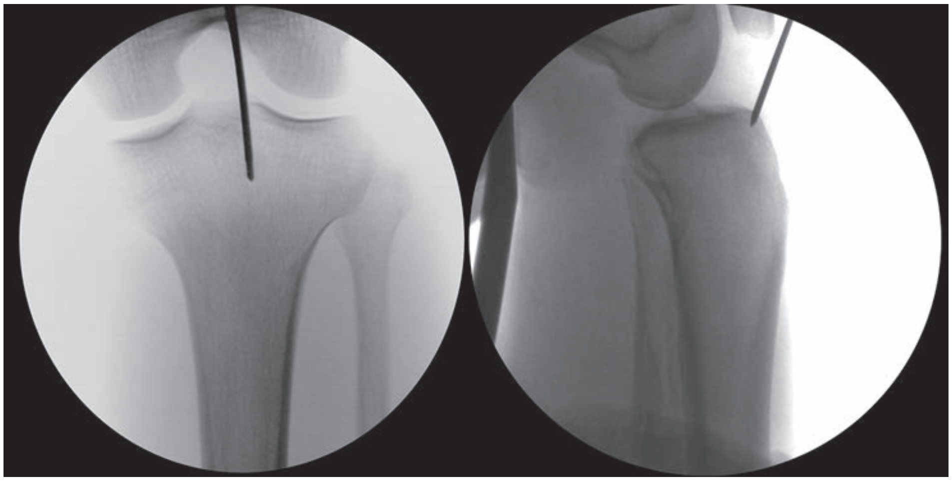


Figure 20-24. The ideal starting point is just medial to the lateral tibial spine on the AP view and on the anterior edge of the tibial plateau on the lateral view.

- Aim the guide wire centrally in the medullary canal on the lateral view as it passes distally.
  - Generally the tendency is to be too posterior.
  - Flex knee to minimize impaction on the posterior cortical surface during guide wire passage, reaming, and nail insertion.
- If starting site is acceptable, but wire is trending away from an ideal nail path as it is passed into the proximal tibia, stop passage after only a few centimeters and use starting drill or awl, which is more stiff, to achieve desired path into proximal metaphysis.
- Create a gentle bend approximately 1cm above the tip of the ball-tipped guidewire to assist in directing the guidewire toward the proper trajectory.
- In revision situations, changing a previous nail path can be difficult.
  - Blocking an off-axis nail entry site may be necessary.
  - Use an intramedullary plate (3.5/4.5 narrow DCP) placed temporarily within the prior nail path to encourage eccentric reaming, thereby moving the entry portal to a preferred location (Fig. 20-25).

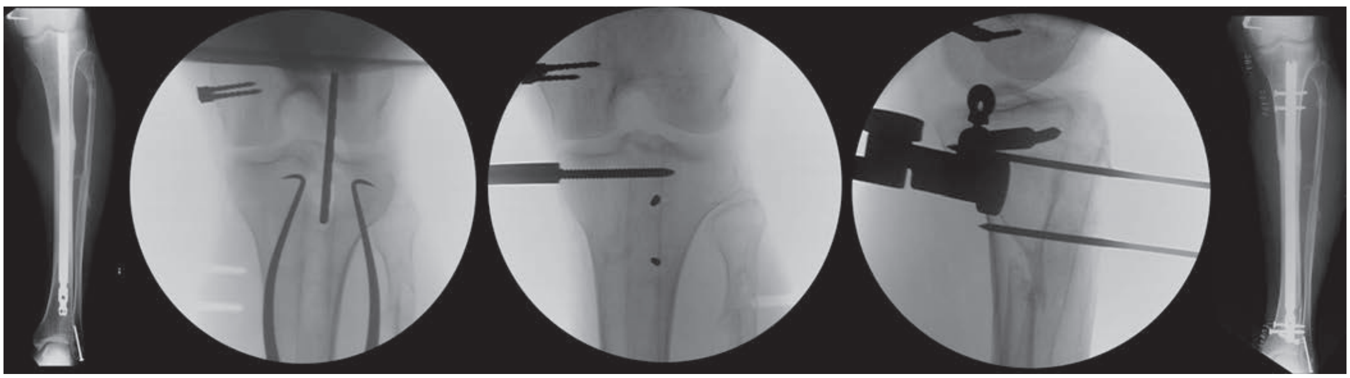


Figure 20-25. In this patient, a tibial varus malunion developed in part due to an improper starting point. During the revision procedure, an intramedullary plate was used to force the reamer medially thereby creating a new entry portal and nail path within the proximal tibia. Prior to nail insertion, two 3.0-mm Steinmann pins were used to "block" the original nail path and these were removed only after locking the new nail in its new position. These techniques permitted a much improved reduction and restored limb alignment.

  - Consider tying a suture to the plate to avoid losing in canal, or use a graft such as a fibular allograft to fill or partially block an improper starting hole, and blocking wires to direct the nail.
- To minimize the posterior translation of the distal fragment in proximal third tibial fractures, sufficient traction must be applied to disengage the posterior tibial cortices so as to permit reduction (e.g., posterior translational displacement) of the distal tibial segment (Fig. 20-26).

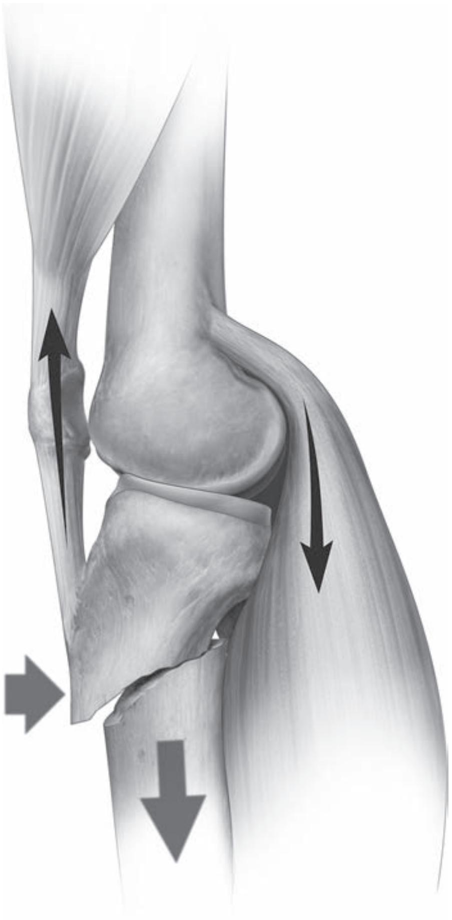


Figure 20-26. Sagittal plane translational and angular deformity following proximal tibial fracture can be accentuated by the pull of the extensor mechanism and the gastrocnemius muscle (*black arrows*) and shortening of the tibia. It is important to correct this deformity prior to placing internal fixation. Maneuvers include traction on the distal segment to "unlock" the posterior cortex, and posterior translation/"derotation" of the proximal fragment (*gray arrows*).

- Place the tip of the ball-tipped guide wire in the center of the distal metaphysis above the center of the talus on the ankle mortise view and over the center of the talar dome on the lateral ankle view.
  - Use the bent ball tip to pivot the wire path, after the ball is anchored in physeal scar (Fig. 20-27).

Figure 20-27. To alter the guide wire position and reamer path, first impact the ball tip firmly into the dense bone of the physeal scar. Rotation around the seated ball tip can rotate the shaft of the guide wire, improving its position prior to reaming.

- Remember that the reamer will only ream to the bend in the wire.
- In dense bone, insertion of the nail beyond the reamed path may result in distraction of the fracture and delay/nonunion.
- Ensure that the wire proximal to the bend is placed in the proper "center-center" position, so as to centralize each reamer within the distal metaphysis.

- Maintain anatomic alignment of the fracture throughout reaming and nail insertion to avoid eccentric reaming and further fracture displacement.
  - Femoral distractor may be useful for this step.
- After nail insertion, avoid fracture distraction.
  - Remove tension on the femoral distractor.
  - Options for compression of the fracture site
    - Insert distal interlocking screws first, then
    - Apply femoral distractor in compression mode, or
    - Retract the nail (backslapping) until compression is achieved (Fig. 20-28)

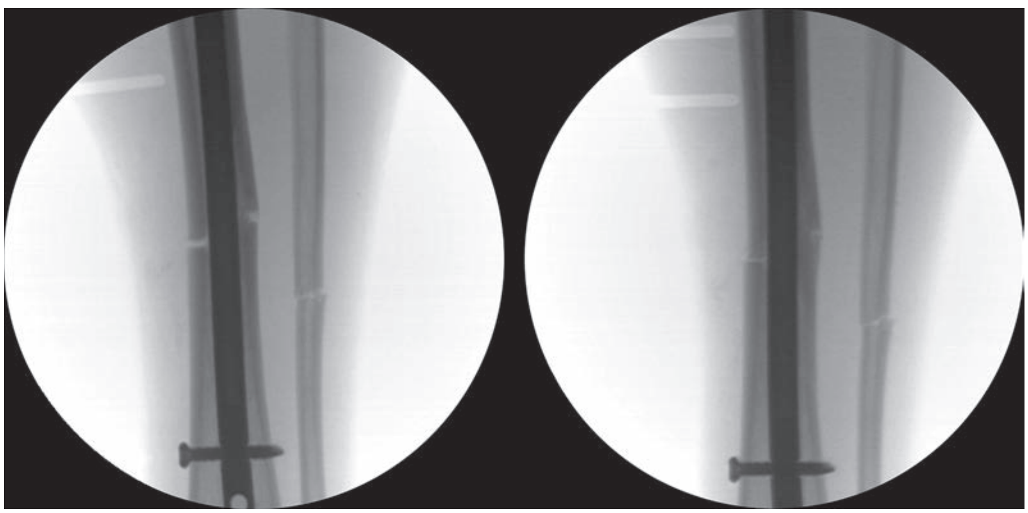


Figure 20-28. By first placing a distal interlocking screw and "backslapping" the nail, transverse and short oblique fracture gaps can be closed.

- If distal interlocking is to be completed prior to proximal locking (e.g., to compress the fracture through backslapping or compression screw application), the radiolucent triangle may not be removed without removing the nail-mounted proximal targeting guide if the knee is to be placed in extension.
  - However, less knee flexion can be obtained by flipping the radiolucent triangle so that the leg lies on the triangle's hypotenuse and the knee remains sufficiently flexed to protect the prepatellar skin and anterior patella from crush injury from the insertion guide/proximal targeting jig.

- To reduce residual distraction of a tibial fracture after nail insertion and proximal locking, consider
  - Placing the femoral distractor in compression mode.
  - Manually axially impact the limb to eliminate the distraction.
  - Placing distal interlocking screws eccentrically by predrilling the initial pilot hole slightly distally (2 to 3 mm) to the axial equator of the hole in the nail. This can usually eliminate distraction of 2 to 3 mm.

- Supplemental locking bolts in multiple planes should be considered when using nails for fixation of proximal or distal tibial fractures.[9]
- Locking bolts may be placed through a plate to assist as a reduction tool (Fig. 20-29).

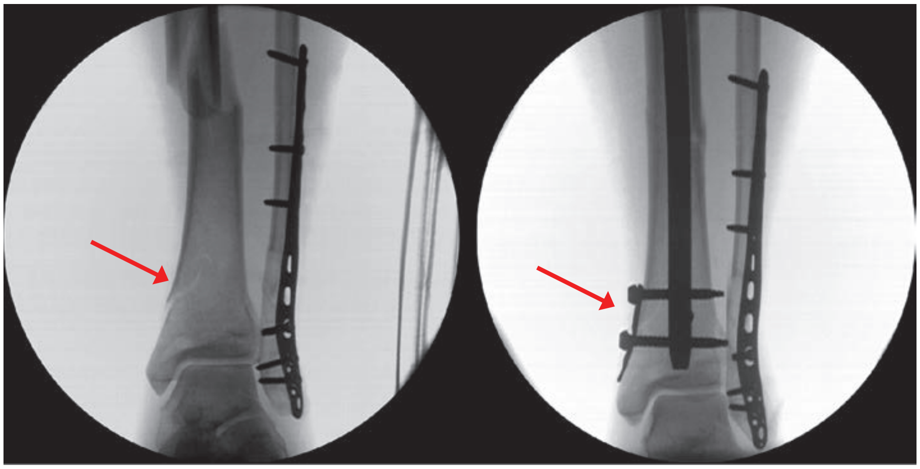


Figure 20-29. In this case, the distal fracture line remained slightly displaced. A one-third tubular plate was used in conjunction with the interlocking screws as an indirect reduction tool.

Fibular Nailing

- If the fibula can be aligned with little difficulty prior to tibial shaft fracture nailing, consider insertion of an antegrade or retrograde fibular rod to further stabilize the limb's soft tissues and this fracture.
- Fibular reduction can assist the surgeon in realigning the tibia if both the proximal and distal tibio-fibular articulations are intact, especially in tibial fractures with segmental bone loss.
- Antegrade fibular nailing.
  - Fluoroscopically, identify the axis of the fibular medullary canal and optimal starting point for nail insertion on the AP and lateral views, collinear with the fibular medullary canal.
  - Make a small longitudinal incision 2 to 5 cm proximal to the fibular head collinear with the fibular canal.
  - Dissect bluntly to the fibular head, avoiding injury to the common peroneal nerve.
    - Nerve is usually located posteriorly and distally to the fibular head, but can be displaced with trauma.
    - If indicated, identify and protect nerve using an open approach.
  - Open the medullary canal with a 2.5-mm drill bit.
  - Introduce a 2.5-mm intramedullary rod (e.g., humeral reaming guide rod or flexible titanium nail).
    - Alternatively, drill entry hole with a 3.5-mm drill to facilitate nail insertion.
  - Once the fibular medullary canal has been accessed and the rod's position confirmed on AP and lateral fluoroscopic views, the rod may be advanced slowly until the tip of the rod has reached the fracture.
  - The fibular fracture should be realigned and the rod advanced into the distal segment(s) for the majority of the fibula's length.
    - Insertion can be aided using an oscillating drill.

- Prior to seating of the rod at the desired fibular length, the rod should be cut to the appropriate length and bent 180 degrees.
- The fibular rod may now be seated with the proximal “hook” (cut end) inserted (but not completely sunk) anteriorly (to avoid common peroneal nerve injury) into the fibular head to prevent rotation and loosening of the fixation.
- Leaving the apex of the proximal rod out of bone facilitates later implant removal if necessary (Fig. 20-30).

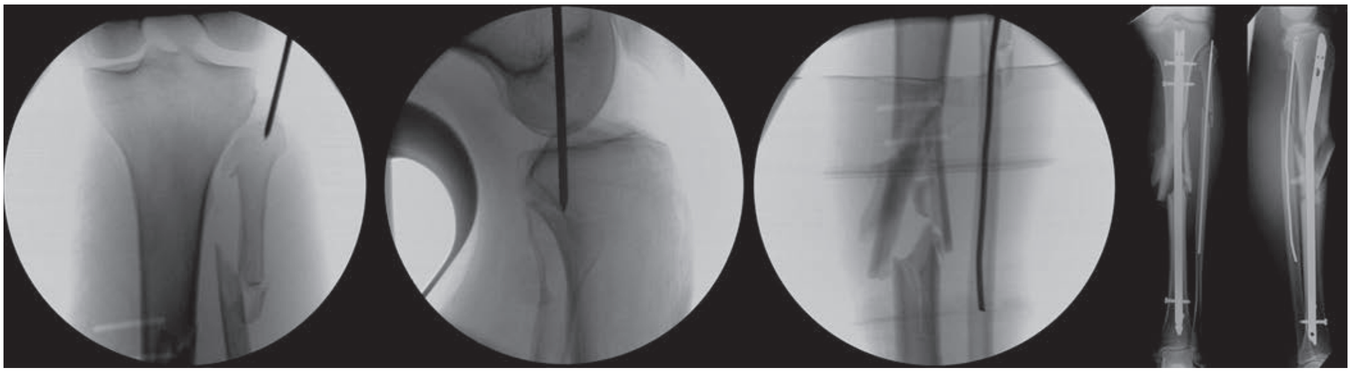


Figure 20-30. Example of antegrade fibular nailing prior to tibial nailing.

- Retrograde fibular nailing
  - Fluoroscopically identify the axis of the fibula and optimal starting point for nail insertion on the AP and lateral views.
  - Make a small longitudinal incision 3 to 5 cm distal to the lateral malleolus, in line with the anticipated entry point and collinear with fibular medullary canal on biplanar fluoroscopic views.
  - Dissect bluntly to the tip of the lateral malleolus.
  - Create a starting point using a 2.5-or 3.5-mm drill (Fig. 20-31).

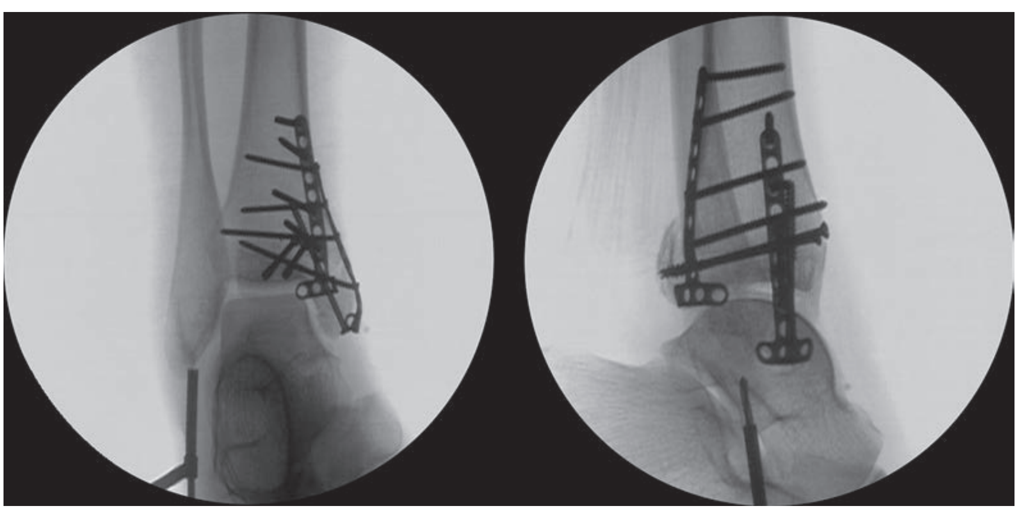


Figure 20-31. For retrograde fibular nailing, the drill bit is placed on the tip of the fibula, and its position and trajectory is verified on AP and lateral fluoroscopy.

- Open the medullary canal with a 2.5- or 3.5-mm drill.
- Insert a 2.5-mm intramedullary device (e.g., humeral reaming rod) into the distal fibula.
- Once the fibular medullary canal has been accessed and the rod's position confirmed on AP and lateral fluoroscopic views, the rod may be advanced in retrograde fashion.
- The fibular fracture should be realigned, and the rod advanced into the proximal segment(s) for the majority of the fibula's length.
- Prior to seating of the rod at the desired fibular length, the rod should be cut to an appropriate length and bent to prevent migration.
- The fibular rod should now be seated with the distal "hook" (cut end) inserted (but not completely sunk) anteriorly into the lateral malleolus to prevent rotation and loosening of the fixation (Fig. 20-32).
- Leaving the apex of the distal rod out of bone facilitates implant removal, if necessary.

Figure 20-32. Retrograde fibular rod used to assist in reduction and augment limb stability of an open tibial and fibular fracture.

Plating of Tibial Shaft Fractures

- Percutaneous or minimally invasive plate fixation of tibial shaft fractures is an option in certain situations.
  - Internal fixation of tibial shaft fractures in skeletally immature patients.
  - Compression plating of simple midshaft tibial fracture patterns; though intramedullary nailing remains preferred in most cases.
    - Medial plates are often best avoided in open fractures and in closed fractures with injured anteromedial soft tissues.
  - High-level athlete to minimize at risk of anterior knee pain.
  - Burn, infection, or other soft tissue trauma at nail insertion site.
  - Obliterated canal.
  - Canal too small.
  - Long term external fixator.
  - Medullary osteomyelitis (prior nailing).
  - Selected nonunions or malunions
- Selected nonunions or malunions
- Bridge plating of comminuted segmental tibial shaft fractures.
  - Management of fractures located at the proximal or distal metadiaphyseal junctions.[10]
  - Management of fractures involving the tibial shaft and tibial plateau or pilon (Fig. 20-33).

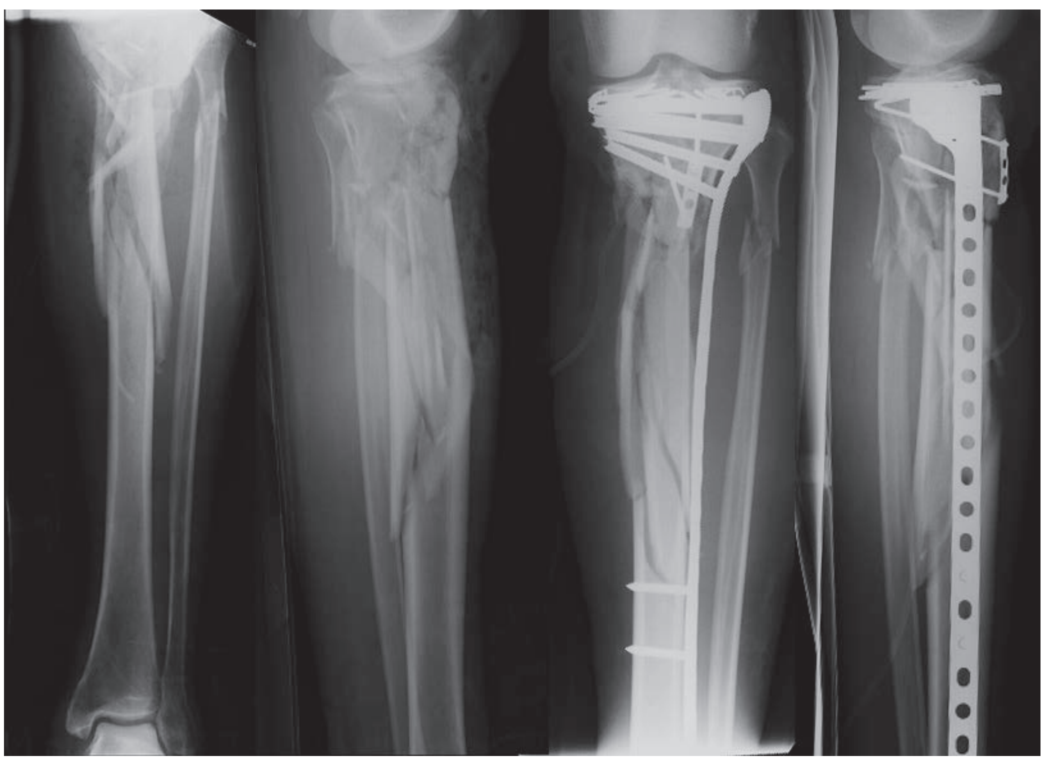


Figure 20-33. Bridge plating can be an effective option for high energy proximal tibial fractures.

- Minimize soft-tissue stripping and further devascularization of the fracture zone.

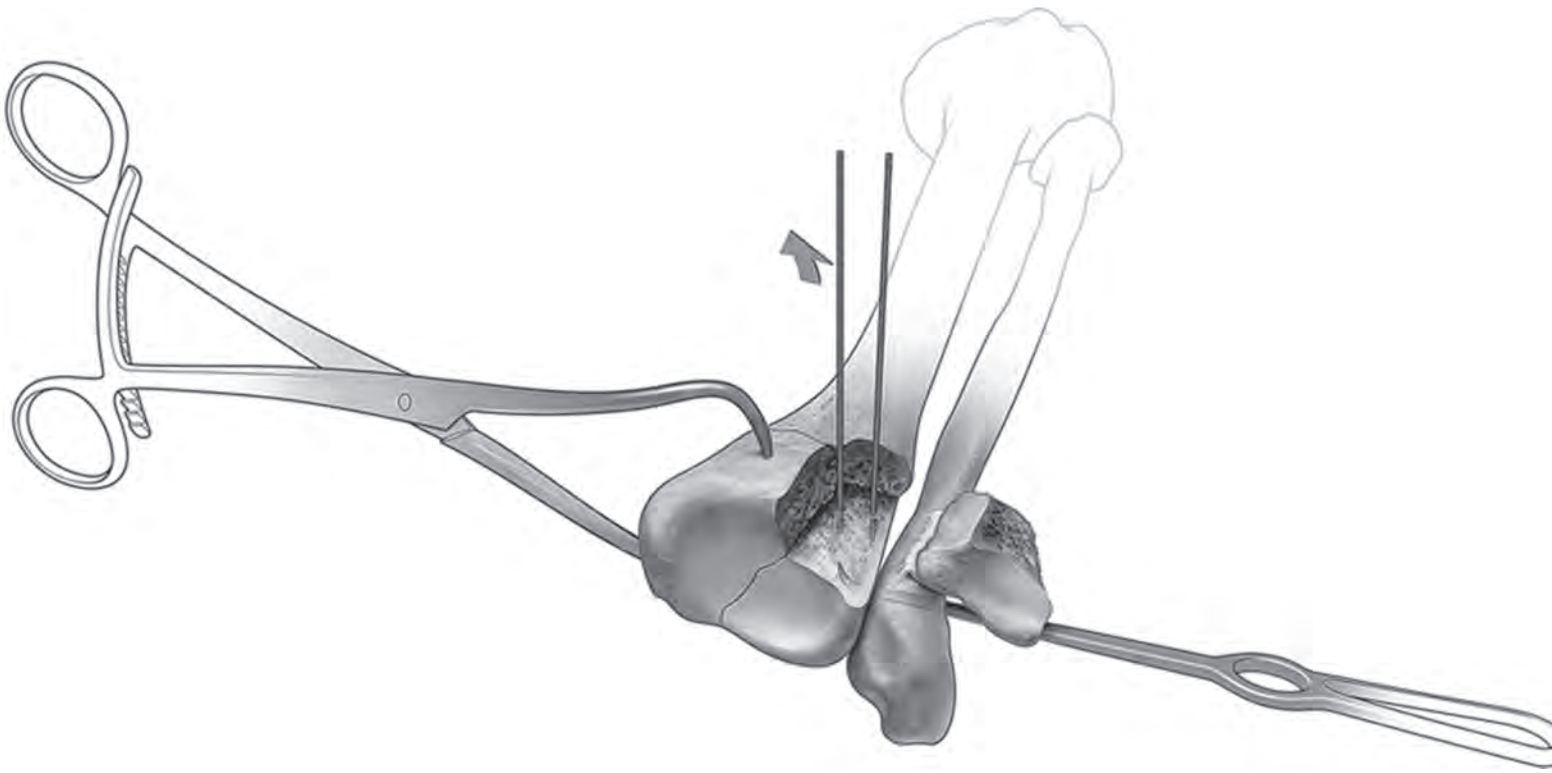
References

1. Tornetta P, III, Riina J, Geller J, et al. Intraarticular anatomic risks of tibial nailing. *J Orthop Trauma*. 1999;13:247–251.
2. Maheshwari R, Taitsman LA, Barei DP. Single-incision fasciotomy for compartmental syndrome of the leg in patients with diaphyseal tibial fractures. *J Orthop Trauma*. 2008;22:723–730.
3. Nowotarski PJ, Turen CH, Brumback RJ, et al. Conversion of external fixation to intramedullary nailing for fractures of the shaft of the femur in multiply injured patients. *J Bone Joint surg Am*. 2000;82(6):781–788.
4. Rubinstein RA, Jr, Green JM, Duwelius PJ. Intramedullary interlocked tibia nailing: a new technique (preliminary report). *J Orthop Trauma*. 1992;6:90–95.
5. Dunbar RP, Nork SE, Barei DP, et al. Provisional plating of Type III open tibia fractures prior to intramedullary nailing. *J Orthop Trauma*. 2005;19:412–414.
6. Krettek C, Miclau T, Schandelmaier P, et al. The mechanical effect of blocking screws ("Poller screws") in stabilizing tibia fractures with short proximal or distal fragments after insertion of small-diameter intramedullary nails. *J Orthop Trauma*. 1999;13:550–553.
7. Boraiah S, Gardner MJ, Helfet DL, et al. High association of posterior malleolus fractures with spiral distal tibial fractures. *Clin Orthop Relat Res*. 2008;466:1692–1698.
8. Schmidt AH, Templeman DC, Tornetta P, et al. Anatomic assessment of the proper insertion site for a tibial intramedullary nail. *J Orthop Trauma*. 2003;17:75–76.
9. Nork SE, Barei DP, Schildhauer TA, et al. Intramedullary nailing of proximal quarter tibial fractures. *J Orthop Trauma*. 2006;20:523–528.
10. Vallier HA, Le TT, Bedi A. Radiographic and clinical comparisons of distal tibia shaft fractures (4 to 11 cm proximal to the plafond): plating versus intramedullary nailing. *J Orthop Trauma*. 2008;22:307–311.

Section 9

Ankle

Sean E. Nork



Chapter 21

Pilon Fractures

Michael J. Gardner

Sterile Instruments/Equipment

- Headlight
- Tourniquet if desired
- Femoral distractor
- Large and small pointed bone reduction clamps (Weber clamps)
- Dental picks and Freer elevators
- Implants: anatomically contoured distal tibial periarticular plates, locked and/or nonlocked; medial and lateral
  - Small fragment plates and screws
  - Periarticular plates
  - Mini-fragment screws and mini-fragment plates (2.0/2.4 mm) depending on fracture requirements
- K-wires and wire driver/drill

Surgical Approaches (Fig. 21-1)

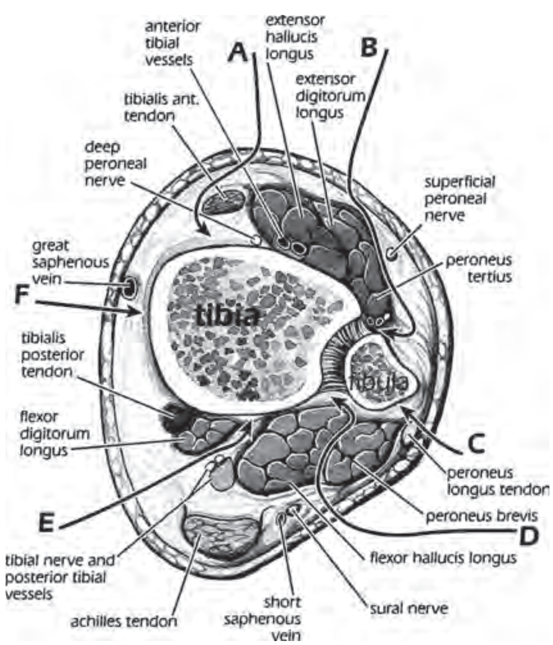


Figure 21-1. Cross-sectional schematic showing the intervals for common approaches to pilon fractures. *A*, Anteromedial. *B*, Anterolateral. *C*, Posterolateral (fibula). *D*, Posterolateral (tibia). *E*, Posteromedial. *F*, Medial. (From Howard JL, Agel J, Barei DP, et al. A prospective study evaluating incision placement and wound healing for tibial plafond fractures. *J Orthop Trauma*. 2008;22:299–305. With permission.)

Anteromedial Approach

- Positioning
  - Supine on a radiolucent table.
  - Bring patient to the foot end of the table.
  - Place small bump under the ipsilateral hip and torso.
  - Place pneumatic tourniquet on the ipsilateral thigh if desired.
  - Elevate the leg on soft ramp cushion to facilitate lateral radiographs and apply exclusionary drape lower limb (Fig. 21-2).

Figure 21-2. Supine patient positioning for anteromedial or anterolateral approach to a pilon fracture.

- Incision starts proximally, 1 cm lateral to tibial crest.
- Curves medially, approximately 60 to 80 degrees at joint line.
- Continues to a point 1 cm distal to medial malleolus (Fig. 21-3).

Figure 21-3. Incision for an extensile anteromedial approach for pilon fractures.

- Superficial dissection to fascia, sweep subcutaneous tissue off fascia, working medially, just to margin of the tibial crest (Fig. 21-4).

Figure 21-4. Superficial dissection of an anteromedial approach to the level of the fascia.

- Make full thickness incision in fascia and periosteum just medial to anterior tibialis tendon and elevate with soft tissue flap.
  - Take care not to violate the tendon sheath, which is elevated extraperiosteally or with periosteum at fracture site (Fig. 21-5).

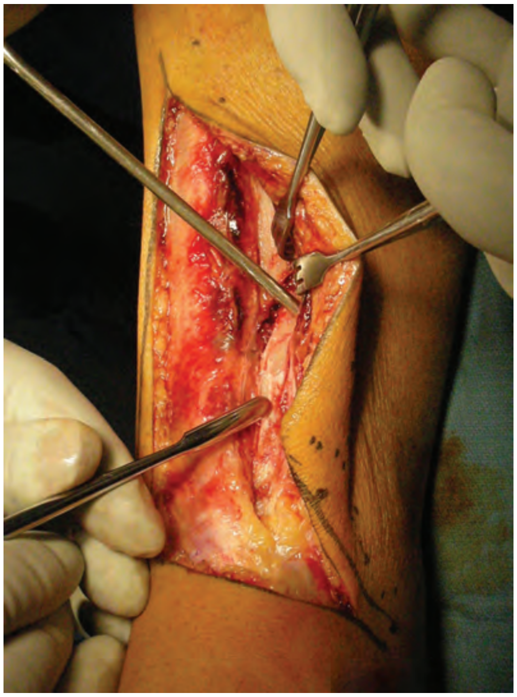


Figure 21-5. A full thickness flap is elevated just medial to the anterior tibialis tendon that allows for anatomic closure.

- Alternatively, elevate the subcutaneous layer off the periosteum medially, and make a separate "window" incision in periosteum, as needed.
  - This results in less periosteal stripping but leaves a thinner subcutaneous flap and perhaps should be avoided in poor hosts (smokers, elderly, compromised vascularity, etc.).

- Avoid the greater saphenous nerve and vein medially in the distal limb of the incision. Retract vein medially, if necessary.
- Make arthrotomy over dominant anterior (sagittal) fracture line.
- Use a laminar spreader in the metaphyseal fracture line, if necessary, to expose the metaphyseal and articular surface.
  - Take care not to injure or comminute cortical interdigitations, especially in patients with brittle bone or osteopenia (Fig. 21-6).

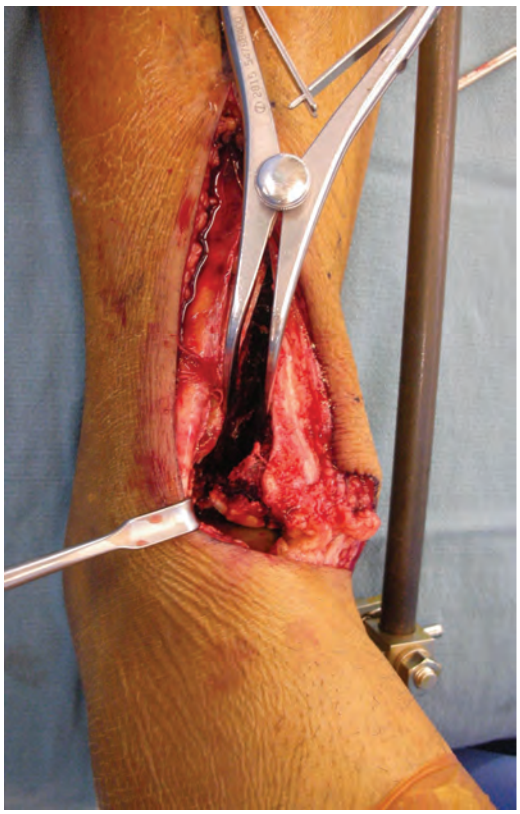


Figure 21-6. Depending on the fracture pattern, the fracture gap may be distracted for access to the articular fragments.

- Deep closure is critical.
  - Reapproximate soft tissue edges of full thickness flaps using absorbable braided suture.
  - Place all sutures and clamps provisionally.
  - After all are in place, use sutures to mobilize retracted soft tissues "en mass." Then tie each suture sequentially.

- Skin is closed with Allgower-Donati stitches using 3-0 Nylon sutures (Fig. 21-7).

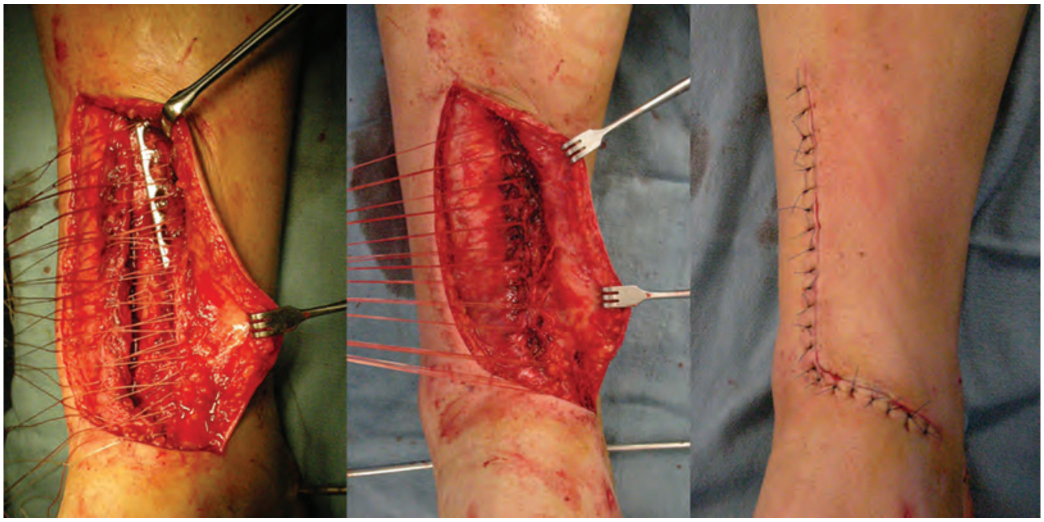


Figure 21-7. The full thickness deep layer is closed with interrupted absorbable suture, and clamped prior to tissue mobilization and knot tying. This allows distribution of tissue tension, ensuring a watertight closure and minimizing tissue tearing. Interrupted Allgöwer-Donati sutures are placed to minimize the skin edge hypoxia.

Anterolateral Approach

- Positioning
  - Supine on a radiolucent table.
  - Bring patient to the end of the table.
  - Place small bump under the ipsilateral hip and torso.
  - Place pneumatic tourniquet on the ipsilateral thigh if desired.
  - Elevate the leg on soft ramp cushion to facilitate lateral radiographs.
- Incision is longitudinal, 2 to 4 cm lateral to tibial crest proximally approximately half way between the tibia and fibula; distally it is in line with the fourth ray of the foot.
- The proximal extension of the incision is usually limited to approximately 7 cm above the joint line due to the orientation and origin of the crossing anterior compartment muscles.
  - The proximal screws in the plate can be inserted percutaneously after assessing the location of the superficial peroneal nerve. With percutaneous placement of proximal screws in the plate, the deep peroneal nerve and vascular structures are at risk and should be avoided during drill and screw insertions.
- At the level of the ankle joint, the incision is centered over the mortise.

- Extends distally in line with the fourth metatarsal over the talar dome and proximal neck, if necessary (Fig. 21-8).

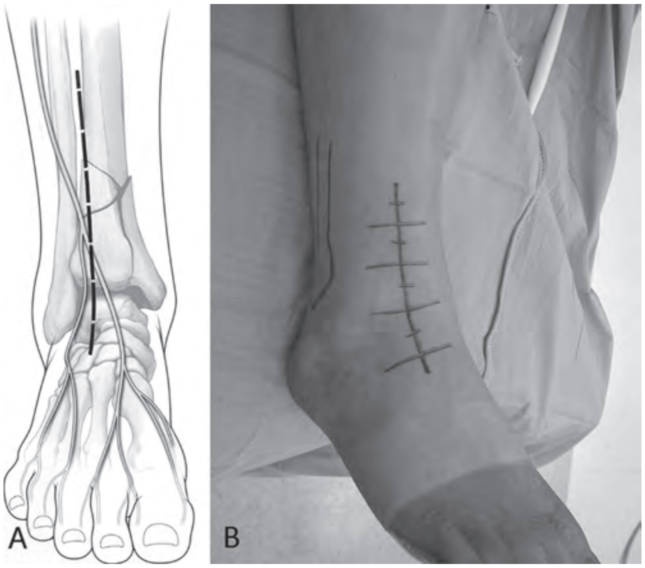


Figure 21-8. **A:** This schematic demonstrates the location of the anterolateral surgical incision. The incision is typically placed in line with the fourth metatarsal and centered at the ankle joint. The proximal extension is usually limited by the origin of the anterior compartment musculature. **B:** A typical incision location and length. This allows for the exposure of the articular surface for reduction and placement of plates at the distal tibial metaphysis. Proximal plate placement and fixation typically requires an additional approach more proximally or, more frequently, multiple small incisions for lateral to medial screw placement. Distally, the talar neck may be exposed to allow for the placement of a pin in the talus and for distraction across the ankle joint. (From Nork SE, Barei DP, Gardner MJ, et al. Anterolateral approach for pilon fractures. *Tech Foot Ankle Surg*. 2009;8(2):53–59. With permission.)

- Identify superficial peroneal nerve in superficial dissection (Fig. 21-9).

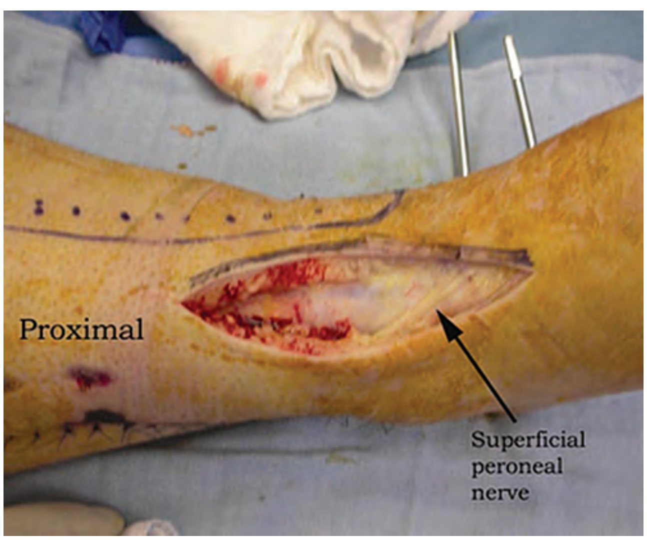


Figure 21-9. With an anterolateral approach, the superficial peroneal nerve must be identified superficial to the fascia. (From Nork SE, Barei DP, Gardner MJ, et al. Anterolateral approach for pilon fractures. *Tech Foot Ankle Surg*. 2009;8(2):53–59. With permission.)

- Retract the anterior compartment medially with its deep peritenon and tenosynovium, to expose the joint capsule.
  - It is easiest to start laterally at the tubercle of Chaput (Fig. 21-10).

Figure 21-10. The anterior compartment is retracted medially. Try to keep the anterior compartment tendons surrounded with their peritenon.

- Find the sagittal fracture plane and incise the periosteum vertically from the metaphysis to the joint, if not already disrupted by the injury.
- "T" the joint capsule tangentially to the distal tibial, leaving a rim or capsular tissue ("coronary ligament") (Fig. 21-11).

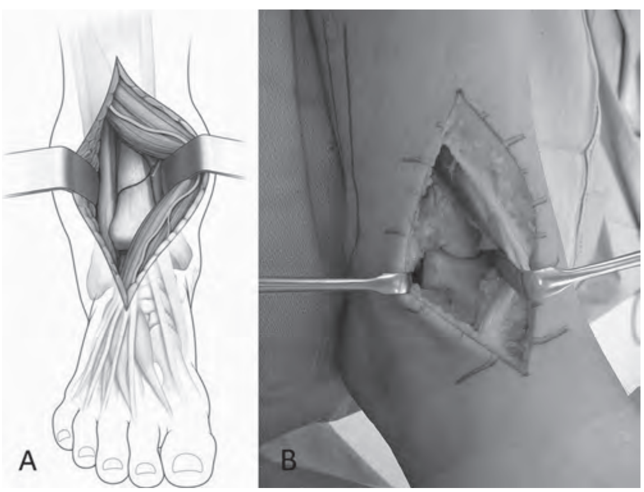


Figure 21-11. **A:** The deep dissection allows for the exposure of the distal tibial metaphysis after medial retraction of the entire anterior compartment. **B:** After an arthrotomy of the ankle joint, the distal tibia and the talar neck are exposed. The anterior tibiofibular ligaments are left attached to the anterolateral articular segment. (From Nork SE, Barei DP, Gardner MJ, et al. Anterolateral approach for pilon fractures. *Tech Foot Ankle Surg*. 2009;8(2):53–59. With permission.)

- If possible, protect the lateral anterior malleolar artery (a branch of the perforating artery, which in turn is a branch of the peroneal artery) which lays transversely on the ankle capsule and anastamoses with the anterior tibial artery.

Posteromedial Approach

- Positioning
  - Supine or prone on a radiolucent table.
    - If prone, allow sufficient space between the dorsum of foot and table for ankle dorsiflexion.
  - Bring patient to the foot end of the table.
    - If prone, consider moving patient a bit distal to the foot end of the table, so as to facilitate ankle dorsiflexion.

  - Place pneumatic tourniquet on the ipsilateral thigh if desired.
  - Elevate the leg on soft ramp cushion to facilitate lateral radiographs.
  - Consider a bump under the contralateral hip to externally rotate the affected leg, improving access for reduction and hardware placement.

- Difficult to visualize the joint (unless a distractor is used); most helpful for extraarticular cortical reductions.
- Incision is centered between the Achilles tendon and the posteromedial tibial border, over PT/FDL/FHL tendons of posterior compartments.
- Several intervals or "windows" can be chosen to approach the fracture for reduction and fixation: between the tibia, the posterior tibialis, the flexor digitorum longus, the posterior tibial neurovascular bundle, and the flexor hallucis longus.
  - One or more windows may be used depending on the location of the fracture line(s) and desired implant placement and screw orientation (Fig. 21-12).

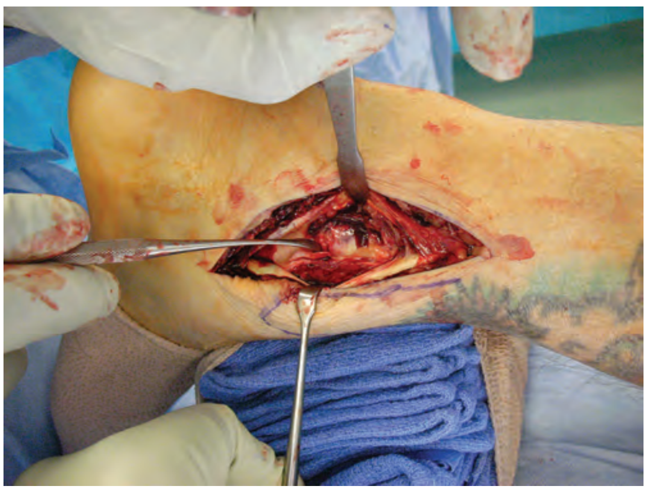


Figure 21-12. Posteromedial approach to a left ankle in the prone position. The posterior tibialis tendon is retracted anteriorly and the flexor digitorum longus and neurovascular bundle are retracted posteriorly for access to the posteromedial distal tibia.

Posterolateral Approach

- Positioning.
  - Semilateral or prone
    - Lateral allows for simultaneous anterior exposure with adequate hip rotation.
    - If prone, see above for positioning tips (see also Fig. 21-12).
  - Bring patient to the foot end of the table.
  - Place pneumatic tourniquet on the ipsilateral thigh if desired.
  - Elevate the leg on soft ramp cushion to facilitate lateral radiographs.
- Difficult to visualize joint (unless a distractor is used); most helpful for cortical reductions.
- Incision is centered between the Achilles tendon and the posterior fibular border, if no prior fibular incision.
- Protect sural nerve crossing from middle of leg to lateral retromalleolar region distally.
- Interval is between FHL and peroneal tendons.
- Dissect lateral to medial to expose posterior tibia.
- Femoral distractor within incision to the calcaneus can help restore length.

Reduction and Implant Techniques

- To obtain intraoperative distraction of the articular surface, a small Schanz pin (4.0-mm pin, predrill with 2.5-mm bit) can be placed in the talar body/neck for a distractor.

- The threaded distractor rod should be placed posteriorly and the talar pin should be placed just distal to the articular surface in the talar body/neck.
- This configuration allows for slight plantarflexion of the talus as well as axial distraction across the tibiotalar joint.
- This improves visualization of the articular surface, and does not distract through the subtalar joint.
- If an anterolateral approach is used, the pin can be placed within the surgical wound.
- The entry point in the talar body/neck is exposed by incising the fascia of the extensor digitorum brevis and elevating the muscle belly (Figs. 21-13 and 21-14).

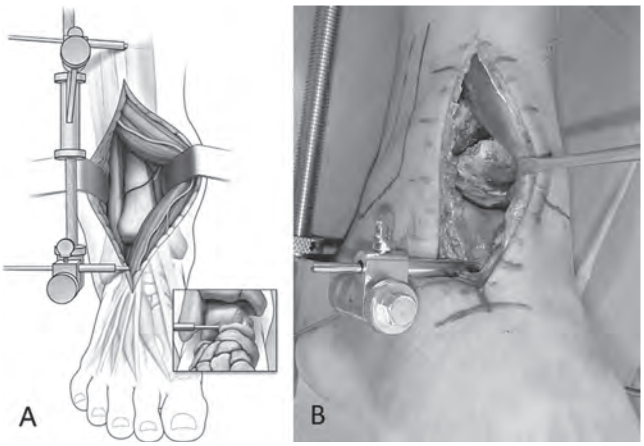


Figure 21-13. **A:** After the placement of a small femoral distractor from the tibia to the talar neck/body junction, the joint is distracted. This allows for complete visualization of the entire articular surface of the distal tibia. **B:** A clinical example of left tibial pilon fracture after the placement of a small femoral distractor. Visualization of the joint can be improved with head lamp illumination. (From Nork SE, Barei DP, Gardner MJ, et al. Anterolateral approach for pilon fractures. *Tech Foot Ankle Surg*. 2009;8(2):53–59. With permission.)

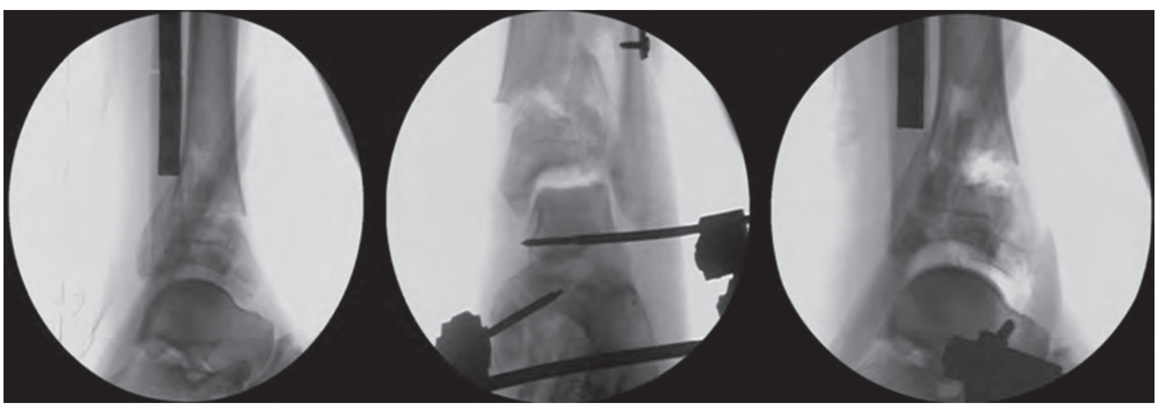


Figure 21-14. A medium distractor, with Schanz pins placed in the tibia and the talar body, creates more working space at both the metaphyseal defect behind the articular surface, and the articular surface itself (**left,** predistraction; **center and right,** postdistraction)

- An alternative to a lateral distractor is a medial distractor.
  - Both the tibial and talar body/neck pins can be placed percutaneously.
  - This allows unencumbered access to the anterolateral incision.
- For additional distraction, the spanning frame can be tensioned through the calcaneus to distract the posterior aspect of the joint.

- Talar neck pin distraction then allows for anterior joint distraction and slight plantarflexion (Fig. 21-15).

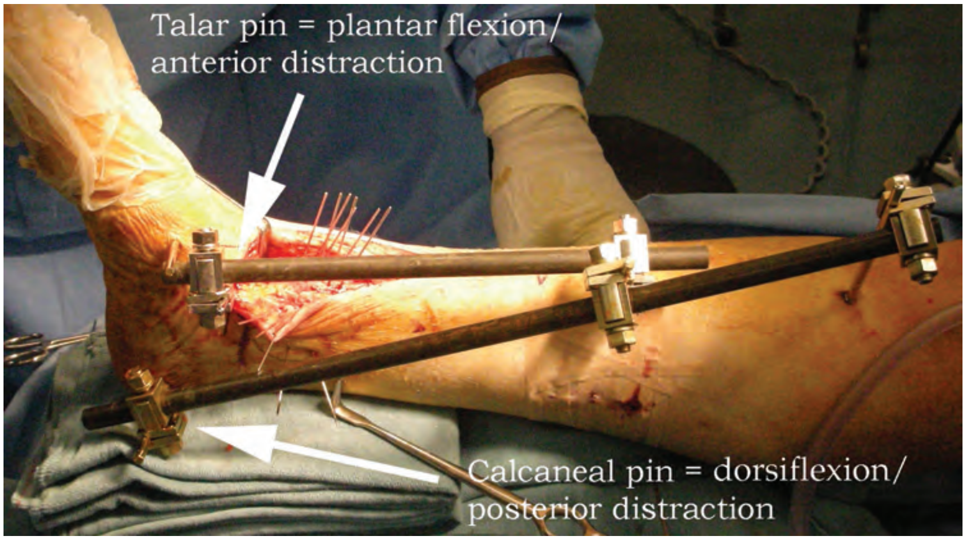


Figure 21-15. External fixation used for articular distraction, posteriorly through a calcaneal pin and anteriorly through a talar neck pin.

- Medial talar body pin placed just distal to tip of the anterior colliculus of medial malleolus results in straight axial distraction across the ankle joint.
- Distraction is usually without ankle dorsi- or plantar flexion as long as distraction moment is collinear with longitudinal axis of leg-ankle (from a proximal medial tibial pin).

- It may be difficult to distract across the ankle joint with significant metaphyseal comminution, especially if the medial malleolus or medial metaphyseal column is a free fragment.
  - In this case, it may be beneficial to apply a mini-fragment plate across metaphysis to allow articular distraction (Fig. 21-16).

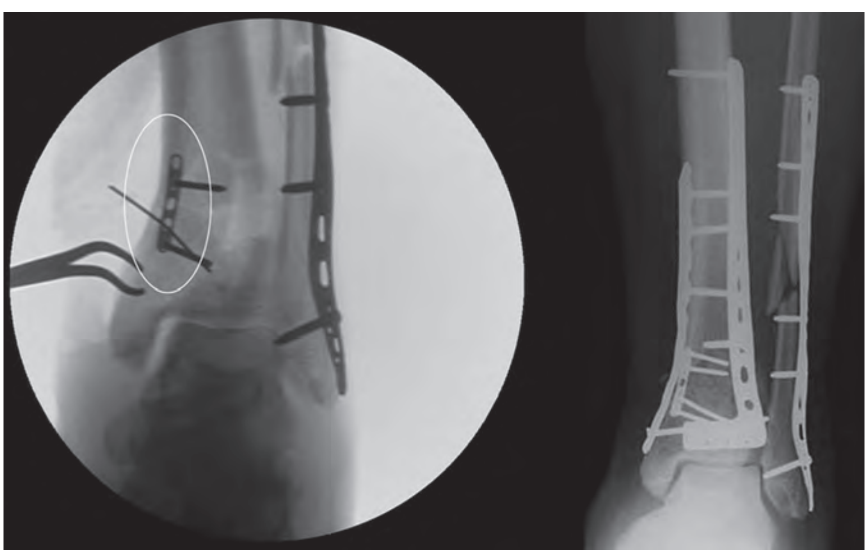


Figure 21-16. A mini-fragment plate across the metaphysis will allow provisional stabilization to allow articular distraction **(left,** *circle***)**.

- A "skid zone" (marginal impaction of the anterior aspect of posterolateral fragment) is frequently present denoting the path of the talus associated with the initial trauma and its impaction/dislocation/subluxation (Fig. 21-17).

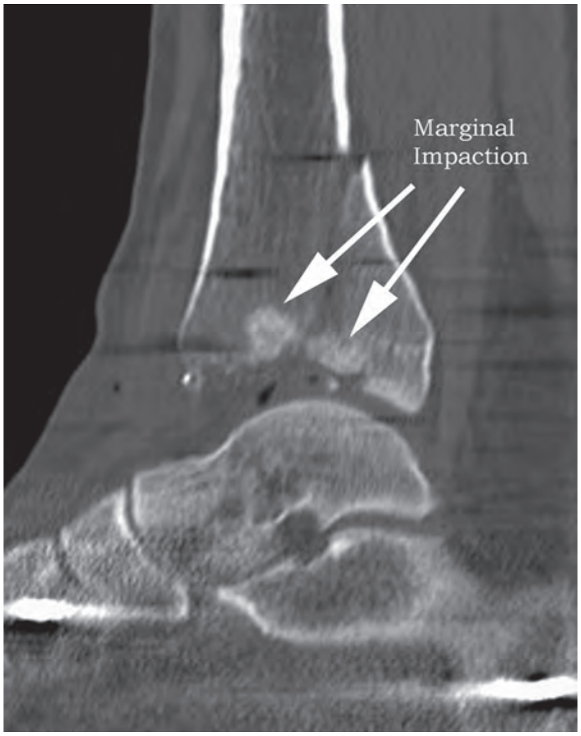


Figure 21-17. Sagittal CT image reformations should be analyzed for anterior marginal impaction of the Volkmann fragment.

- Use a curved osteotome followed by a straight osteotome to disimpact the impacted metaphyseal and subchondral bone with the attached articular surface.
- Alternatively, stacked osteotomes can be used in succession to reduce the articular surface (Figs. 21-18 and 21-19).

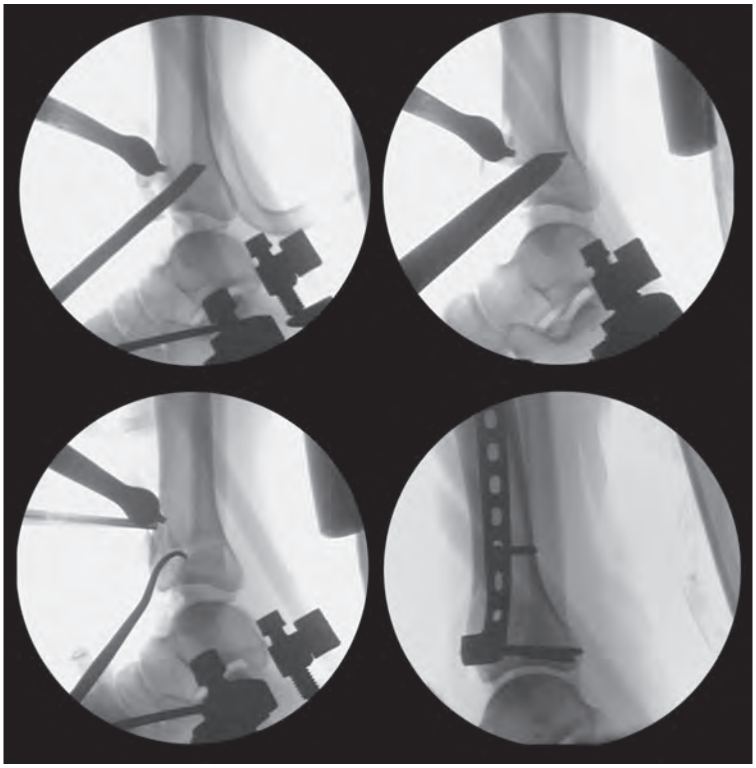


Figure 21-18. Stacked osteotomes can be used in succession to disimpact the articular surface.

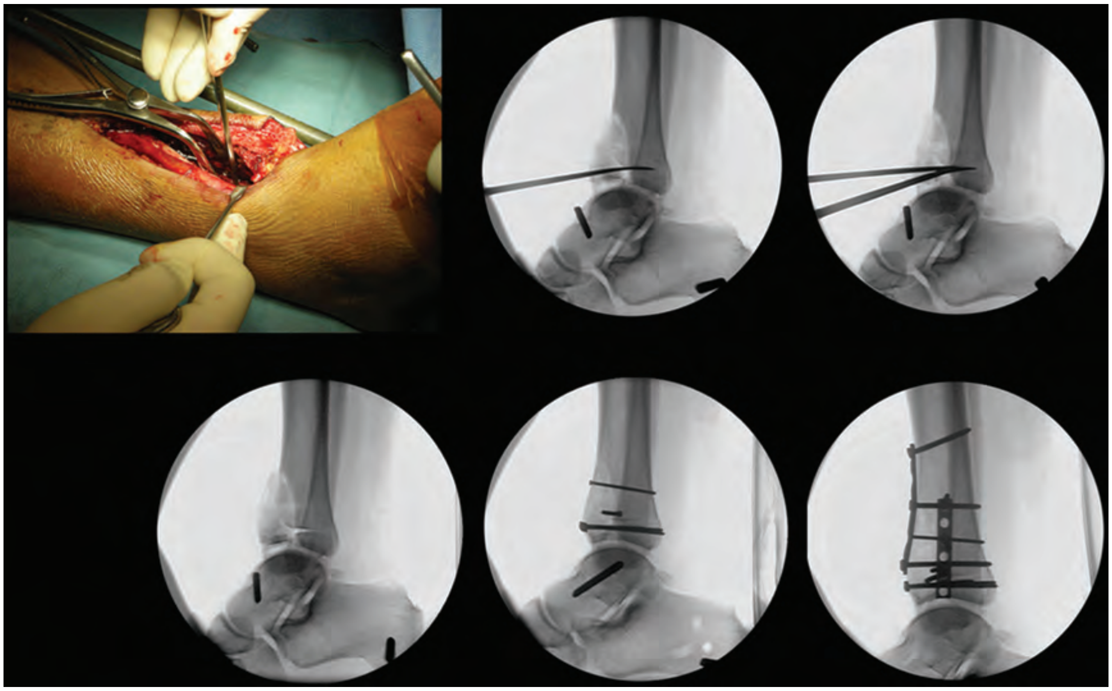


Figure 21-19. Another example of using osteotomes to disimpact and reduce the "skid zone" of anterior articular surface of posterior fragment. A rim plate is then placed to secure the disimpacted Volkmann fragment, and final fixation is applied.

- If the posterior Volkmann fragment is not impacted, but is displaced, the typical deformity assumed by this fragment is sagittal plane malrotation in dorsiflexion.
  - Reduction of this fragment is critical.
  - There are several options to achieve this.
    - The anterior cancellous surface of the posterolateral fragment can be accessed either after the Chaput fragment is rotated externally on the AITFL, or through metaphyseal comminution.
      - This permits exposure to central articular comminution, hematoma and debris, and the posterior Volkmann fragment.
      - The posterior fragment can then be derotated and pinned into place using K-wires from the tibial shaft angling distally (Fig. 21-20).

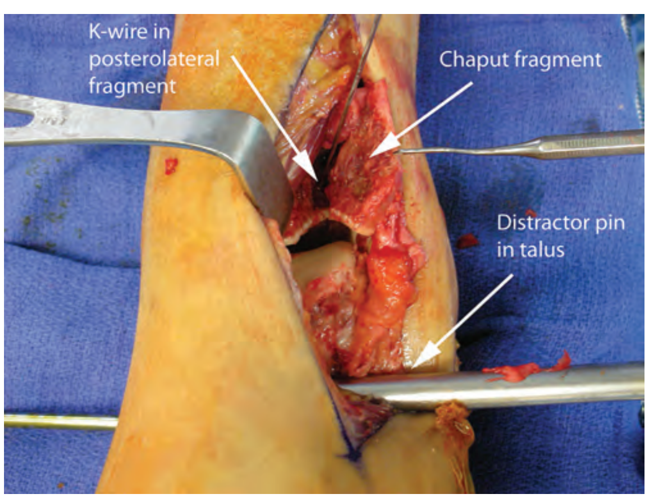


Figure 21-20. The Volkmann posterolateral fragment can be accessed through the fracture site anteriorly.

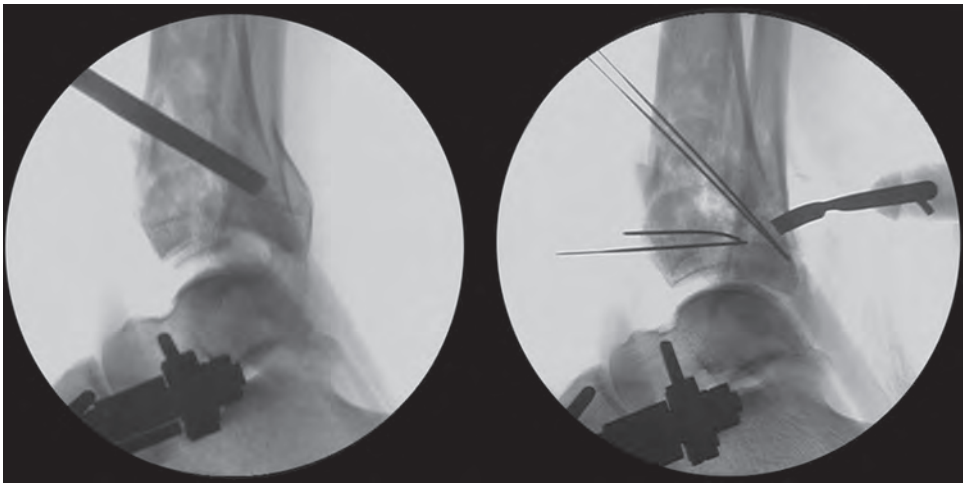


Figure 21-20. Continued.

- Alternatively, after reduction, the Volkmann fragment can be provisionally stabilized with two or three K-wires inserted percutaneously, from lateral to medial through the fibula (transfibular K-wires).
  - The wires' bicortical points of fixation in the fibula serve to increase their cantilever bending stiffness.
  - Since they are placed outside of the immediate operating field, subsequent pilon fracture repair proceeds unimpeded.

- A clamp tine can be passed through a posterolateral approach, through either a small stab incision or the previous fibular incision.
  - Depending on the fracture pattern, available clamp configuration, and the size of the Volkmann fragment, the clamp tine may be placed either anterior to the peroneal tendons and posterior to the fibula or posterior to the peroneal tendons.
  - The tine will cross the posterior syndesmotic ligaments and will then be placed onto the posterior malleolus fragment (Fig. 21-21).

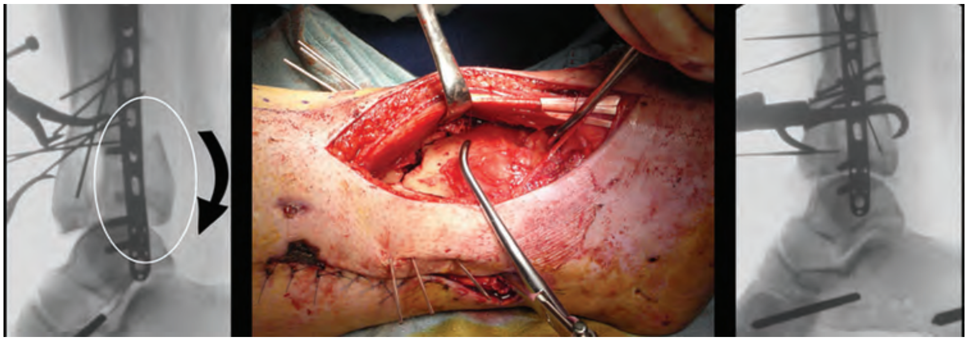


Figure 21-21. The posterolateral Volkmann fragment is typically displaced in dorsiflexion (**A,** *circle, rotational arrow*). A critical step in the overall reduction strategy is addressing this reduction. This can be reduced by using a pointed Weber clamp through a small posterolateral approach **(B)**. On a lateral fluoroscopic view, the position of the fragment is improved, and is stabilized provisionally using an antegrade K-wire from the tibial shaft.

- Alternatively, a shoulder hook or small elevator can be inserted percutaneously to manipulate and compress the Volkmann fragment.
  - Anterior to posterior K-wires can then be placed across the fragment to stabilize it provisionally (Fig. 21-22).

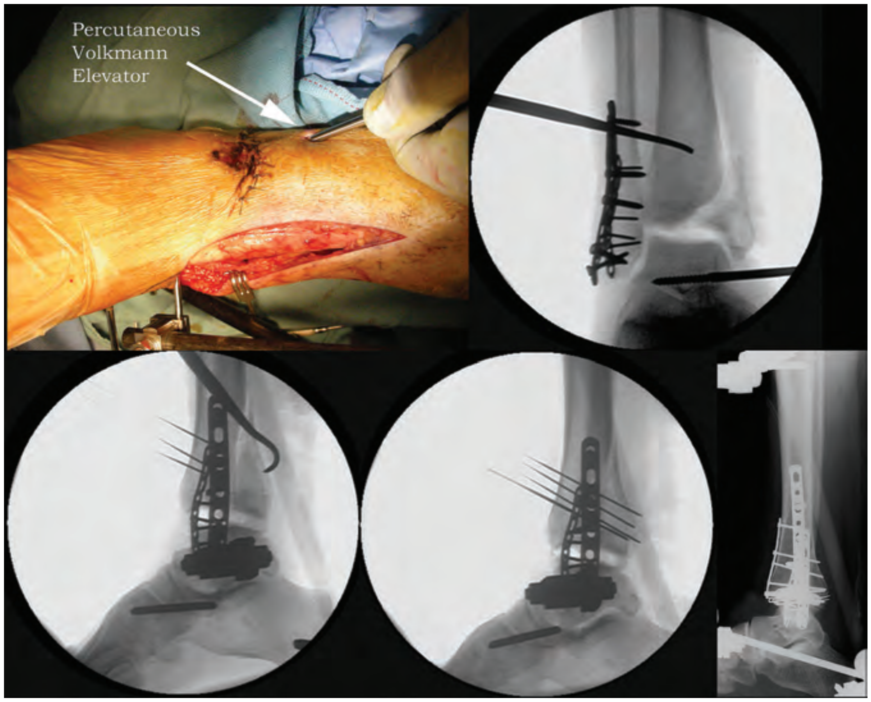


Figure 21-22. To obtain reduction of the Volkmann fragment, one option is to use an elevator or hook through a percutaneous approach.

- Place one tine of a large pointed reduction clamp through the interosseous membrane, taking care to avoid the posterior tibial neurovascular bundle (Fig. 21-23).

Figure 21-23. A clamp may be placed through the syndesmosis to reduce the posterior Volkmann fragment.

- A separate posterolateral approach may be used to anatomically reduce the proximal spike of the posterior malleolus fragment.
  - An antiglide plate should be placed at the apex of the fracture's spike.
  - Screws placed should be short enough not to interfere with unreduced anterior fragments (Fig. 21-24).

Figure 21-24. Provisional plate placement with short screws can be used. Anatomic reduction of the spike of the proximal cortex indirectly reduces the articular surface of this fragment (**left,** Volkmann fragment in *circle*).

- If a large displaced osteochondral fragment is present, its orientation can be marked and the fragment removed temporarily.
  - This facilitates direct access to the Volkmann fragment anteriorly (Fig. 21-25).

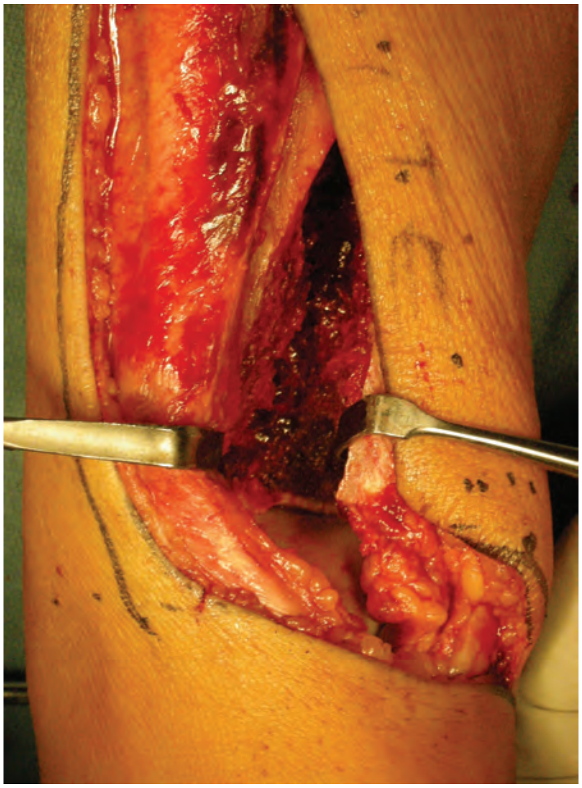


Figure 21-25. Temporary removal of a large osteochondral fragment facilitates access to the posterior Volkmann fragment through the fracture for manipulation and reduction.

- Another option for reducing the Volkmann fragment is through the metaphyseal fracture, via the anterolateral or anteromedial approach.
  - A small hole (2.0 to 2.5 mm) is placed in the central portion of the fragment by drilling from anterior to posterior.
    - Use a dental pick, shoulder hook, or threaded pin to manipulate the fragment and correct the sagittal plane rotation.
    - Secure its position with K-wires.

- If Volkmann fragment reduction is performed as a first step, this can provide a stable segment to which the remainder of the articular surface may be reduced (Fig. 21-26).

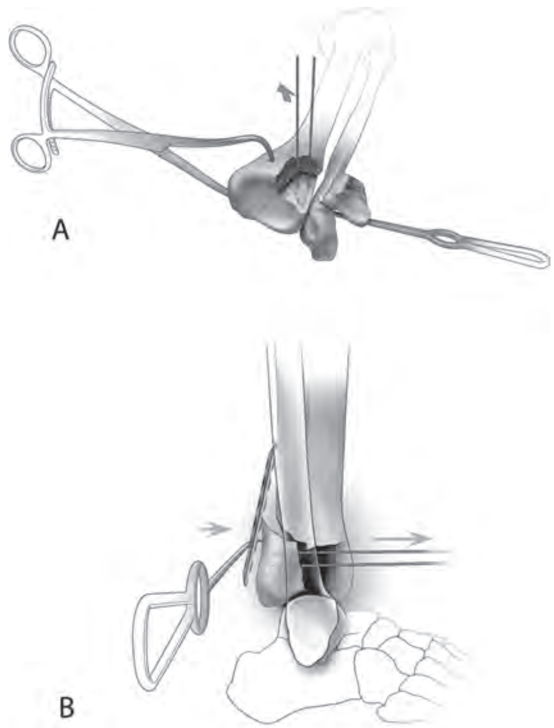


Figure 21-26. Multiple effective options exist for Volkmann fragment reduction, including anteriorly placed K-wires (**A,B**), clamp placement (**A**), posterolateral shoulder hook placement (**A,B**), or an antiglide plate (**B**).

- The remainder of the articular segment can be reduced to this stable and reduced fragment. (Figs. 21-27 and 21-28).

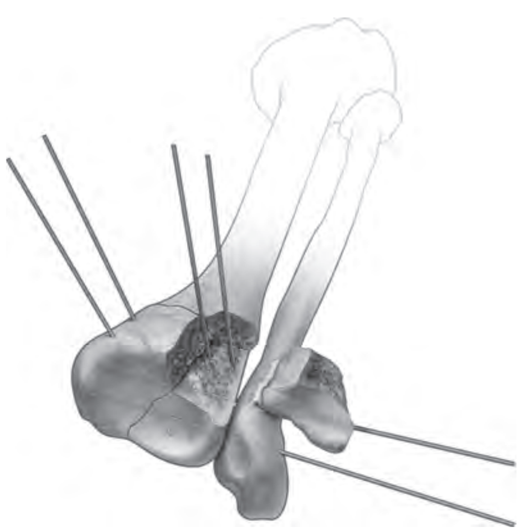


Figure 21-27. Following reduction of the posterolateral fragment, a typical reduction sequence proceeds with central comminution (not shown) and the medial fragment.

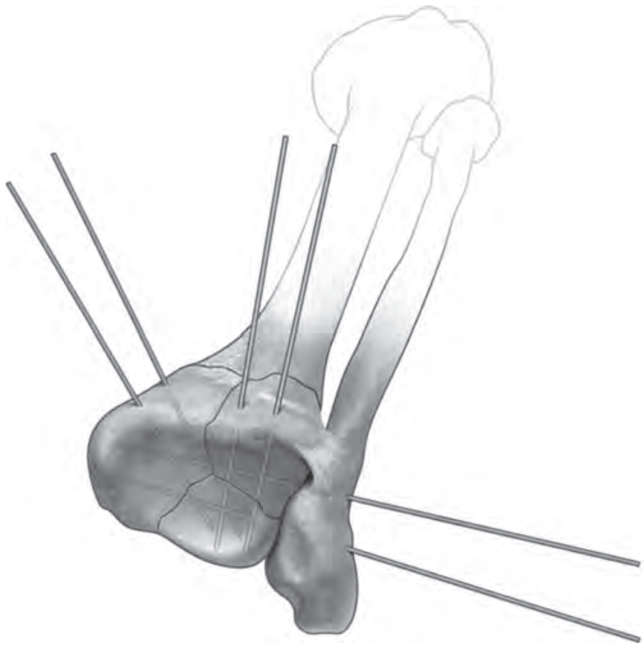


Figure 21-28. As a final step, the anterolateral Chaput fragment is reduced and K-wires are inserted.

- After reduction of the distal segment and its articular surface, if the articular block is displaced from the shaft, it can be reduced with a Schanz pin or other instruments to the distal diaphysis.
  - Reconstruction can then proceed with K-wire provisional fixation (Fig. 21-29).

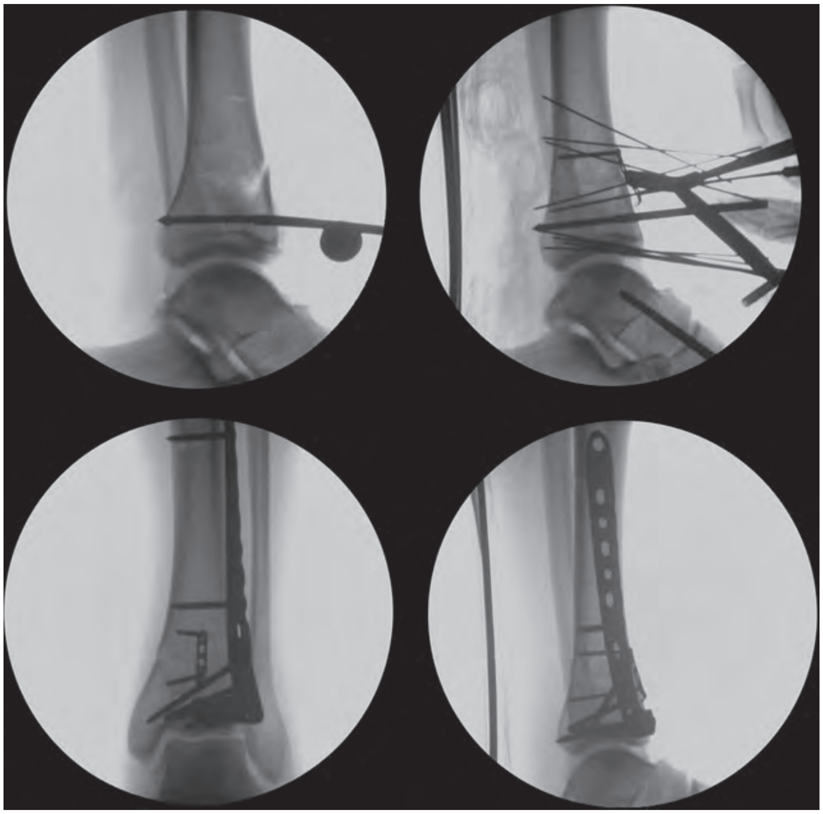


Figure 21-29. A Schanz pin can be used to derotate the entire articular block. Reduction and provisional fixation can then continue with K-wires and plates.

- Anterior rim plate
  - Useful for sagittal plane compression of articular surface.
  - To span the entire surface of the anterior cortex of the distal tibia, a 2.0-mm ten-hole plate can be contoured.
  - Hooks may be created at one (or both) end(s) by cutting through a hole and bending the remaining hole edges for additional fixation (Fig. 21-30).

Figure 21-30. A 2.0-mm rim plate can be used as a buttress for articular compression. A plate length of ten holes allows for fixation across the entire cortical surface of the distal tibia, though shorter plates may also suffice.

- The articular surface is first reconstructed and stabilized provisionally with K-wires (Fig. 21-31).

Figure 21-31. Reduction of the articular surface is first performed, which can be visualized directly and palpated with a blunt elevator.

- The rim plate is then applied to the distal aspect of the anterior tibial cortex (Fig. 21-32).

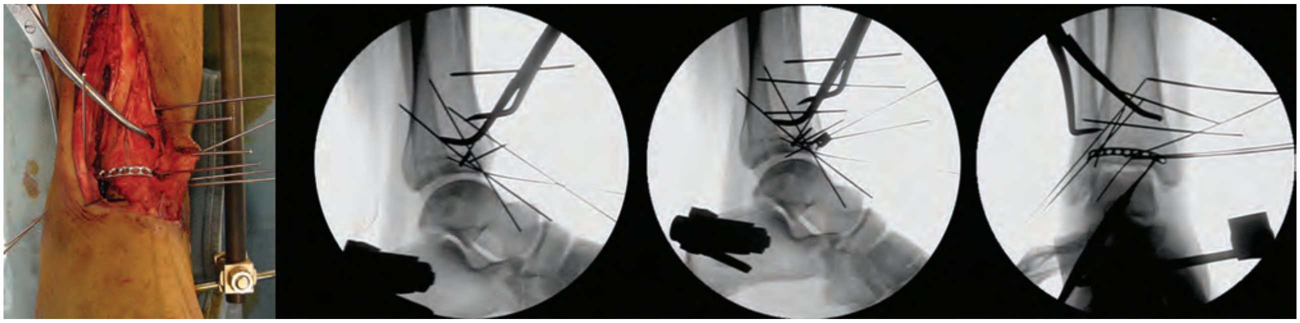


Figure 21-32. The rim plate on the cortical surface, and its position and alignment is verified on lateral and AP fluoroscopy.

- Using lateral fluoroscopic guidance, anterior to posterior screws are placed (Fig. 21-33).

Figure 21-33. 2.4-mm lag screws are placed from anterior to posterior under fluoroscopic guidance.

- Alternatively, a five-hole 2.0-mm straight plate can be used to span a single fracture line and capture several larger articular fragments.
- Again, 2.4-mm screws are placed in a lag fashion (Fig. 21-34).

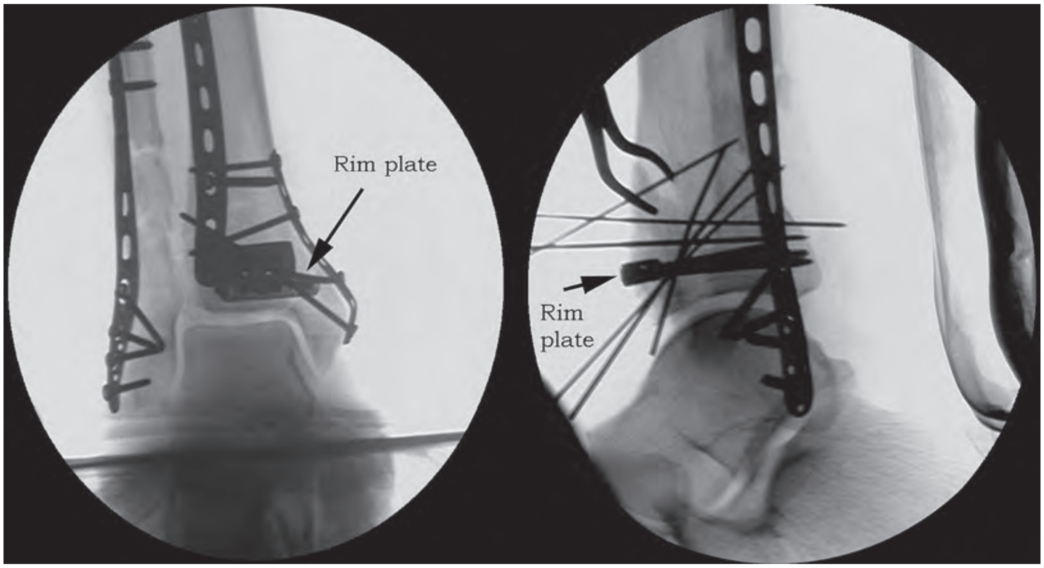


Figure 21-34. A smaller rim plate can be used selectively for individual fracture lines.

- A six-hole plate should be selected if fixation into a medial malleolar fragment is needed (Fig. 21-35).

Figure 21-35. A six-hole plate should be used for screw placement into a medial malleolus fragment.

- A more laterally placed rim plate can be used for a separate Chaput fragment (Fig. 21-36).

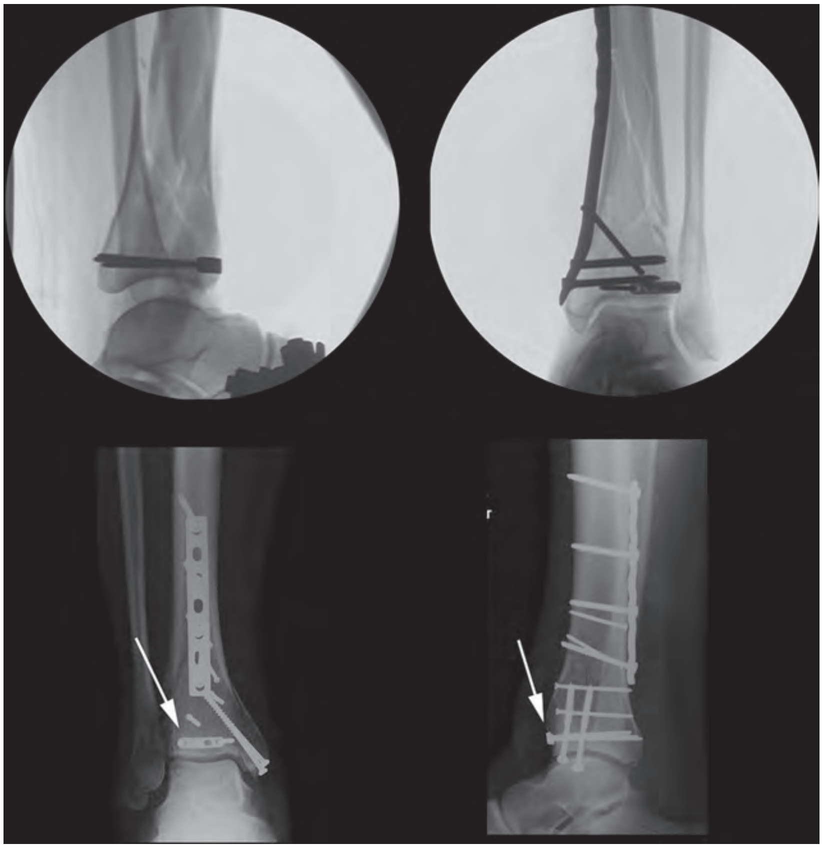


Figure 21-36. Two examples of small rim plates with selective fixation into the anterolateral Chaput fragment.

- One side of two adjacent holes can be cut to form a "side" hook plate.
  - This allows the tab to be bent along the axis of the plate, and to bend the plate in the plane of its flat surface, similar to a reconstruction plate (Fig. 21-37).

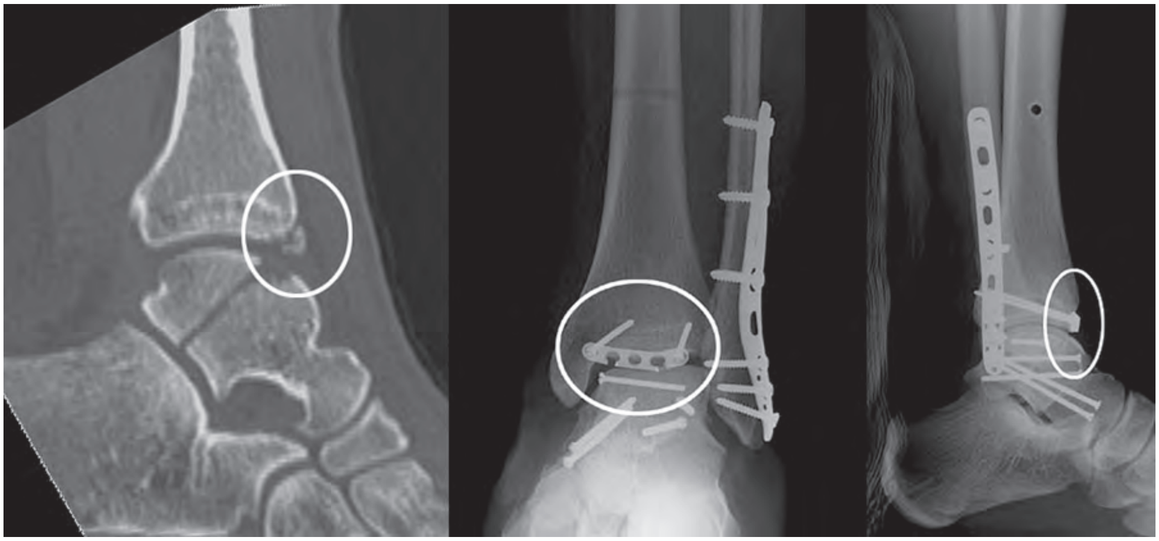


Figure 21-37. A mini-fragment plate can be used to create a side hook to capture small periarticular fragments.

- If multiple small osteochondral fragments are present anteriorly, a malleable maxillofacial 2.0-mm plate can be contoured and placed along the anterior rim of the distal tibia as a buttress (Fig. 21-38).

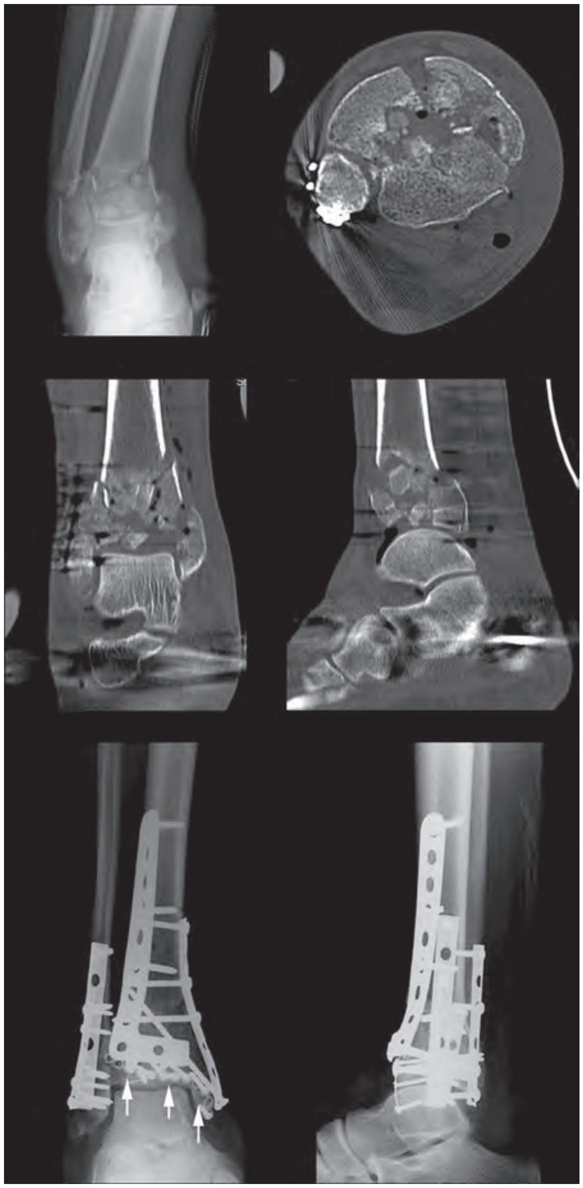


Figure 21-38. A malleable 2.0-mm plate can be contoured to the distal tibial rim to buttress small osteochondral fragments.

- To stabilize the reduced articular segment to the metaphysis through an anterolateral approach, an anterolateral plate may be placed (Figs. 21-39 and 21-40).

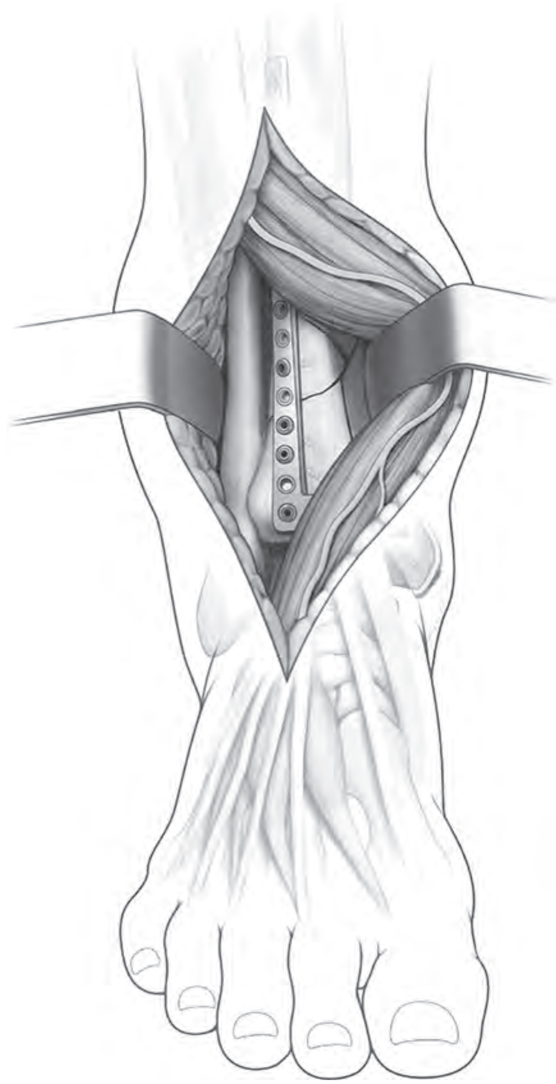


Figure 21-39. After the reduction of the articular surface, an anterolateral plate can be slid in a submuscular fashion through the anterolateral approach. The plate is fixed to the distal articular block followed by fixation proximally to the tibial diaphysis. (From Nork SE, Barei DP, Gardner MJ, et al. Anterolateral approach for pilon fractures. *Tech Foot Ankle Surg*. 2009;8(2):53–59. With permission.)

Figure 21-40. Radiographic example of an anterolateral plate placed through an anterolateral approach.

- If an anteromedial approach is performed, a medial plate may be advanced subcutaneously from distal to proximal through the medial extent of the incision.
    - Avoid injury to the greater saphenous vein and nerve when extending the transverse limb of the incision medially.

- Proximal screws may be placed percutaneously (Fig. 21-41).

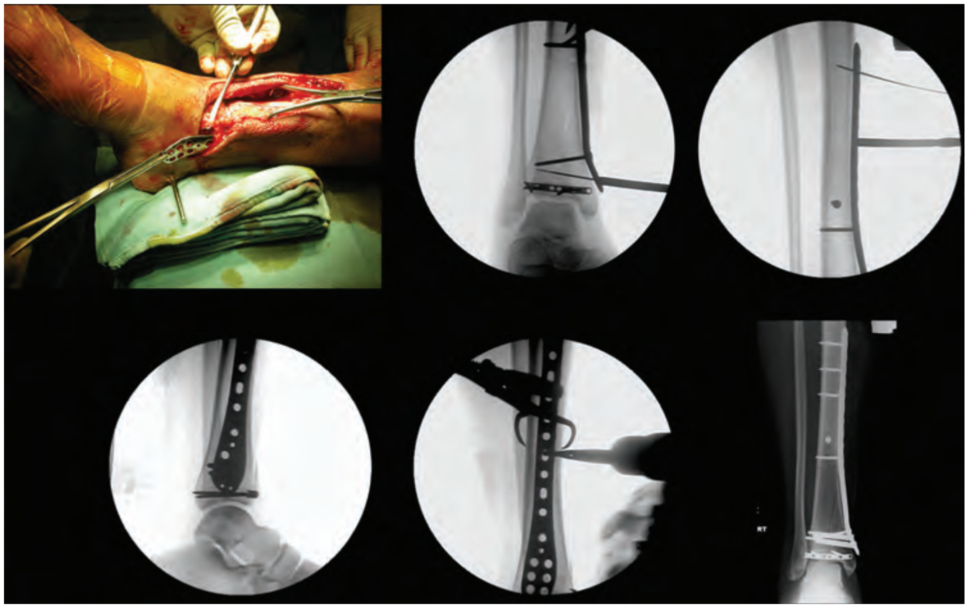


Figure 21-41. Depending on the need for medial stabilization, a plate can be slid through the medial extent of an anteromedial approach. The plate can then be stabilized distally, and the proximal screws can be placed percutaneously.

- An anterolateral plate may also be placed through an anteromedial approach, depending on the fracture pattern.

- If the pilon fracture resulted in a valgus deformity, and the medial malleolus failed in tension, a small tensioned plate can be used to stabilize this fragment.
  - In this pattern, a large buttress plate is not necessary for medial column fixation (Fig. 21-42).

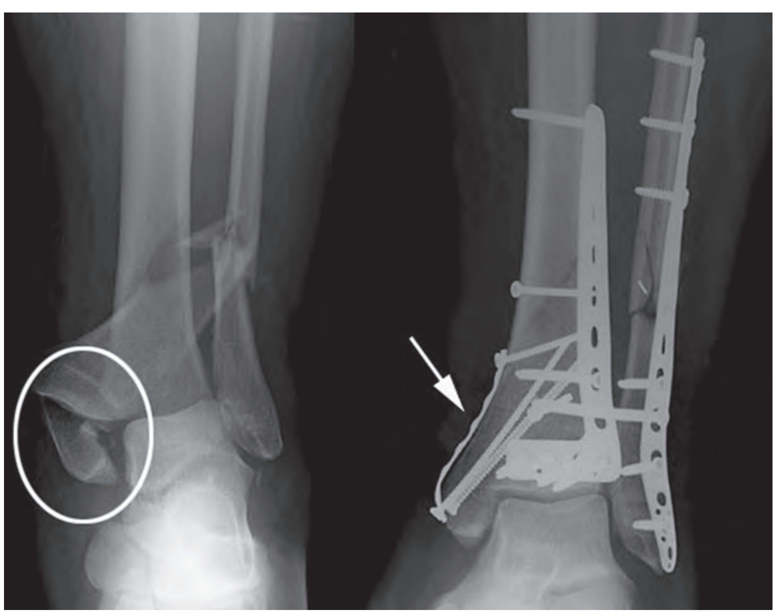


Figure 21-42. When the medial malleolus fails in tension, a small fragment tension plate adequately stabilizes this fragment.

- A dorsal distal radius plate designed for the contralateral side fits well on a large medial malleolus fragment (Fig. 21-43).

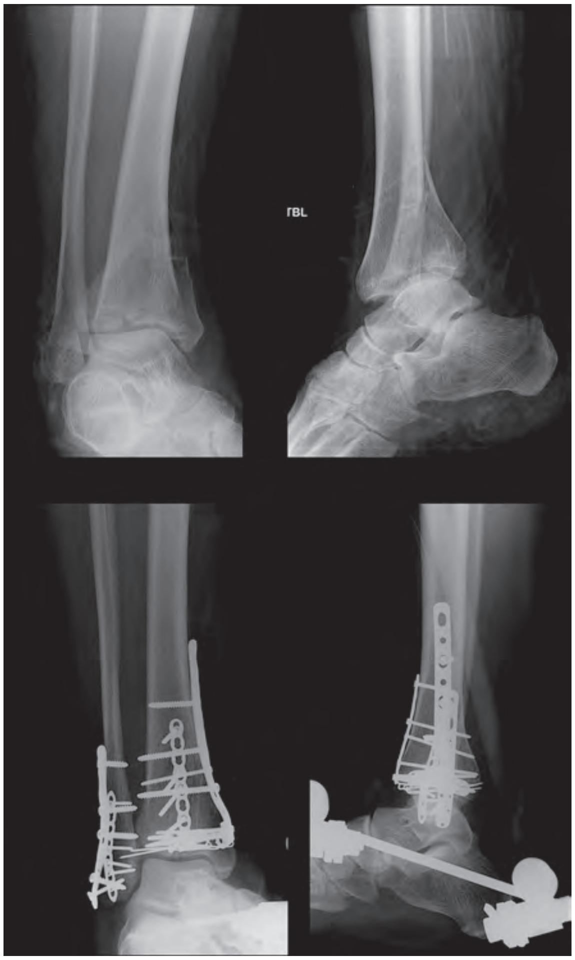


Figure 21-43. Example of a left dorsal distal radius plate applied to the large medial malleolus fragment in the right pilon fracture.

Special Situations and Techniques

- Analyze the axial CT for presence of posteromedial tendon(s) (posterior tibialis/flexor digitorum longus) in fracture site.

- This will significantly impede indirect reduction of fracture planes, such as reducing a posteromedial fracture line from an anterior approach (Fig. 21-44).

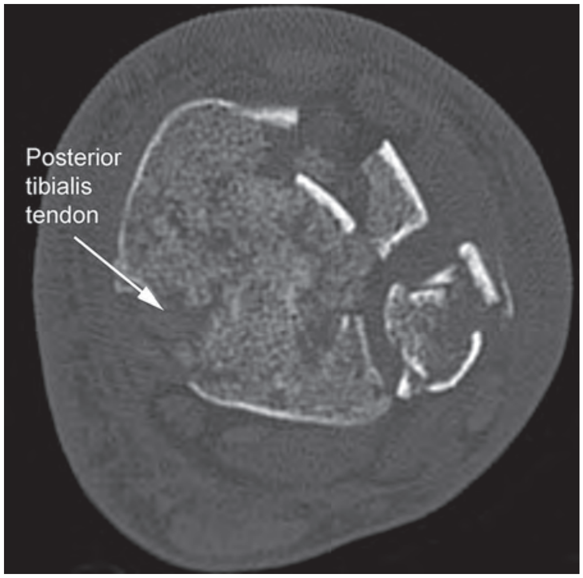


Figure 21-44. On the axial CT scan, the posterior tibialis tendon can be seen in the fracture site. This requires attention prior to reduction of this fracture line. Use of a femoral distractor, which aids significantly with articular reductions, may be an impediment when a tendon is interposed in a fracture plane. As the limb segment is lengthened and the tendon is placed under tension, tendon mobility is reduced and reduction is impeded. Loosening the distractor will usually facilitate the maneuver to extract the tendon.

- In cases where the Chaput and Volkmann fragments are small and unable to be captured by implants, the syndesmosis will likely remain unstable, and a transsyndesmotic “positioning” screw should be considered (Fig. 21-45).

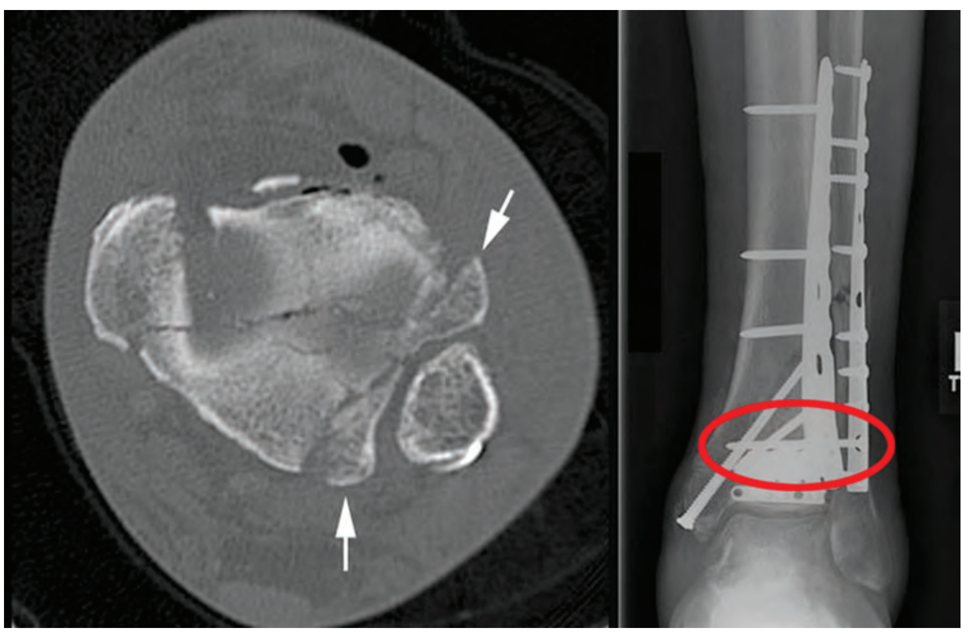


Figure 21-45. When the Chaput and Volkmann fragments are small (*arrows*), transsyndesmotic fixation should be anticipated (*circle*).

- An alternative approach to temporizing fixation is to convert a Type C to a Type B pilon fracture if the soft tissues and fracture type allow.
  - This is best performed through a posteromedial (sometimes posterolateral) approach using small fragment plates and screws.
    - While more malleable plates are preferred for distal metaphyseal fractures, a 3.5-mm LC-DC plate should be considered for fractures involving the tibial diaphysis.
  - This step can be performed initially through a clean open wound or as an intermediate stage while the anterior soft tissue edema resolves.
  - Definitive articular reduction is greatly facilitated after this is performed by creating a stable column as a base for the staged reconstruction (Fig. 21-46).

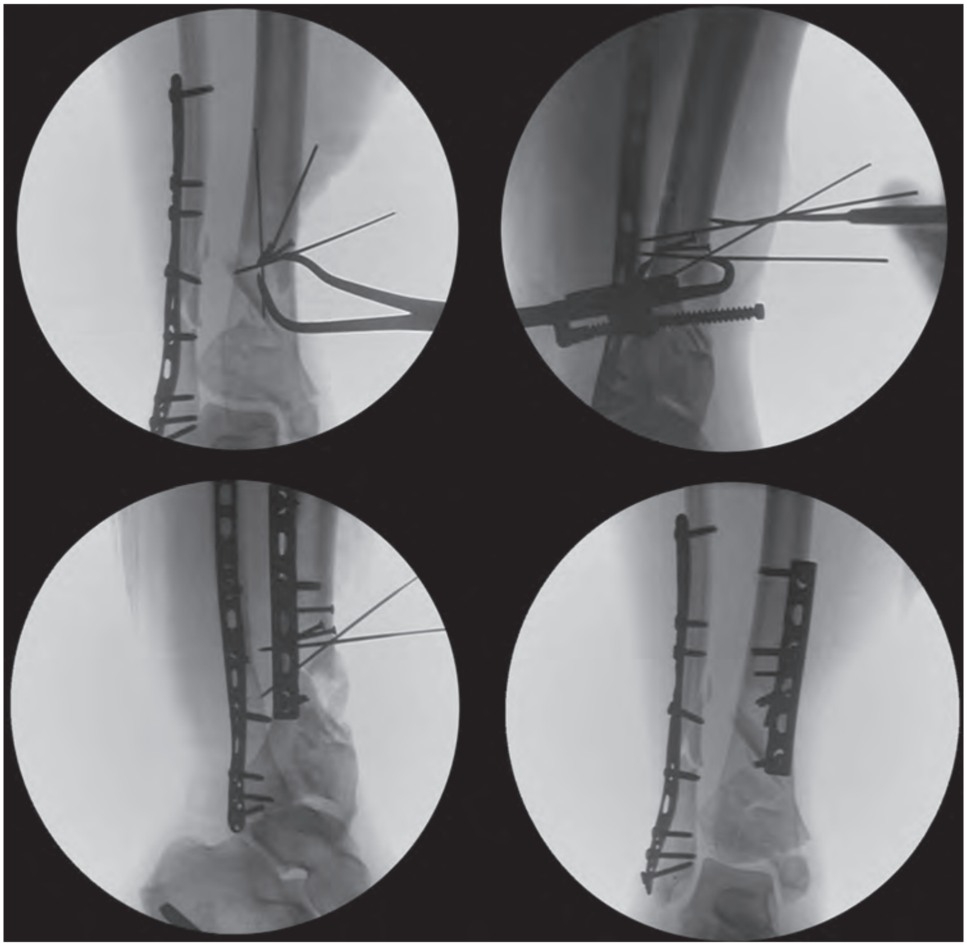


Figure 21-46. In this case, a large posteromedial articular fragment was stabilized to the tibial diaphysis using a small fragment plate and independent lag screws.

- To reduce posterior fragments from an anterior approach, lag screws in multiple directions can be used to pull in multiple sequential vectors (Fig. 21-47).

Figure 21-47. Initially a lag screw was placed from anterior to posterior to reduce a displaced posterior fragment (**left**, *circle*). To reduce the coronal plane displacement, the first screw was loosened and a second screw was placed from medial to lateral (**center**, *circle*).

- If the fracture pattern is predominantly posterior, a posterior plate may be preferable, and is best applied through a posteromedial or posterolateral approach.
    - A periarticular plate designed specifically for this location or a plate designed for the contralateral proximal tibia fit well after some contouring (Fig. 21-48).

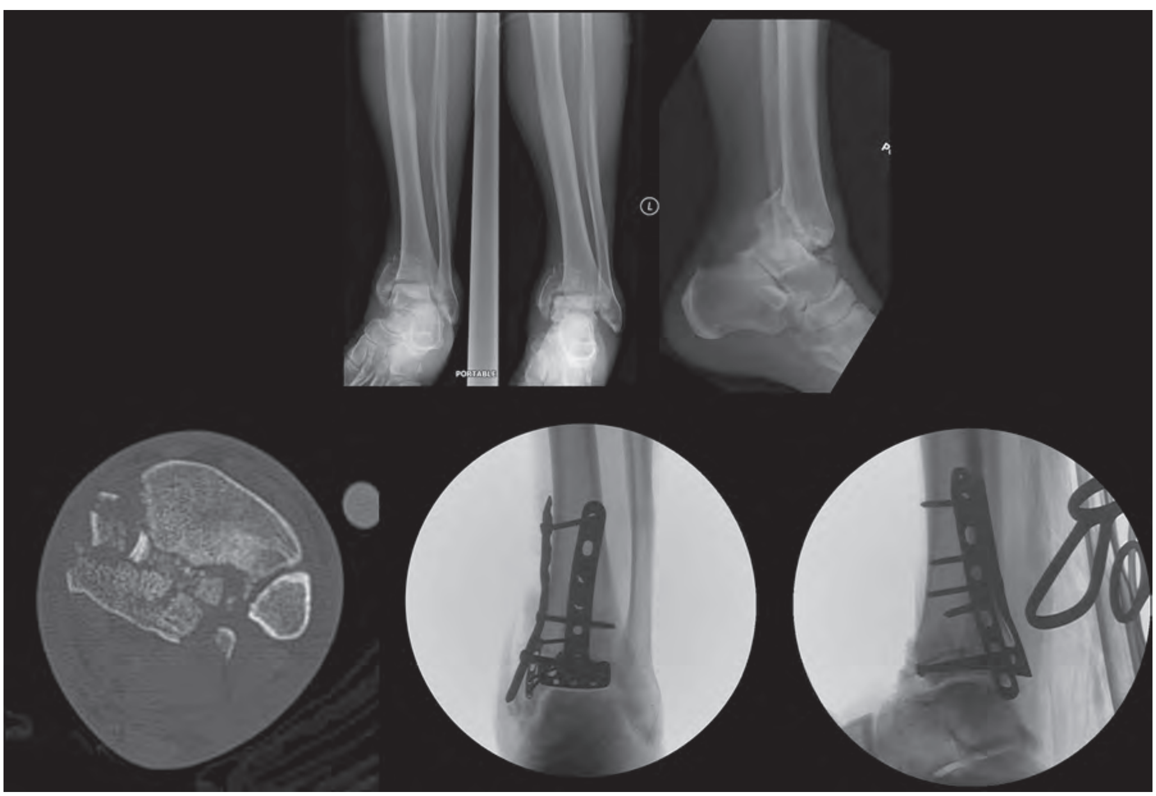


Figure 21-48. When the fracture fragments are posterior, a periarticular buttress plate may be placed posteriorly through a posterior approach.

- A liability of a posterior approach is the difficulty visualizing the articular surface.
  - An anterior approach allows direct reduction of the medial extent of the fracture line as well as the articular surface, and the posterior fragment can be stabilized with antero-posterior lag screws (Fig. 21-49).

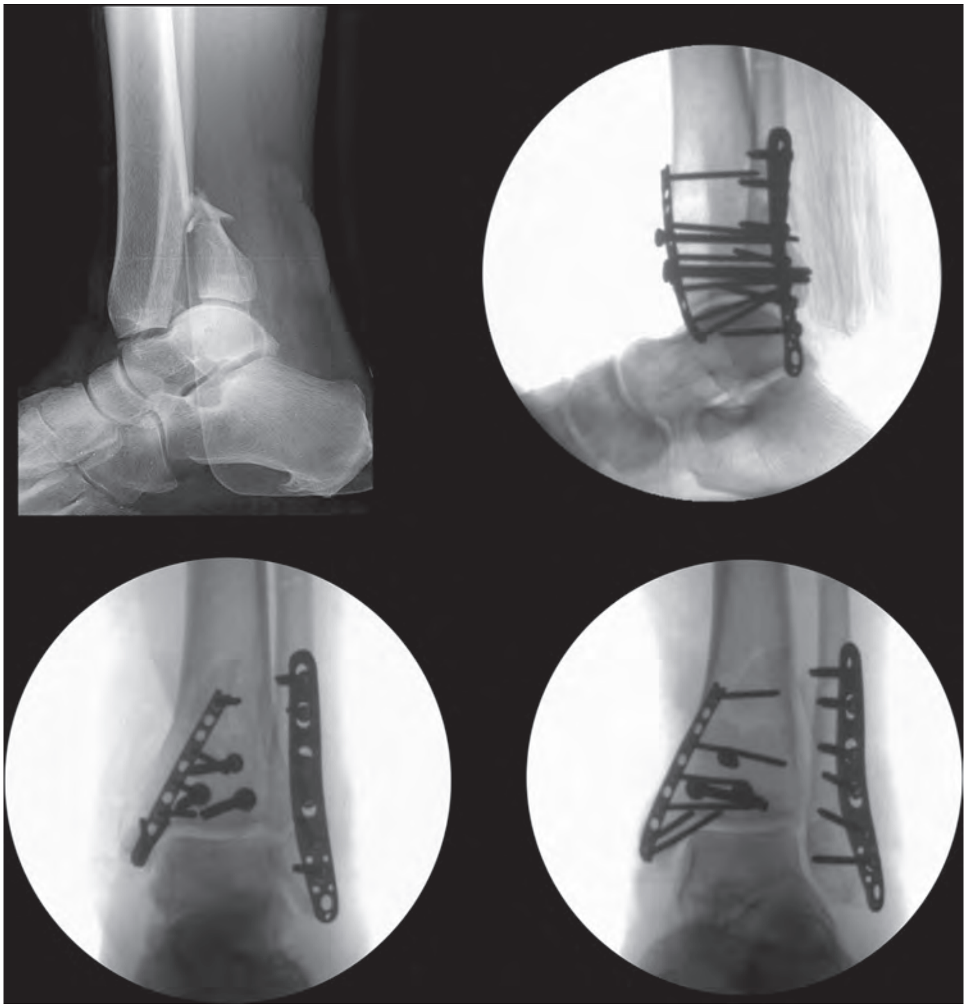


Figure 21-49. To address a posterior Type B pilon from an anterior approach, medial dissection allows visualization of the cortical fracture line and removal or repositioning of intercalary articular comminution. Joint distraction allows direct inspection of the intra-articular reduction. Anterior to posterior or posterior to anterior lag screws can be placed to stabilize the fragment.

- Depending on the fracture pattern, another valuable reduction strategy is to first obtain a reduction of the medial malleolar fragment by interdigitating its cortical fracture lines.
  - This then becomes a stable foundation on which to reduce the remaining fracture fragments.
  - Initially, the medial plate should be placed provisionally with unicortical screws.
  - After reduction of the entire fracture, these unicortical screws can be replaced with bicortical screws.
  - The plate can be inserted subcutaneously, in either direction, so a formal extensile medial approach for reduction and plate application is not needed routinely.

- This avoids making an incision through injured medial soft tissues as is common in these injuries (Fig. 21-50).

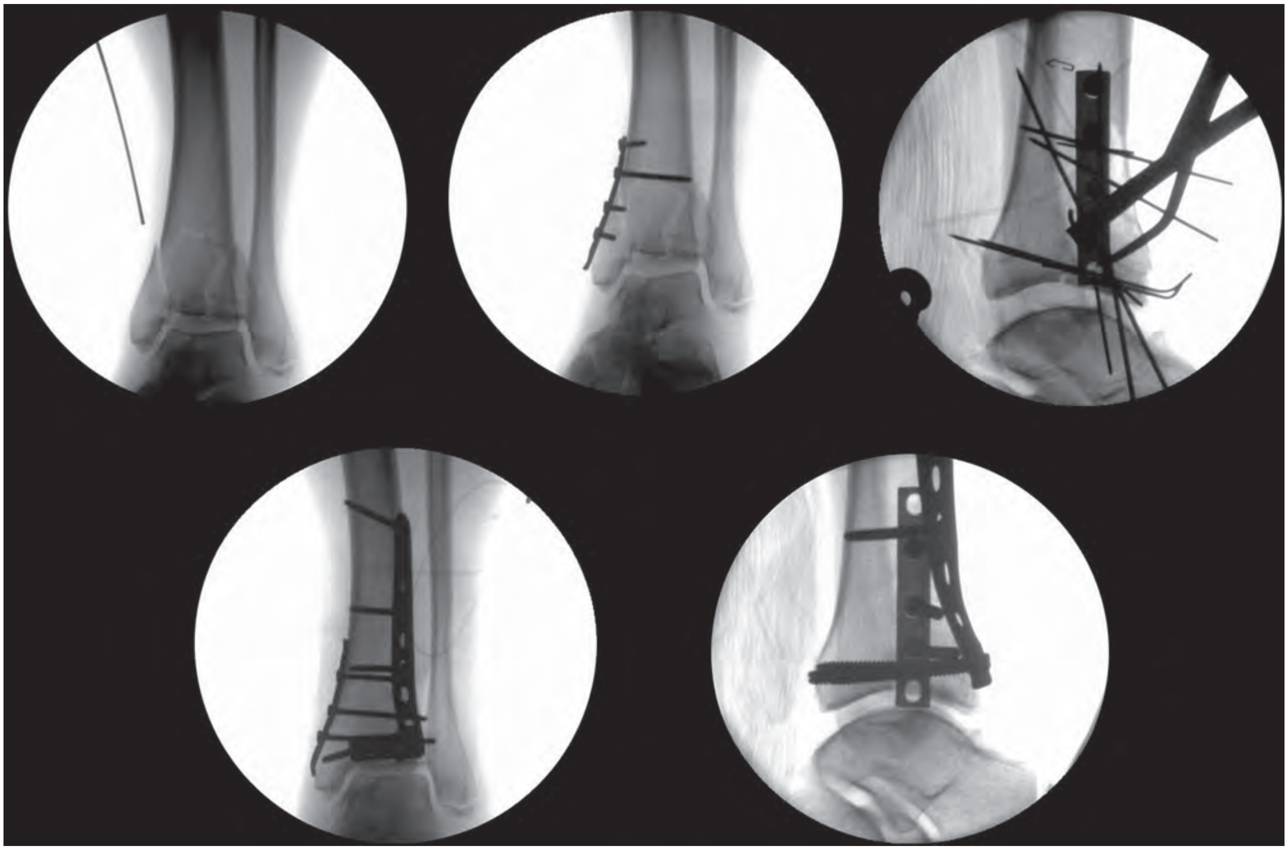


Figure 21-50. Reduction of the medial malleolus may be the first step in repair of a pilon fracture, especially when it fails in tension. Anatomical reduction using cortical interdigitations followed by provisional fixation creates a stable fragment to which the remaining tibial plafond components may be reduced. The small medial incision is marked with a K-wire. After the medial malleolar fracture is reduced, a small fragment plate is placed extraperiosteally, followed by insertion of unicortical screws. The remainder of the fracture is then reduced to the stable fragments.

- If the fibular fracture is transverse, not comminuted, and minimally displaced, an intramedullary fibular screw or wire can be used for stabilization.
  - Cortical interdigitations should provide rotational stability.
  - If rotationally unstable, a second screw can be used to neutralize forces.
  - Be aware that open reduction is the surest method of achieving an anatomical fibular reduction.
  - A 2.5-mm drill should be used first, and a 3.5-mm drill can be used in the distal fragment to achieve compression.
    - A triple fluted 2.5-mm drill bit is preferred to a double fluted drill bit as it is easier to control and less likely to "wander" at its entry point.
    - The drill should be oscillated to minimize the risk of cortical perforation as it contacts the endosteal surface obliquely.

- The starting point on the lateral view is critical and is similar to any intramedullary nail, in that it will affect reduction of the fracture.
- It can be offset to achieve tension or compression in the desired direction in the sagittal plane (Fig. 21-51).

Figure 21-51. An intramedullary fibular screw was used with a slightly anterior entry point on the lateral view to correct the apex posterior fracture deformity.

- To fill the metaphyseal voids with cylindrical small cancellous dowels, use a 4.5-, 5.5-, or 6.5-mm drill guide to harvest cancellous bone "plugs."
  - The proximal tibial metaphysis is a useful donor site.
  - Alternatively, autograft may be obtained by making one of more stab incisions in lateral calcaneus.

Figure 21-52. To obtain local cancellous bone graft that is more compact and has some structural integrity, a 4.5-, 5.5-, or 6.5-mm drill guide can be used to harvest from the calcaneus through stab incisions (*arrows*)

- It is possible to make several passes at different angles to obtain several cylinders of bone graft (Fig. 21-52).

Chapter 22

Ankle Fractures

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Sterile Instruments/Equipment

- Tourniquet if desired
- Small pointed bone reduction clamps (Weber clamps)
- Small serrated bone reduction clamps
- Dental picks and Freer elevators
- Laminar spreader for fibular "push screw"
- Large quadrangular ball-spike clamp for syndesmosis reduction
- Implants: Anatomically contoured periarticular fibular plates (lateral or posterolateral), one-third tubular plates; 2.0 and 2.4 plates/screws
  - Long 3.5-mm (or 4.0-mm) cortical screws for syndesmosis
  - Long 3.0 mm, 3.5 mm or 4.0 mm cortical, cancellous or cannulated screws for medial malleous/anterior colliculus
  - Mini-fragment screws and mini-fragment plates (2.0/2.4 mm) for independent fibular lag screws and for posterior or medial malleolar comminution, depending on the fracture pattern
- K-wires and wire driver/drill

Surgical Approaches/Positioning

- Variable and depends on the injury pattern.
- Supine with a bolster under the ipsilateral hip for most lateral malleolar, bimalleolar, and trimalleolar injuries.
  - Consider no bolster for isolated medial malleolar fractures (or posteromedial approaches to posterior malleolus), provided adequate internal/external hip rotation for imaging ankle and mortise.
- Lateral or prone position facilitates access to the posterior malleolus.
  - Prone position makes ORIF of lateral and medial malleoli accessible but provides a less familiar perspective.
  - Lateral position may allow for reduction and fixation of the medial malleolus following fixation of the posterior and/or lateral malleolus, assuming the patient's hip anatomy allows adequate external rotation.
- Posterolateral approach
  - Plane between posterior border of fibula and peroneal tendons.
  - May be preferable
    - For concomitant access to the posterior malleolus (interval between flexor hallucis longus [FHL] and peroneal tendons), if necessary.
    - Allows a separate anterolateral approach for pilon fractures.

  - There is less risk of injury to the superficial peroneal nerve.
  - The implant is not directly under the skin incision.
- Posteromedial approach
  - Several "windows" may be used to access the posterior portion of the medial malleolus and posterior malleolus: anterior to the PT tendon or posterior to the PT/FDL tendons.
  - Generally, FHL is retracted posteriorly and laterally with the posterior tibial neurovascular bundle.

Reduction and Fixation Tips

Fibula Fractures—Rotational Mechanism

- Most spiral fibular fractures (SER-type fracture patterns) are amenable to 2.4- or 2.7-mm lag screws (in addition to plate fixation of the fracture).
  - May be placed independently, prior to lateral plate placement, or through a posterolateral plate.
  - Posterior-to-anterior placement avoids soft tissue stripping anteriorly.
- K-wires for provisional fixation.
  - Transcutaneous K-wire placement from anterior to posterior avoids interference with posterolateral plate (Fig. 22-1). Wires are removed after plate application.

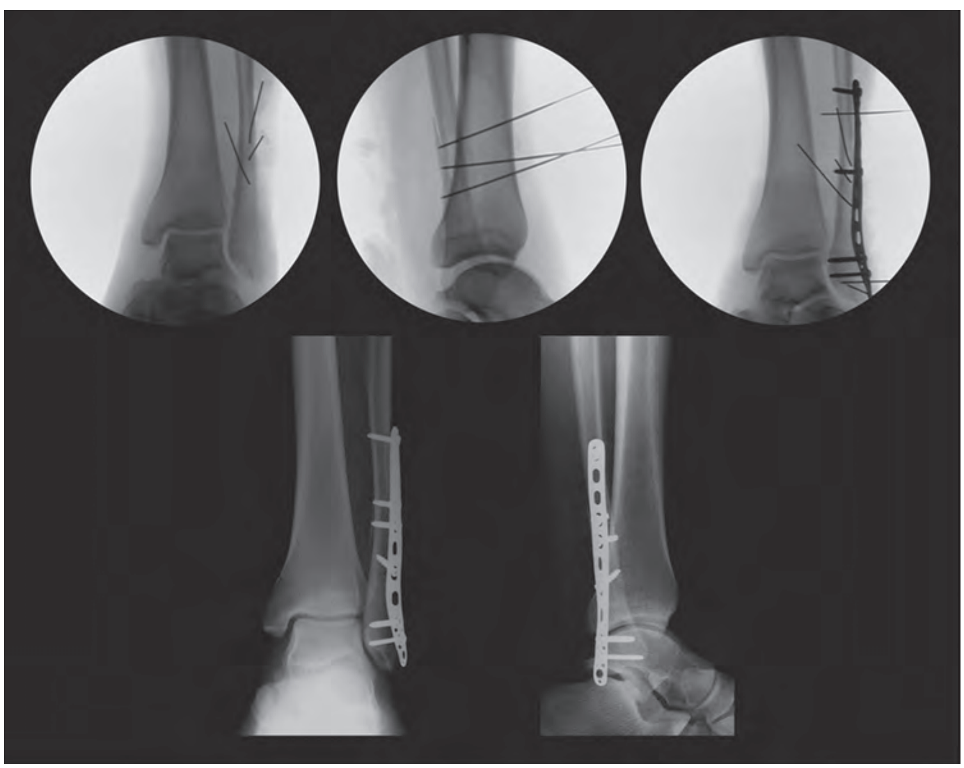

Figure 22-1. Anterior-to-posterior transcutaneous K-wires avoid interference with a posterolateral plate and posterior-to-anterior lag screw.

- Consider use of small lag screws for more proximal (Weber C) fractures.
  - 2.0-, 2.4-, or 2.7-mm screws provide excellent fixation and have a small head that will not interfere with plate application (Fig. 22-2).

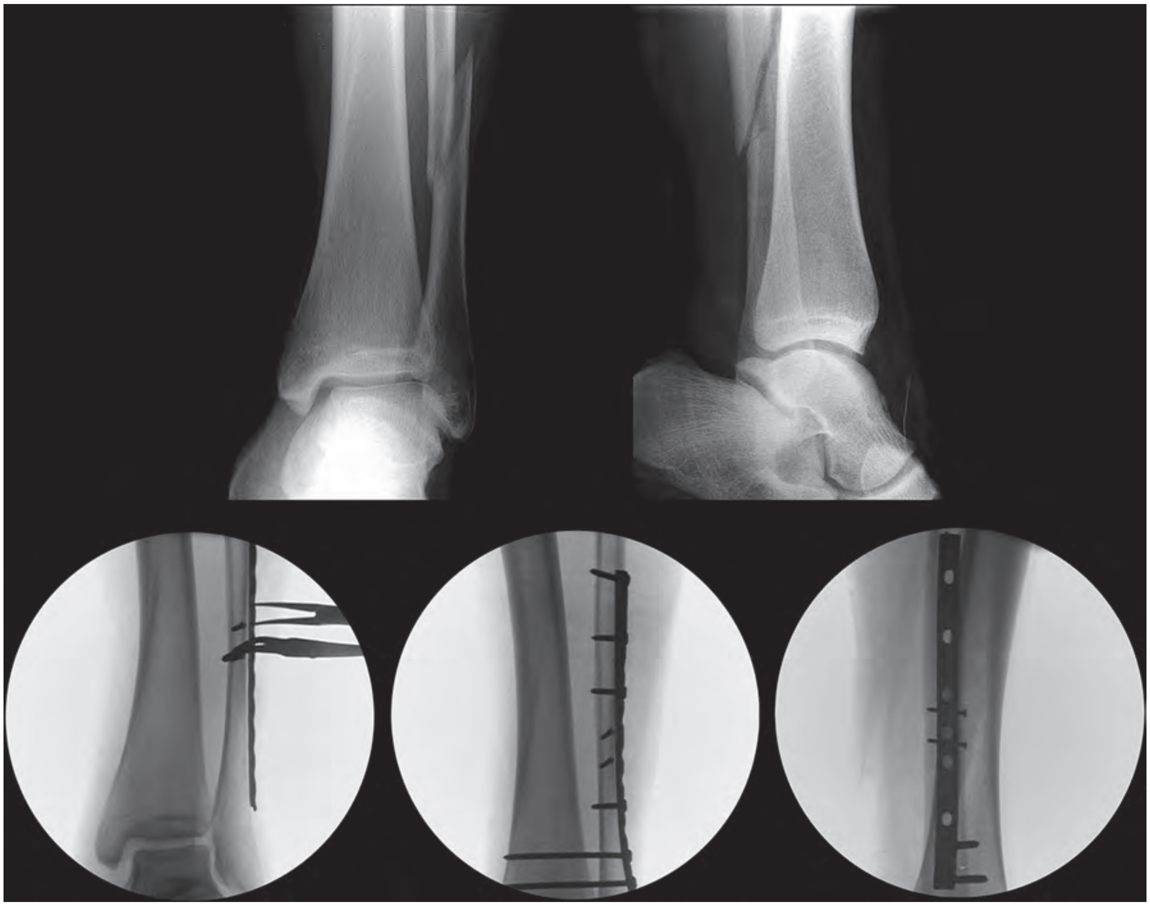

Figure 22-2. Two mini-fragment lag screws achieve excellent provisional fixation and do not impede neutralization of plate placement.

- Keep the plate posterolateral distally (Fig. 22-3).

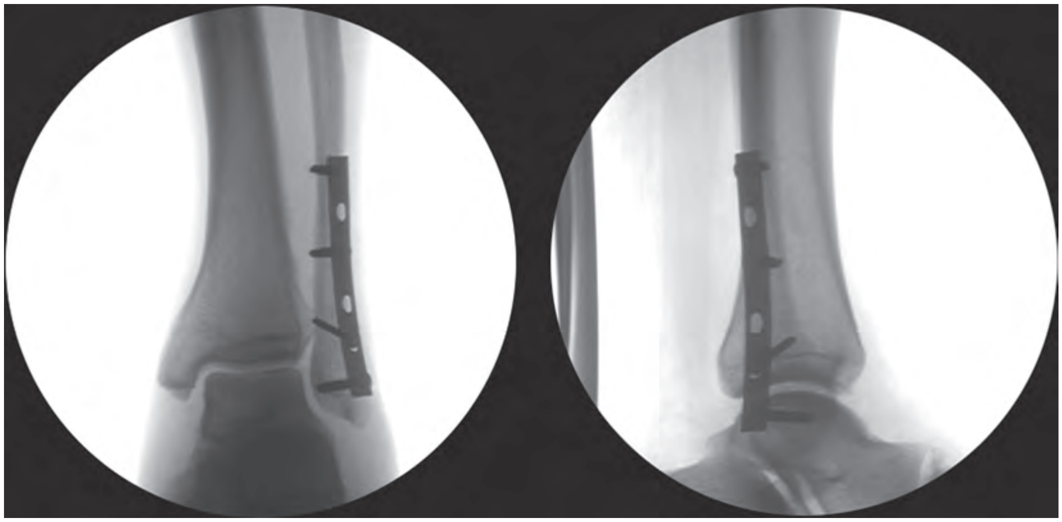

Figure 22-3. Posterolateral plating of the distal fibula is attractive for several reasons. Applied posterolaterally, the plate is mechanically suited to prevent the shortening and posterolateral translation that occur in most SER-type fractures. Additionally, the lag screw can be placed through the plate and anchored proximally in the thicker anterior cortical bone. The posterior-to-anterior screw(s) in the distal fragment also tend to be longer (24 to 30 mm), thus improving the distal fixation. This case demonstrates the use of a one-third tubular plate, a 2.7-mm lag screw, and 3.5-mm proximal and distal screws.

- Longer, posterior-to-anterior distal screws in the lateral malleolus may provide better distal fixation as they are frequently 24 to 30 mm in length.
- Often allows bicortical screw placement with screw tips exiting anteriorly, away from the articular cartilage of ankle joint.
- Antiglide plate position on fracture apex is biomechanically favorable.
- Reduced implant prominence and low frequency of hardware removal with posterior placement.
- Lag screws may be placed through the plate after antiglide and distal/proximal fixation to augment compressive fixation force at fracture.
  - Use of a 2.7-mm lag screw leads to less screw head prominence and less potential for irritation of the peroneal tendons (see Fig. 22-3).
  - An additional benefit of placing a 2.7-mm lag screw through the plate is the ability to replace it with a slightly larger screw if insufficient fixation is suspected.
    - Permits "rescuing" the interfragmentary lag screw fixation with a slightly larger 3.5-mm lag screw (usually with a 2.7-mm head) when 2.7-mm lag fixation is inadequate.

- To augment distal fixation, consider converging the tips of the distal screws.
  - “Interlocking” the screws with each other can improve the fixation by allowing interference fit between the threads of the two screws (Fig. 22-4).

Figure 22-4. Interference fit with distal screws (**left**, *arrow*). The distal 2.7-mm screws are triangulated to improve fixation with interference between the threads of the two screws.

Fibula Fractures—Abduction Mechanism

- Transverse or short oblique fibular fractures with variable comminution are usually the hallmarks of these injuries.
- Use fragments to help determine length, alignment, and rotation of the fibula.
  - Use X-rays of the contralateral ankle for comparison.
  - Recreate the “dime sign.”
  - Compare fibular lengths.
  - Compare the fibulo-talar articulation (lateral talar facet/gutter) for symmetry.

- Reconstitute "Shenton's Line" of the ankle mortise at the distal lateral tibio-fibular articular (Fig. 22-5).

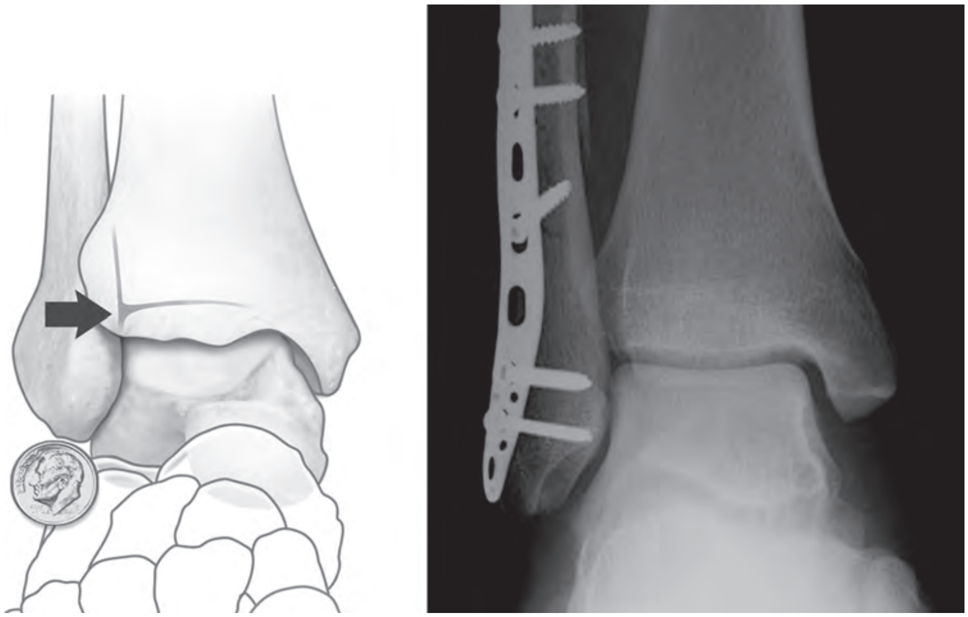

Figure 22-5. Several radiographic markers can be helpful for reconstructing the anatomic fibular length in comminuted fractures. These include the "dime sign" (seen as the dime at the distal end of the fibula) and the fibular Shenton line (*arrow*).

- Mini-fragment screws are useful to reconstruct the comminuted fragments.
- Stacked one-third tubular plates, or a thicker periarticular plate, can increase the stiffness of the fixation construct across comminuted segments.
    - When applying a stacked plate construct, tie the two plates together at each end with a 2–O resorbable suture to make them easier to handle (Fig. 22-6).

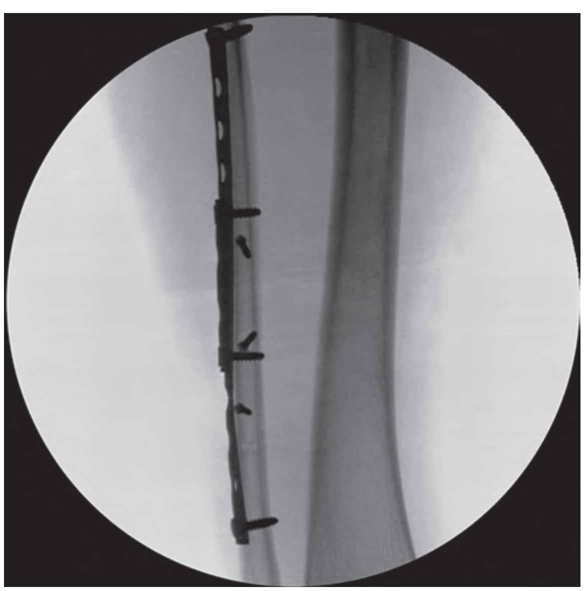

Figure 22-6. Stacking one-third tubular plates can stiffen the lateral construct and help support areas of comminution. Tying the plates together with 2–O suture(s) makes them easier to manipulate.

- Use indirect reduction technique for restoration of the fibular length.
  - Stabilize the plate distally with multiple K-wires and/or screws.
  - Insert a bicortical fibular screw proximal to the plate.
  - Apply a laminar spreader to distract and restore length (Fig. 22-7).

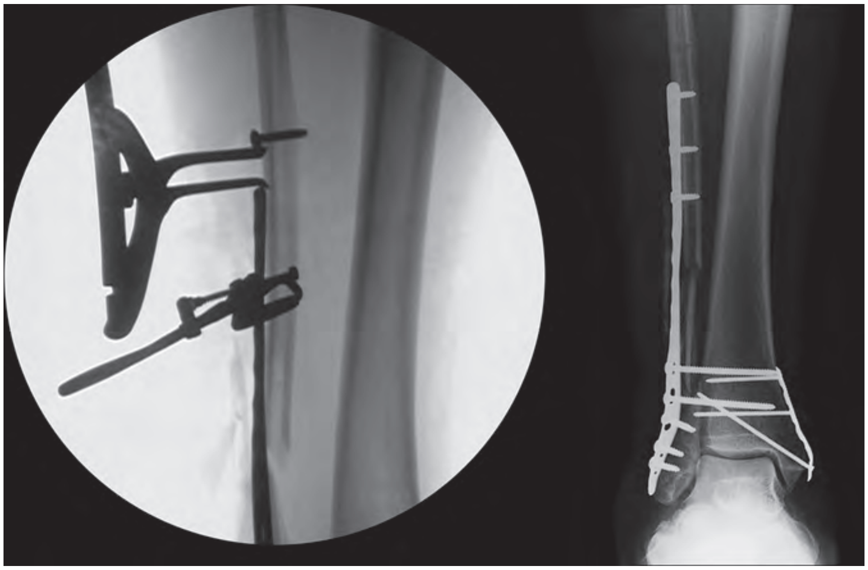

Figure 22-7. Use of a push screw with a laminar spreader to restore fibular length indirectly.

  - Control the plate with a Verbrugge or serrated clamp to maintain proximal plate–bone apposition.
    - These clamps permit translation of the plate along the fibular shaft, thereby permitting restoration of the fibular length.
- When using indirect reduction techniques, initially support the distal fixation with wires through the plate and/or one screw.
  - The use of multiple wires placed distally helps prevent loss of fixation during indirection reduction techniques.
  - When screws are used alone in soft bone, distraction forces may result in cavitation of metaphyseal bone, potentially compromising definitive distal screw fixation.
  - Place the wires bicortically and orthogonally to the plate or at a slightly more acute angle (i.e., 60 to 90 degrees) so as to maintain contact of the plate and bone during distraction.
  - Remove these wires with a pliers and not a drill to decrease the likelihood of breakage of any bent wires during removal.

- This minimizes stressing the screw-bone interface without distracting against definitive screws (Fig. 22-8).

Figure 22-8. A laminar spreader between a push screw and the proximal edge of the plate is a good tool to help restore the fibular length. This figure shows the plate fixed to the distal fragment with K-wires alone, a useful technique to keep from stressing distal fixation during the reduction process.

- Use a small anterior fibular plate to augment fixation if significant comminution of either medial or lateral malleolus (Fig. 22-9).

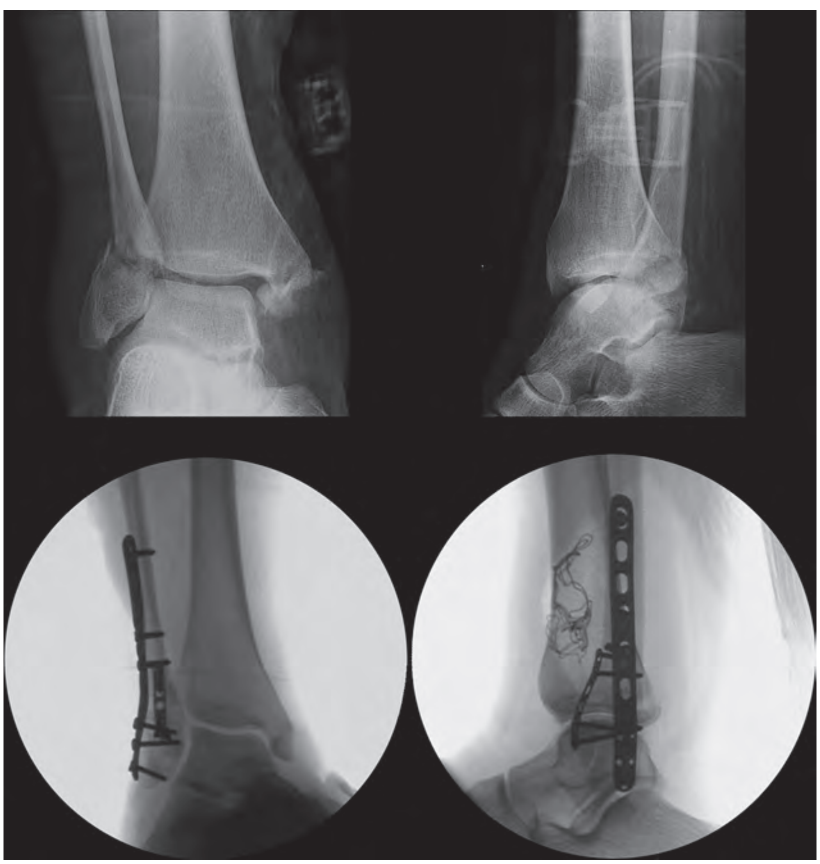

Figure 22-9. In this bimalleolar fracture, the fibula was treated with a posterolateral periarticular plate and an anterior mini-fragment plate for stabilization of comminuted intercalary fragments.

Fibular Fractures—Adduction Mechanism

- The fibular fracture is typically a perisyndesmotic or an infrasyndesmotic transverse (or short oblique) fracture.
  - May be suitable for medullary screw fixation
  - Requires a rotationally stable fracture pattern (i.e., fragment interdigitation and compression)
  - Overdrill the starting hole with a 3.2- or 3.5-mm drill to make the screw insertion easier.
  - Use long 2.5-mm calibrated drill bit to prepare the medullary canal of the fibula and estimate the screw length.
  - Starting point is critical, make sure that it is center/center on the AP and lateral views and collinear with fibular canal, if not collinear, then angulation at the fracture site may occur if the screw is stiffer than the reduction afforded by fracture interdigitation.
- Alternatively, a small tensioned plate can provide sufficient rotational stability of small fibular avulsion fragments (Fig. 22-10).

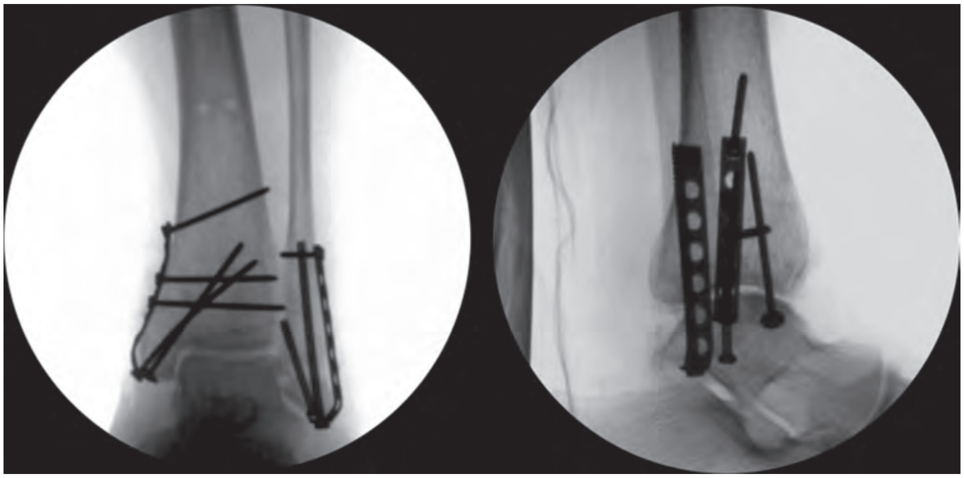

Figure 22-10. A mini-fragment tension plate for fibular avulsion fracture stabilization.

- Consider smaller implants for the medial malleolus when the fracture is comminuted and/or the fragments are small.
  - Anterior and/or posterior one-fourth tubular plates with 2.7-mm screws, or 2.4/2.0 plates and screws.

- Marginal articular impaction of the medial shoulder of the plafond often exists, ensure this is diagnosed and treated with "elevation" and supportive grafting (Fig. 22-11).

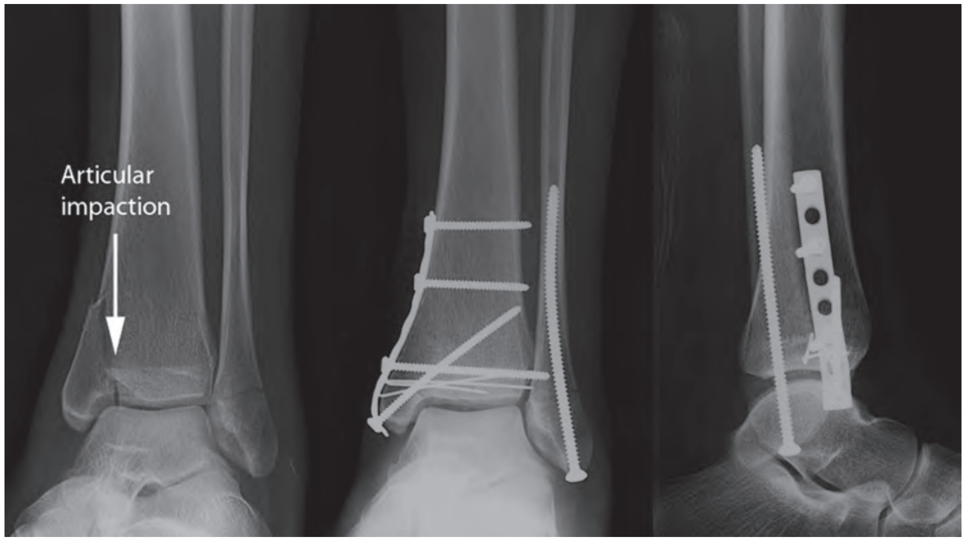

Figure 22-11. Fixation of the supination adduction injury: the medial plafond impaction has been reduced and stabilized with wires and bone graft. An antiglide plate buttresses the medial malleolus, and a medullary screw stabilizes the fibula.

Medial Malleolar Fractures

- Approaches should provide surgical exposure and visualization from the anterior ankle joint to the posterior tibialis tendon, as well as the cortical surface.
- For large fracture fragments, two 3.5- or 4.0-mm cancellous lag screws or two 3.5-mm cortical screws inserted using a lag technique are usually sufficient, depending on the size of the fracture fragment (Fig. 22-12).

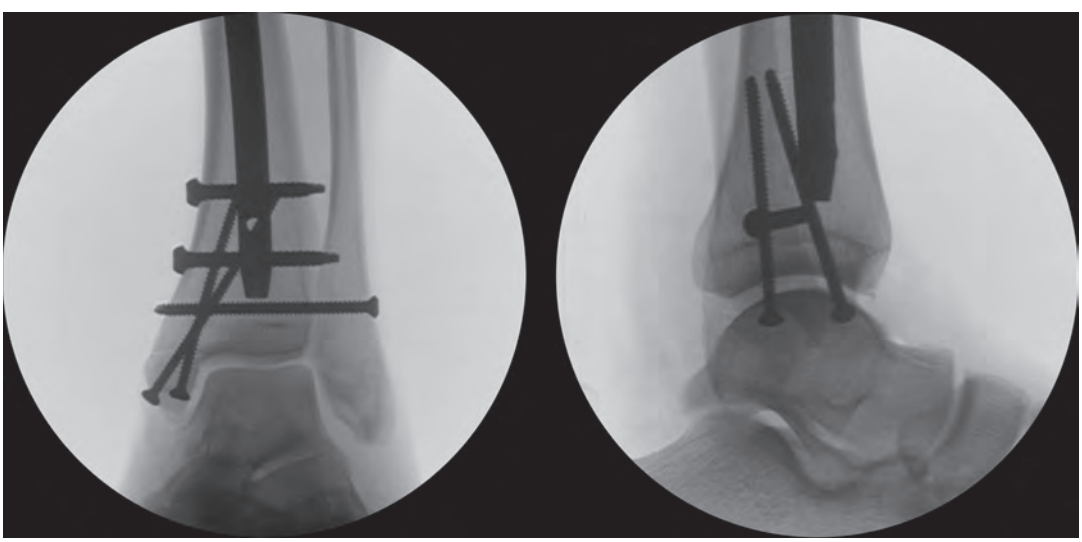

Figure 22-12. Two 3.5 cortical screws, inserted using lag technique, are used to fix this medial malleolar fracture.

- Consider smaller screws (3.0/2.7/2.4 mm) for anterior or posterior collicular fractures.

- Placing bicortical medial malleolar lag screws can increase the strength of the medial fixation and are useful in osteoporotic bone.
  - For easier insertion, place provisional K-wires away from, but roughly parallel to, the anticipated screw trajectory.
  - These can be used as an external visual guide during screw insertion.
  - Overdrilling the near cortex will make it easier to find the hole with the screw tip.
  - Tapping both cortices will assist in screw insertion as the screw may skid along the endosteal surface due to the obtuse angle of intersection (Fig. 22-13).

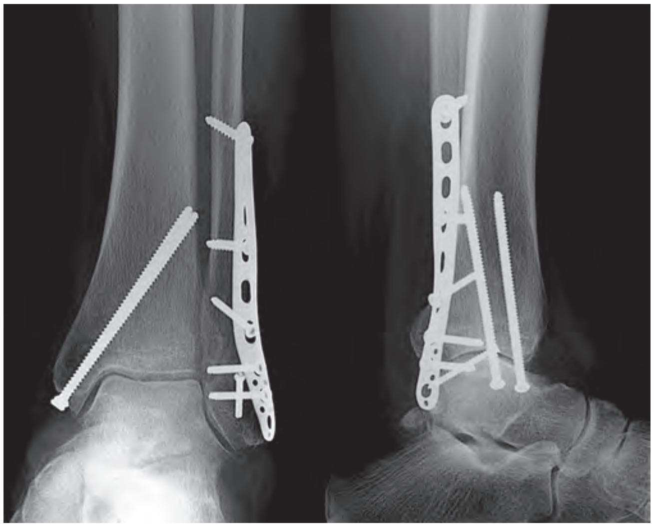

Figure 22-13. Improve medial fixation by placing bicortical 3.5-mm screws (with 2.7-mm heads). This may be especially important in patients with osteoporotic bone.

- When drilling the far cortex, advance the drill bit slowly to avoid bending or breaking the drill bit.
  - If the drill bit bends, remove the bit and create a distal cortical hole by drilling the lateral tibial cortex with a stiffer instrument, such as a 2.4-mm smooth Steinmann pin.
- Another method of obtaining bicortical fixation is to use a K-wire, a cannulated drill bit, and a cannulated tap to create both the gliding and threaded holes for lag screw fixation.
  - After creating the screw path, fix the fracture with noncannulated screws.
- In osteoporotic bone, be careful not to over compress the fracture.
  - The denser meta-diaphyseal bone permits good screw purchase and may result in fracture angulation and a malreduction.

- 2.0-mm plates are useful for comminuted or multifragmentary avulsion medial malleolus fractures (Fig. 22-14).

Figure 22-14. 2.0-mm straight plates with 2.4-mm screws are useful implants for comminuted medial malleolus fractures. Note the stacked one-third tubular plates to increase the rigidity of the lateral fixation across the intercalary comminution. The avulsed Chaput fragment has been repaired with a four-hole 2.0-mm straight plate.

The Chaput (or Tillaux-Chaput) Fracture Fragment and/or the Wagstaf-Lefort Avulsion Fracture Fragment

- May be approached through a separate anterolateral approach, if fibular approach is sufficiently posterior to provide for an adequate skin bridge.
- A 2.0-mm straight plate placed anteriorly is used both as a tension band and as a washer or spiked washer for fixation.

The Posterior Malleolus

- Fracture morphology—the lateral view underestimates the size of the posterior malleolar fracture fragment and the articular involvement.
    - Consider using a lateral view with approximately 30 degrees of external limb rotation for a view tangential to the fracture line.
    - This view, in addition to a mortise view guides the direction of lag screw fixation.

- Direct reduction and ORIF through posterolateral or posteromedial approach (Fig. 22-15).

Figure 22-15. Posterior antiglide plate. This large posterior malleolus fracture was reduced using a posterolateral approach with the patient in the lateral position. A one-third tubular plate (fashioned as a hook plate) was used with 3.5-mm screws. The fibular fracture was reduced and fixed subsequently through the same skin incision. Alternatively, a posteriomedial approach anterior to the posterior tibial tendon would allow direct access to the fracture (figure), but would not be ideal for orthogonal screw placement. The Chaput fracture was repaired through a separate, smaller anterolateral approach with a quarter tubular plate and 2.7-mm screws.

- Posterolateral approach
  - The posterolateral approach allows access to the cortical surface of the posterior tibia, but limited access to the ankle joint.
    - The fracture is accessible superiorly and laterally above the posterior tibiofibular ligament and along its posteromedial border.
    - The posterior tibiofibular ligament prevents access to the lateral fracture border, except above the ligament near the fracture's apex.
  - It is helpful to obtain a CT scan preoperatively to identify the interfragmentary fragments or articular impaction that will block the reduction of the posterior malleolus.
  - The fracture plane is usually best imaged with some external rotation (variable), tangentially to the fracture plane, which can be determined more accurately using the CT scan's axial images to identify the orientation.
  - Lateral or prone positioning can be used.
  - The skin incision is along the posterior border of the peroneal tendons.
  - Dissect posterior and medial to the peroneal tendons to access the posterior malleolus distally.
    - Develop the plane anteromedial to the peroneal tendons to access the medial border of the fibula.
      - Do not injure the posterior tibiofibular ligament running transversely.
      - Reflect the FHL but preserve the peroneal artery which courses along the interosseous membrane deep to this muscle.

    - Alternatively, access the posterior surface of the fibula through the FHL/peroneal interval.
        - This is much easier with patient prone.
- To minimize dissection, a portion of the posterior malleolar fragment can sometimes be accessed for cleaning and reduction through the medial malleolar fracture, if present, or through the fibular fracture (prior to its reduction).
- A one-third tubular or smaller plate placed in an antiglide position with supplementary lag screws is usually a sufficient fixation for this fracture.
    - Alternatively, smaller plates can effectively buttress a small posterior malleolar fragment; 2.4- and 2.0-mm straight or T-plates should also be considered.
- Clamp application can be necessary for anatomic articular reduction (Fig. 22-16).

Figure 22-16. If indirect reduction with a plate does not obtain an anatomical articular reduction, place a clamp tine through a small anterior incision and the other tine directly on the Volkmann fragment (**upper right**).

- Posteromedial approach
    - Patient may be positioned prone or supine, assuming that there is adequate hip external rotation to allow access and reduction. Alternatively, a "figure of four" position of the limb with the patient positioned supine can be used.
    - Allows direct access to the fracture plane.
    - Fibula is not "in the way" with this approach compared to the posterolateral approach.
    - Several "windows" may be used to access the posterior malleolus: posterior to the PT tendon and anterior to the FDL tendon, posterior to the PT and FDL tendons, and anterior to posterior tibial neurovascular bundle or posterolateral to PT/FDL and NV bundle, retracting FHL laterally.

- Generally, the interval is posterior to the PT/FDL, while the FHL is retracted posteriorly and laterally with posterior tibial neurovascular bundle.

- Indirect reduction
  - Indirect reduction with screw fixation of the posterior malleolus is an attractive option in trimalleolar ankle fracture patterns as it allows the patient to be positioned supine for the entire procedure.
  - Disadvantages are reliance on indirect or percutaneous methods to manipulate the posterior malleolus, radiographic assessment of the reduction, and a less secure fixation construct.
    - A shoulder hook or large pointed bone reduction clamp (Weber) is a useful tool to manipulate and reduce the posterior malleolus percutaneously (Fig. 22-17).

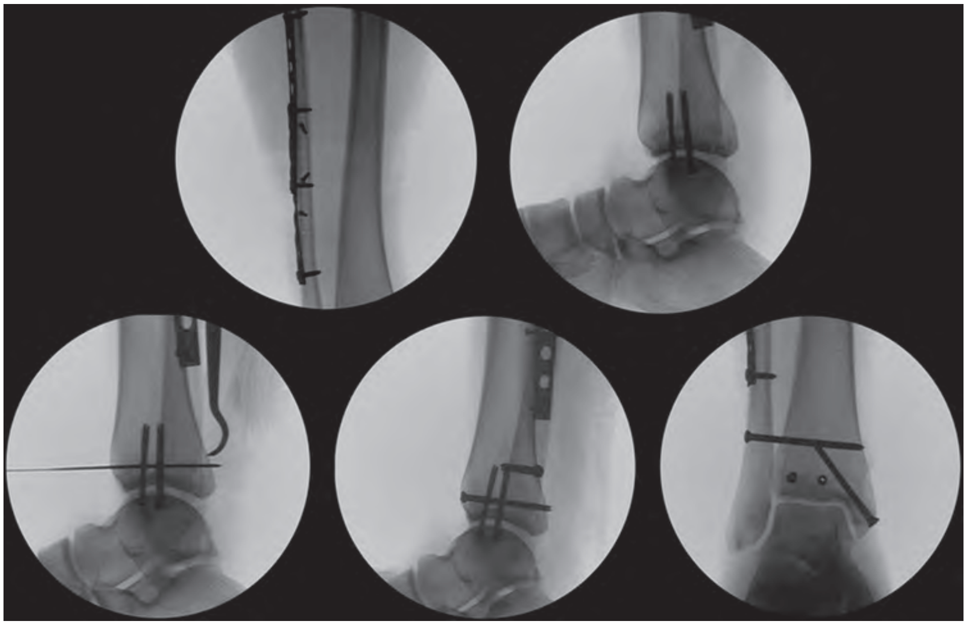

Figure 22-17. Initial anatomical reduction of the diaphyseal fibula fracture in this trimalleolar ankle injury provides near anatomic reduction of the posterior malleolus. Note that if the fibular plate continued distally, it would obscure the radiographic assessment of the posterior malleolar reduction. A shoulder hook is used to manipulate the Volkmann fragment into a more distal position using fluoroscopic guidance (**lower left**). The posterior malleolus is stabilized using anterior-to-posterior cannulated lag screws and the syndesmotic reduction is secured with a transsyndesmotic 4.0-mm cortical screw.

  - Anatomical reduction of the fibula will often reduce the posterior malleolus indirectly.
    - However, plate fixation of the fibula can obscure the radiographic assessment of the articular surface and the posterior malleolar fracture plane.
    - Use K-wires or lag screws to provisionally stabilize the fibular reduction prior to reduction of the posterior malleolus.
    - Apply definitive fibular fixation after articular reduction is confirmed radiographically.

- Scrutinize the AP and lateral views for a medial (and posterior) double density, potentially indicating a posteromedial fracture fragment.
  - Consider obtaining a CT scan to further assess (Fig. 22-18).

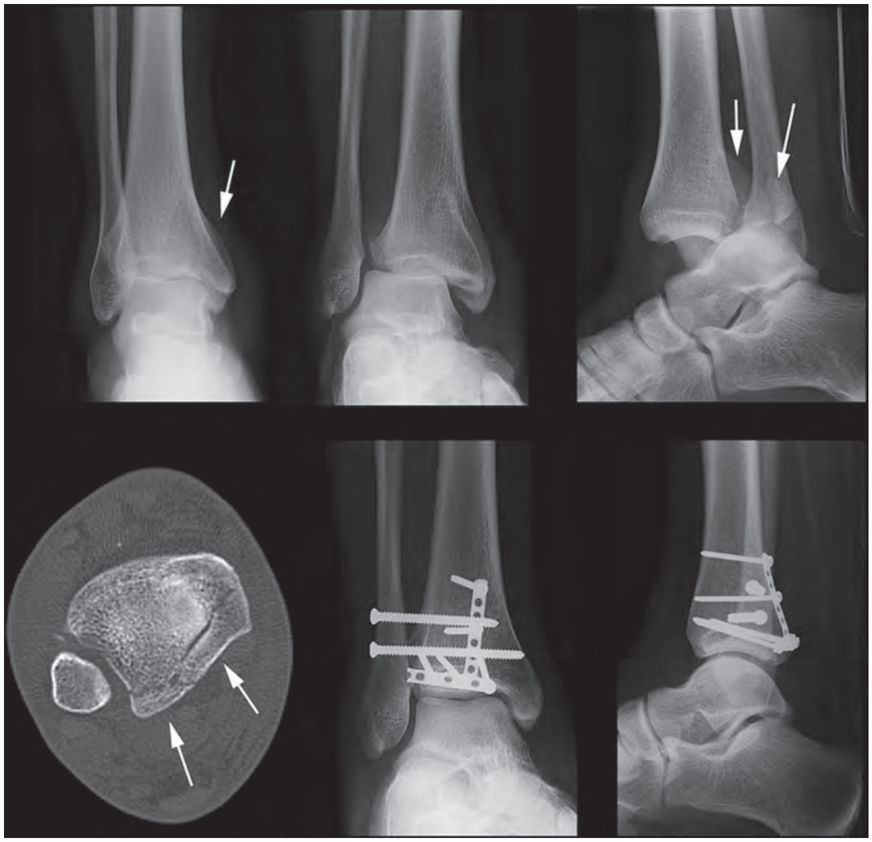

Figure 22-18. A double density was seen medially on the AP view (*arrow*, **upper left**) and posteriorly (*arrows*, **upper right**). A CT scan was obtained to further evaluate the morphology of the posterior distal tibia. This injury was treated with a posteromedial approach, and a transverse mini-fragment plate to stabilize both the posterolateral and posteromedial fragments.

Syndesmosis

- When comminution of the incisura exists, or for patients with an old or chronic syndesmotic injury, consider an open syndesmotic reduction (Fig. 22-19).

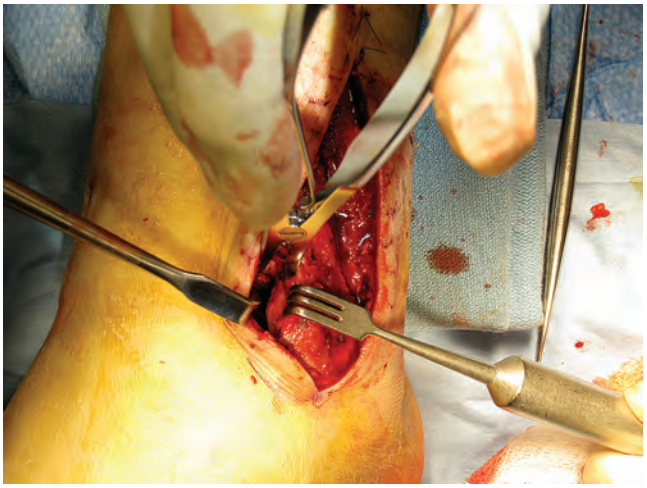

Figure 22-19. The distal tibiofibular syndesmosis can be approached by extending the posterolateral incision sufficiently to permit soft tissue retraction (shown) or through a separate anterolateral incision in line with the fourth metatarsal. A laminar spreader is used to distract the disrupted joint so that interposed hematoma, callus, ligaments, or fracture fragments can be cleared from the tibiofibular articulation.

- Sagittal plane instability.
  - Check for fibular and talar subluxation in the sagittal plane using the lateral view.
- After reduction maneuvers, use a percutaneously placed periarticular or linear bone clamp and place one or two 0.062 inch K-wires to provisionally stabilize the ankle mortise and syndesmosis.
  - This is followed by definitive fixation (Fig. 22-20).

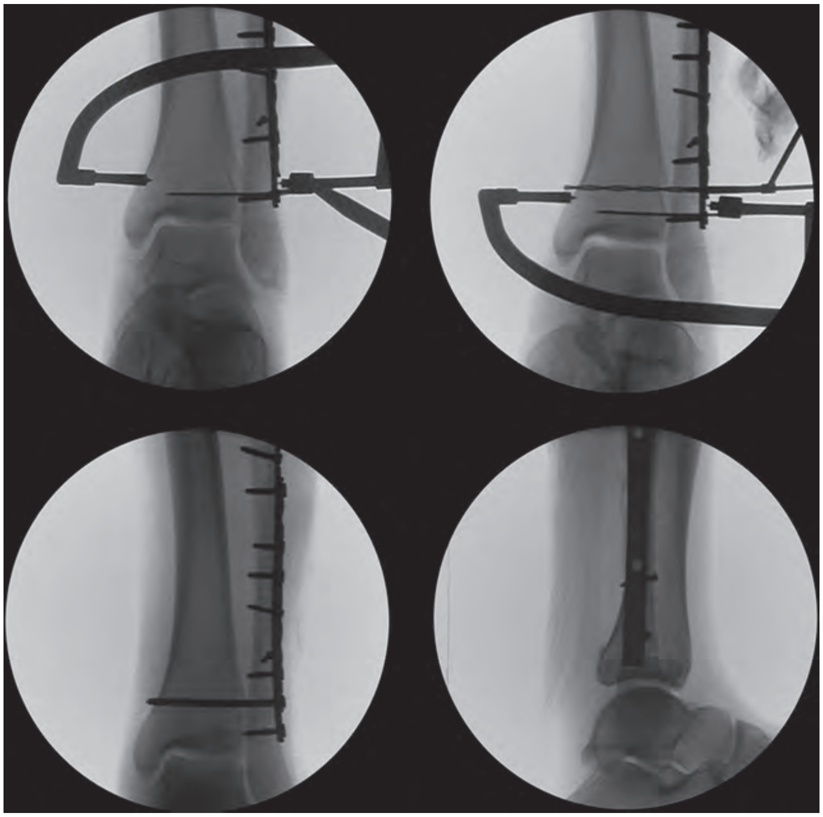

Figure 22-20. The syndesmosis is first reduced and stabilized using a linear bone clamp. The reduction is assessed on both the AP and lateral views, and a 0.062 inch K-wire is used to maintain reduction and as additional temporary stabilization. Definitive fixation is then applied.

- Syndesmosis screws may be inserted through a lateral fibula plate as the location of this plate facilitates screw insertion which is orthogonal to the incisura (see Fig. 22-20).
  - Ideally, these screws should be inserted perpendicular to the incisura and orthogonal to the fibula (same figure below).
  - However, syndesmotic screws placed through a posterior or posterolateral fibular plate may cause the fibular to translate anteriorly along the screw's trajectory if the fibula is not stabilized in a reduced position prior to creating the path for the interosseous screw.
  - Thus, it is important to provisionally stabilize the syndesmotic reduction with one or two transsyndesmotic K-wires prior to drilling the syndesmosis screw path, especially if placed through a posterolateral fibula plate.
- The protruding tips of screws in a lateral or posterolateral fibular plate may cause a syndesmotic malreduction as a long screw may encroach upon the tibial incisura, thus preventing a concentric reduction of the fibula (Fig. 22-21).

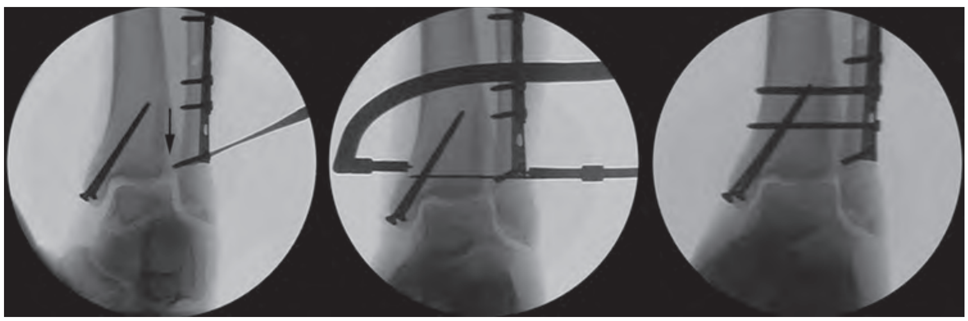

Figure 22-21. The long screw in the distal end of the one-third tubular plate on the fibula prevents anatomic reduction of the syndesmosis (*arrow*, **left**). Note the apparent widening of the syndesmosis despite the symmetric appearance of the tibiotalar joint space. The distal screw has been shortened and an open reduction of the syndesmosis has been preformed (**center**). Syndesmotic fixation is complete and the clamp has been removed (**right**).

- If the syndesmotic injury involves an avulsion of the tibial insertion of the anterior syndesmotic ligament (Chaput or Tillaux-Chaput tubercle), an open reduction and fixation with a small hook plate ensures anatomic repair of this ligament (Fig. 22-22).

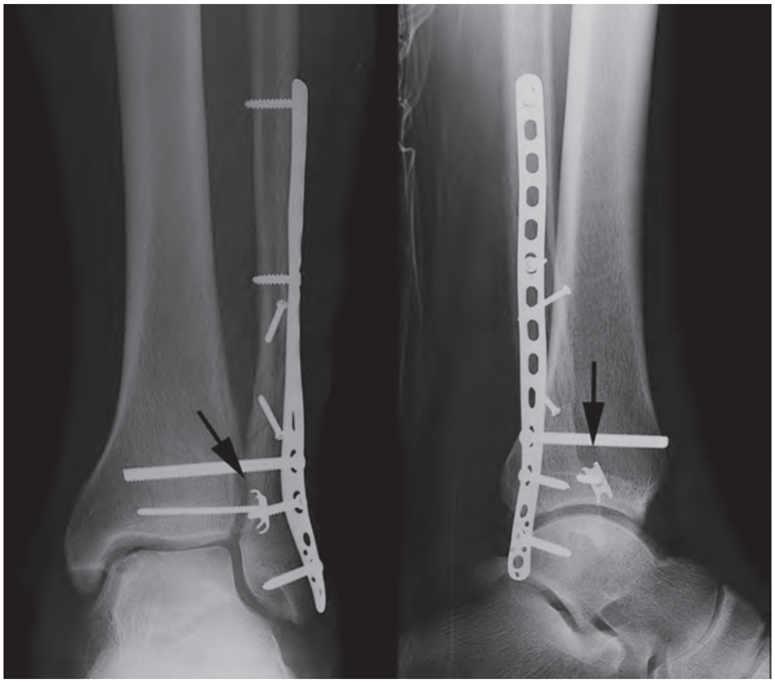

Figure 22-22. Open reduction of an avulsion-type syndesmotic injury with a small hook plate, made by modifying a three-hole 2.0 straight plate (*arrows*). This was supported with a quadricortical syndesmotic screw.

- The syndesmosis may be overtightened if comminution is present on the fibular or tibial side of the syndesmotic joint (Fig. 22-23).

Figure 22-23. Be cautious if there is significant comminution involving the syndesmotic area. If the fracture disrupts the articular areas on either side of the distal tibiofibular articulation, the sydesmosis can be overtightened.

Fixation Considerations in Osteoporotic Bone (Figs. 22-24 and 22-25)

- Augment fibular fixation with syndesmotic screws.
- Double plate the fibula.
- Consider locking implants.

Figure 22-24. In this osteoporotic ankle fracture dislocation, both a medial plate and multiple transsyndesmotic screws were used to augment fixation.

Figure 22-25. Another osteoporotic ankle fracture stabilized using similar principles.

- Use multiple syndesmotic screws through a plate.
- Use bicortical medial malleolar screws.
- Be gentle during clamp application, do not comminute fragments.

Chapter 23

Talus Fractures

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Sterile Instruments/Equipment

- Tourniquet if desired
- Headlight
- Small pointed bone reduction clamps (Weber clamps)
- Dental picks and Freer elevators
- Schanz pins (2.5 to 4.0 mm)
- Femoral distractor (small)
- Micro-oscillating saw if medial malleolar osteotomy needed
  - 3.5- to 4.0-mm cancellous and cortical screws for osteotomy fixation
- Implants
  - Mini- and small-fragment screws and mini-fragment plates and screws (2.0/2.4/2.7/3.5 mm)
  - Autograft, cancellous allograft or other bone substitute for structural defects
- K-wires and wire driver/drill

Positioning and Imaging

- Supine at the foot end of the radiolucent cantilever table.
- Small bump underneath the ipsilateral hip.
- Three views are used to assess talar fracture reductions: lateral of talus/ankle, Canale view, and ankle mortise.

Surgical Approaches

- Simultaneous medial and lateral approaches.[1]
  - Two approaches needed invariably, as it is difficult to assess reduction on opposite side of talus, if inferred from side approached by single incision.

- Anteromedial approach is between anterior and posterior tibialis tendons (Figs. 23-1 and 23-2).

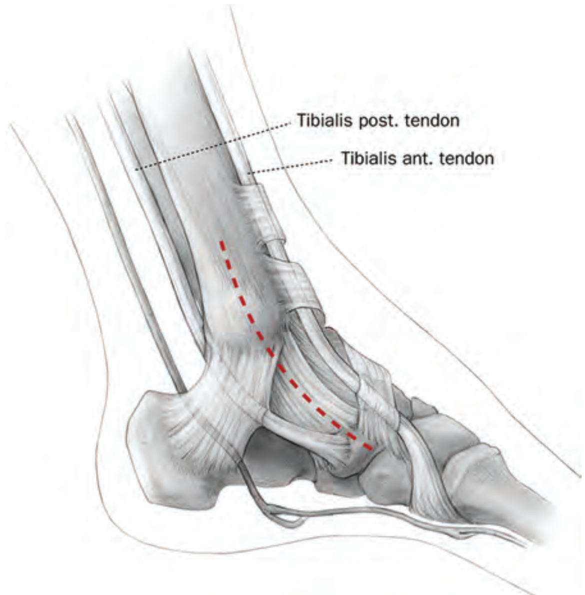


Figure 23-1. Plane of an anteromedial incision. (From Vallier HA, Nork SE, Benirschke SK, et al. Surgical treatment of talar body fractures. *J Bone Joint Surg Am*. 2004;86: 180–192. Reprinted with permission.)

Figure 23-2. Deep dissection for an anteromedial approach. (From Vallier HA, Nork SE, Benirschke SK, et al. Surgical treatment of talar body fractures. *J Bone Joint Surg Am*. 2004;86:180–192. Reprinted with permission.)

- From anterior medial malleolus to navicular.
- Deltoid protected.
- Plantar dissection avoided.
- Incise the talonavicular joint capsule, proximal to medial tarsal artery.
- Expose the dorsomedial talar neck and medial body.
- Visualization includes medial talar dome, medial talar neck, and talar head.
  - Retraction of capsule and dorsal soft tissues allows visualization of the anterior aspect of the talar dome to the lateral side.
  - Plan incision to allow medial malleolar osteotomy depending on the fracture pattern.

- Anterolateral incision is in line with the fourth ray of foot (Figs. 23-3 and 23-4).

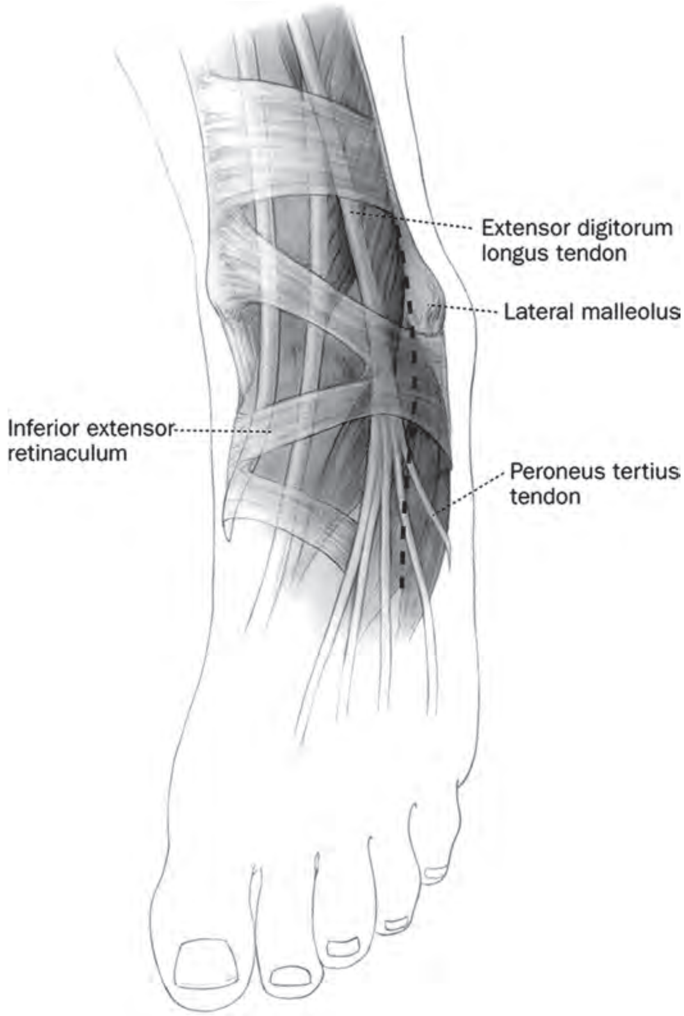


Figure 23-3. Incision for an anterolateral approach for a talus fracture. (From Vallier HA, Nork SE, Benirschke SK, et al . Surgical treatment of talar body fractures. *J Bone Joint Surg Am.* 2004;86:180–192. Reprinted with permission.

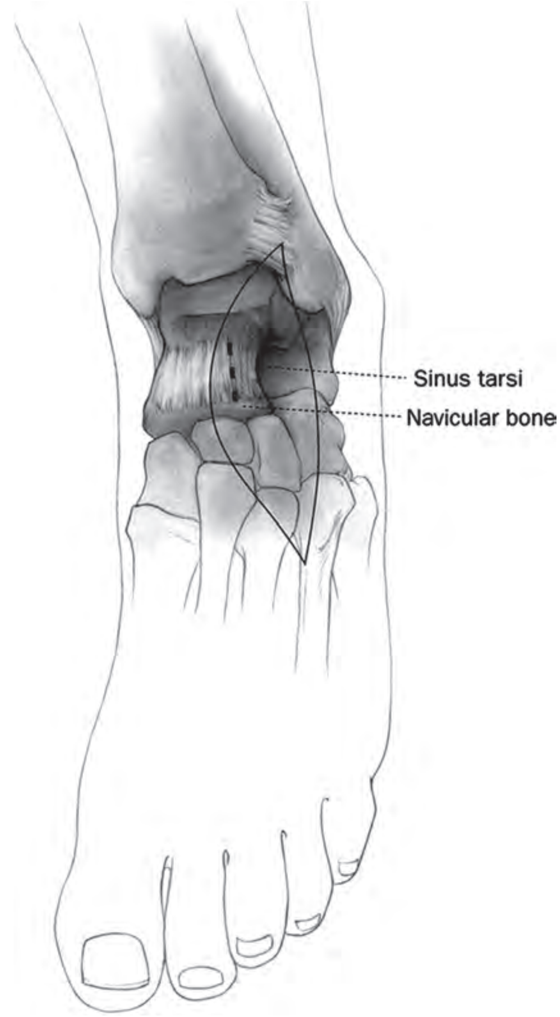


Figure 23-4. Deep dissection for an anterolateral approach to the talus. (From Vallier HA, Nork SE, Benirschke SK, et al. Surgical treatment of talar body fractures. *J Bone Joint Surg Am.* 2004;86:180–192. Reprinted with permission.)

- Sharp dissection, full thickness flaps.
- Avoid superficial peroneal nerve in proximal incision.
- Develop interval between long toe extensors and extensor brevis musculature.
  - Brevis musculature typically retracted plantar/lateral.
  - Avoid branches of dorsalis pedis, muscular branches to EHB and EDB, and lateral tarsal artery.
- Retract anterior compartment tendons medially.
- Reflect or excise sinus tarsi fat.
- Visualization should include the lateral dome of the talus, lateral process of talus, lateral talar neck, lateral talar head, and the talofibular articulation.
- Dissection plantar to the lateral process of the talus allows access to the posterior facet of the subtalar joint, facilitating debridement of osseous and chondral debris.

Reduction and Fixation Tips

Talar Neck

- Use cortical interdigitations for reduction; more commonly this is on the lateral side or inferomedially, as impaction/comminution is typically dorsomedially.
- Some vertical neck fractures traverse the anterior chondral surface of the talar body.
  - Often the chondral interdigitations along this portion of the fracture provide an excellent assessment of reduction accuracy.
- Visually assess the quality of reduction, medially and laterally using both incisions.
  - Subtle rotational and angulatory malreductions can be appreciated from one side or the other.
- Radiographic correlation requires understanding of the normal talar relationships with the rest of the foot.
  - Talar axis on the AP view.
    - Common malreduction deformity is varus.
  - Talar axis on the lateral view.
    - Common malreduction deformity is extension, especially in high energy fractures.
    - These high energy injuries often require tricortical or cancellous bone graft to "strut" the area of impaction and comminution (dorsally) so as to restore the talar-first metatarsal angle.
    - The talar-first metatarsal angle should be nearly parallel on the AP and lateral radiographs.
  - The anterior and middle facets are on the talar head fragment; the posterior facet is on the body fragment.
    - Check to ensure that these are congruent radiographically.
- Managing circumferential comminution
  - Difficult problem.
  - Small external fixator from the distal medial tibia to the medial aspect of the navicular and from the fibula to the lateral aspect of the navicular will allow controlled restoration of talar neck length and angulation.
  - Radiographically reduce the anterior and middle facet (i.e., head fragment) and the posterior facet (i.e., body fragment) to the calcaneus.
  - If these joints are congruent, then the talar neck length is correct.

Provisional Fixation

- Multiple retrograde K-wires from both the anteromedial and anterolateral exposures.
  - Avoid placing wires in the fibula or across the tibiotalar/subtalar articulations.

- A femoral distractor with Schanz pins in the medial distal tibia and the cuneiforms can be used to aid in fracture visualization and reduction (Fig. 23-5).

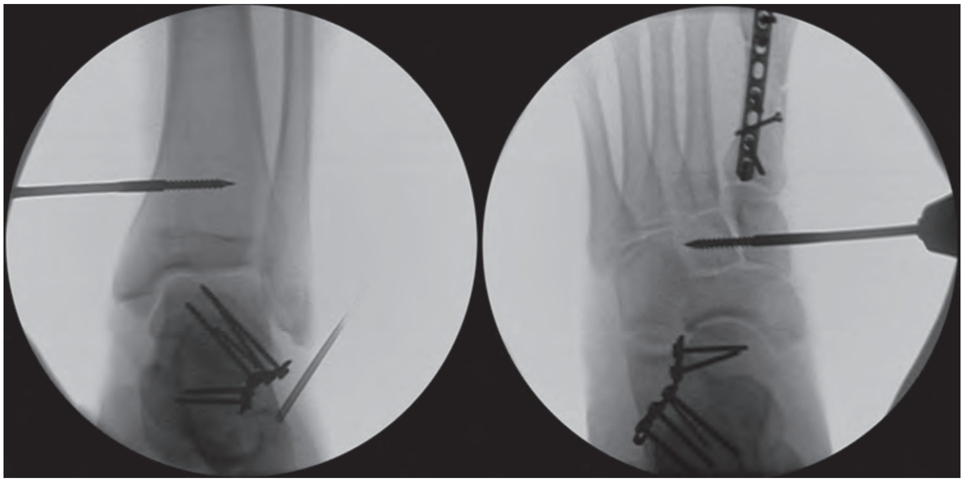


Figure 23-5. A universal distractor placed from the tibia to the midfoot can restore talar neck length.

- A Weber clamp can be used to compress across the talar neck fracture.
  - The posterior tine of the clamp is placed posterior to the medial malleolus, avoiding neurological, vascular, and tendinous structures (Fig. 23-6).

Figure 23-6. A clamp may be placed across the talar neck to compress noncomminuted fracture lines.

- When access to the talar body is limited due to a proximal neck fracture (or one that extends into the anterior portion of the talo-tibial articulation), fracture reduction can be facilitated by stabilizing the talar body prior to addressing the fracture.
  - This can be performed by plantar flexing the foot so as to bring the fracture into view (avoid being obscured by anterior lip of tibia).
  - The talus is held in this plantar flexed position by placing one or two small Steinmann pins from the tibia or fibula into the talar body (avoid the weight bearing articular surface).
  - Reduction of the midfoot onto the stabilized hindfoot is thereby facilitated as only one fracture fragment is freely mobile.

- A K-wire can be placed transversely across the talar head segment through both incisions to manipulate the distal talar neck fragment.
  - Avoid dorsal dissection over the talar neck to minimize vascular disruption (Fig. 23-7).

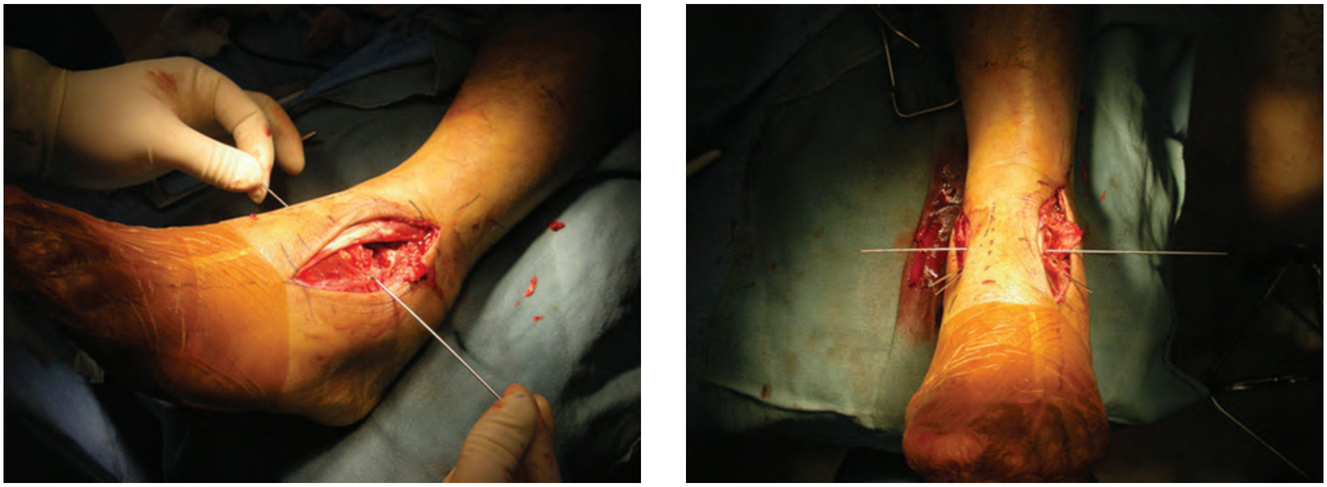


Figure 23-7. A K-wire placed through the distal fragment is useful for multiplanar manipulation.

- Alternatively, use dental picks and elevators to reduce the fracture.

Extruded Talar Body Reduction

- Talar body is typically extruded posteromedially, adjacent to the neurovascular and tendinous structures contained within the tarsal tunnel.
- Very difficult to reduce in an awake patient, but an attempt is worthwhile in the ED with conscious sedation.
- Basic principles include
  - Knee flexion to relax gastrocnemius musculature.
  - Longitudinal traction applied to the calcaneus.
  - Counter-traction applied to the posterior aspect of the distal femur.
  - Valgus angulation of the calcaneus.
  - Direct pressure over the talar body toward the mortise.
- When this does not work
  - A symmetrical external fixator can be created in an attempt to create adequate space to reduce the dislocated talar body.
  - Insert transcalcaneal Schanz pin.
  - Insert two bicortical tibial shaft Schanz pins (medial and lateral).
  - Construct biplanar frame connecting the lateral tibial pin to the lateral aspect of the transcalcaneal pin; medial tibial pin to the medial aspect of the transcalcaneal pin.
  - Medial and lateral open-ended compressor-distractor devices will create symmetric, controlled distraction between the calcaneus and the tibial plafond to accept the talar body.
- When this does not work
  - Ensure that the distraction provided by an external fixator is adequate.
  - Proceed with two exposures described (anterolateral and anteromedial).

- Remove entrapped soft tissue, if present, that may impede relocation.
- Perform direct manipulation of the body with a bone hook, or placement of a Schanz pin into a nonarticular surface of the talar body.

- When this does not work
  - Medial malleolar osteotomy (rarely required)

Definitive Implant Placement

- K-wires are mechanically weak, so screws are favored for definitive fixation.
- Despite posterior to anterior screws identified as more mechanically sound than anterior to posterior screws, small-and mini-fragment implants placed anteriorly are favored for comminuted fractures and are preferred currently.
  - 1.5-, 2.0-, 2.4-, 2.7-, and 3.5-mm screws.
  - Plates are 2.0- or 2.4-mm mini-fragment implants.
  - Many of these can be found on modular hand or modular foot sets.
  - Both straight plates and T-plates are useful.
  - Make sure to verify the maximum screw lengths in implant sets.
- After fracture reduction and provisional stabilization, definitive fixation usually begins on the lateral side, unless there is no medial comminution.
  - In fractures without comminution, an anatomic reduction, and good bone quality, screw fixation alone is satisfactory.
- Plating a talus is not intuitive, but is an excellent technique for fixation.
  - The lateral aspect of the talus is more amenable to plate application than the medial side.
  - Typically, a four- or five-hole 2.0-mm straight plate is contoured with approximately 50 to 70 degrees of bend (extension) to follow the extraarticular surface along the lateral talar neck, between the talar head and lateral process (Figs. 23-8–23-12).

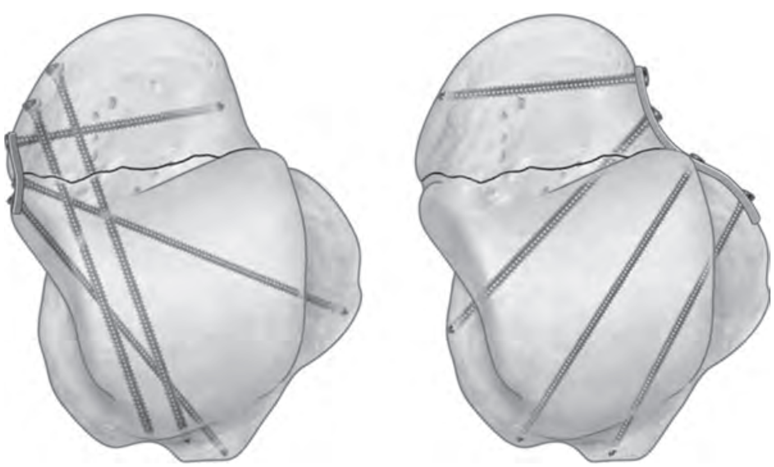


Figure 23-8. Typical implant placements for the medial talar column include longitudinal screws, countersunk in the talar head, and small plates (**left**). A small portion of the overhanging navicular tuberosity can be removed to facilitate implant placement without functional consequence. For the lateral column of the talus, plate fixation is used across the typically tension failure fracture line. The methods shown are used in multiple combinations depending on the fracture requirements.

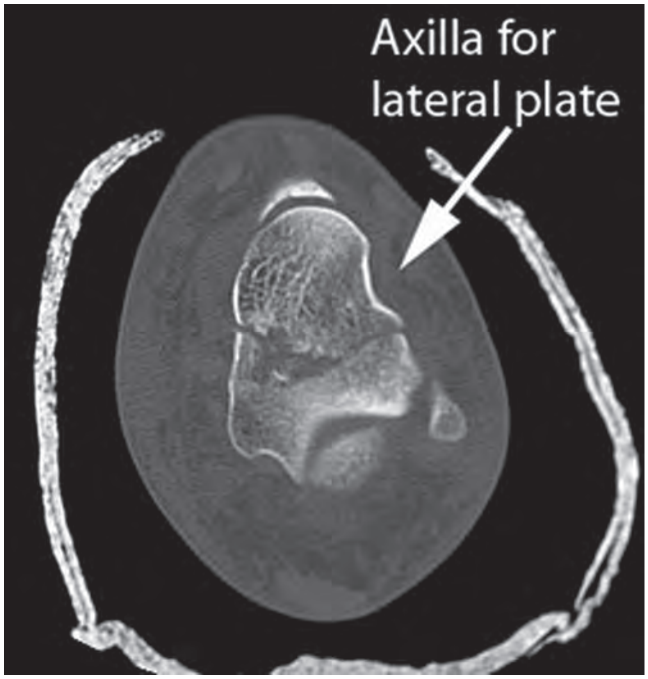


Figure 23-9. CT scan demonstrating the lateral talar plating surface. Note the lateral tension failure and the medial talar neck comminution.

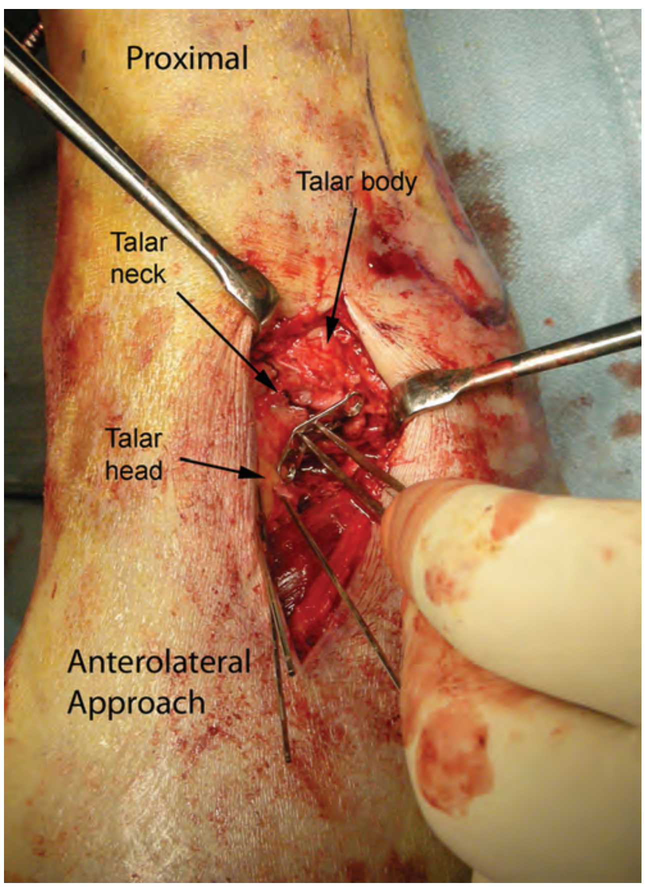


Figure 23-10. Clinical example of a lateral plate application for a talar neck fracture.

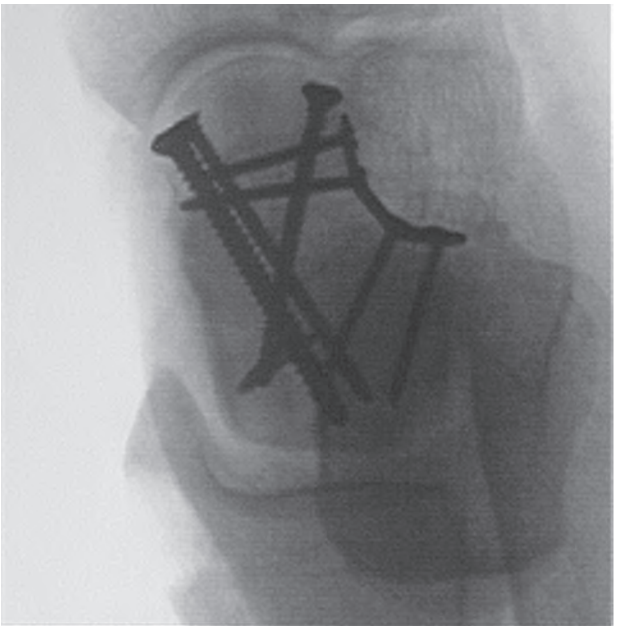


Figure 23-11. Fluoroscopic example of typical implant position for a talar neck fracture.

Figure 23-12. Another example of a talar neck fracture stabilized with a lateral plate and medial column screws.

- Ensure this plate does not impinge on the fibular facet of the talus with foot eversion and abduction
- When additional fixation through a plate is desired, a 2.0-mm T-plate can be used, with the horizontal portion of the "T" placed vertically along the anterior portion of the talar neck, just proximal to the talar head articular margin.

- This allows additional fixation into the talar head through the plate (Fig. 23-13).

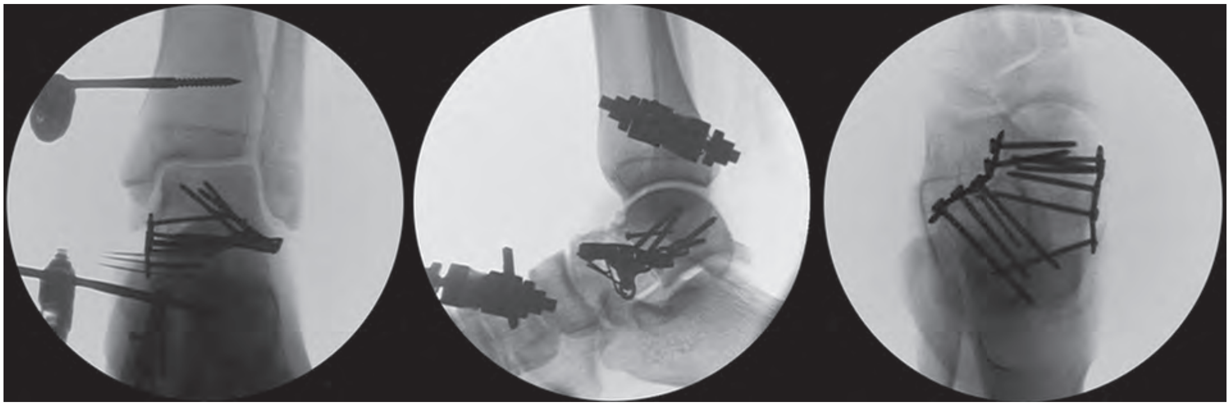


Figure 23-13. Case example of medial and lateral plating for a comminuted talar neck fracture. A T-plate was used on the medial side for additional distal fixation.

- Medial-sided plating is more difficult, as there is very little space available between the chondral surfaces of the talar head and the anteromedial talar body.
  - Flatter surface.
  - Fully invert foot to determine proximal extent of plate placement without impinging on medial malleolus.
- Screws placed independently of the plate are typically 2.7 or 3.5 mm.
  - Commonly, these screws are used to neutralize the medial column of the talus and act as a fully threaded strut across the medial portion of talar neck, so as not to shorten the medial column (varus).
  - The foot is abducted at the talonavicular articulation uncovering the medial chondral surface of the talar head.
  - Screws are placed through the chondral surface with the screw heads countersunk.
    - For improved access to the medial talar head, a small portion of the overhanging navicular tuberosity may be removed.
  - Similar principles are applied when placing lateral longitudinal screws.
- Bone defects of the neck are managed with morselized bone graft or structural bone graft depending on the size of the defect and stability of the fracture reduction.

Talar Body Fractures

- Goal: restoration of articular surface of both the talar dome (tibiotalar articulation) and the posterior facet (subtalar articulation).
- CT scans are useful.
  - Use the CT scan to determine the best approach.
  - Study the location of the major fracture lines relative to the medial and lateral malleoli.
  - Determine if osteotomy of the medial or lateral malleolus would aid in visualization, reduction, and/or fixation.

- Three major approaches
  - Anteromedial—may be extended with medial malleolar osteotomy if needed.
  - Anterolateral—may be extended with lateral malleolar osteotomy if needed (rare).
  - Posteromedial—may be extended with medial malleolar osteotomy if needed.
- Visualization is improved with the use of a small femoral distractor or external fixator, and headlamp illumination.
- Talar body fractures affect the talar portion of the subtalar articulation (posterior facet).
  - Posterior facet fragments are typically impacted into the cancellous surface of the talar body and impede reduction of larger peripheral fragments.
    - Identifying and reducing displaced and impacted posterior facet fragments is typically the initial focus, followed by reduction of the talar dome and peripheral fragments.
- Provisional fixation is performed with multiple K-wires.
- Definitive fixation is with multiple mini-fragment screws (1.5, 2.0, 2.4, 2.7 mm).
- Osteonecrosis and delayed union is increased
  - With major joint fracture lines or crush injury.
  - With associated dislocation.

Posteromedial Talus Fractures

- Fracture reduction and posteromedial plate placed through posteromedial approach for posterior talus fractures (Figs. 23-14 and 23-15).

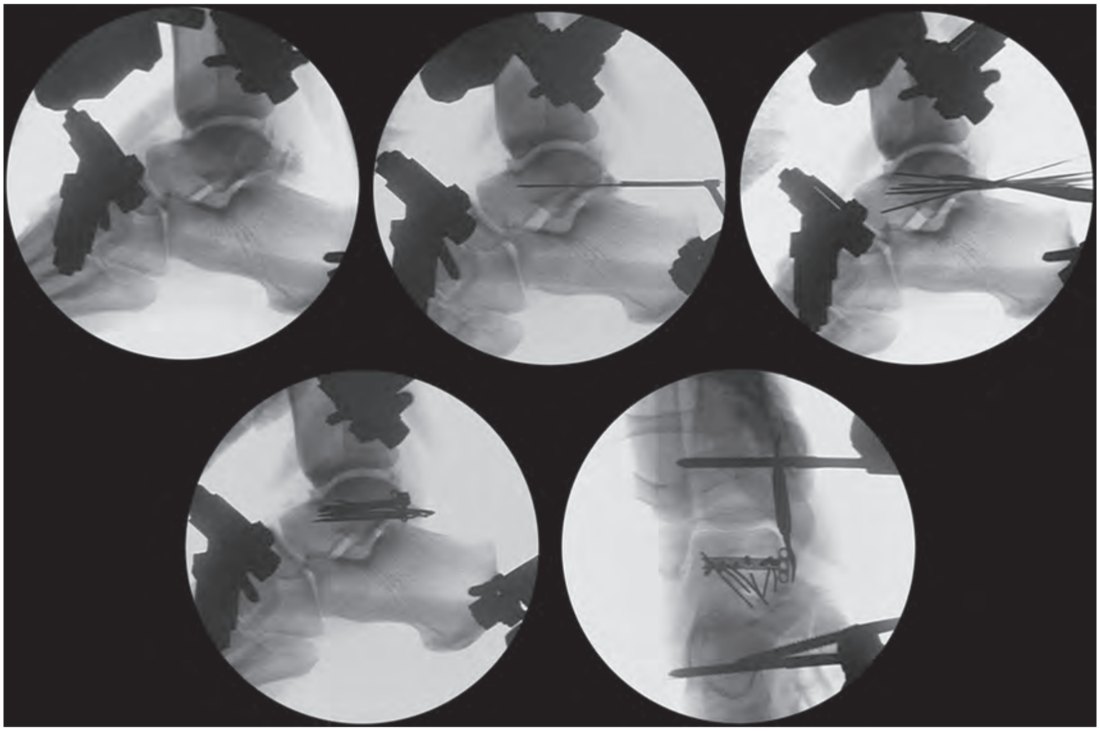


Figure 23-14. Case example of posteromedial talar fracture plate placement.

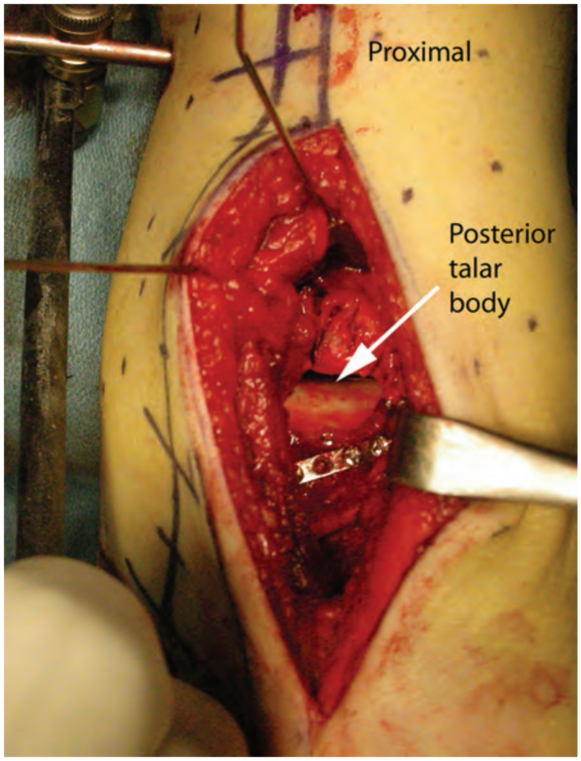


Figure 23-15. Clinical view of posterior talar body following operative fixation. The K-wires retract the FHL.

- Position prone.
- Headlamp is very helpful; distractor is usually necessary.
  - Pin in medial distal tibia and medial posterior tuberosity of calcaneus.
- Incision just medial to Achilles tendon.
- Elevate and retract the FHL, and incise capsule of ankle joint to expose posterior talus.
- Use a K-wire through the incision in the posterior malleolus of the tibia to maintain retraction of FHL.
- Ankle dorsiflexion with distraction exposes a large portion of the talar body.

Lateral Process Fracture

- Transverse incision beginning at the distal tip of the fibula and extending anteriorly 2 to 3 cm, parallel to plantar border of foot (Fig. 23-16).

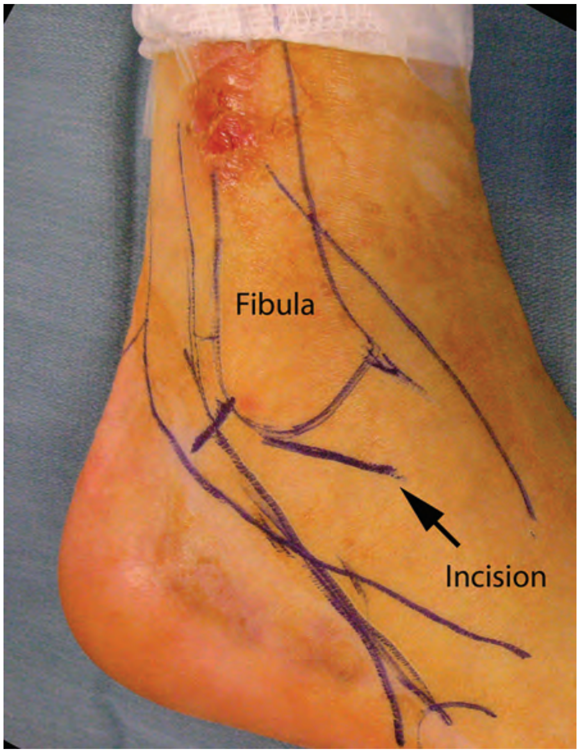


Figure 23-16. Incision marked for exposure of the lateral talar process.

- Direct reduction.
- Often a contoured 4-hole 2.0-mm plate is of appropriate size.
    - Cut outer two holes to form each end into a hook, leaving central two holes for 2.4-mm screws (Fig. 23-17).

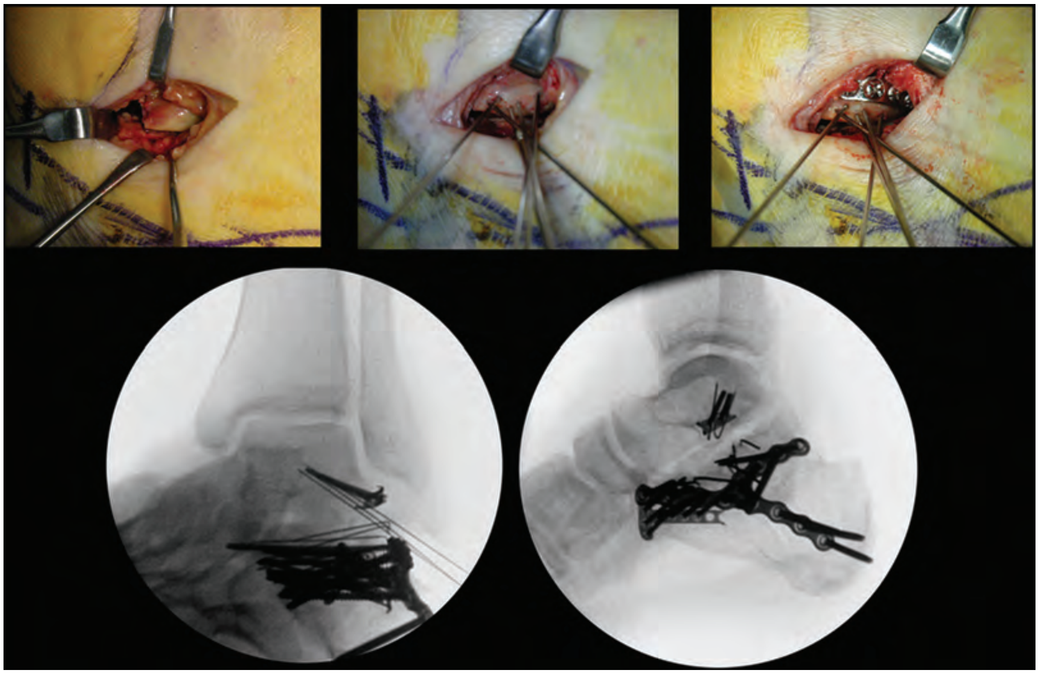


Figure 23-17. Clinical and fluoroscopic examples of lateral talar process reduction and fixation.

Posterolateral Talus Fracture

- Distractor from fibula to calcaneus.
  - Drill the fibula with a 2.5-mm drill.
  - Place a 4-mm short-threaded Schanz half pin into the fibula.
  - Place a similar Schanz pin in the calcaneal tuberosity from lateral to medial.
  - Dorsiflex the ankle.
  - An 8-mm bar with two clamps provides distraction.
  - A distractor is then applied to provide distraction of the lateral column of the ankle (Fig. 23-18).

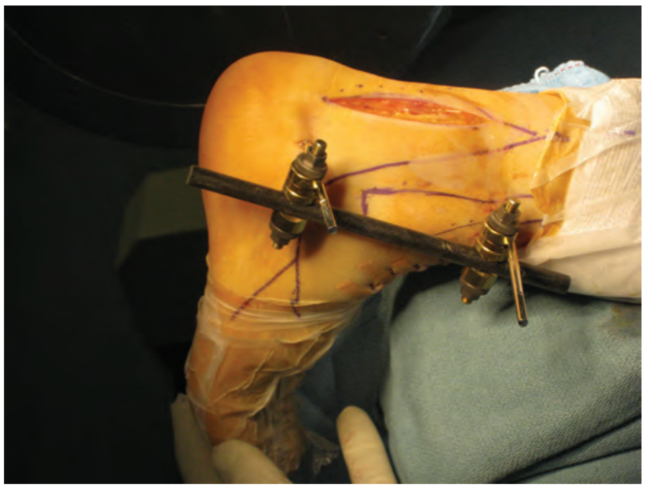


Figure 23-18. An external fixator used as a distractor between the fibula and calcaneus.

- Posterolateral approach
  - A posterolateral approach is made to the ankle directly lateral to the Achilles tendon, with care being taken to stay outside the Achilles tendon sheath.
  - Dissection is medial to the sural nerve.
  - Use a Doppler probe to ensure incision is medial to the peroneal artery (Fig. 23-19).

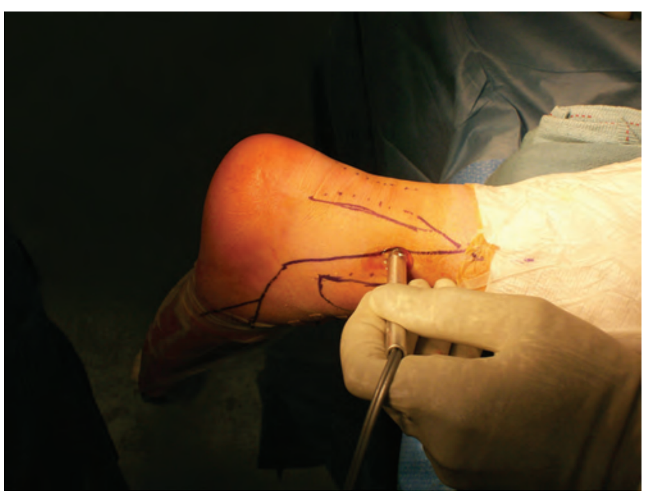


Figure 23-19. A vascular probe ensures that the posterolateral incision does not endanger the peroneal artery.

- Dissect to the level of the capsule.
- The capsule is incised, providing direct access to the subtalar joint as well as to the tibiotalar joint (Fig. 23-20).

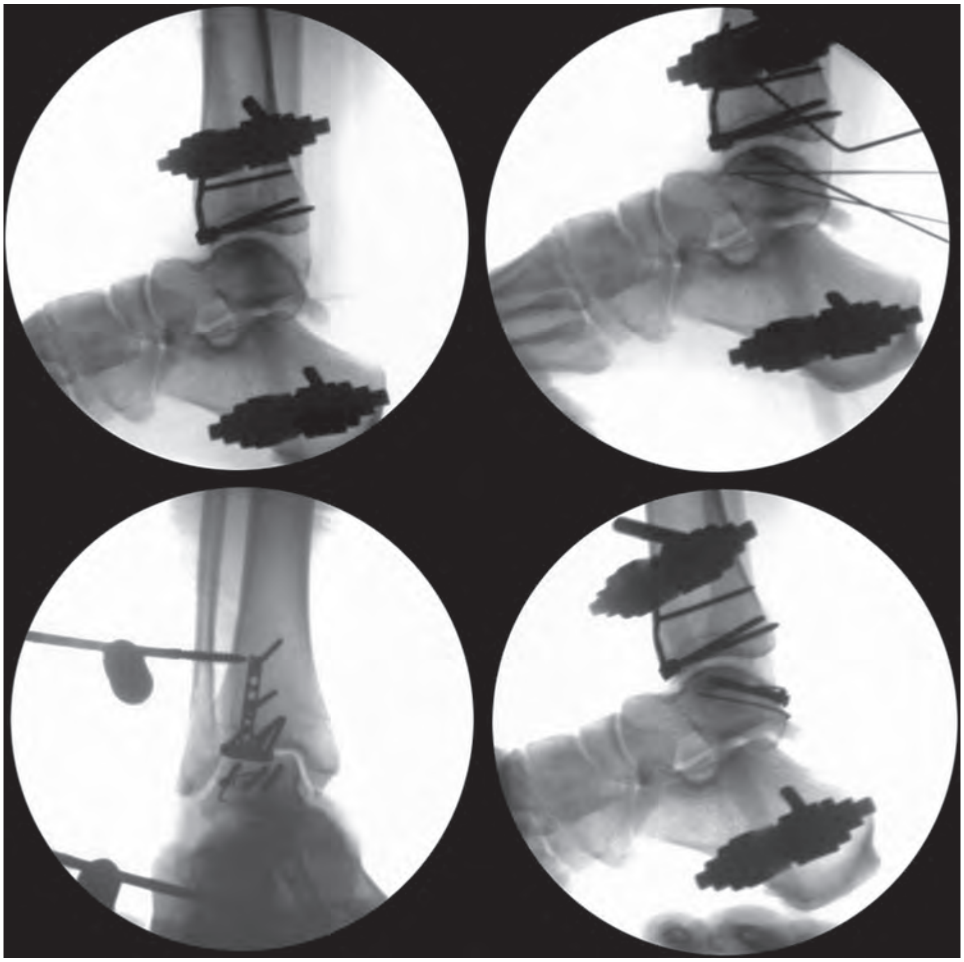


Figure 23-20. Case example of posterolateral talar fixation for a talar body fracture.

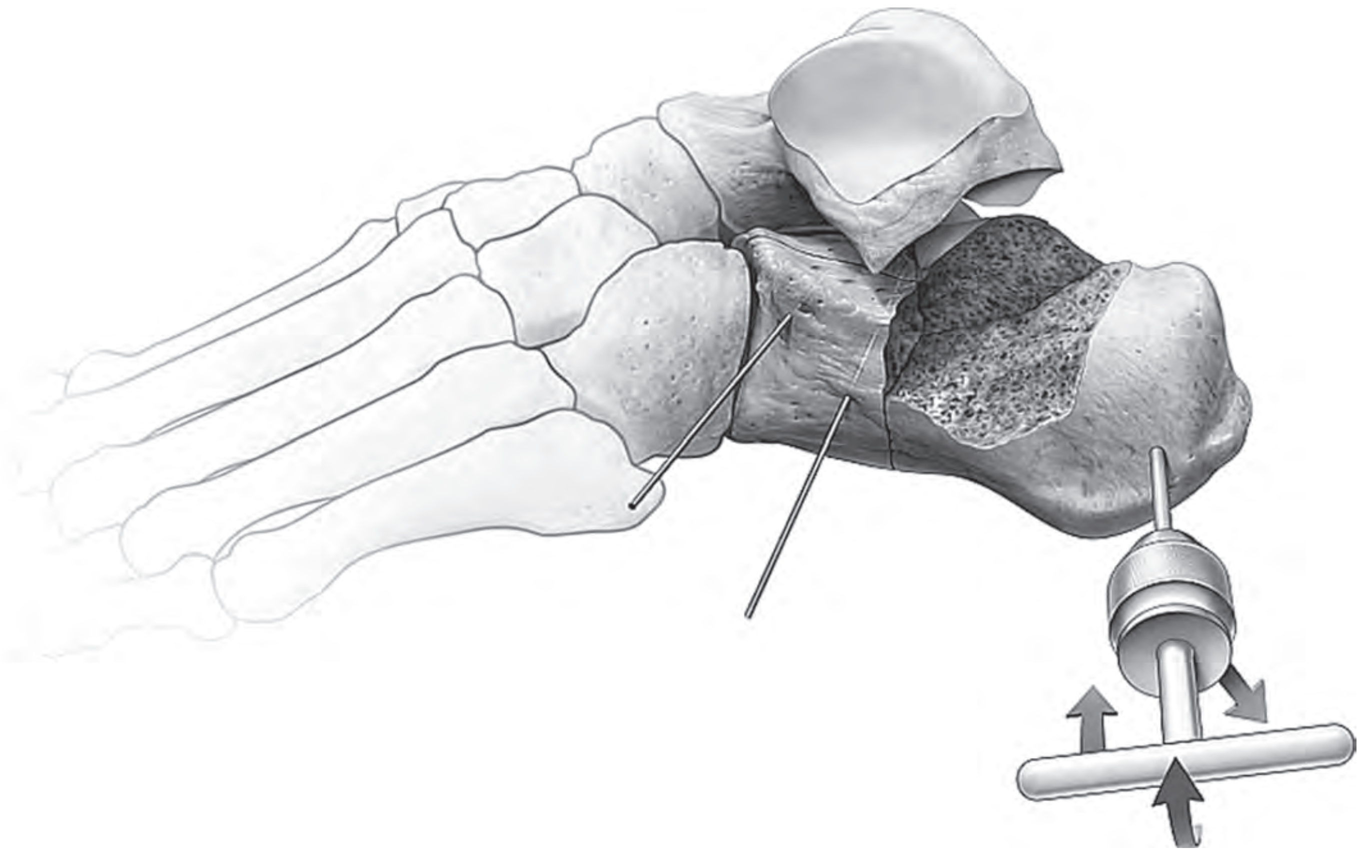
Reference

1. Vallier HA, Nork SE, Benirschke SK, et al. Surgical treatment of talar body fractures. *J Bone Joint Surg Am*. 2003;85-A:1716–1724.

Section 10

Foot

Stephen K. Benirschke



Metatarsal Neck Fractures

Chapter 24

Michael J. Gardner

Sterile Instruments/Equipment

- Small pointed bone reduction clamps (Weber clamps)
- Shoulder hook, dental picks, and Freer elevators
- Finger traps and Mastasol for traction
- Implants
  - 0.062 inch K-wires
  - Mini-fragment plates and screws (2.0 and 2.4 mm)
- K-wire driver/drill

Positioning

- Supine on radiolucent table.
- Place a small bump under ipsilateral hip so that the patella faces anteriorly.
- Use tibial nailing triangle turned long-side down to get good AP and oblique views of midfoot.
- C-arm should enter from opposite side of the table.
- Alternatively, flex knee to 90 degrees over a tibial nailing triangle. With the fluoroscopic beam perpendicular to floor, five folded towels under the forefoot gives a good view and a stable platform for reduction and pin placement (Fig. 24-1).

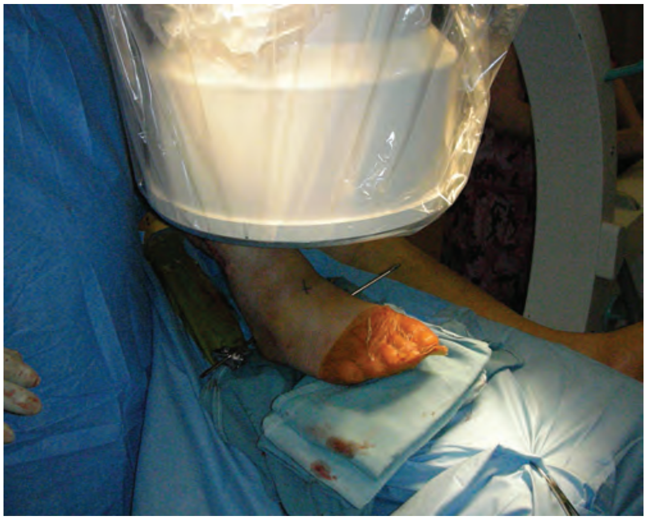


Figure 24-1. Five folded towels under the forefoot with the fluoroscopic beam perpendicular to the floor gives good visualization of the forefoot.

- The C-arm angle is often best determined on a lateral view so that the beam for AP and oblique images are oriented perpendicular to the metatarsal necks and shafts.
- Roll the foot between AP and oblique views to determine both mediolateral and dorsal-plantar K-wire vectors.

Surgical Approaches

- Percutaneous reduction and pinning
    - Strategically placed small incisions for reduction instruments and K-wires.

Reduction and Implant Techniques

- Pull toe axially, and manipulate medially or laterally depending on the fracture obliquity and displacement (Fig. 24-2).

Figure 24-2. Pulling the toe axially, with medial or lateral translation, assists in fracture reduction.

- If there is difficulty gripping toe, put a finger trap on toes with mastasol (Fig. 24-3).

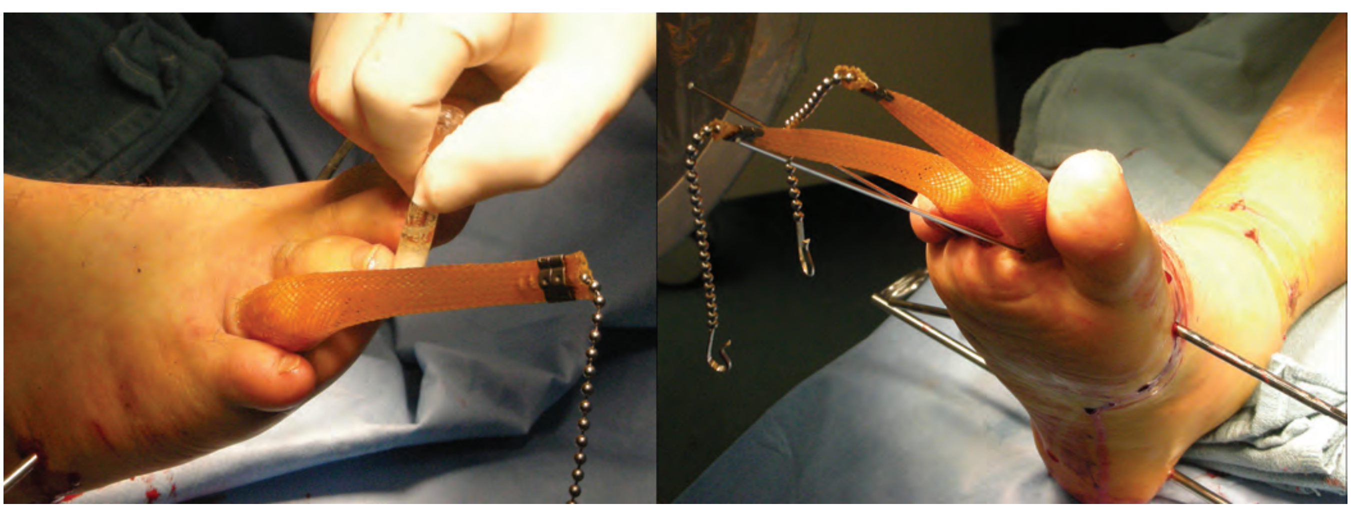


Figure 24-3. To assist in pulling axial traction on the toes to disimpact the fracture and achieve reduction, mastasol and finger traps can be a useful technique.

- The starting point is critical and will affect reduction, just as with any intramedullary nailing (Fig. 24-4).

Figure 24-4. A starting point that is centered on the metatarsal head, regardless of its position relative to the shaft, is critical.

- There are two methods of fixation:
  - In the first method, the K-wire passes under the base of the proximal phalanx.
  - In the second method, the K-wire transfixes the MTP joint.
- Method under base of proximal phalanx
  - Extend and distract the toe slightly for K-wire to enter plantar surface of toe crease.
  - Insert a 0.062 inch K-wire plantarly to clear the base of the proximal phalanx and anchor wire tip on metatarsal head.
  - This technique will result in some extension at the MTP joint, depending on where the K-wire enters the MT head.
  - The K-wire will block MTP flexion, but dorsiflexion will be possible.
- Method of MTP transfixion
  - Start K-wire inferiorly on plantar flare of proximal phalanx base.
  - Penetrate the base of the proximal phalanx at an acute angle.
  - Advance K-wire through articular surface of proximal phalanx base, but not into head of metatarsal.
  - Position MTP in neutral and advance K-wire into MT head and either up MT shaft or just out of the plantar surface of MT shaft.

- Reduction aids
  - Percutaneous K-wire: use a 0.054- or 0.062 inch K-wire as a mini spiked pusher to translate metatarsal shafts in any direction: medial, lateral, dorsal, plantar.
  - Control wire by placing in a universal chuck (Fig. 24-5).

Figure 24-5. A K-wire on a universal chuck can be a useful reduction tool to manipulate the metatarsal shaft underneath the head. While distal traction is placed on the second phalanx, its MT shaft/neck is translated medially with a chucked K-wire so as to be collinear with the MT head. Then the K-wire is inserted across the reduced fracture.

- Shoulder hook or dental pick
  - Alternatively, make a stab incision and place a shoulder hook or dental pick to manipulate shaft relative to metatarsal head (Fig. 24-6).

Figure 24-6. Through small stab incisions on the dorsum of the foot, a shoulder hook can be inserted percutaneously to reduce the metatarsal shaft.

- Anchor pins in the base of the metatarsals, but take care not to perforate the TMT joints (Fig. 24-7).

Figure 24-7. The K-wires are anchored in the bases of the metatarsals.

- After a K-wire is placed, can flex or extend MT to bend K-wire and make small corrections.
- Bend K-wires using needle-nose pliers and metal suction tip.
  - Making two 90- degree bends allows the final curve to be approximately 180 degrees and cut short (Fig. 24-8).
  - Cover the ends with a protective cap.

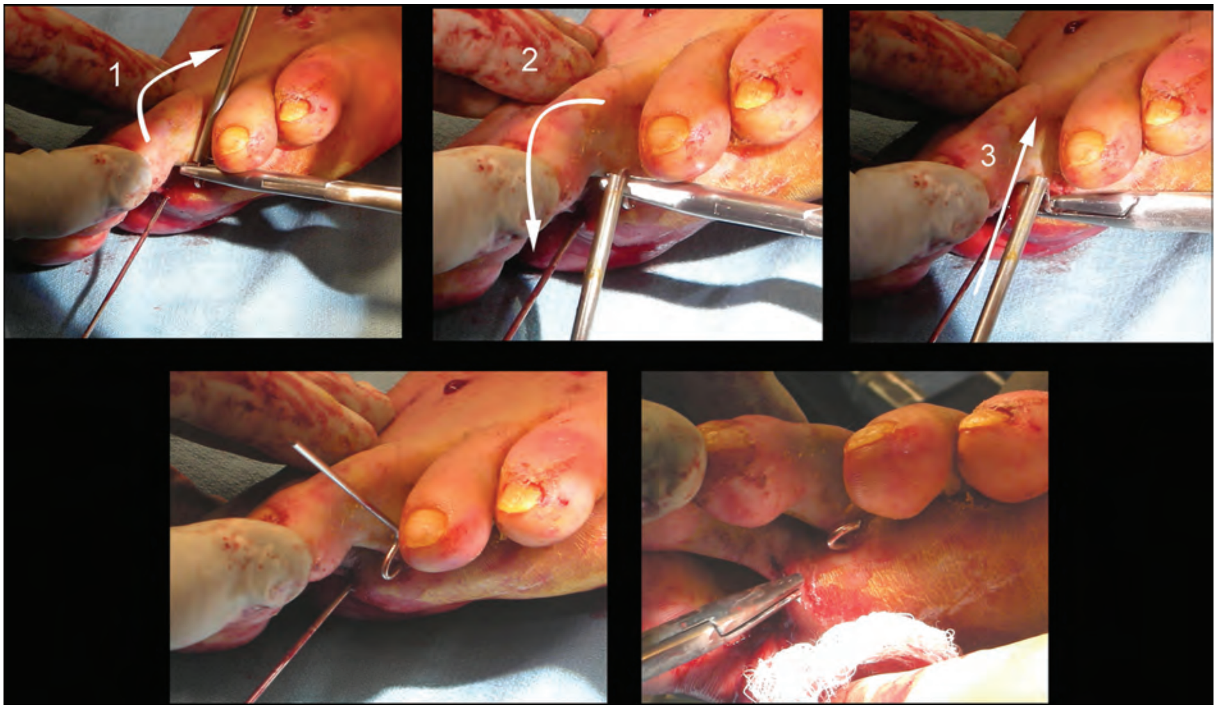


Figure 24-8. To bend the pins at an acute angle, a three-step technique can be used using a needle-nose pliers and a metal tip suction tip.

Chapter 25 Lisfranc Injuries

Andrew R. Evans

Sterile Instruments/Equipment

- Dental picks
- Freer and AO elevators
- Spiked pusher
- Kirschner wires (0.35, 0.45, 0.54, and 0.62 mm)
- Small point-to-point bone clamps
- 2.0- and 2.4-mm screws
- 3.5- and 4.0-mm cortical screws
- 2.4- and 2.7-mm plate/screw sets (straight and T-shaped)

Surgical Approaches

Dorsal Approach to the Midfoot

- Patient positioning
  - Supine.
  - Radiolucent table of cantilever type.
  - Bring the patient to cantilever (foot) end of the table.
  - Place a bump beneath the ipsilateral buttock and flank to neutralize limb rotation.
  - Prep and drape the affected lower extremity to the ipsilateral groin.
  - Place the appropriately sized sterile radiolucent triangle under the knee.
- Fluoroscopically, locate the first intermetatarsal space on the AP view.
- Incise the skin and subcutaneous tissue longitudinally directly over the first intermetatarsal space.
  - Take care to preserve the branches of the superficial and deep peroneal nerves and the dorsalis pedis artery.
    - Retract medially or laterally depending upon their position.
- Dissect the capsules overlying the first and second metatarsocuneiform joints.
  - Typically, these capsules will have been disrupted traumatically.
- Incise the joint capsule along the articular borders of the first metatarsocuneiform articulation to visualize the articular surfaces dorsally, medially, and plantarly.
- Incise the joint capsule along the articular borders of the second metatarsocuneiform articulation to visualize the articular surface dorsally, dorsomedially, and dorsolaterally.
- When the third, fourth, and/or fifth metatarsocuneiform joints are subluxated, dislocated, or fractured, a second incision should be made over the interspace between the third and fourth metatarsals.

- Adequate visualization of the third metatarsocuneiform joint is difficult through an incision placed over the first intermetatarsal space, requiring the use of this second incision.
- Determine the location of this incision by identifying the metatarsocuneiform joints and the interspace between the third and fourth metatarsals fluoroscopically.
- Incise the skin longitudinally directly over the interspace between the third and fourth metatarsals and extend this incision proximally, dissecting through skin and subcutaneous tissue.
- Dissect to bone, retracting tendons and neurovascular structures (medially or laterally, as appropriate) to visualize the third and fourth metatarsocuneiform joints.

Crush/Open Injuries

- Consider the use of spanning external fixation to temporize and provisionally stabilize the bony and/or ligamentous midfoot injury.
  - Definitive open reduction and internal fixation should be performed once edema has subsided and the soft tissue injury has healed sufficiently to allow a safe surgical approach.
  - Soft tissues must be followed closely for 1 to 6 weeks in order to determine the time at which incisions for open reduction can be made so as to minimize associated complications.
- Severe crush or open injuries, particularly plantar degloving "slipper foot" injuries and extensive plantar lacerations, should be considered for amputation (Fig. 25-1).

Figure 25-1. Examples of severe mangled foot injuries that should be considered for amputation.

Reduction and Implant Techniques

External Fixation

- Recommended for initial (provisional) treatment of severe crush or open injuries of the foot, especially in the presence of instability, shortening, dislocation, or deformity.
  - Typically, this first treatment stage is converted to internal fixation when the condition of the soft tissues allows a safe surgical approach.
  - May also be used to supplement internal fixation constructs.
- Objective of this method for provisional stabilization is to restore the foot alignment, especially to restore the length of the medial and/or lateral columns of the foot.
  - Ligamentotaxis assists in the reduction of fractured, impacted, or dislocated tarsal/metatarsal bones.
  - Stabilization of the bones and soft tissues encourages the resolution of inflammation and edema.

- A medial and lateral midfoot external fixation frame typically consists of
  - 5.0- or 6.0-mm centrally threaded calcaneal transfixion pin (or a medial 5.0-mm half pin for medial column stabilization alone).
  - 4.0-mm first metatarsal Schanz pin.
  - 3.0- or 4.0-mm fourth/fifth metatarsal base Schanz pin.
  - One medial and one lateral bar spanning the medial and lateral columns, respectively (Fig. 25-2).

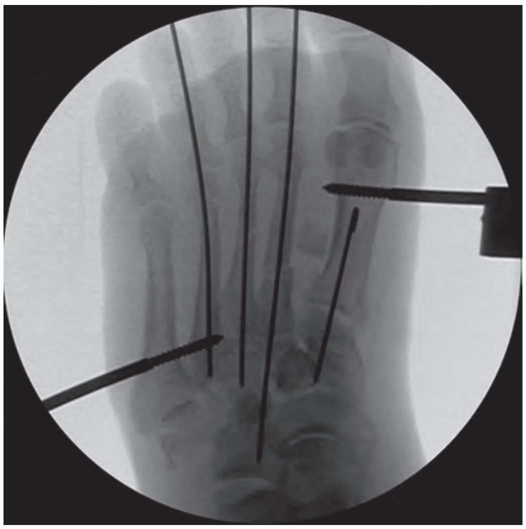


Figure 25-2. Provisional external fixation of medial and lateral columns using two bars connecting a transcalcaneal pin to a 4.0-mm pin in the bases of the fourth and fifth metatarsals, and a 4.0-mm pin in the first metatarsal. Intramedullary K-wires have been placed to provisionally stabilize metatarsal head, neck, shaft fractures (2, 3, and 4), and their TMT articulations. The first TMT dislocation is stabilized temporarily with a transarticular K-wire. The intramedullary K-wires in the third and fourth rays will be withdrawn from the mid-tarsals, to the bases of their respective metatarsals upon definitive fixation of these TMT articulations.

  - See the chapter (29) for additional figures.
- Alternatively, a half-pin configuration can be used either medially or laterally for homolateral injuries.
- Manual distraction may be applied to achieve the desired ligamentotaxis.
  - Supplemental distraction may be applied using the open compressor/distractor to facilitate alignment and reduction of fractures/dislocations.
  - Splinting or ankle-spanning external fixator configurations should be considered to maintain neutral ankle dorsiflexion and thereby prevent gastroc-soleus equinus contracture.

Open Reduction and Internal Fixation

- Operative fixation of a Lisfranc fracture dislocation should proceed in a medial to lateral direction.
  - Typically, the initial step in the reduction sequence is reduction of the first tarsometatarsal joint followed by provisional K-wire stabilization.
    - Confirmation of an anatomical reduction requires direct visualization and palpation of the dorsal, medial, and plantar-medial aspect of the first TMT joint (to assess any incongruity) and radiographic correlation.

- This is followed by reduction and provisional K-wire stabilization of the second TMT joint, and the lateral TMT joints as necessary (Fig. 25-3).

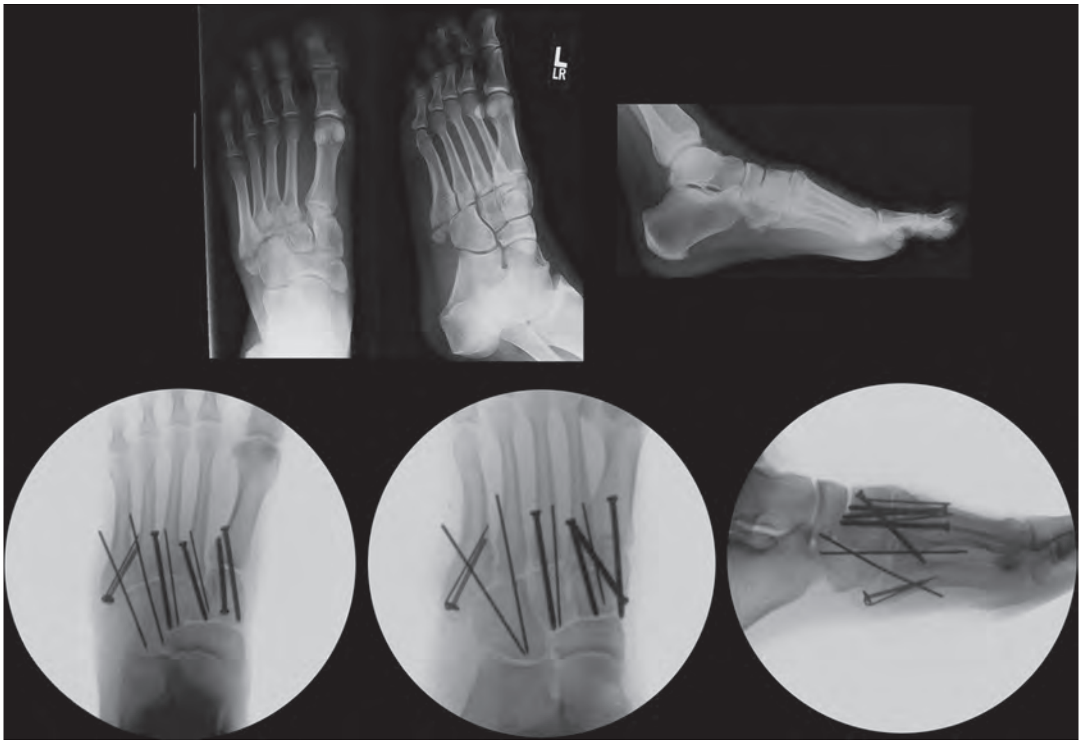


Figure 25-3. Case example of operative fixation of a complete Lisfranc injury.

- Prior to initiating operative fixation of the Lisfranc injury, evaluate intertarsal joints for the presence of instability.
  - Talonavicular
  - Intercuneiform (Fig. 25-4)

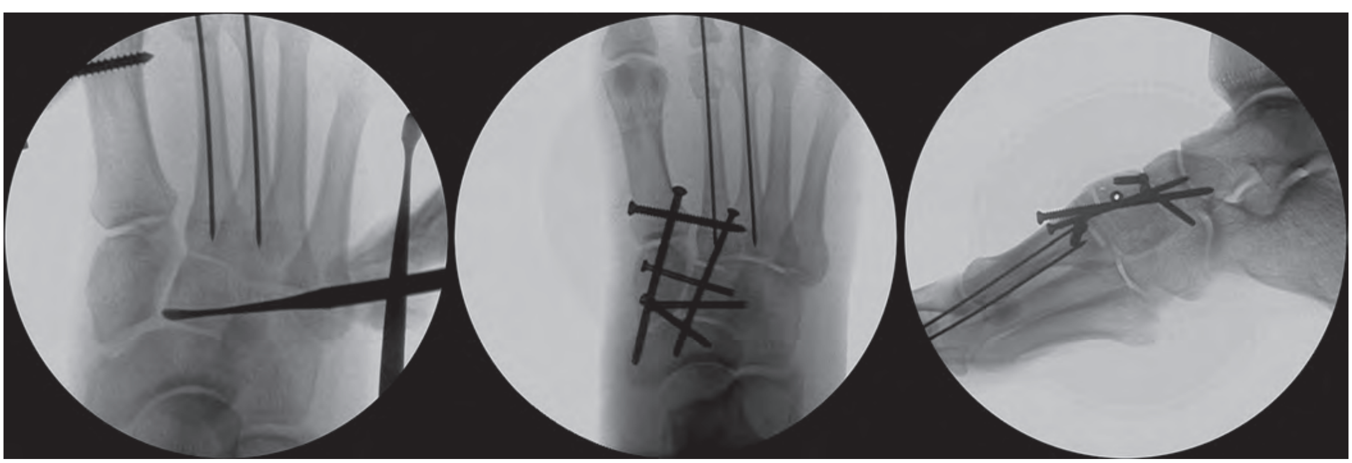


Figure 25-4. Intercuneiform instability should be assessed prior to reduction initiation to plan the reduction sequence and fixation construct. These intertarsal articulations proved to be unstable and were stabilized in addition to the TMT joints.

- Reduce the first metatarsocuneiform joint, assessing the reduction dorsally, medially, and plantarly to confirm joint congruity.
  - Fracture fragments associated with comminution should be preserved and reduced concomitantly with the TMT dislocations/subluxations.
  - Very small irreducible fracture fragments and hematoma should be irrigated and removed.
  - Given the saucer-like articulation of the first metatarsocuneiform joint, congruity must be confirmed from all sides, especially plantarly.
  - Malreduction of the first metatarsocuneiform joint will likely result in the malreduction of all remaining injured (lateral) metatarsocuneiform joints.
- Once joint congruity and reduction has been established, stabilize it temporarily with K-wires.
  - Subsequently, reduce and stabilize the lateral tarsometatarsal joints with K-wires.
- If dislocated (without fractures), definitively stabilize the first metatarsocuneiform with a 3.5- or 4.0-mm cortical (i.e., "Lisfranc") screw directed dorsal-to-plantar and distal-to-proximal, leaving room for a second screw to be placed in the same plane but in the opposite direction, from proximally to distally across this joint.[1]
  - Be sure to countersink these screw heads to distribute their contact pressures over a larger surface area and to avoid prominence of the screw heads.
  - Confirm fluoroscopically on AP, oblique, and lateral views that the screw does not enter the naviculocuneiform joint.
  - Maintain at least two points of fixation in the joint at all times to prevent rotation of the metatarsal and subsequent malreduction.
  - Fracture dislocations or fracture comminution of the first metatarsal base, cuneiform, and/or the navicular may necessitate the use of spanning plates/screws from the talus or navicular distally to the first metatarsal.
    - A 2.7-mm compression plate or nonannealed (stiff) 2.7-mm reconstruction plate is generally of adequate strength and low profile for this application (Fig. 25-5).

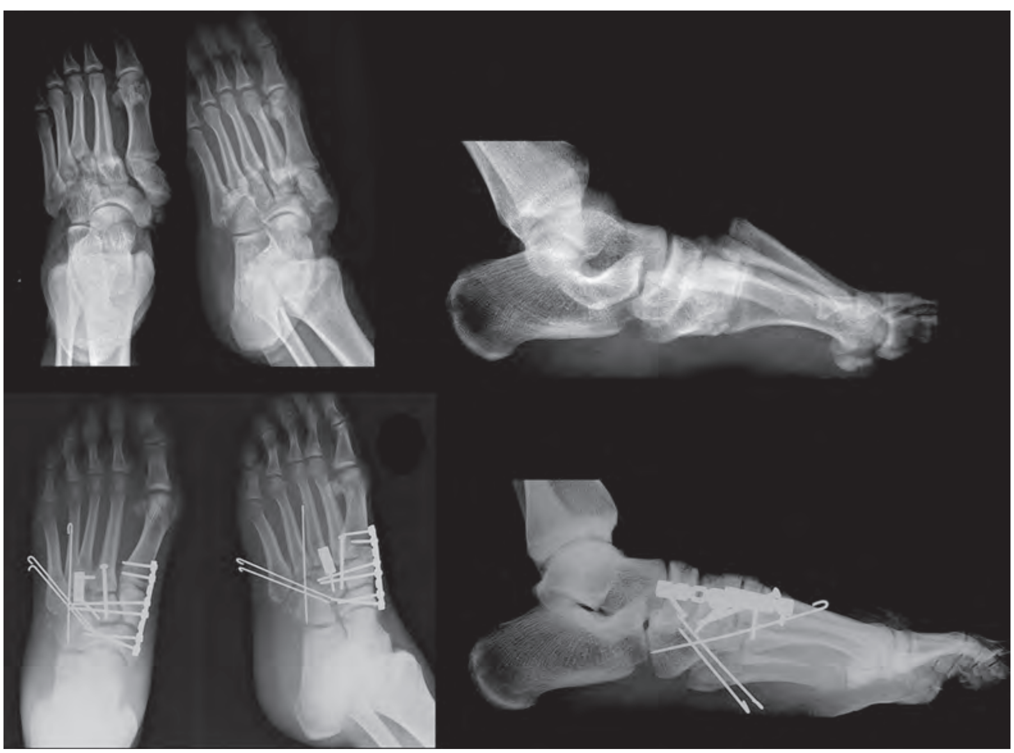


Figure 25-5. To bridge comminuted segments, a nonannealed (stiff) 2.7-mm reconstruction plate may be used.

- Use of spanning plates should be avoided in fixation of the fourth/fifth metatarsal-cuboid joints, the talonavicular, and calcaneocuboid joints due to the significant mobility required for locomotion and function by these articulations.
  - These plates may be placed for initial stabilization, but should be removed by approximately 4 months to restore joint motion.
- External fixation of either column may also be used instead of, or in combination with, spanning plate fixation.

- Reduce the second metatarsal base so that it fits into its mortise at the first metatarsal and middle cuneiform.
- Small point-to-point clamps are useful to achieve adequate axial compression for anatomic reduction of the second metatarsal base and may also aid in reducing displacement between the second metatarsal base and the first metatarsal/medial cuneiform (Fig. 25-6).

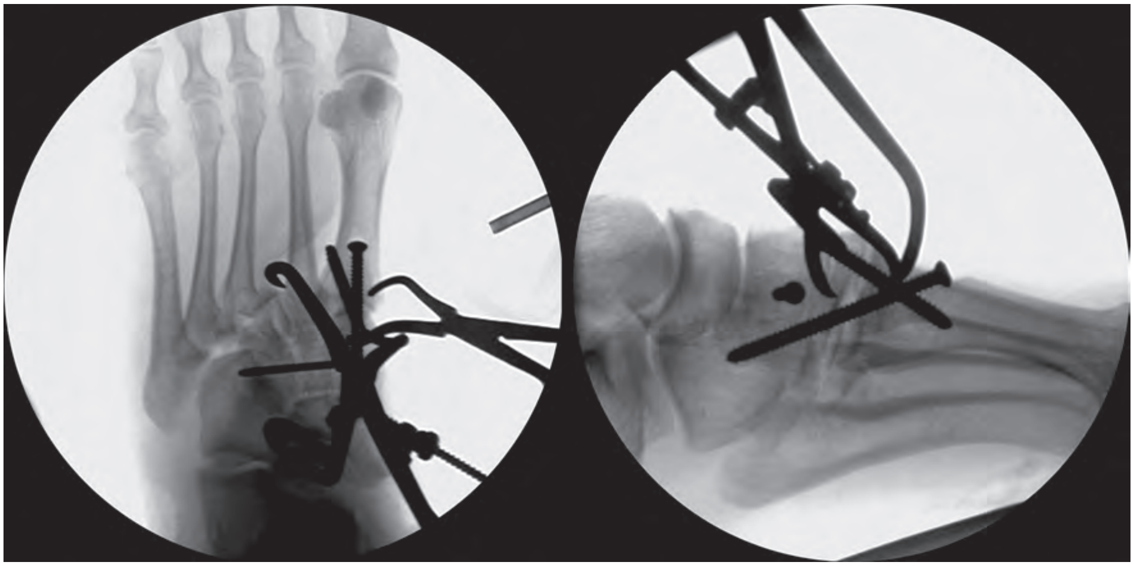


Figure 25-6. Example of small and large Weber clamps (pointed bone reduction clamps) placed across first tarsometatarsal joint and between medial cuneiform and base of the second metatarsal.

- Provisionally stabilize the second TMT joint with K-wires.

- Extensive comminution of the second and/or third metatarsal bases is not uncommon, and if cortical lag screw application is not feasible, then consideration should be given to the use of a spanning 2.4-mm plate and screws from the cuneiform to the respective metatarsal for definitive fixation (Fig. 25-7).

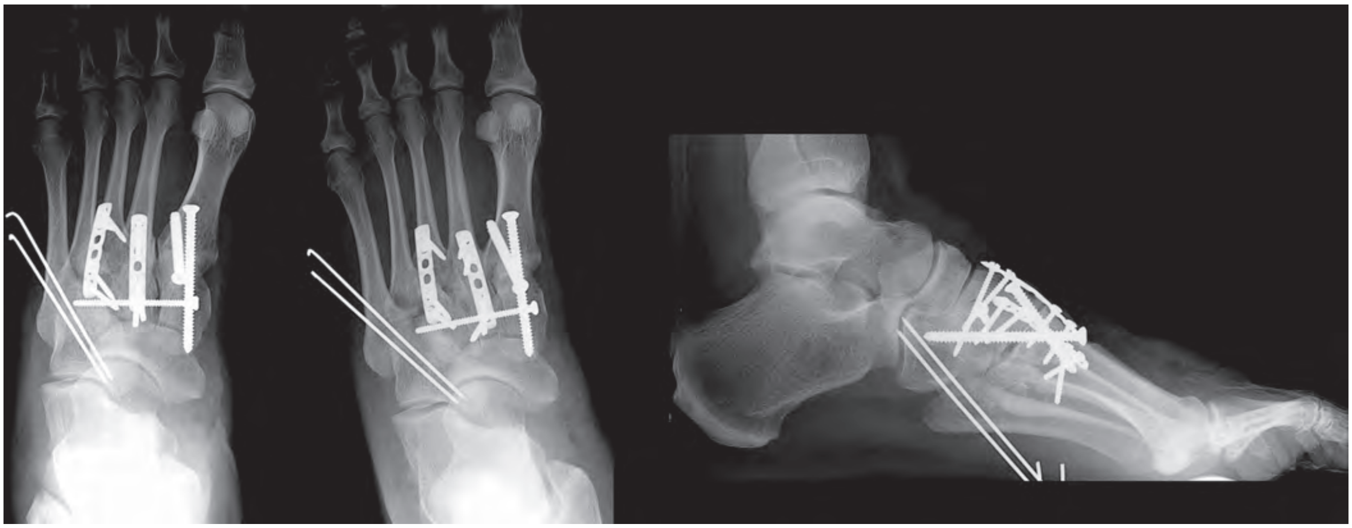


Figure 25-7. In the presence of comminution of the lesser TMT joints, mini-fragment plates are a good alternative to screw fixation.

- Avoid incorporation of the naviculocuneiform joint, if possible; however, the navicular may be used for supplemental proximal fixation in selected cases with extensive cuneiform comminution or impaction.

- Reduce and provisionally stabilize the third TMT joint with K-wires in similar fashion to the second metatarsocuneiform joint and stabilize definitively.
- Perform open reduction and stabilization of the fourth and fifth metatarsocuboid joints with K-wires inserted from the lateral surfaces of the metatarsal bases across the TMT joint, into the cuboid.
  - This reduction maneuver often requires pushing directly on the fourth metatarsal base in a plantar and medial direction.
  - By aiming K-wires toward the proximal-medial corner of the cuboid, the greatest span of cuboid is traversed.
  - These K-wires may be inserted percutaneously with their lateral ends left outside the skin, or these ends may be cut short so that they may be buried just underneath the skin.
    - This decision depends on the surgeon's preference, the condition of the skin, and the anticipated length of time required for healing.
- Open reduction and internal fixation of tarsal or hindfoot fractures should also be performed in order to restore articular anatomy, stabilize unstable tarsal segments, and/or reconstruct the medial and lateral column lengths.
- Postoperatively, patients should be maintained in a well-molded splint that maintains the ankle dorsiflexed to neutral.

Midfoot Arthrodesis

- An appropriate treatment option for patients with severe articular comminution and osseous injury, for patients with persistent midfoot instability after fixation, or those with severe posttraumatic arthritis of the midfoot.[2,3]

Associated Gastrosoleus Equinus

- It is the belief of some surgeons that patients with gastrosoleus equinus have a predilection for Lisfranc injuries, among other fracture patterns.
- In patients who present with this condition (usually bilateral), consideration should be given to performing a Strayer gastrocnemius recession, either at the first stage of provisional treatment (e.g., external fixation) or at the time of definitive stabilization.

References

1. Kuo RS, Tejwani NC, Digiovanni CW, et al. Outcome after open reduction and internal fixation of Lisfranc joint injuries. *J Bone Joint Surg Am.* 2000;82-A:1609–1618.
2. Coetzee JC, Ly TV. Treatment of primarily ligamentous Lisfranc joint injuries: primary arthrodesis compared with open reduction and internal fixation. Surgical technique. *J Bone Joint Surg Am.* 2007;89(Suppl 2 Pt1):122–127.
3. Ly TV, Coetzee JC. Treatment of primarily ligamentous Lisfranc joint injuries: primary arthrodesis compared with open reduction and internal fixation. A prospective, randomized study. *J Bone Joint Surg Am.* 2006;88(3):514–520.

Chapter 26

Calcaneus Fractures

Michael L. Brennan

Sterile Instruments/Equipment

- Tourniquet
- Headlight
- Large pointed bone reduction clamps (Weber clamps)
- Laminar spreader
- Dental picks and Freer elevators
- Shoulder hook
- Schanz pins (2.5 to 4.0 mm)
- Femoral distractor (small)
- Implants
    - Mini- and small-fragment screws and mini-fragment plates (2.0/2.4/2.7/3.5 mm)
    - Calcaneal plates, locking or nonlocking
    - Autograft, cancellous allograft, or other bone substitute for structural defects
- K-wires and wire driver/drill

Positioning

- The patient is positioned in the lateral decubitus position.
    - Take care to pad all bony prominences, including down greater trochanter, fibular head (peroneal nerve), and elbow (radial nerve).
- See the chapter (1) for full description.

Surgical Approach

- Extensile lateral approach, as described by Benirschke and Sangeorzan.[1]
- Vertical limb should be approximately 1 cm anterior to the Achilles tendon.
    - The vessel that supplies the flap can be located with a Doppler.
    - Proximal extension of the vertical limb should be performed without injuring this vessel.

- Take caution not to injure the lateral calcaneal artery, which is directly across the vertical limb and supplies the majority of the flap (Fig. 26-1).

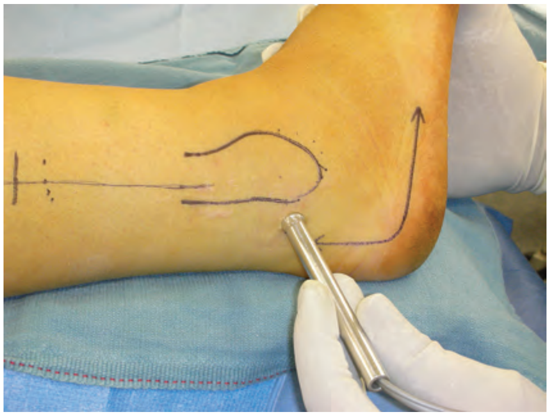


Figure 26-1. Doppler showing the position of the arterial inflow to the lateral heel flap.

- To determine the course of the sural nerve, mark a point one thumb breadth posterior to the distal tip of the fibula, and connect it to the base of the fifth metatarsal (Fig. 26-2).

Figure 26-2. The approximate course of the sural nerve based on the fibula and the fifth metatarsal.

- Gently curve incision, make horizontal limb along the glabrous border of the heel (Fig. 26-3).

Figure 26-3. The lateral extensile incision.

- Meticulous subperiosteal elevation of soft tissues off of the lateral wall.
  - Place small rakes under periosteum, and avoid separating soft tissue layers.
- Elevate the calcaneofibular ligament.
- Dissect beneath the osseous reflection of the peroneal sheath, and elevate the peroneal tendons anterosuperiorly.
- 0.062 inch K-wires can be inserted into the fibula and talus, and bent for soft tissue retraction.
  - Be mindful of point pressure on soft tissues.

Reduction and Fixation Techniques

- Spanning calcaneus external fixation (Figs. 26-4 and 26-5).
  - Place the frame medially to preserve lateral soft tissues for lateral exposure after soft tissues heal.
  - A medial incision is made over the medial cuneiform.
  - A 170 mm × 5.0 mm Schanz half pin is placed from the medial to the middle of the lateral cuneiform.
  - A second 170 mm × 5.0 mm Schanz half pin is placed via the percutaneous incision through the medial tibia to provide a point of fixation on the tibia.
  - External fixation clamps are then applied and a bar is placed from the cuneiform pin to the tibial pin.
  - A third 5.0 mm Schanz pin is placed in the calcaneal tuberosity via a medial incision, and a distraction is then applied via a pin-bar clamp to the already established bar apparatus from the medial cuneiform to the tibia, forming a "T."
  - A distraction vector of height, length, and translation is facilitated to disimpact the fracture.
    - This facilitates the restoration of anatomic height and length at the time of definitive reconstruction.
  - Additional distraction vectors can be applied as needed through additional bars.
  - A laminar spreader between two pin-bar clamps or a pin-bar clamp and a universal chuck can be used to medialize the tuberosity fragment.
  - After the distraction has been achieved, lateral, axial, and AP views of the foot document the position of the pins and distraction that is achieved.

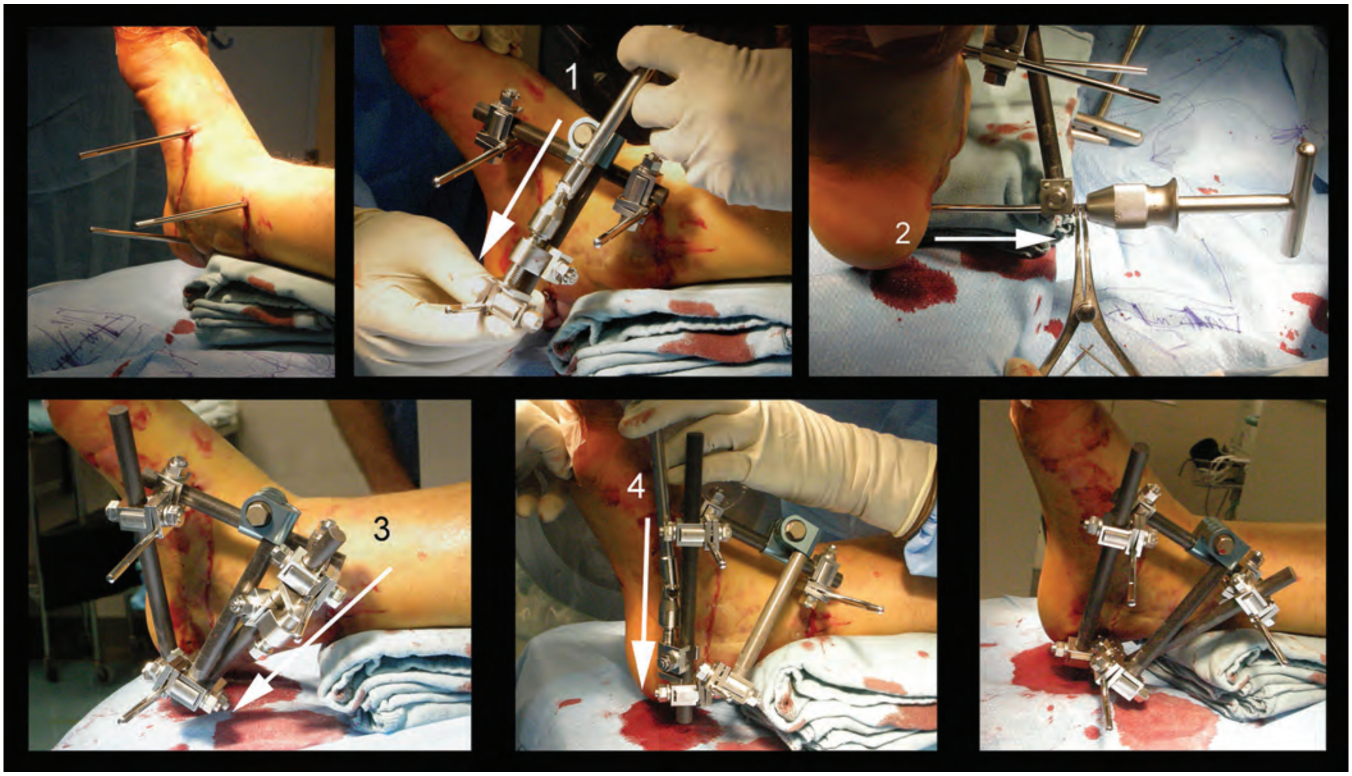


Figure 26-4. Calcaneal external fixation placement. Half pins are placed medially in the cuneiforms, the calcaneal tuberosity, and the distal tibia. Length is reestablished initially (*1*), followed by reduction of the tuberosity varus and translation (*2*). Height and length are once again fine tuned (*3*, *4*).

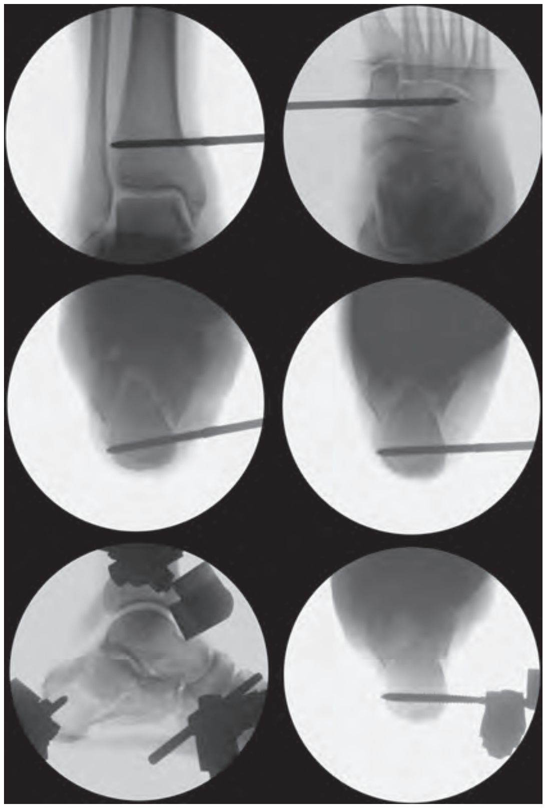


Figure 26-5. After placement of Schanz pins in the distal tibia, cuneiforms, and calcaneal tuberosity (**top row**), the calcaneal height, length, varus, and translation are progressively reduced (**second and third rows**).

Tongue-type Fractures

- High vigilance must be maintained for threatened posterior soft tissues.[2]
- Tongue variant with impaction
  - Via a small incision posteriorly, a Schanz pin is placed into the tuberosity to provide a manipulative reduction of the tuberosity and to disimpact the articular segment from the critical angle of Gissane (Fig. 26-6).

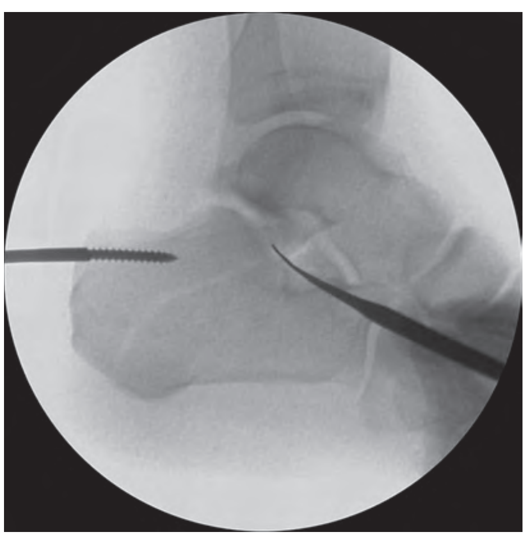


Figure 26-6. For reduction of tongue-type fractures, a Schanz pin can be placed in the displaced tuberosity fragment and used as a joystick. When the fracture involves the posterior facet, a small incision allows for direct palpation with an elevator to ensure articular congruity.

- A sinus tarsi approach is made just distal to the tip of the fibula to assess the articular reduction.

- The reduction is then provisionally stabilized with a series of percutaneously placed 0.062 inch wires (Fig. 26-7).

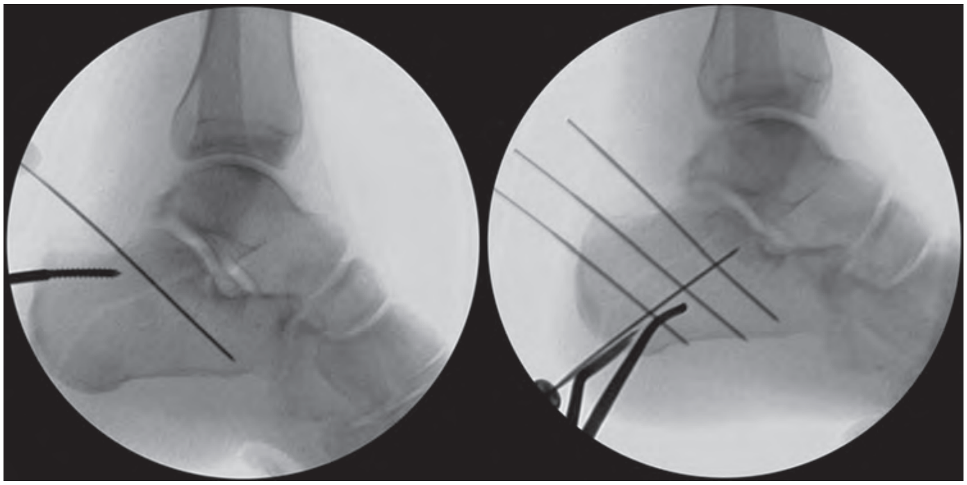


Figure 26-7. Following reduction, the fracture is stabilized with multiple K-wires provisionally.

  - The most anterior K-wire is just anterior to the Achilles insertion, and the remaining K-wires are placed posterior to the first one.
- If necessary, a small incision is made medially and additional manipulation of the tuberosity can be performed using a large pointed clamp or a shoulder hook.
- Axial K-wires are then placed from posterolateral to anteromedial into the sustentaculum (Fig. 26-8).

Figure 26-8. An AP view of the foot demonstrates wire and subsequent screw placement into the sustentaculum, which provides good bone for implant anchorage.

- After all K-wires are placed, using lateral and Harris axial views to confirm reduction and K-wire position, a 3.5-mm cannulated screw is placed over the middle wire in a lag fashion.
  - This provides compression, and is tightened down to anchor through the plantar cortex.
  - The remaining superior to inferior screws are then placed over the K-wires.
  - Axial cannulated screws are then placed through a small incision over the two axial K-wires (Fig. 26-9).
- A small plate may be utilized as a washer to prevent perforating the cortex with the screw head.

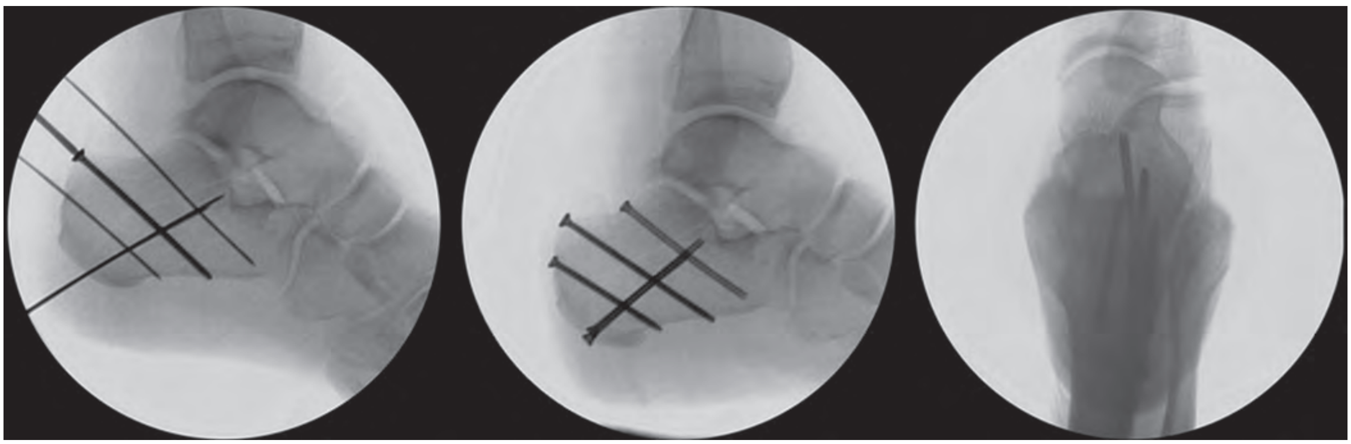


Figure 26-9. Multiple cannulated or noncannulated screws are then placed for definitive fixation.

- Tongue-type fracture (alternative technique No. 1)
  - Use an elevator through a segment of the extensile incision to disimpact the posterior facet.
  - Use 2.5-mm Schanz pin posteriorly in tuberosity to assist in reduction.
  - When reduced, place lateral to medial lag screws across the posterior facet and longitudinal screws to stabilize the tongue fragment (Fig. 26-10).

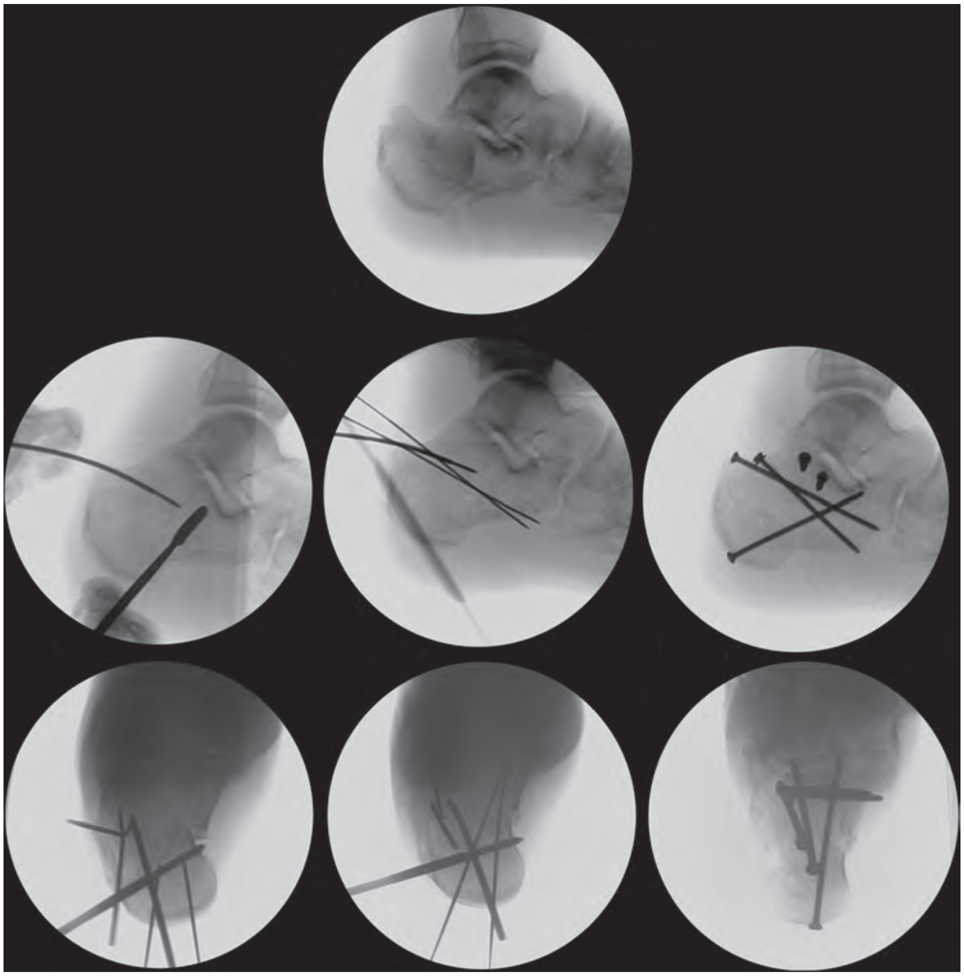


Figure 26-10. Depending on the fracture pattern, an elevator can be used to elevate the posterior facet fragment.

- Tongue-type fracture (alternative technique No. 2)
  - Percutaneous clamp across the fracture line.
  - Make incision at the edge of the glabrous skin laterally in line with the extensile incision.

- Slide clamp deep to the heel pad and clamp inferior cortex of tuberosity (Fig. 26-11).

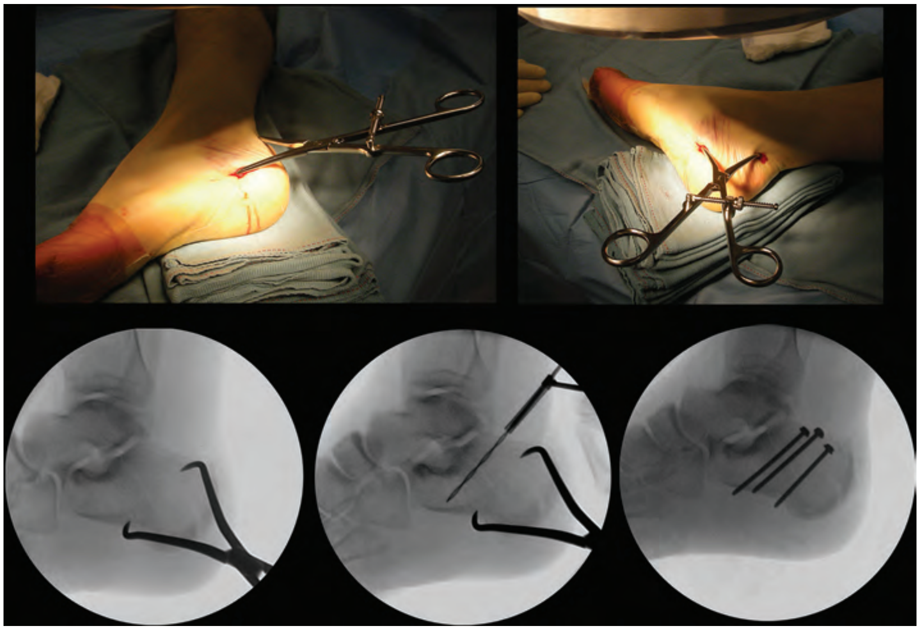


Figure 26-11. A large pointed reduction clamp can also be very effective for fracture reduction.

- Tuberosity avulsion fracture
  - Skin is particularly at risk with this injury.
  - Reduce emergently, and closely monitor the skin.
  - Directly clamp through stab incisions, followed by K-wires and lag screws (Fig. 26-12).

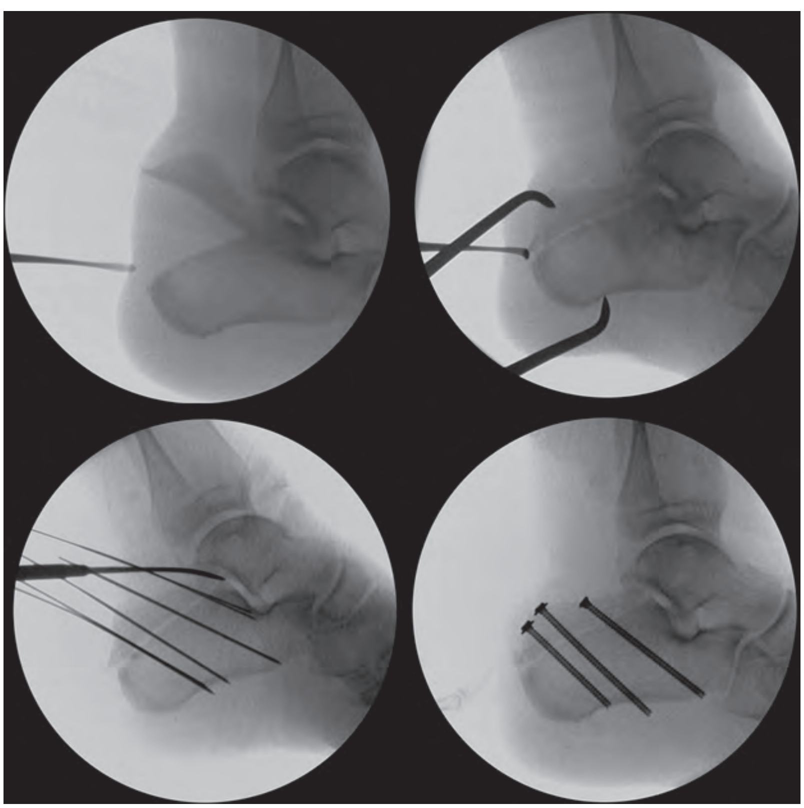


Figure 26-12. Widely displaced tuberosity fractures can place the posterior soft tissues at risk of necrosis, and emergent treatment should be considered.

- Medial process fracture
  - Anchors a large portion of the plantar fascia and facilitates a competent windlass mechanism.
  - Displaced medial process fracture (>~1 cm) can result in a painful heel and altered gait mechanics, if not reduced and stabilized.
    - Heel pad is displaced medially.
  - Following reduction using an oblique incision, taking care to protect the medial plantar nerve, a cervical H-plate is ideally suited for stabilization (Fig. 26-13).

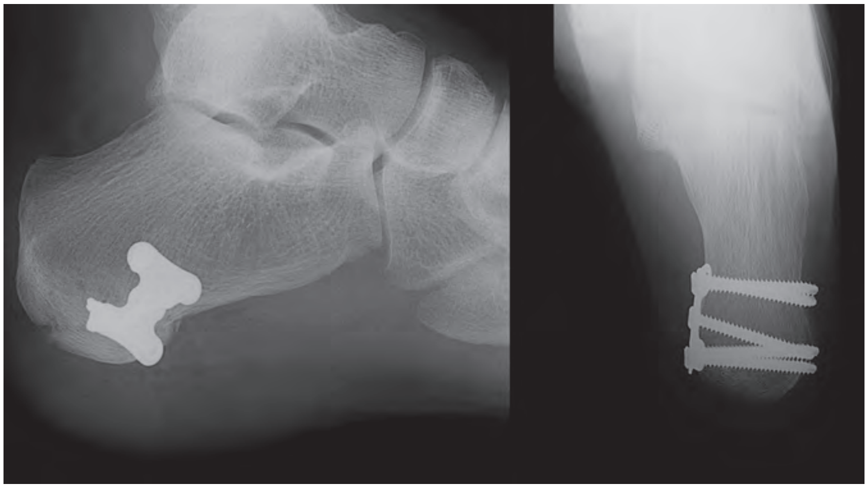


Figure 26-13. Example of reduction and fixation of medial process avulsion fracture.

- Joint depression fractures
  - Many fractures have very predictable and consistent fracture line configurations.
    - It is important to learn the three-dimensional fracture pattern and fragment positions, and to preoperatively plan reduction sequence and techniques, and implant placements (Fig. 26-14).

Figure 26-14A. Lateral view of a typical joint depression calcaneal fracture pattern. The primary fracture line runs from the angle of Gissane posteromedially and separates the sustenatculum from the remainder of the calcaneus. The posterior facet fragment is depressed, and the lateral wall displaces laterally. In this example, there is a sagittal plane secondary fracture line in the anterior process.

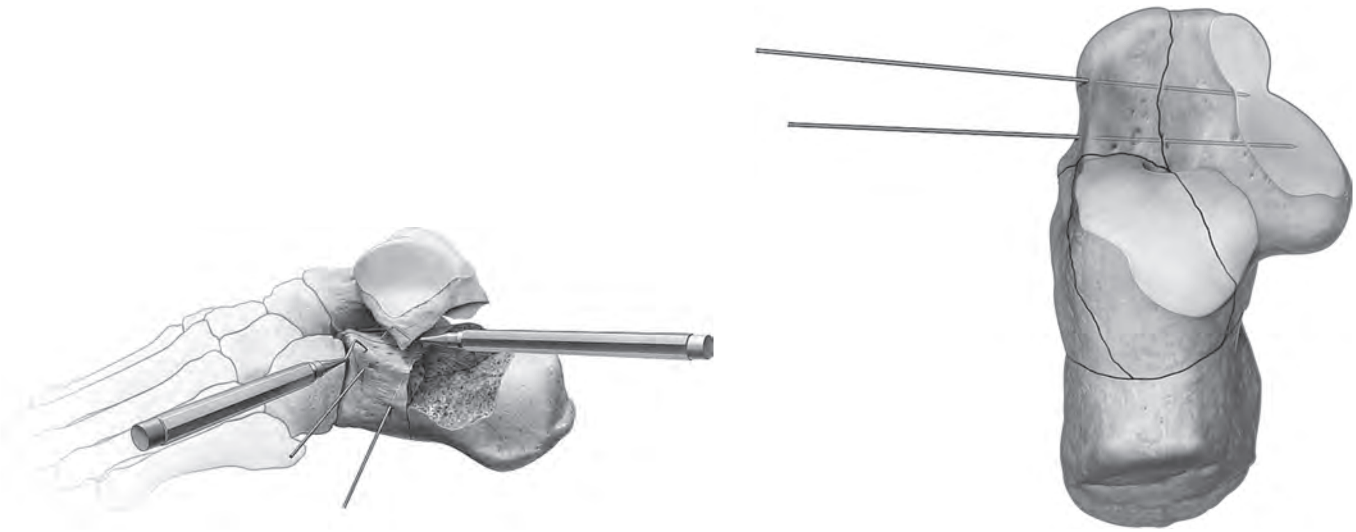


Figure 26-14B. Reductions typically proceed from anteromedial in a posterior and lateral direction. Dental picks and other reduction instruments are used to reduce the anterior process fracture lines under direct vision, and K-wires are placed provisionally from lateral to medial. The position of these wires is also demonstrated from a superior vantage point.

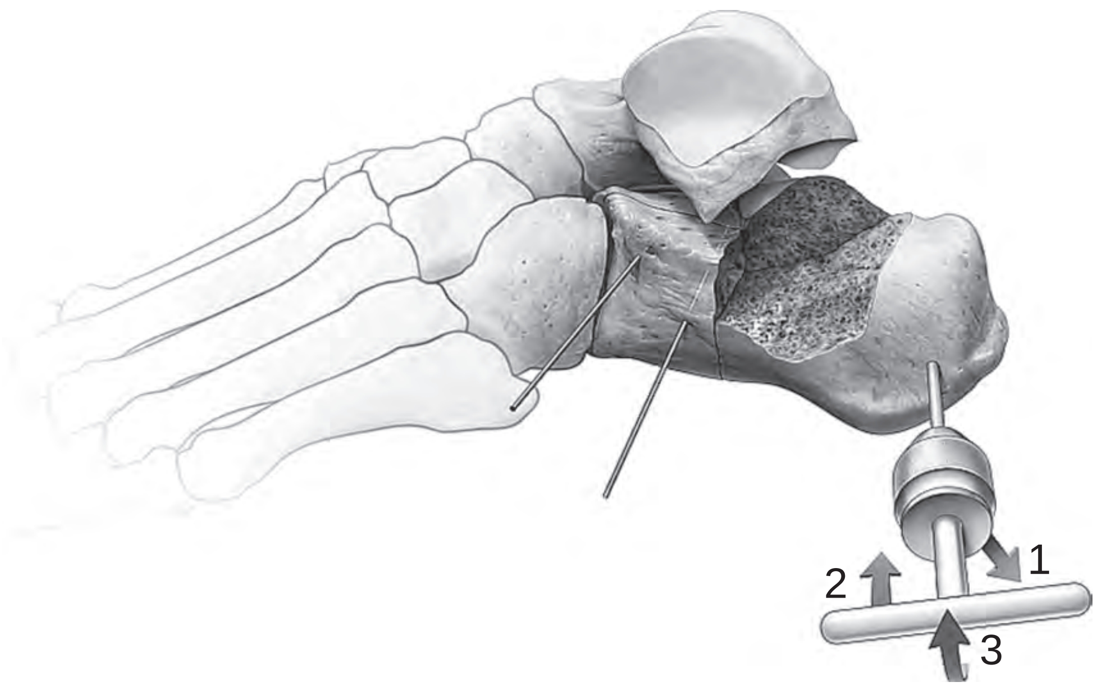


Figure 26-14C. Next the posterior facet is disimpacted, or can be completely removed and placed on the sterile back table. A Schanz pin is inserted in the postero-inferior corner of the incision from lateral to medial. This is used to manipulate the tuberosity out of its typical deformity. The usual tuberosity reduction maneuvers include: (1) postero-inferior translation (to restore height and length); (2) medial translation (to reduce lateral displacement); and (3) valgus rotation (to reduce varus deformity).

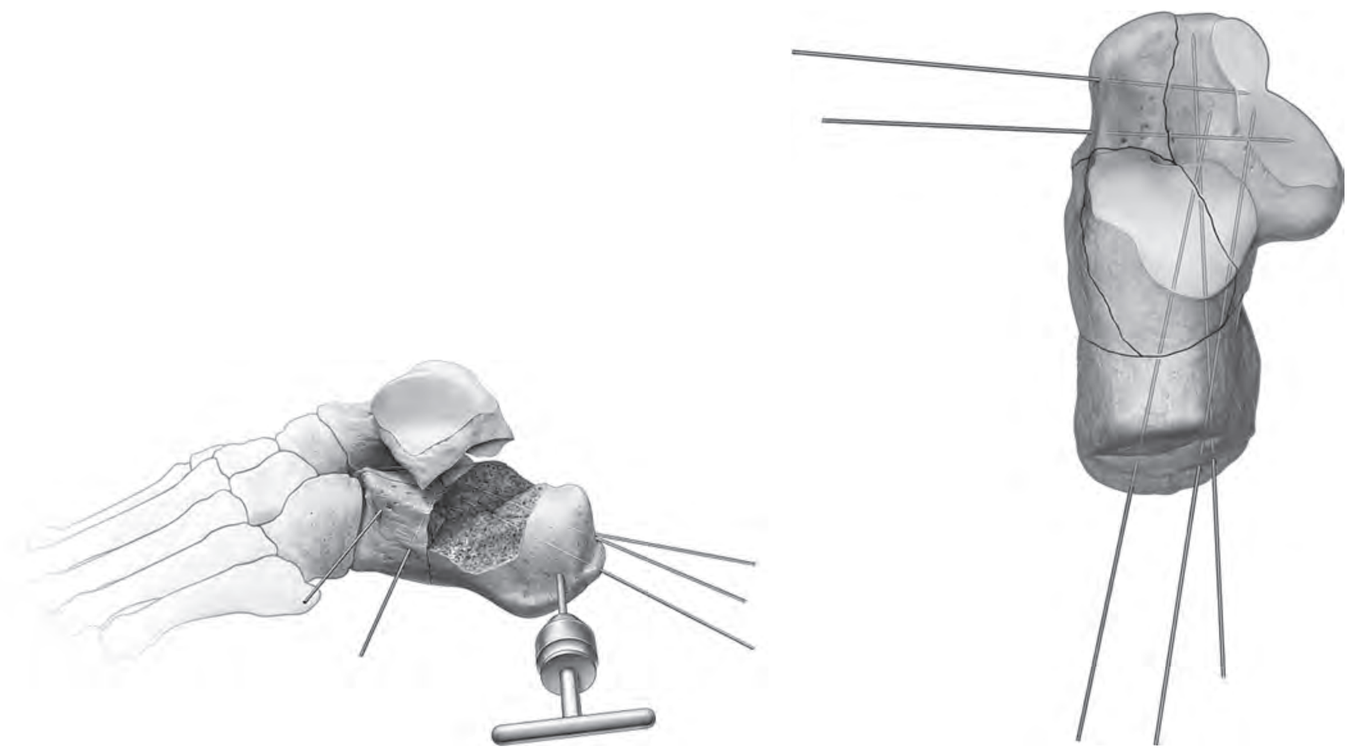


Figure 26-14D. With the tubeoristy reduced, axial K-wires are placed percutaneously from the tuberosity into the anteromedial sustentaculum fragment.

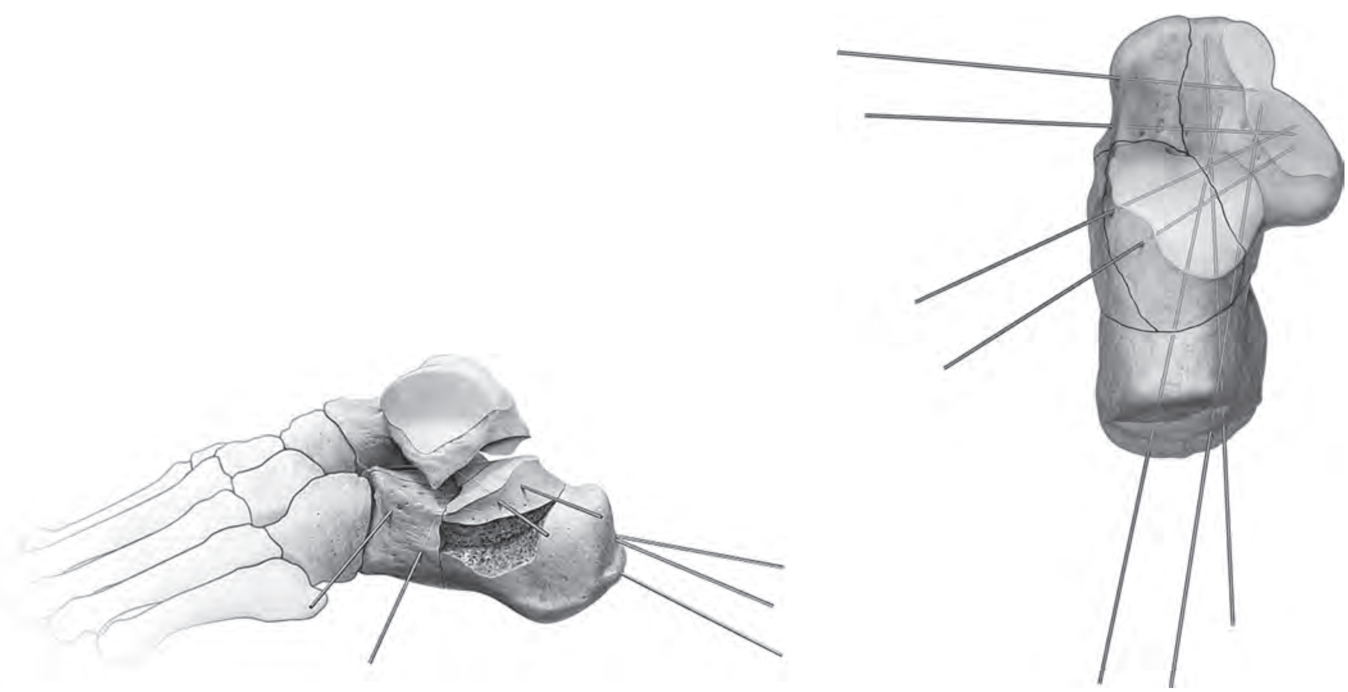


Figure 26-14E. With the anterior process and the tuberosity reduced, a defect should remain that allows for anatomic reduction of the posterior facet fragment. The anterior aspect of the posterior facet at the angle of Gissane often provides a critical reduction assessment. Additionally, the posterior aspect of the articular fragment should be assessed at the junction with the tuberosity fragment. K-wires are then placed from the posterior facet into the sustanteculum.

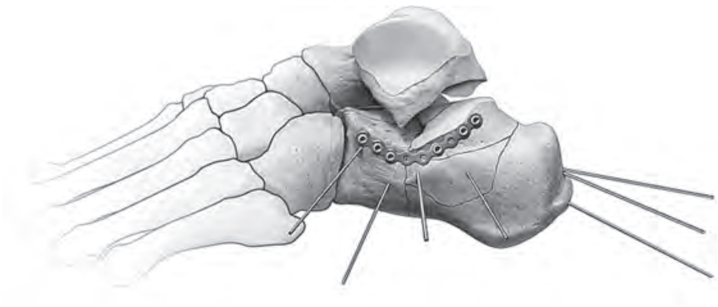


Figure 26-14F. The lateral wall is then replaced. A small curved plate positioned along the angle of Gissane allows for lag screws in the posterior facet and the anterior process fractures.

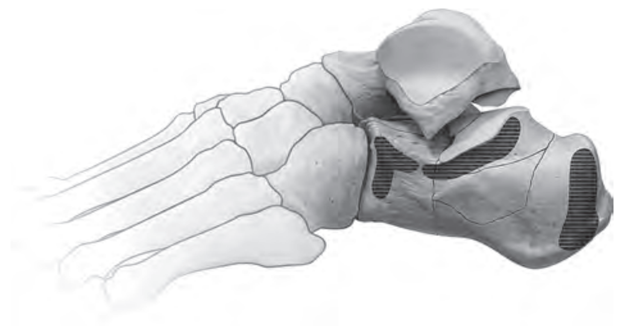


Figure 26-14G. Several anatomic regions of the calcaneus offer strong bone for optimal implant anchorage. These include the anterior process, the angle of Gissane, the subchondral bone of the posterior facet, and the posterior aspect of the tuberosity.

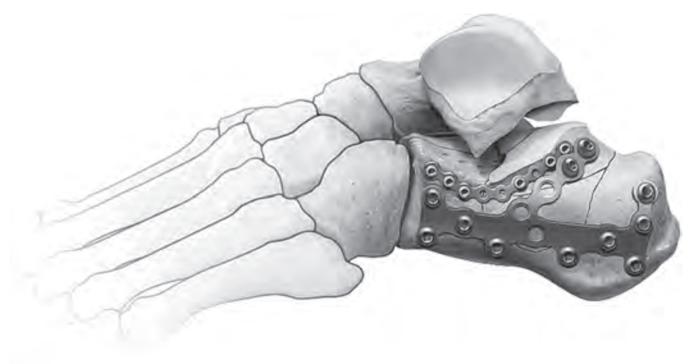


Figure 26-14H. Finally, a calcaneal plate of appropriate size is placed with strategic screw placement to complete fixation.

- Reduction of the tuberosity is critical in restoring the overall morphology of the calcaneus and the spatial relationship of the facets to each other.
  - It is particularly important to focus on reduction in the region of the critical angle of Gissane and the anterior process.
  - When addressing this, ensure visualization is possible medially at the level of the middle facet.
  - It is possible to work anterior to the interosseous talocalcaneal ligament without destablilizing it.
- Because the posterior facet is relatively long in its anterior to posterior dimension, make sure the posterior surface is evaluated from a posterior-superior vantage point through the vertical limb of the incision.

- Place a 4.0-mm Schanz pin laterally, and use a 4.5-mm drill guide for manipulation (Fig. 26-15).

Figure 26-15. Use a drill guide or Schanz pin holder for efficient manipulation of the Schanz pin in the tuberosity.

  - This avoids the hand getting in the way of visualization.
- A laminar spreader can be helpful to reestablish the tuberosity length and height (Fig. 26-16).

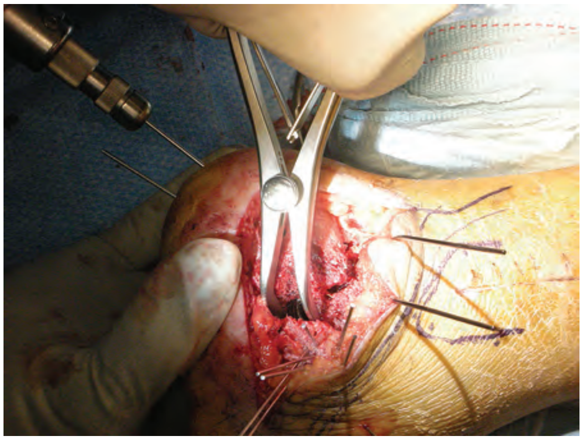


Figure 26-16. A laminar spreader can be used to disimpact the posterior facet from the tuberosity.

- Aim K-wires and nonlocking screws from the lateral wall with a slight anterior vector to obtain purchase in the strong sustentacular bone medially (Fig. 26-17).

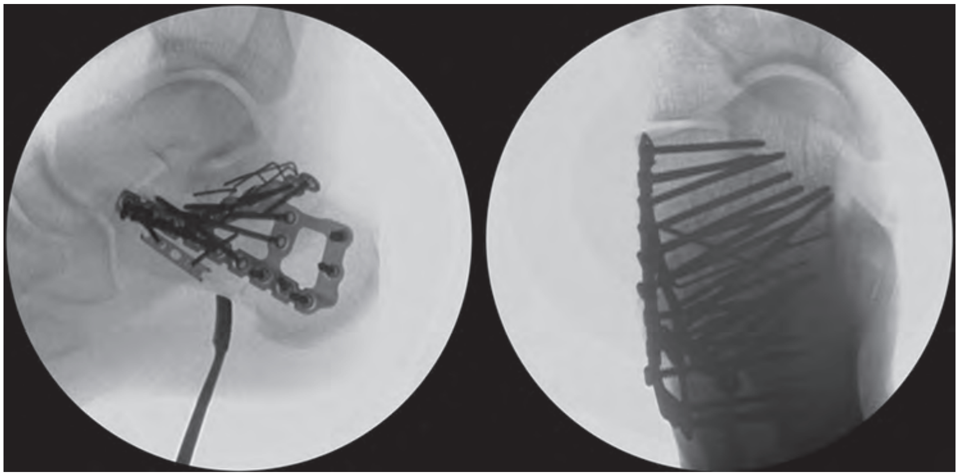


Figure 26-17. K-wires and screws are preferentially anchored in the strong bone of the sustentaculum.

- Screw positions and lengths can be verified on the AP view of the foot.

- Fracture comminution and impaction between the posterior facet and posterior tuberosity often leaves a large cancellous void between these anatomic landmarks.
  - A tricortical iliac crest auto/allograft can be used to occupy this void area and aid in structural support of the posterior facet (Fig. 26-18).

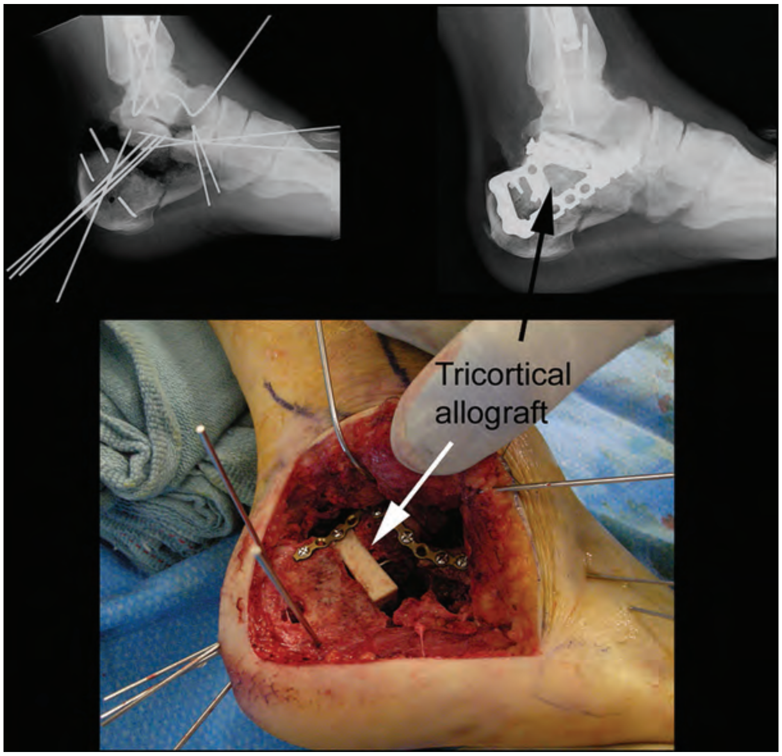


Figure 26-18. Tricortical allograft or fibular allograft can be effective in providing mechanical support for the elevated articular segment.

Gastrocnemius Slide (Strayer Procedure)

- The leg is elevated and placed on a triangular pillow.
- An incision is made over the posteromedial aspect of the right calf (approximately half way between the medial joint line of the knee and the palpable medial malleolus), and carried down through the skin and subcutaneous tissue to the level of the fascia.
- The fascia is then incised longitudinally and the interval between the gastrocnemius and the soleus muscles is identified and freed from medial to lateral.
  - Take care to identify and cauterize any perforating vessels.
- The plantaris tendon is identified and a 5- cm section is excised.
- The dorsal aspect of the gastrocnemius is then freed from medial to lateral with care being taken to identify and free up all of the dorsal soft tissues including the sural nerve.
- With retraction of all these soft tissues posteriorly and retraction of soleus anteriorly, the gastrocnemius aponeurosis is divided where it blends into the soleus fascia.

References

1. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot. Surgical management of calcaneal fractures. *Clin Orthop Relat Res.* 1993;292:128–134.
2. Gardner MJ, Nork SE, Barei DP, et al. Secondary soft tissue compromise in tongue-type calcaneus fractures. *J Orthop Trauma.* 2008;22(7):439–445.

Section 11

External Fixation

M. Bradford Henley

Knee-Spanning External Fixation

Chapter 27

Michael J. Gardner
M. Bradford Henley

Sterile Instruments/Equipment

- Large external fixation system
- Open compressor-distractor device
- 4.0-mm partially threaded pins for midfoot pin
- Towel bumps

Positioning

- Supine on a cantilever-type table.
- Bring patient to the end of the table.
- Place a small bump under ipsilateral hip and torso.
- Elevate leg on a soft ramp cushion to facilitate lateral radiographs.

Indications

- Staged treatment of complex periarticular fractures about the knee.
- Damage control orthopedic surgery.
- It is suggested not to obtain CT scans to plan definitive fixation prior to the application of a spanning external fixator, unless the external fixator will be used for definitive fracture management.
- It is best to obtain CT scans after a spanning external fixator is applied.
  - An external fixator can maintain limb length, alignment, and the improvements in fracture reduction achieved through ligamentotaxis.
  - Thus, it is cost-effective and often more efficient to obtain advanced imaging studies, such as CT, prior to definitive fixation, if used as a preoperative tool for planning surgical tactics after external fixation.

Reduction and Implant Techniques

- Assess the fracture pattern on the AP view to determine where the distraction forces will effect the best reduction.
  - Varus deformities will respond to distraction across the joint if the force vector is collinear with the mechanical axis of the limb or just medial to this on an AP image (Fig. 27-1).

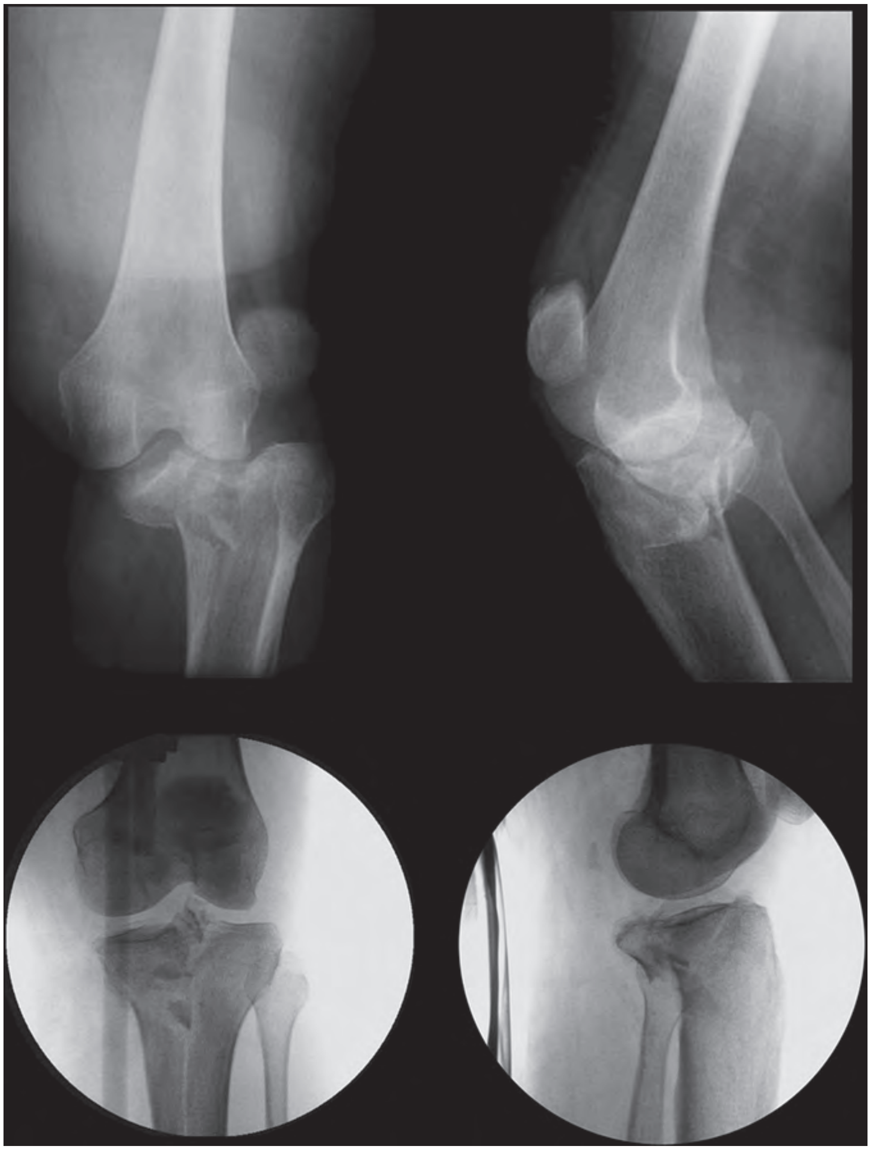


Figure 27-1. Following fracture-dislocation of the knee, ligamentotaxis through the initial two pin construct provided accurate length and alignment. Note the initial varus deformity and the position of the external fixator bars medial to the mechanical axis of the extremity.

- Similarly, valgus deformities will respond to distraction across the joint if the force vector is collinear with the mechanical axis of the limb or just lateral to this on an AP image.
- Place pins and pin-bar clamps so as to achieve the above by moving bar to one side of a pin or the other.

- Place one pin in proximal third of femur (5.0 mm × ~200 mm), and one pin distally in distal tibia (5.0 mm × ~170 mm) using soft tissue protection sleeves (triple guide) for soft tissue protection.
  - Both pins in the sagittal plane, anterior to posterior.
  - Correct rotational alignment to "near anatomical" before inserting the first two pins in same orientations, orthogonal to proximal femur and distal tibia.
    - If the orientation of these first two pins differs (e.g., the distal tibial pin is not in the same sagittal plane as the proximal femoral pin, but rotationally misaligned) using the external fixator to effect a change in limb length will necessarily effect limb rotation, when the bars are connected to the pins directly.
      - However, if the bars can be aligned so as to be collinear to the axis of the limb (usually requires another connecting bar to offset the longitudinal bar away from the offset pin), using the external fixator to effect a change in limb length should not adversely affect the limb rotation.

    - If after distraction, rotation is not anatomical, this should be adjusted using the two pins as joysticks in the femur and tibia.
    - Do not insert a third pin until correct rotation has been achieved as by doing so, rotation cannot be adjusted by most external fixation systems unless the bar-to-bar clamps have a "ball-joint" connection allowing multiplanar corrections.
  - Ideally, when completed, the first three pins (or even all four pins) will be in the same plane (e.g., sagittal).
- Connect bars to the pins, and connect the two bars with a bar-to-bar clamp in the middle.
  - Ensure the metallic clamps are not overlying joint line to facilitate later imaging.
    - For proximal tibial fractures, place this bar-to-bar connecting clamp over the distal femur.
    - For distal femur fractures, place this bar-to-bar connecting clamp over the proximal tibia.
    - This will facilitate both radiographic imaging, post operatively and later with the C-arm during definitive fixation if the fixator is left in place.
    - Such placement will also reduce scanning artifact on the CT scans obtained after provisional fixation.
- The goal is a stabilized lower extremity in a "comfortable" amount of knee flexion, similar to when a long-leg cast is used; approximately 5 to 15 degrees.
  - When the external fixator is placed anteriorly on the lower extremity, distraction will usually increase knee flexion or fracture flexion.
    - Similarly, if the fixator is placed laterally (pins in the coronal plane), it will usually increase the varus.
    - The magnitude of this increase is dependent upon the amount of initial knee flexion/extension (or varus/valgus for coronal pins) and the amount of fixed angulation in the bar-to-bar clamp.
  - To account for this, the limb should be placed in a minimum amount of flexion (−5 to +5 degrees), and the bar-to-bar clamp fixed in a position of minimal angulation (5 to 15 degrees) prior to manual distraction.
    - The final amount of limb angulation will also depend on initial amount of limb shortening and initial position of fracture as it relates to sagittal plane rotation (flexion/extension).
- Distract manually for initial ligamentotaxis and assess reduction on AP and lateral views.
- Correct coronal plane angular deformity (varus/valgus) with manipulation, rotating each fragment around pin axes.
  - Assure that coronal plane translational deformity can also be corrected (this usually requires a minimal amount of manual manipulation).
- Correct sagittal plane translational deformity (anterior/posterior translation) with strategic bumps under the proximal tibia, knee, and/or distal femur.
  - If additional sagittal plane correction is necessary, it may be manually reduced by manipulating the tibia.
- Prior to insertion of the third pin, correct any residual rotational abnormalities.
- Next, use the dynamic compressor-distractor to restore anatomical length to the limb (or minimally overdistract the joint/fracture) before insertion of the third external fixator pin.
- The third pin inserted should be closer to the injury in the nonfractured bone, but not in the surgical field anticipated for definitive fixation.
  - For tibial plateau fractures, this would be the second femoral pin.
  - For supracondylar femoral fractures, this would be the second tibial pin.
  - This pin increases the stability of the reduction and can be used to maintain residual translational or angular deformities corrected just prior to its insertion.

- The final pin, the second tibial pin, should then be inserted. This pin can be used to improve and maintain sagittal reduction in tibial plateau fractures (Fig. 27-2).

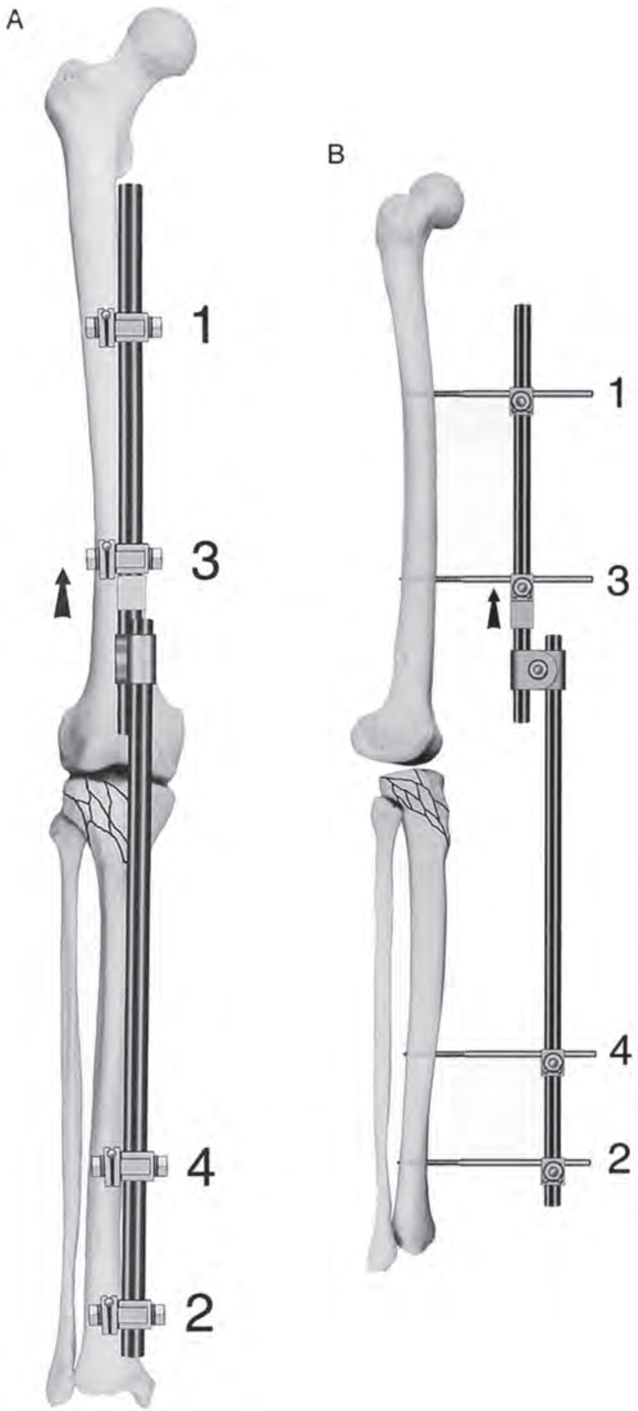


Figure 27-2. The order of pin placement for knee-spanning external fixation. (From Ertl W, Henley MB. Provisional external fixation for periarticular fractures of the tibia. *Tech Orthop.* 2002;17(2):135–144. With permission.)

- An alternative order of pin insertion includes placing the two femoral pins initially, followed by one distal tibial pin. This allows a stable "arm" (e.g., the femur) to reduce the tibia.
  - The disadvantage of this method is that if this "arm" is not collinear with the limb's sagittal plane, the distal bar must be attached to the proximal bar through a bar-to-bar clamp with biplanar angulation.
  - This means that any additional distraction will impart a force vector that affects the fracture reduction in at least two planes and possibly all three (sagittal, coronal, and rotational), in addition to the desired axial distraction.
- After placement of the final pin in the tibia, it can be used to "push" or "pull" the reduction in the sagittal plane, for small additional corrections in translation (Fig. 27-3).

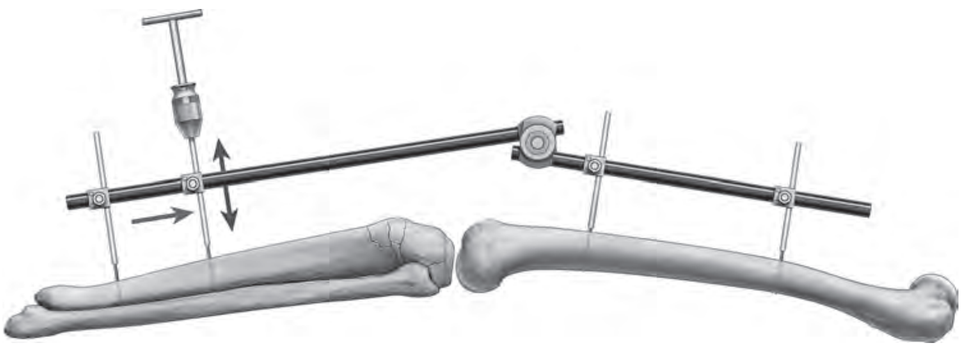


Figure 27-3. In the case of a tibial plateau fracture, the second (proximal tibial) pin can be inserted last, used as a joystick to fine tune both the sagittal and coronal planes, and secured to the bar.

  - Larger sagittal plane corrections may require loosening of the clamp-pin fixation (not clamp-bar connection) in this limb segment.

- Using the last pin to adjust the reduction should be planned carefully.
  - This pin position is constrained by the position of the bar and the tibial shaft.
  - The required pin position may result in a pin vector that is not perpendicular to the plane of residual deformity.
- Ensure that the closest pins are away from the planned future incisions.
- In obese, muscular patients, those with a large body habitus, patients who may be agitated (e.g., traumatic brain injury), or in patients for whom the external fixator will be used for a long period of time, consider augmenting a single bar system with a second bar (e.g., "double stacked" anterior half-pin unilateral frame) for additional stability (Fig. 27-4).

Figure 27-4. Example of a four-pin knee-spanning external fixator. Note the incision for the definitive fixation of the tibial plateau fracture, and the additional augmenting bar between the middle two pins.

- Ensure that there is adequate clearance between the lowest bar and the skin; generally 2 cm is sufficient.
- At the time of definitive fixation and removal of the external fixator pins, manipulate knee under anesthesia to minimize the potential for quadriceps scarring, adhesions, and heterotopic ossification at the femoral pin sites.
- This technique should only be used for short term, provisional knee-spanning external fixation.
  - Other pin placement locations and external fixator configurations should be used for external fixators planned for long-term use.

Chapter 28

Ankle-Spanning External Fixation

Michael J. Gardner
M. Bradford Henley

Sterile Instruments/Equipment

- Large or medium external fixation system
- Open compressor/distractor device
- 4.0-mm partially threaded pins for midfoot fixation
- Towel bolsters

Positioning

- Supine on a cantilever-type, radiolucent table
- Bring patient to the cantilever (foot) end of the table
- Place small bolster (e.g., bump) under ipsilateral hip and torso
- Elevate the leg on soft ramp cushion to facilitate lateral imaging

Reduction and Implant Techniques

- Centrally threaded 5.0- or 6.0-mm pin through calcaneus for medial and lateral, "triangular" uniplanar frame.
- Medial 5.0-mm Schanz half pin for medial half-pin frame.
- Calcaneal insertion point is critical to avoid injury to lateral plantar and medial calcaneal nerves, and posterior tibial neurovascular bundle more anteriorly (Fig. 28-1).

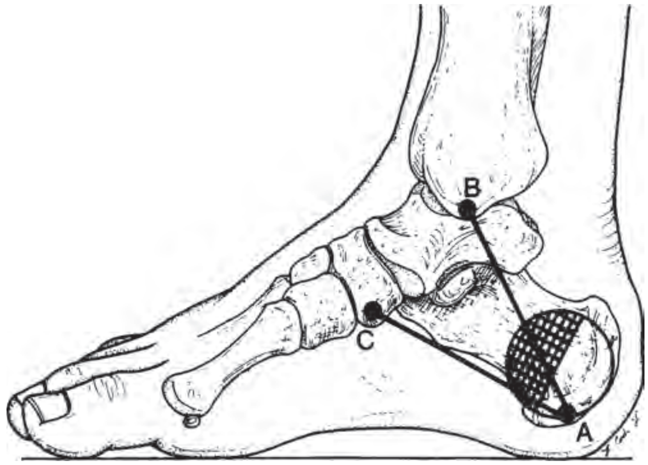


Figure 28-1. The calcaneal pin should be placed from medial to lateral and in the posterior-inferior half of a circle that approximates the contour of the posterior tuberosity. Avoid inserting the pin into cross-hatched area. Place the pin in coronal plane. It may be inserted as either medial half pin or transcalcaneal pin. Point A: (posteroinferior medial calcaneus); Point: B (inferior medial malleolus); and Point C (navicular tuberosity). (Adapted from Casey D, McConnell T, Parekh S, et al. Percutaneous pin placement in the medial calcaneus: is anywhere safe? *J Orthop Trauma*. 2004;18 (8 Suppl):S39–S42. With permission.)

- Place calcaneal pin first, posteriorly and inferiorly in the tuberosity, using a lateral fluoroscopic view (Fig. 28-2).

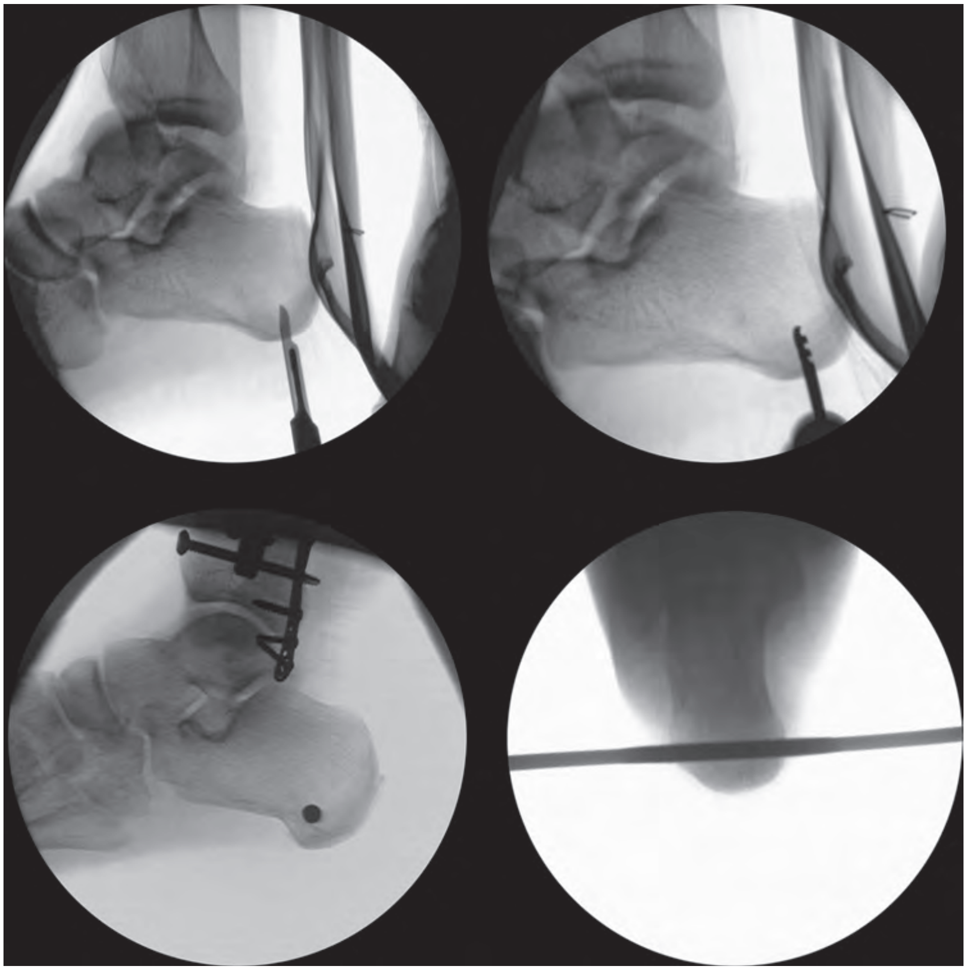


Figure 28-2. For placement of a transcalcaneal pin, the location for the incision should be estimated with a knife under fluoroscopy, and the position of the drill bit and pin should be confirmed. Ideally, the pin should be transverse on the axial view.

- If the fibula is intact or was treated with acute ORIF, the stable lateral column can be used to tension a medial frame (medial calcaneal half pin only) against the lateral fibular plate to restore limb length and angulatory alignment (Fig. 28-3).

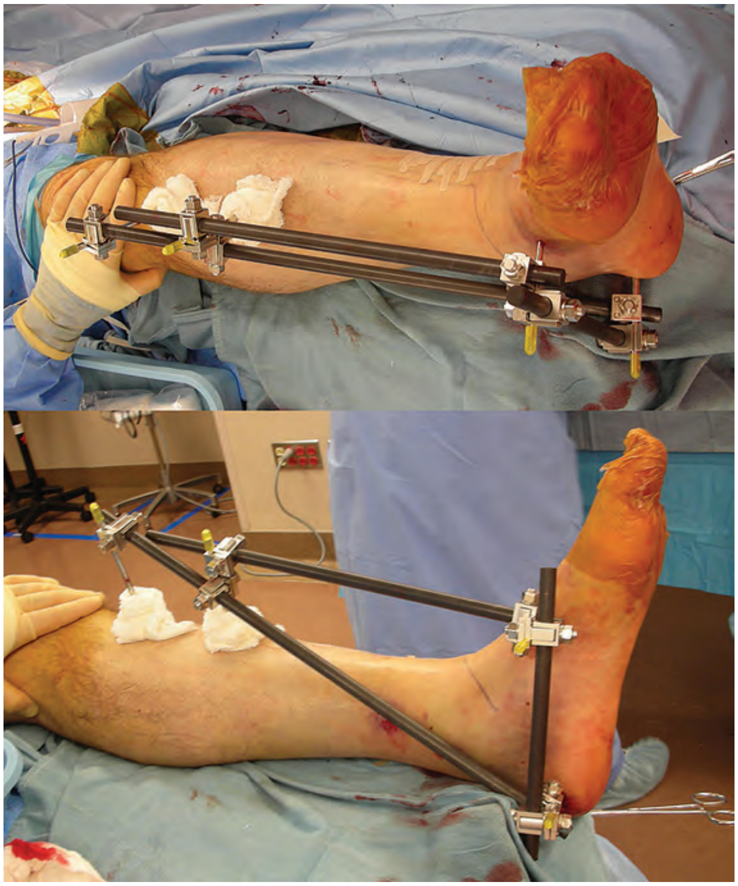


Figure 28-3. Following fixation of the fibula, a medial frame can be used to tension against the reconstructed lateral column to restore anatomic length. An alternative to a sagittal half pin in the anterior tibia is to place a coronal half pin in the medial aspect of the proximal tibia. This configuration allows for precise control of fracture reduction, as distraction along the tibial-calcaneal bar's axis will result in uniplanar changes. With distraction, in this example this configuration will result in multiplanar corrections (e.g., distraction and posterior translation with an additional rotational moment).

- Midfoot pin is placed from medial to lateral through the two medial cuneiforms or through all three cuneiforms.
  - Because the midfoot architecture is an arch, it is important to stay in the dorsal half of the medial cuneiform, on the lateral view to avoid exiting plantarly and potentially resulting in a neural or vascular injury (Fig. 28-4).

Figure 28-4. An axial CT scan of the foot demonstrates the arch configuration of the cuneiforms (*asterisks*). A medial to lateral pin should enter the dorsal half of the most medial cuneiform to avoid the structures plantar to the arch (*arrow*).

- Use a 2.5-mm drill bit to drill a pilot hole for a 4.0 mm × 100 mm partially threaded Schanz half pin (Fig. 28-5).

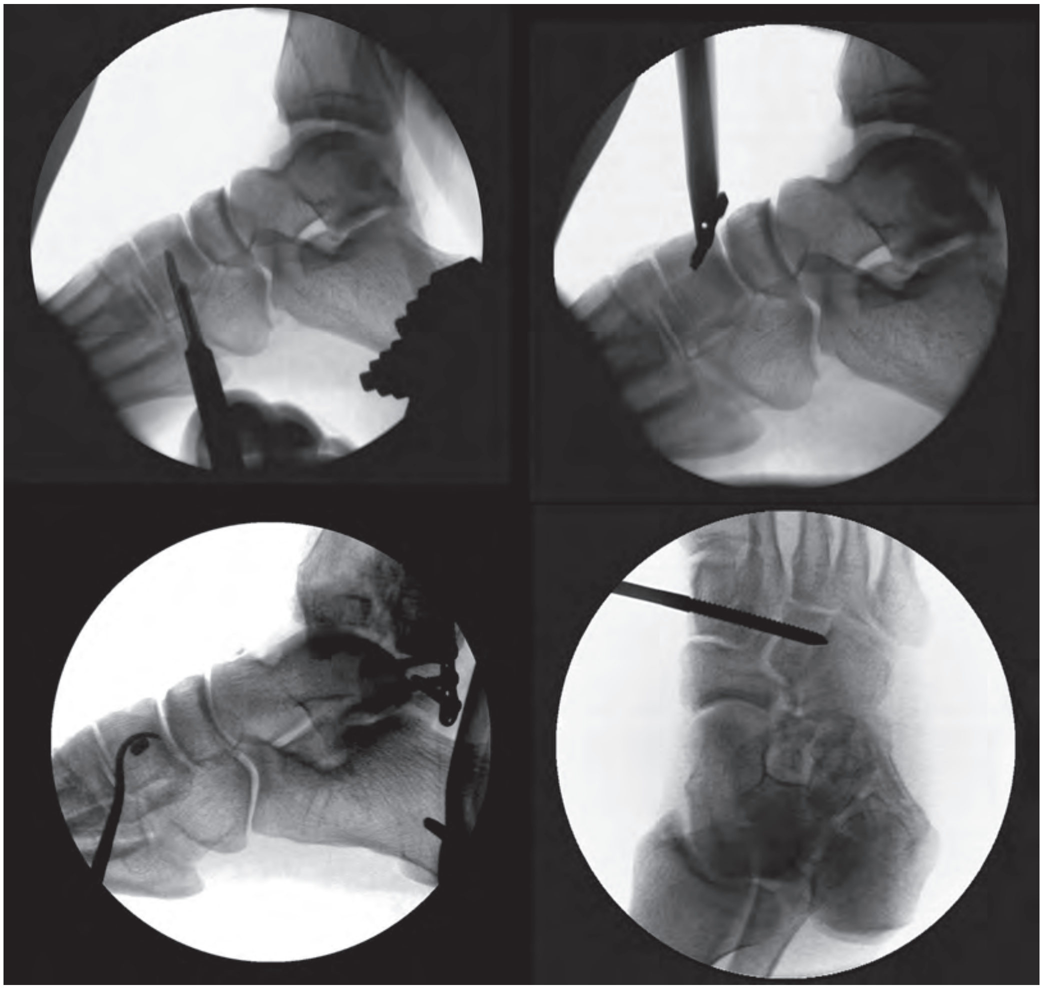


Figure 28-5. The dorsal starting point is marked with a knife, and the drill entry site and pin position are confirmed on lateral and oblique views.

- It is easier to place the midfoot pin first, prior to distracting across the ankle joint.
  - After distraction across the ankle and subtalar joints, the gastrocsoleus complex tightens, making it more difficult to dorsiflex the foot and obtain an AP fluoroscopic view of the foot.
- To place the midfoot pin, flex the knee to 90 degrees.
  - An assistant can hold the knee flexed, or a tibial triangle can be useful when placed under the knee to assist flexion.

- To obtain a true AP view of the Lisfranc joints, place five folded towels under the forefoot and orient the fluoroscopic beam vertically to the floor (orthogonal to the midfoot and parallel to the TMT joints).
- The cuneiform pin should be placed using this view (Fig. 28-6).

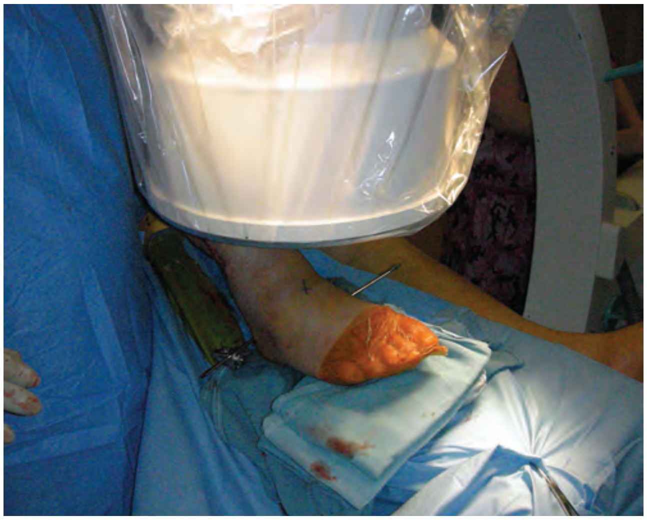


Figure 28-6. Five folded towels under the forefoot with the fluoroscopic beam perpendicular to the floor gives good visualization of the midfoot for insertion of the medial cuneiform pin.

- As the last step of the procedure, the foot is brought to neutral and a short bar is used to connect the midfoot to the tibial shaft pin(s) (Fig. 28-7).

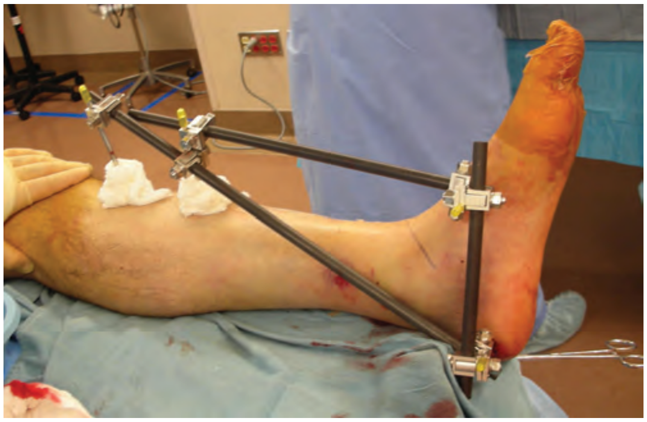


Figure 28-7. The midfoot pin is connected to the distal of the tibial pins, as the final step to maintain the foot in neutral.

- Two pins anteriorly, anteromedially, or medially in tibia.
  - Ensure that these are distal to the knee joint, proximal to the future surgical field, and not through any muscular or fascial compartment (i.e., avoid all lateral tibial diaphyseal pins).
  - In particular, avoid traversing the anterior (or lateral) compartment, as this is associated with an increase in pin drainage, loosening, muscle necrosis, neurovascular injury, and infection.
  - 5.0 mm × 170 mm pins are generally of appropriate size and should be inserted after predrilling the cortical bone with a 3.5-mm drill bit.
- Place bar(s) from proximal tibial pin to calcaneus pin either medially or medially and laterally, depending on the frame configuration desired.
- Tighten both pin-clamp connections and one of the two bar-clamp connections.

- Apply traction manually and tighten pin-bar clamps loosely (Fig. 28-8).

Figure 28-8. After tightening one end of the pin-bar connections, manual traction will reduce the majority of the limb shortening.

- If a medial frame is used, the first step is restoring the length and tightening the clamps between the proximal tibial pin and the calcaneal pin (Fig. 28-9).

Figure 28-9. With a medial frame, the first step is establishing the length with a single medial bar between a proximal tibial pin and the calcaneus. If the type of clamps available do not clip on to the open section of the bar, an extra clamp should be placed on the bar between the others pin-bar clamps, for insertion of the second tibial pin.

- When attention is focused on the multiplanar reduction, the clamps and bars may unknowingly slip toward the skin, resting in an undesirable position.
  - These are then in a poor position to tighten once the manipulative reduction is achieved.
  - To prevent this, place several towels or sponges between the bars and skin to maintain the skin-bar distance during manipulation (Fig. 28-10).

Figure 28-10. Towels placed under the bars keep them in an acceptable position in which to tighten after a manual reduction is obtained.

- The open compressor/distractor device for the external fixator can be useful for obtaining additional controlled axial distraction.
  - This can also be used to fine-tune the varus/valgus reduction (Fig. 28-11).

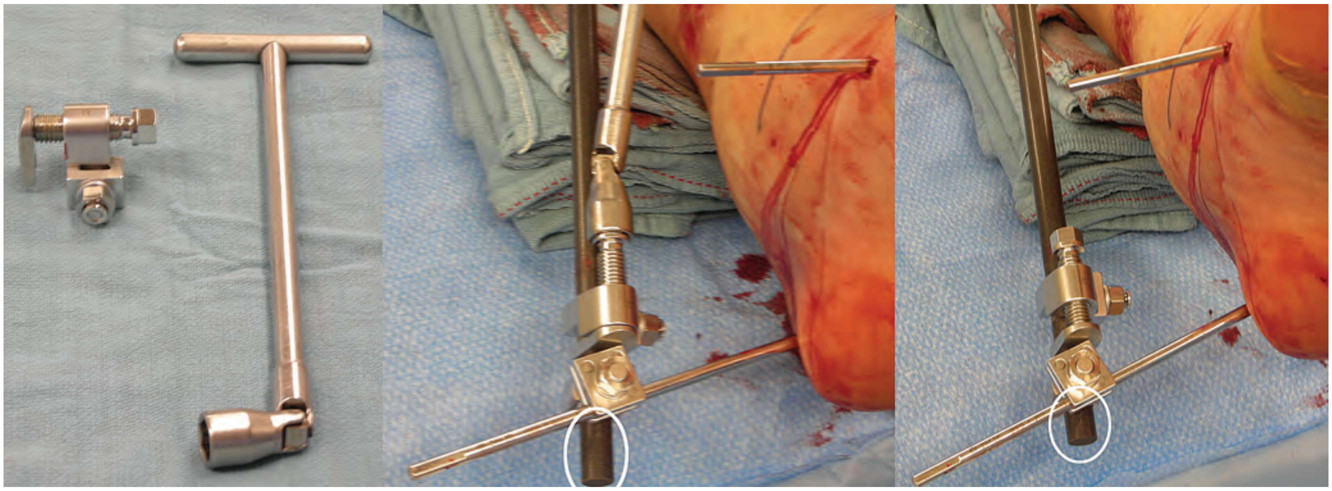


Figure 28-11. The open compressor-distractor device for external fixation (**left**) can be useful. After the compressor is tightened to the bar, the pin-bar clamp is loosened. The amount of distraction can be tracked by the change in bar excess (**center**: before distraction; **right**: after distraction).

- When using an anterior to posterior sagittal half pin, distraction will create an apex anterior deformity at the fracture site.
  - This can be anticipated and avoided prior to distraction if a bolster is placed under the heel to produce a slight apex posterior deformity.
  - Also the fracture should be placed in slight varus when distracting on the medial bar when using an external fixator in this configuration.
  - Both planes will be corrected with distraction of a medially based frame.
  - These multiplanar deformities (posterior angulation, valgus with rotation) can be avoided by applying a uniplanar (coronal plane only) external fixator, with the tibia pin(s) and the calcaneal pins inserted from medial to lateral in the same plane.
    - If pin-bar clamps are applied to these pins, such that the medial bar is in the exact same coronal plane as the tibial-talar axis, distraction will only create a valgus moment.
    - This is often the preferred configuration (especially if the fibula has been plated so as to create a lateral buttress) as it avoids posterior angulation and rotation.

- The valgus can be anticipated and counteracted by placing the limb in slight varus, before distraction along the medial bar, between the tibial and calcaneal pins.[1]

- It is important to assess the sagittal plane angular deformity, all translational deformities, and limb rotation prior to the insertion of the third pin.
  - Initially, bumps placed under the heel, Achilles tendon, or calf can partially correct the deformities seen with external fixation of pilon fractures.
  - The position and direction of the initial tibial pin and the position of the pin-bar clamps can be planned strategically to produce variations in the force vector(s) and rotational moments so as to preferentially move a subluxated or dislocated talus anteriorly or posteriorly, medially or laterally, etc.

- If the fracture pattern involves a posterior tibiotalar fracture dislocation, a proximal-posterior to distal-anterior force vector needs to be established "along" the axis of the limb to maintain the talar reduction.
  - The proximal tibial pin can be placed posteromedially to allow for a posterior starting point for the force vector (Fig. 28-12).

Figure 28-12. In this case, the proximal tibial pin was placed from posteromedially to anterolaterally to accentuate the posterior to anterior vector across the ankle, when connected to a medial calcaneal half pin.

  - The clamps should be rotated such that the bar is angled maximally from proximal-posterior to distal-anterior (Fig. 28-13).

Figure 28-13. Multiple configurations of a medial external fixation frame to create variable force vectors in the sagittal plane, from anterior to posterior (**left**) to progressively more posterior to anterior (**right**). standard frame; rotated clamps; posteromedial proximal tibial pin; posterior extension bar from tibial pin.

- An anterior extension bar is frequently required to connect to the second tibial pin to avoid placing the pin through the posteromedial soft tissue (e.g., gastrocsoleus).
- If a substantially large posterior to anterior vector is needed, a short bar can be run posteriorly from the anteromedial tibial pin, with the longitudinal bar connecting the posterior extension bar and the calcaneus pin.

- The second and more distal of the two proximal tibial pins is placed proximal to the planned surgical incision.
  - The position is based on the path determined by the line created between the first two pins inserted at each end of the longitudinal bar.
  - As such, its position and vector are relatively constrained.
    - The pin should be inserted once the fracture is reduced to further stabilize the reduction and prevent any rotation around the pins at each end of the bar.
  - Pushing along the axis of the pin to improve the reduction is not reliable, because it cannot be placed along the exact vector of the deformity.
  - However, if the pin is straight anterior to posterior, and the talus is still translated slightly anteriorly (or posteriorly), or the metaphyseal fracture shows translational displacement, a laminar spreader can be used between a pin-bar clamp and a universal T-chuck to correct a small sagittal plane deformity (Fig. 28-14).

Figure 28-14. A laminar spreader between the clamp and a universal chuck can be used to pull the tibial fracture fragment anteriorly to correct sagittal plane deformity.

Reference

1. Ertl W, Henley MB. Provisional external fixation for periarticular fractures of the tibia. *Tech Orthop.* 2002;17(2):135–144.

Chapter 29

Foot External Fixation

Michael L. Brennan

Sterile Instruments/Equipment

- Large/medium external fixation system
- Open compressor/distractor device
- 4.0-mm partially threaded pins for forefoot fixation
- Towel bolsters/bumps
- Dental pick
- Traingular bolster

Positioning

- Supine on a radiolucent cantilever-type table.
- Bring patient to the radiolucent (foot) end of the table.
- Place small bolster/bump under the ipsilateral hemipelvis and torso.
- Elevate the leg on soft ramp cushion to facilitate lateral imaging.
- Triangular bolster improves imaging of foot (Fig. 29-1).

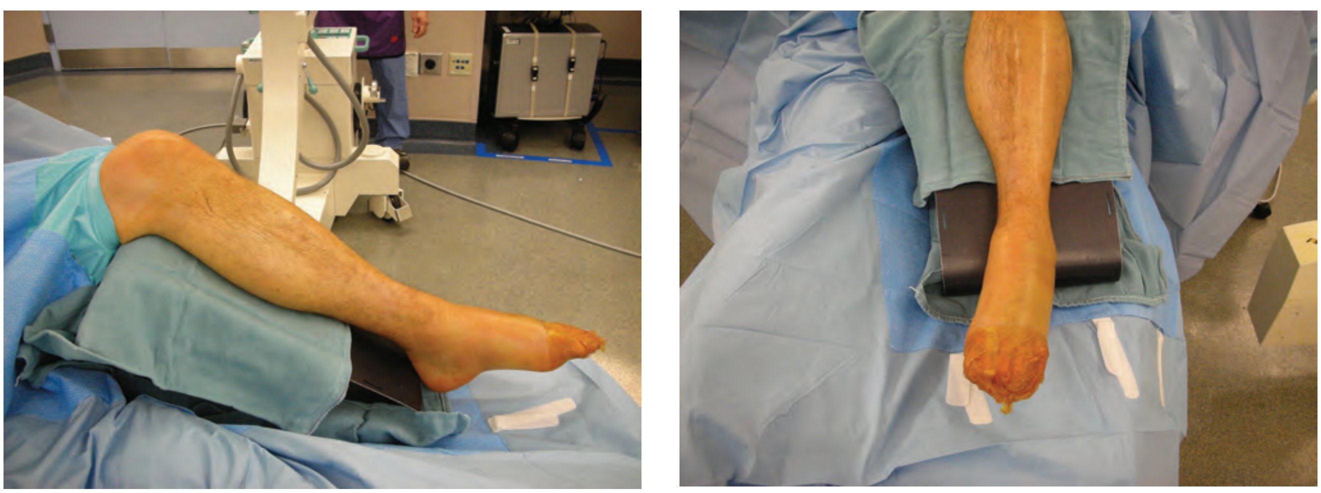


Figure 29-1. Foot position for external fixation. Note radiolucent triangle flexing hip and knee to facilitate obtaining true AP and oblique views of foot, when C-arm is in vertical position.

- With the knee fully flexed, five folded towels under the forefoot allow correct radiographic view of Lisfranc joint with AP fluoroscopy, if necessary.

Surgical Approach

- Percutaneous placement of Schanz pins using fluoroscopy.

Reduction and Implant Techniques

- Centrally-threaded 5.0- or 6.0-mm Schanz pin in calcaneus or medial/lateral 5.0-mm half pins depending on the injury pattern and deformity.
- 4.0 mm × 100 mm pin in the first and second cuneiforms or in the first metatarsal.
- K-wire through base of fourth and fifth metatarsals.
- Use wire hole in drill guide with K-wire to drill, place a 4.0- or 5.0-mm pin.
    - This is used if the lateral column has been disrupted.
- Distraction applied between Schanz pins.
- For Lisfranc injuries, place a medium external fixator frame medially and tighten provisionally.
- Universal T-handle chucks on Schanz pins used as joysticks to manipulate and reduce fracture/dislocations under fluoroscopy (Fig. 29-2).

Figure 29-2. Medial Schanz pins are used with universal chucks to restore length and facilitate realignment of the medial column.

- Assistant tightens the ex-fix pin-bar clamps.
- Fragment reduction using percutaneous incisions and dental pick (Figs. 29-3–29-6).

Figure 29-3. Case example of a severe midfoot crush injury. A 4.0-mm half pin is placed in the distal first metatarsal and connected to the medial side of a calcaneal pin to span the medial column.

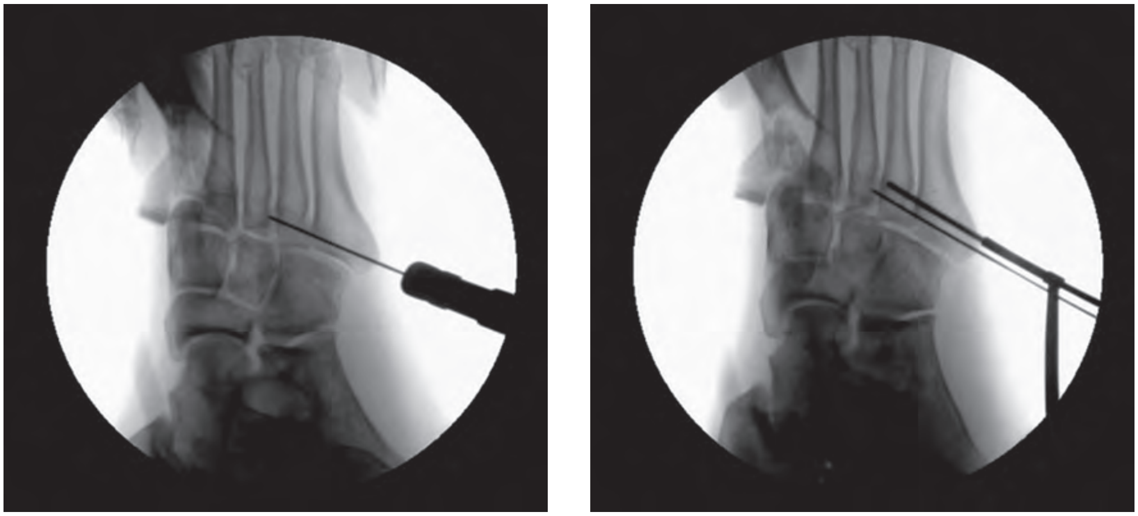
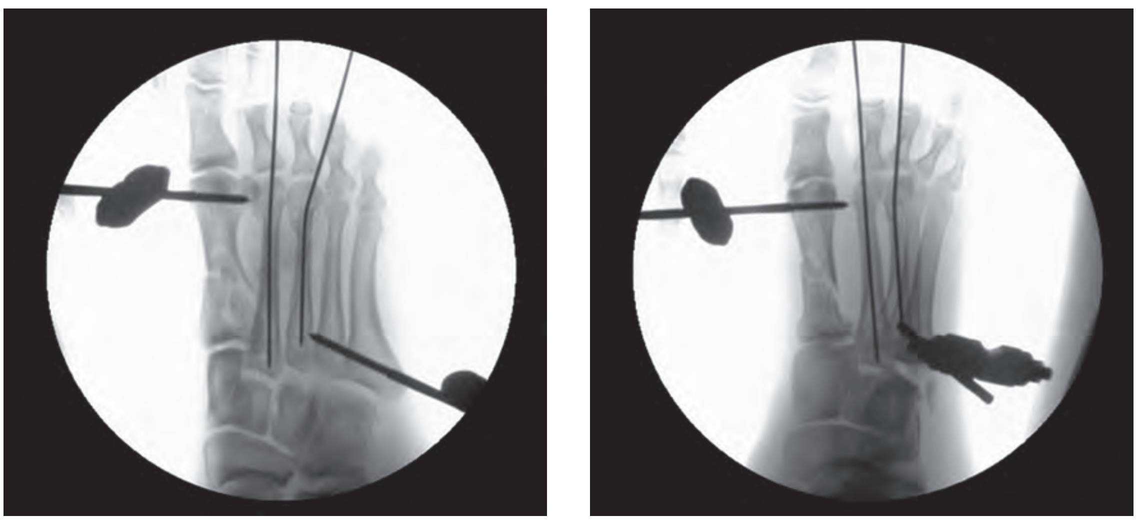


Figure 29-4. If necessary, a lateral 4.0-mm half pin is placed in the base of the fourth and fifth metatarsals. A K-wire is first inserted through the parallel adjacent hole in the 2.5-mm drill guide to facilitate alignment of the drill bit/drill hole prior to pin insertion.



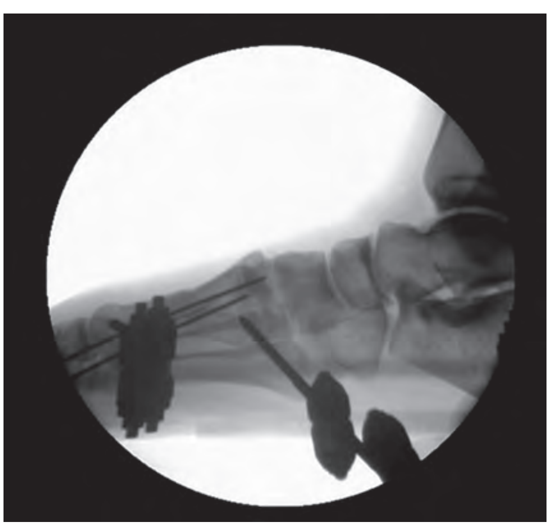


Figure 29-5. Subsequent to insertion of the 4-mm Schanz pin, the alignment K-wire is removed. Final construct showing ex-fix pins in place.

Figure 29-6. Another clinical example of provisional external fixation applied to a Lisfranc fracture/dislocation. Due to significant lateral soft tissue injury, a medially-based frame was selected.

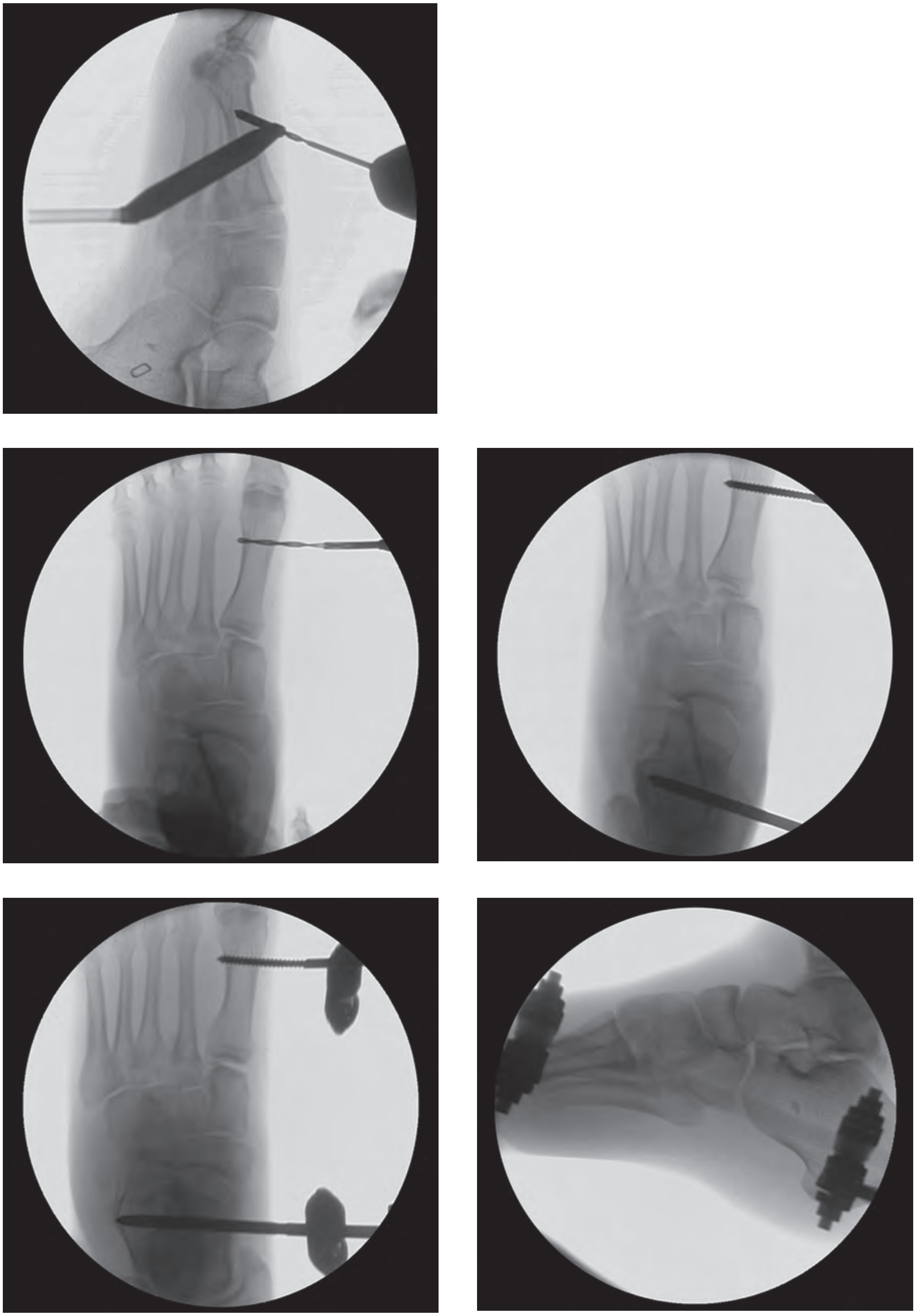


Figure 29-6. Continued.

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