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EMIL SCHEMITSCH
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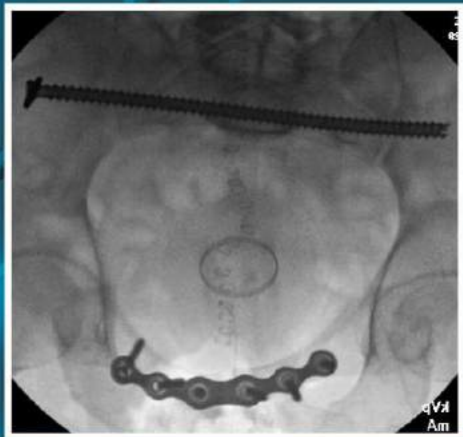
ORTHOPAEDIC TRAUMA SURGERY

SECOND EDITION



OPERATIVE TECHNIQUES

ELSEVIER

Operative Techniques: Orthopaedic Trauma Surgery

Second Edition

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This book is dedicated to my wife Maureen
and our four wonderful children Laura,
Geoffrey, Christine and Thomas.

Emil H. Schemitsch

I dedicate this book to the guidance
of my parents David and Nancy.
The love and support of my wife Niloofar.
My children Sacha, Tyler, Robbin, Everett,
and Darya who enrich my life every day.
And the promise of the new generation
Mickey, Felix, and Declan.

Michael David McKee

Preface

Fracture surgery occupies a special place in the hearts and minds of orthopaedic surgeons. This book is designed to be a user-friendly and clinically relevant text on common fracture surgery procedures. Every orthopaedic surgeon may be required to have knowledge or involvement in some aspect of fracture care despite their subspecialty practice. The text is designed for those who wish to review the surgical treatment of the conditions that commonly confront them while on call.

As fracture surgery becomes more and more sophisticated, it is obvious that the technical component of operative intervention is critical to clinical success or failure. Therefore, there continues to be an important need to understand the technical aspects of fracture surgery. Many pearls of wisdom are detailed by the authors in order to deal with the multiple potential pitfalls seen in patients with complex fracture patterns.

A large number of chapters have been written by a member of the Canadian Orthopaedic Trauma Society (COTS) who is an expert in that particular area. COTS is a group of orthopaedic trauma surgeons with outstanding surgical skills who are recognized leaders in their field. In addition, through prospective and randomized trials, they are at the forefront of developing the evidence that exists for management of the patient with a fracture. Each chapter provides comprehensive technical descriptions supported by the best evidence in that area.

We believe that the production qualities of this text are the highest possible. The illustrations in particular are outstanding and clearly define the complex technical aspects of fracture surgery. We would like to thank all the members of COTS who were contributors to this volume for their outstanding efforts in making it a success. We feel this text should prove to be the "resource of choice" for modern fracture care over the next several years. It will serve those who are novices in the field who wish to concentrate on principles, those experienced surgeons who wish to "fine–tune" their approach, and everyone in between.

Emil H. Schemitsch, MD, FRCS(C)
Michael D. McKee, MD, FRCS(C)

Foreword

This textbook represents the thoughts of a unique group of orthopaedic surgeons. It is a synopsis of current thinking in surgery from a diverse but united group of physicians known as COTS. The Canadian Orthopaedic Trauma Society (COTS) is active as a sub-section of the Canadian Orthopaedic Association. COTS has been an avid leader in multi-center research studies for about two decades. This group has grown to over 50 members with the responsibilities of biannual research meetings and multiple study designs. They are a multiple award-winning group that has changed the way many simple and some complex problems are solved. The success of this group as a major force in conducting prospective multicenter randomized trials has been well recognized by many including the Canadian Orthopaedic Association who awarded the group the Award of Merit for their performance. The COTS group has won many awards from the world trauma organizations as a testament to their excellence in the field of clinical randomized trials and their impact on changing the way we treat fractures in our day-to-day practice. The ability of this group to produce world-leading research is a testament to the Canadian norm of friendly accommodation. Canadian demeanor is often a joke in other countries; Canada is seen as the overly polite country. It certainly has been in this spirit of accommodation that the varied COTS undertakings were shuttled along to completion with input from dozens of people in almost every phase of project development and completion. Ross Leighton, the current and only president of the organization since COTS was founded, has been instrumental in maintaining the collegiality that drives purposeful projects.

The current group of authors, led by editors Emil H. Schemitsch and Michael D. McKee, has once again been able to produce a literary gem that can be used by residents and staff as a resource for expert opinion on the best ways to "skin the cat." Certainly there is more than one way to tackle the problems than presented here; but the textbook shows a tried and true method in the hands of each author. The method of approaching each area with pearls and pitfalls will be of great benefit to everyone involved in patient care. This book should find its way into every program's library and the bookcase of most surgeons performing trauma cases.

I have to reiterate Dr. Leighton's words in saying that the COTS group is a great group of orthopaedic surgeons and I am lucky to have been around to participate with the cohort of surgeons and thinkers that make up this organization. Some of the world's best speakers, teachers, and researchers make up COTS. Many surgeons from other countries wish they were members of COTS and in practice many of them have become members in spirit, having adopted the basic principles and mechanisms of COTS. I know that COTS will continue to thrive for years to come. Their influence will grow and they will be a positive force in orthopaedic surgery. This text from that group should be a prime resource for current orthopaedic trauma care.

The COTS group would like to dedicate this book to the families who continue to support us despite the long hours and many missed family events, due to the erratic nature of our specialty. Their support is essential to our continued success. We also acknowledge the tireless dedication of the research coordinators and staff who make COTS a rich and viable association.

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PROCEDURE 1

Acromioclavicular Joint Injuries: Open Reduction and Internal Fixation

Michael D. McKee and Alireza Naderipour

INDICATIONS

- Acute injury
  - Grades IV, V, and VI in most patients unless surgery is contraindicated owing to medical or psychological factors
  - Grade III in selected patients, including heavy laborers (lifting, carrying) and overhead athletes/workers
- Chronic injury
  - Grade II in patients with symptomatic anterior-posterior instability
  - Grades III, IV, and V in patients with symptomatic instability

PHYSICAL EXAMINATION

- Evaluate shoulder posture.
- Determine the position of the distal clavicle relative to the acromion.
  - The deformity is more visible in standing or sitting position without support for the injured arm.
  - In grade IV dislocations, the clavicle is posterior to the acromion and stuck in the trapezius.
  - The distal end of the clavicle is level or superior to the acromion in other grades.
  - The distal clavicle is sitting subcutaneously, through the trapezius, in grade V injuries.
  - In contrast to higher grades, the acromioclavicular (AC) joint is reducible in grade III by applying an upward force on the ipsilateral elbow.
- Assess horizontal stability by grasping and moving the clavicle.
- Examine sternoclavicular (SC) joint for possible bipolar dislocation (synchronous AC and SC dislocation).
- Assess active and passive shoulder motions.
  - AC joint pain is accentuated by abduction and cross-body adduction.
  - Manage glenohumeral stiffness prior to reconstruction of chronic separation.
  - Isolated AC injury does not typically produce decreased shoulder range of motion.
- Evaluate deltoid and rotator cuff strength.
  - Consider the rare occurrence of concomitant rotator cuff pathology.
- Perform neurovascular examination.

IMAGING STUDIES

- Plain radiographs
  - True anteroposterior view of the shoulder
    - Evaluate the glenohumeral joint.
    - Look for bony signs of rotator cuff pathology.
  - Axillary view will demonstrate posterior displacement of the clavicle in grade IV injuries.
  - Outlet/scapular Y view
    - Evaluate acromial anatomy.
    - The presence of a spur may warrant acromioplasty.
  - Bilateral anteroposterior acromioclavicular views (Zanca view)
    - Evaluate the acromioclavicular joint position.
    - Look for possible arthritic changes.
    - Compare coracoclavicular distance on both sides.
    - Normal coracoclavicular distance is 11 to 13 mm.

PITFALLS

- Acute injury
  - Skin abrasion: wait until healed
  - Noncompliant patient
  - Patient with substance abuse
- Chronic injury
  - Noncompliant patient

CONTROVERSIES

There is no consensus on

- Optimum timing of surgery
- Anatomic vs. nonanatomic reconstruction
- Best type of graft
- Acute repair of grade III injuries
  - Operative treatment of acute injuries is the only treatment that will restore normal anatomy, but it is associated with greater risk of complications.
  - Although often recommended, insufficient evidence exists to recommend surgery for heavy laborers or overhead athletes.
  - Successful nonsurgical treatment of type III injuries in professional athletes has been reported.
- Inclusion of distal clavicle excision in management of chronic cases
  - Preserving distal clavicle may add to the stability of reduction.
  - Reduction of an already arthritic distal clavicle may produce or aggravate pain.
  - Resection of distal 1 cm of clavicle results in a 32% increase in posterior translation.
  - Resection of as little as 2.3 mm in women and 2.6 mm in men could release the clavicular insertion of the acromioclavicular (AC) ligaments in some patients.
  - Some studies suggest improved outcomes with preservation of the distal clavicle during AC reconstruction.

TREATMENT OPTIONS

- Nonoperative treatment
  - Indicated for grade I and II and most grade III injuries
    - Good short-term results
    - 10% to 20% of patients will have residual symptoms and may need subsequent surgery.
  - Nonoperative treatment of high-grade injuries (IV, V) may be acceptable, but has a higher rate of poor outcome.
  - A short course (1–3 weeks) of sling support or immobilization may be used for comfort,

Continued

TREATMENT OPTIONS—cont'd

but strict or prolonged immobilization should be avoided.

- Physical therapy
  - Early passive and active assisted range of motion (ROM) exercises
  - When painless ROM is achieved, proceed to isometric periscapular and rotator cuff strengthening, followed by isotonic exercises.
  - Avoid contact sports and heavy lifting for 3 months.
- Operative treatment
  - Components of optimal surgical technique
    - Anatomic reduction of acromioclavicular joint
    - Coracoclavicular ligament repair/reconstruction
    - Acromioclavicular ligament repair/reconstruction
    - Protection/augmentation of repair/reconstruction
    - Deltoid/trapezoid fascia repair
    - Distal clavicle resection, if arthritic
- Acute injury
- Coracoclavicular ligament repair and augmentation
    - Multiple techniques have been described to stabilize the AC joint with autograft/allograft tendon or ligament augmentation devices around the coracoid.
  - Transarticular acromioclavicular pin fixation
    - Needs limited dissection
    - Risk of pin migration/breakage significant, largely abandoned
  - Acromioclavicular hook plate
    - Mechanically very effective
    - May result in acromial wear or fracture
    - Newer hook designs that match acromial anatomy preferred
    - Avoid over-reduction
    - Most, but not all, patients require eventual hook plate removal.
  - Weaver-Dunn acromioclavicular ligament transfer
    - 40% failure rate, not used in isolation
    - Provides 25% of intact coracoclavicular ligament strength
    - Strength can be drastically increased by adding synthetic loop augmentation
  - Coracoclavicular screw fixation
- Has a high failure rate, not used in isolation
    - Acromioclavicluar ligament repair
    - Imbrication of the torn AC ligaments
- Chronic injury
  - Coracoclavicular ligament reconstruction with
    - Tendon graft
    - Synthetic loops
    - Weaver-Dunn procedure
    - Conjoined tendon transfer
  - Acromioclavicluar ligament reconstruction with
    - Suturing of the remaining coraco-calvicular (CC) graft around the AC joint
    - Intramedullary free tendon graft
    - Reverse coracoacromial ligament

- Stress views
  - Originally described to differentiate between type II and type III injuries
  - Stress views are costly and uncomfortable for the patient and rarely provide new information to help diagnose an unstable injury.
- Advanced imaging should be considered only if evaluation suggests rotator cuff or intraarticular glenohumeral pathology.
- Magnetic resonance imaging may be indicated to evaluate the rotator cuff in chronic injury.

SURGICAL ANATOMY

- Clavicle
  - The distal clavicle forms the medial articulation of the acromioclavicular joint.
- Acromion
  - The acromion forms the lateral aspect of the acromioclavicular joint and typically slopes posteriorly and laterally. Newer designs of hook plates recognize this.
  - The anterior acromion is also the site of coracoacromial ligament insertion, which is used in the Weaver-Dunn procedure.
- Acromioclavicular joint
  - The orientation of the joint varies from vertical to 50 degrees oblique from inferomedial to superolateral.
- The intraarticular meniscus
  - Made of fibrocartilage
  - True function unknown
  - Undergoes significant degeneration over time
- Acromioclavicular ligaments
  - The posterior acromioclavicular ligament is an important restraint to posterior translation of the acromioclavicular joint.
  - The superior acromioclavicular ligament contributes to a lesser extent to restraint of posterior translation of the acromioclavicular joint.
  - The inferior acromioclavicular ligament contributes to restraint of anterior translation of the acromioclavicular joint.
  - Isolated disruption of the acromioclavicular ligament occurs in grade II injuries.
- Coracoclavicular ligaments
  - The conoid ligament is a more medial structure that attaches on the conoid tubercle on the underside of the distal clavicle. The conoid tubercle is located at the juncture of the lateral and medial thirds of the clavicle.
  - The trapezoid ligament is more lateral and attaches on the trapezoid line of the inferior clavicle.
  - Disruption of the acromioclavicular and coracoclavicular ligaments occurs in grades III, IV, V, and VI injuries.
- Muscular anatomy
  - Trapezius, pectoralis major, and anterior deltoid muscles attach to the distal clavicle and acromion.
  - Their combined action provides dynamic stability to the acromioclavicular joint.
- Neurologic anatomy
  - Brachial plexus, suprascapular, and musculocutaneous nerves are in the vicinity and could be injured in reconstruction surgeries.
  - AC joint is innervated by lateral pectoral, axillary, and suprascapular nerves.
- Vascular anatomy
  - Branches of the thoracoacromial artery run in the vicinity of the distal clavicle and can bleed during the dissection and exposure of the base of the coracoid.

POSITIONING

- The patient is placed in the beach chair position, with the surgical field draped out, bony landmarks outlined, and the skin incision marked.
- Neck alignment should be in a neutral position with the head on an adjustable articulating headrest or gel pad “donut.”

- If desired, an articulating arm holder is used to support and position the arm during the procedure. Alternatively, the arm may be secured at the patient's side.
- A side pad is placed against the lateral chest to keep the patient from falling off the side of the table.

PORTALS/EXPOSURES

- A superior surgical approach is used.
- An incision is made along Langer's lines over the distal end of the clavicle.
- Begin just posterior to the clavicle and extend toward the coracoid process.

PROCEDURE: HOOK PLATE FIXATION

Step 1: Skin Incision and Surgical Dissection

- Surgical incision is made along Langer's lines.
- Continue dissection through the subcutaneous tissue.
- The skin and subcutaneous tissue are elevated to extend exposure medially and laterally to expose the distal 3 to 4 cm of the clavicle and the acromion.

Step 2: Acromioclavicular Joint Exposure and Mobilization

- The deltotrapezial fascia is split over the distal clavicle and acromion.
- Typically the acromioclavicular joint capsule and ligaments are disrupted by the injury. Be alert for this disruption and work through any defects created by the injury.
- The meniscus is debrided.
- Look for arthritic changes. Distal clavicle resection should be considered in chronic cases with frank arthritic changes.
- Mobilize the distal clavicle and ensure that it can be reduced.

Step 3: Hook Plate Insertion

- Anterior deltoid is elevated off the distal clavicle, subperiosteally and retracted anteriorly.
- Cauterize vessels imbedded in subdeltoid fatty tissue.
- Open the subacromial space with a Cobb or periosteal elevator and insert the hook portion of the hook plate. This typically will be posterior in the subacromial space.
- Use the hook plate trials to determine the correct height of the hook plate to be inserted; be careful not to over-reduce the joint. The clavicle should not require excessive force to reduce (Fig. 1.1).
- Insert the chosen hook plate and then place the screws in the plate, which will bring the plate down to the clavicle.
- Be careful that insertion of the screws in the shaft portion of the clavicle does not "lever" the clavicle down further.
- If there is any question as to reduction, use radiographic imaging to ascertain this. Considerable variation exists in AC joint pathology: a preoperative radiograph of the opposite side can be useful to gauge proper reduction.

Step 4: Optional Coraco-Acromial (CA) Ligament Transfer

- If desired, especially in the chronic situation where an acute healing response will not occur, a CA ligament transfer can be performed in addition.
- This Weaver-Dunn transfer can be performed by releasing the CA ligament from the acromion and inserting it through drill holes in the distal clavicle.
- Alternatively, a small fragment of acromion can be resected with the CA ligament and then secured with a lag screw to a corresponding slot cut into the distal anterior acromion. This provides biologic healing and ligamentous stability following eventual hook plate removal.

Step 5: Optional Coracoclavicular Augmentation

- Acute repair
  - The coracoclavicular sutures (nonabsorbable no. 5 suture or 5-mm suture tape) are passed under the coracoid.
  - The clavicle is held reduced to the acromion with direct downward push on the distal clavicle and upward pressure on the arm through the elbow.
  - Tie the sutures over the plate.

EQUIPMENT

- Articulating sterile arm holder
- Gel headrest
- Side pad

PITFALLS

- Keep the neck aligned in neutral rotation and flexion/extension position to protect the cervical spine and prevent brachial plexus injury.

PEARLS

- Drape high on the neck and inferior enough on the chest to have an adequate surgical field.
- If a difficult reduction is anticipated, drape the operative arm free.
- Position the shoulder in a way that imaging can be used if needed.

PEARLS

- An incision parallel to Langer's lines will heal with a very cosmetic scar.

PITFALLS

- An incision that is too lateral limits exposure of the clavicle.
- An incision that is too medial limits access to the acromion.
- A longitudinal incision in line with the clavicle, across Langer's lines, may heal with a thick, noncosmetic scar.

INSTRUMENTATION/IMPLANTATION

- Place a self-retaining retractor to hold the skin and subcutaneous tissue apart.

PEARLS

- Release enough capsule and soft tissue to facilitate anatomic reduction of the distal clavicle.
- Have a preoperative radiograph of the opposite side.

PITFALLS

- Avoid over-reduction of the AC joint: this leads to a painful, stiff shoulder with a high rate of subsequent mechanical failure (plate pull-off, acromial fracture) (Fig. 1.2)
- Excessive distal clavicle resection potentially destabilizes the acromioclavicular joint by releasing the acromioclavicular ligaments.

INSTRUMENTATION/IMPLANTATION

- Hook plate implants, including trials and definitive implants
- Newer hook plate designs provide a better fit to the undersurface of the acromion and may minimize complication and removal rates (Fig. 1.3).
- Power saw, osteotome or chisel for distal clavicle resection

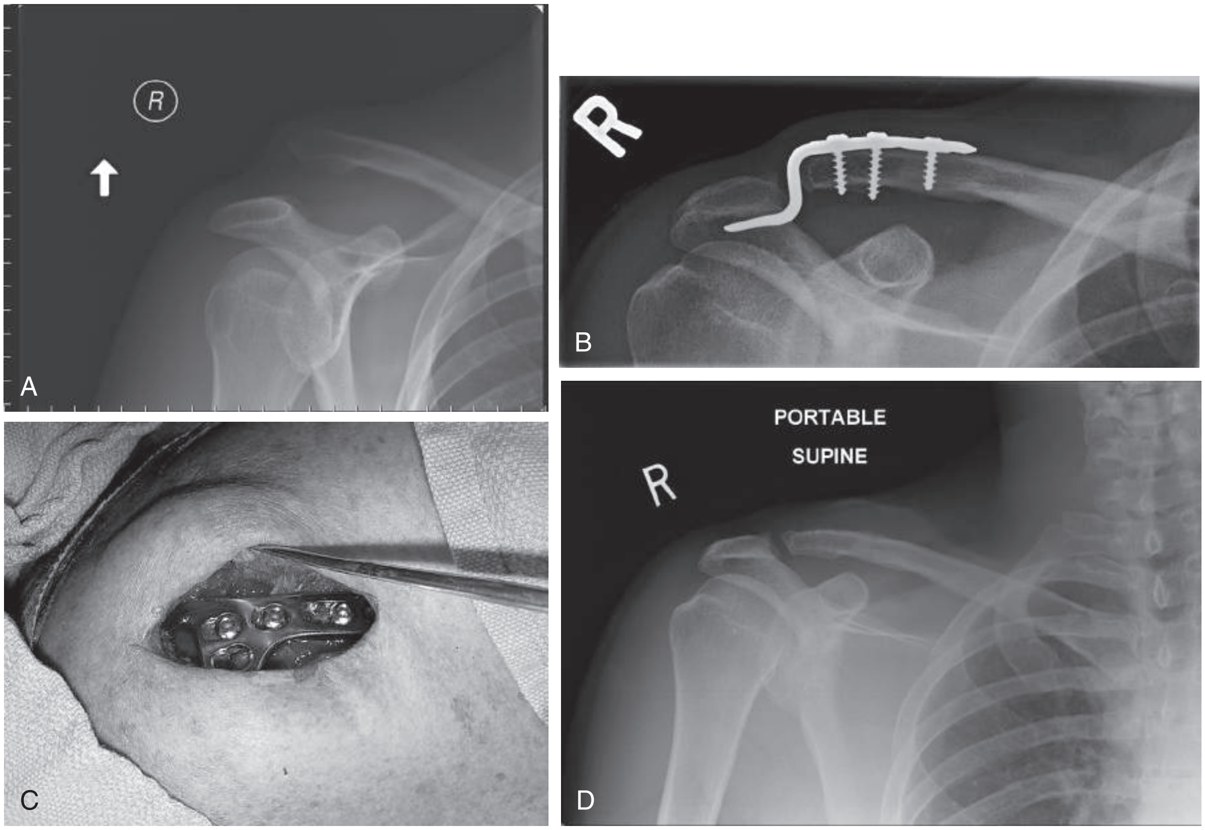

FIG. 1.1 Proper alignment and positioning of the hook plate results in rapid healing in an anatomic position.

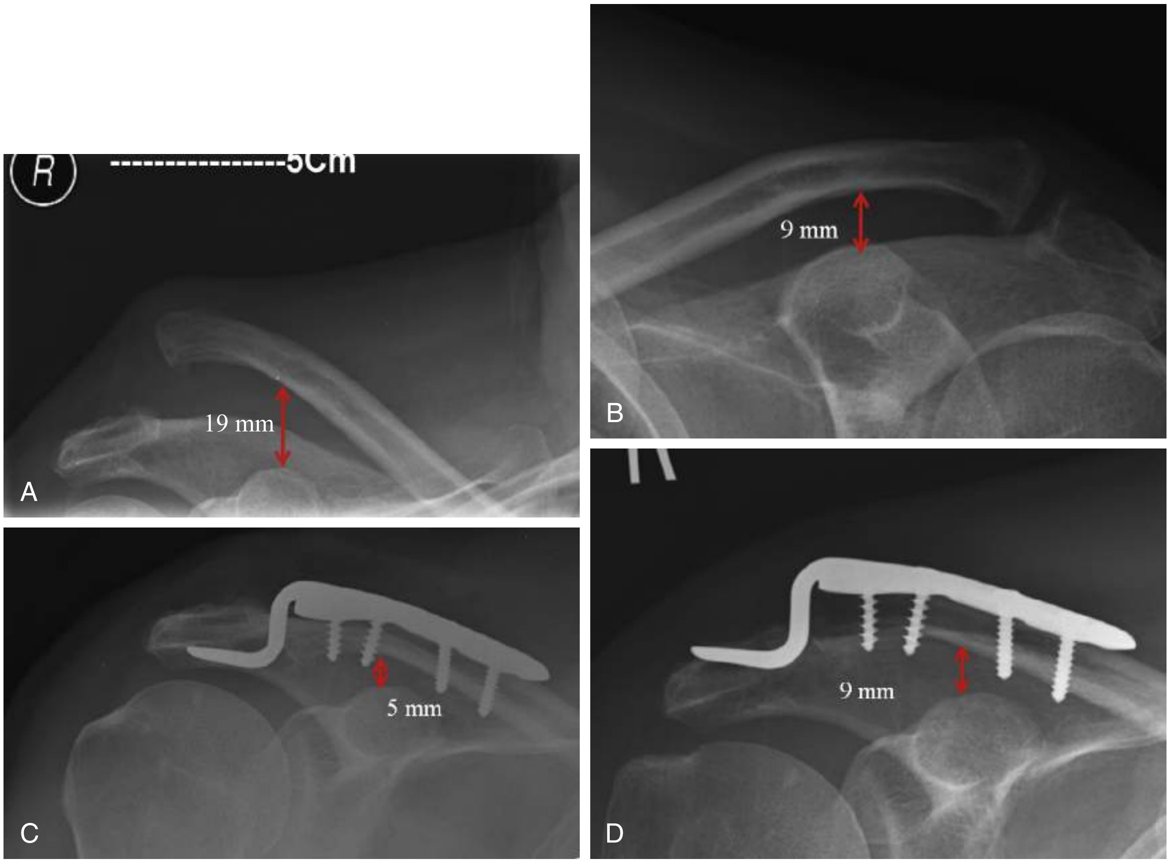

FIG. 1.2 Over reduction of the clavicle is to be avoided as it increases pain and can lead to acromial erosion of the hook.

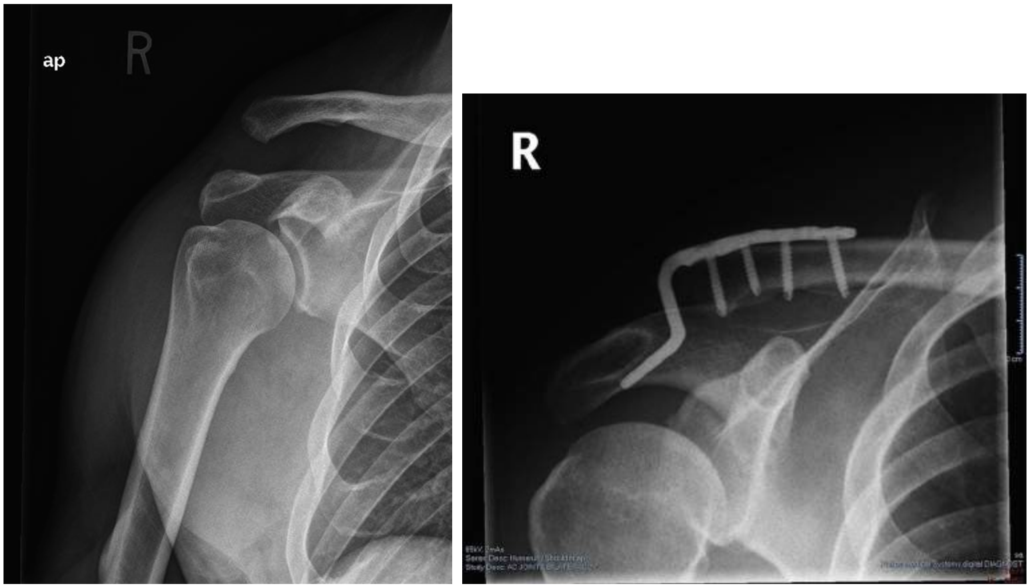

FIG. 1.3 The angle of the hook should match the usually sloped angle of the acromion.

- Chronic reconstruction
  - Tendon ends are prepared with passing sutures.
  - Tendon ends are passed under the coracoid.
  - The tendon ends are pulled up through clavicle drill holes or over the clavicle itself and tied into place. Avoid making the superior aspect of the graft too bulky: it will interfere with the hook plate placement.
  - Stability is then enhanced by the addition of the hook plate over top of the tendon graft. Once graft healing has occurred, typically 6 to 8 months postoperatively, the hook plate may be removed.

Step 6: Deltotrapezial and Acromioclavicular Repair

- The acromioclavicular ligaments and capsule are repaired over the acromioclavicular joint, incorporating the lateral extension of the tendon graft for a chronic reconstruction.
- The deltotrapezial fascia is sutured over the clavicle with nonabsorbable suture.

POSTOPERATIVE CARE AND EXPECTED OUTCOMES

- A sling is used to support the arm for 6 weeks.
- Physiotherapy protocol
  - 0–2 weeks: No shoulder motion is permitted.
  - 2–6 weeks: The sling is discontinued and supine passive and active assisted external rotation and scapular plane elevation is begun.
  - 6–12 weeks: Passive and active-assisted range of motion in all planes. Isometric deltoid and rotator cuff exercises below chest level are started.
  - >12 weeks: Progressive resisted exercises are begun.
  - 16 weeks: Return to sports is allowed if range of motion is full and strength is adequate.
  - Most patients attain a shoulder rating of 90+ after hook plate fixation of acute AC joint disruptions. The major complication rate is low, as long as over-reduction is avoided.
  - Most, but not all, patients require hook plate removal: it is recommended that the plate be left in place for at least 6 months prior to removal to allow adequate healing to occur to prevent re-displacement of the joint.

CONTROVERSIES

- Distal clavicle resection is controversial.
- Distal clavicle resection
  - May facilitate reduction
  - May prevent late acromioclavicular arthritis
  - At least partial resection is required for Weaver-Dunn procedure for ligament reattachment.
- Preserving the distal clavicle
  - May facilitate acromioclavicular ligament repair
  - May improve acromioclavicular joint stability
  - Isolated coracoclavicular ligament reconstruction does not require distal clavicle resection.

INSTRUMENTATION/IMPLANTATION

- Power drill or burr to make holes in the clavicle for suture and tendon passing

CONTROVERSIES

- Coracoclavicular fixation can be achieved with heavy sutures, acromioclavicular hook plate, coracoclavicular screw, transarticular acromioclavicular screw, or pins.
- When patient compliance is a concern, early motion is desired, or in a revision setting, the tendon graft is best supplemented with a hook plate.
- Supplementing the graft with hook plate has been shown to result in less displacement in biomechanical testing.

PEARLS

- Early motion is advantageous.

PITFALLS

- Overly aggressive early rehabilitation can lead to attenuation or failure of the repair or reconstruction.

EVIDENCE

Li X, Ma R, Bedi A, Dines DM, Altchek DW, Dines JS. Management of acromioclavicular joint injuries. *J Bone Joint Surg [Am]*. 2014;96:73–84.

A comprehensive review of modern treatment methods for acromioclavicular joint injuries.

Galpin RD, Hawkins RJ, Grainger RW. A comparative analysis of operative versus nonoperative treatment of grade III acromioclavicular separations. *Clin Orthop*. 1985;193:150–155.

This older retrospective review revealed that there was little improvement with surgical treatment of acute acromioclavicular joint injuries and recommended nonoperative treatment in general.

Gstettner C, Tauber M, Hitzl W, Resch H. Rockwood type III acromioclavicular dislocation: surgical versus conservative treatment. *J Shoulder Elbow Surg*. 2008;17:220–225.

A retrospective study (mean follow-up 34 months) of 24 patients treated surgically with a hook plate and 17 patients treated conservatively. The mean Constant score was 80.7 in the conservative group and 90.4 in the hook plate group. The mean coracoclavicular distance was 15.9 mm in the conservatively treated group and 12.1 mm in the surgically treated group. In this study, better results were achieved by surgical treatment with the hook plate than by conservative treatment.

Salem KH, Schmelz A. Treatment of Tossy III acromioclavicular joint injuries using hook plates and ligament suture. *J Orthop Trauma*. 2009;23:565–569.

A study of 25 patients revealed the hook plate was a reliable fixation tool for complete AC joint dislocations, ensuring immediate stability and allowing early mobilization with good functional and cosmetic results (mean Constant score 97 points).

Bannister GC, Wallace WA, Stableforth PG, Hutson MA. The management of acute acromioclavicular dislocation. A randomized prospective controlled trial. *J Bone Joint Surg*. 1989;71B(5):848–850.

This study of 60 patients failed to reveal any improvement with surgery, in general. The authors postulate that patients with severe displacement (>2 cm) may benefit from surgery.

von Heideken J, Windhamre HB, Une-larsson V, Ekelund A. Acute surgical treatment of acromioclavicular dislocation type V with a hook plate: superiority to late reconstruction. *J Shoulder Elbow Surg*. 2013;22:9–17.

Patients treated with acute surgery (22) had a more satisfactory outcome than those with late surgery (15) after failed conservative treatment.

Pauly S, Kraus N, Greiner S, Scheibel M. Prevalence and pattern of glenohumeral injuries among acute high-grade acromioclavicular joint instabilities. *J Shoulder Elbow Surg*. 2013;22:760–766.

A review of 125 patients with high grade AC joint injuries who underwent shoulder arthroscopy revealed a high rate of intra-articular glenohumeral pathology (30%).

Canadian Orthopaedic Trauma Society. Multicenter randomized clinical trial of nonoperative versus operative treatment of acute acromio-clavicular joint dislocation. *J Orthop Trauma*. 2015;29(11):479–487.

A clinical trial of 83 patients randomized to hook plate fixation versus nonoperative treatment. Although hook plate fixation resulted in superior radiographic alignment, it was not clinically superior to nonoperative treatment of acute complete dislocations of the acromioclavicular joint. Both groups improved from a significant level of initial disability to a good or excellent result (mean DASH score, 5–6; mean Constant score, 91–95 in both groups) at 2 years.

PROCEDURE 65

Sacroiliac Joint Injuries: Iliosacral Screws

Milton Lee (Chip) Routt, Jr.

INDICATIONS

- Unstable sacroiliac (SI) joint traumatic disruptions
- Unstable SI fracture-dislocations
- Symptomatic sacroiliac joint arthritis
- Symptomatic chronic posterior pelvic instability

INDICATIONS PITFALLS

- Accurate assessment of SI joint instability is based on physical examination, plain pelvic radiographs, computed tomography (CT) scans, and dynamic imaging during stress examination.
- Complete and incomplete SI joint instability is commonly noted on pelvic imaging.
- SI joint instability may not be obvious if the pelvic imaging was performed after a circumferential pelvic wrap was applied; the pelvic wrap often produces an accurate SI joint reduction.

INDICATIONS CONTROVERSIES

- Controversy still exists in reliably diagnosing and safely treating incomplete posterior pelvic injuries.
- The role of posterior pelvic instability in chronic symptomatic symphysis pubis instability remains controversial.

TREATMENT OPTIONS

- Closed reduction and percutaneous fixation (CRPF) is used whenever possible.
- CRPF relies routinely on intraoperative fluoroscopy to both assess the reduction and direct the iliosacral screw insertion.
- Usually incomplete SI joint injuries will indirectly reduce when the anterior pelvic injury is reduced, or when the precisely oriented lag screw compresses the residual SI joint distraction.
- Open reduction internal fixation (ORIF) of the SI joint is selected when closed reduction techniques fail or are not possible.
- Open reduction of the SI joint is performed using either an anterior exposure with the patient positioned supine, or via posterior surgical exposure in the prone position.

EXAMINATION/IMAGING

- The physical examination identifies open wounds, closed degloving injuries, ecchymoses, prior scars, urethral meatal blood, rectal blood, vaginal-labial injuries, and neurovascular injuries.
- Manual compression toward the midline applied over each iliac crest during the physical examination reveals instability.
- For the injured patient, anteroposterior (AP) pelvic radiograph prior to circumferential pelvic wrapping
- Same patient, AP pelvic radiograph after wrap application
- The pelvic CT reveals injury sites, displacements, deformities, body habitus, hematoma location and extent, and associated injuries.

SURGICAL ANATOMY

- The SI joint is an unusual articulation composed of iliac and sacral articular pads surrounded by strong ligaments.
- The fifth lumbar nerve root is located on the sacral ala just medial to the anterior SI joint.
- For reliable and safe iliosacral screw insertions, the upper sacral osteology (including sacral dysmorphism) must be identified and quantified on the preoperative imaging.
- Hip flexion during the anterior surgical exposure for ORIF relaxes the iliopsoas muscle, eases retraction, and improves exposure of the anterior joint surface.
- Aggressive medial retraction and/or clamp application along the lateral sacral ala during the anterior ORIF risks injury of the fifth lumbar nerve root.
- Wound complications are more common when the posterior exposure is selected for ORIF.
- Iliosacral screws can be safely inserted with the patient properly positioned either supine or prone.

POSITIONING

- When the supine position is selected, a folded operating room (OR) blanket is used to elevate the patient and pelvis from the OR table so the iliosacral screws can be inserted easily.
- Skeletal traction is used as a reduction aid when necessary.
- Positioning the patient supine allows surgical access to both the anterior pelvic ring and the anterior SI joint.
- Prone positioning is more difficult in patients with anterior external fixation devices.
- The prone position denies the anesthesiologist easy access to the airway, and the surgeon must ensure that there is no pressure on the eyes during the surgery.
- The upper extremities are positioned so they do not obstruct either pelvic imaging or iliosacral screw insertion.

PEARLS

- The folded blanket is adjusted in thickness to elevate the pelvis from the OR table sufficiently to allow iliosacral screw insertion.
- The surgeon must ensure that the eyes are free of pressure, the genitals are positioned appropriately, and that all bony prominences are well padded when the patient is positioned prone.
- Prior to draping, use the C-arm to ensure that the patient is well positioned so that all appropriate images can be easily obtained.

PORTALS/EXPOSURES

- The anterior SI joint is accessed using the lateral surgical interval of the ilioinguinal exposure. Hip flexion relaxes the iliopsoas muscle for easier retraction and improved visualization.
- Because of the SI joint's unusual osteology, the posterior surgical exposure only reveals the caudal articular facet, whereas the anterior articular reduction is assessed by palpation.
- The iliosacral screw's starting point and directional aim are planned preoperatively using the pelvic CT scan and then determined intraoperatively using inlet, outlet, and true lateral sacral fluoroscopic imaging.

PORTALS/EXPOSURES PEARLS

- A comprehensive preoperative plan includes the details of patient positioning, reduction maneuvers, clamp application, and iliosacral screw insertion.
- The pelvic CT scan identifies and quantifies the parameters for the planned osseus fixation pathways.
- To optimize screw accuracy, the three-dimensional (3D) surface rendered pelvic CT models are correlated with the intraoperative fluoroscopy views.

PITFALLS

- SI joint malreduction decreases the area available for the iliosacral screw within the osseus fixation pathway.
- Reduction clamps or the screws used to attach them to the bone should be positioned so that they do not obstruct the iliosacral screw insertion.

PORTALS/EXPOSURES EQUIPMENT

- A poor quality C-arm unit will not produce sufficient images for safe screw insertion.
- A radiology technician who does not pay attention to the intraoperative imaging details will add unnecessary radiation exposure, time, and cost to the operation. For numerous reasons, an attentive and skilled radiology technician is a critical part of the procedure.

CONTROVERSIES

- When prone posterior ORIF is selected, the reduction clamp is applied to the anterior sacral ala through the greater sciatic notch based on digital palpation of the anterior SI joint alone. This "blind" clamp application remains quite controversial and is not advocated.
- The prone posterior surgical exposure remains controversial because it has been associated with higher wound complication rates.

PROCEDURE

Step 1

- In patients with an incomplete SI joint injury, accurate reduction of the anterior pelvic ring injury (symphysis pubis, pubic ramus, combination injury) often will indirectly reduce the SI joint. In these patients, iliosacral screws are inserted to stabilize the SI joint injury and support the overall fixation construct. Some evidence indicates that iliosacral screw fixation of incomplete SI joint injury decreases the rate of failure of anterior fixation. If compression is needed to complete the SI joint indirect reduction, an initial iliosacral lag screw is inserted.
- In patients with complete SI joint injuries, the anterior pelvic reduction may aid in the SI joint reduction. In these patients with residual SI joint uniform distraction after anterior pelvic reduction, an iliosacral lag screw is used to complete the reduction. Additional screws provide improved support for the SI joint. Multiple iliosacral screws inserted at multiple posterior pelvic levels have lower failure rates.
- Open reduction is selected for those injuries when closed reduction fails. The clamp is applied so that it does not injure the fifth lumbar nerve root and does not obstruct the iliosacral screw fixation.

PITFALLS

- If the folded blanket is too thick, the pelvis will be overly elevated from the OR table causing un unstable patient position.
- Once the patient is positioned and before draping, the necessary intraoperative fluoroscopy images should be obtained. Any positioning changes should be made prior to draping.
- The surgical draping should be inclusive of all necessary exposures and implants.
- Urethral meatal necrosis can result when the urinary catheter is poorly positioned. Similarly, the patient's scrotum should not be crushed between his thighs during surgery.
- Femoral vein and/or artery catheters and suprapubic catheters should be prepared and draped into the sterile field when necessary rather than removed.

POSITIONING EQUIPMENT

- The C-arm is located on the opposite side from the surgeon.
- The C-unit tilts and positioning are adjusted after the patient is positioned and prior to draping. The x-ray technician should mark the floor and C-arm machine so the necessary intraoperative images remain consistent throughout the operation.

CONTROVERSIES

- Some surgeons prefer prone patient positioning for the ease of access to the posterior pelvic ring during iliosacral screw insertion.
- Supine positioning allows the surgeon to access the anterior pelvic ring without compromising surgical access to the SI joint.
- Insufficient imaging may result from poor patient positioning, morbid obesity, osteoporosis, residual bladder or bowel contrast agents, excessive flatus, among others.

PEARLS

- Accurate reduction of the anterior pelvic injury will often result in an excellent indirect reduction of the SI joint.
- In ORIF, the clamp must be properly located in order to provide uniform compression across the SI joint during the iliosacral screw fixation.

PITFALLS

- The reduction clamp should not obstruct the optimal iliosacral screw pathway.
- Poor positioning of the reduction clamp usually results in a poor reduction.

INSTRUMENTATION/IMPLANTATION

- The optimal location for the iliosacral screw is best planned preoperatively using the CT scan.
- For patients with a symmetric upper sacrum and a unilateral SI joint injury, the uninjured side is used for preoperative iliosacral screw planning.

Step 2

- The caudal anterior pathway of the sacral alar ellipsoid is selected because it is the most reliable initial iliosacral screw site.
- Using inlet and outlet posterior pelvic imaging, a narrow diameter smooth Kirschner wire (K-wire) is used to identify the optimal skin insertion site and ideal directional aim. The wire is then inserted approximately 1 cm through the lateral iliac cortical bone.
- The skin incision is then made and the cannulated drill is applied over the K-wire and oscillated into the lateral iliac bone.
- The caudal-anterior location allows the drill to be advanced safely until the drill tip is located 2 to 3 mL lateral to the visible S1 nerve root tunnel, best seen on the outlet image.
- The true lateral image is then obtained by superimposing the greater sciatic notches and iliac cortical densities.
- The true lateral image is used to confirm the accurate location of the drill tip within the safe osseous fixation pathway. The drill tip should be located caudal to the sacral ala-iliac cortical density, posterior to the anterior cortical limit of the vertebral body, cranial to the S1 tunnel, and well anterior to the spinal canal.

PEARLS

- The intraoperative pelvic inlet image is optimized by superimposing the upper and second sacral vertebral bodies.
- The mid-sagittal image on the injury pelvic CT scan demonstrates the ideal inlet tilt for each patient.
- The intraoperative outlet tilt is best achieved when the cranial edge of the symphysis pubis is superimposed on the second sacral vertebral body. That tilt reveals the S1 nerve root tunnel anterior foramen.
- For morbidly obese patients, the injury CT scan lateral scout image alerts the surgeon to potential intraoperative lateral fluoroscopic imaging difficulties. If the sacrum is not distinct on the CT scout lateral image, then the intraoperative lateral will be similarly obstructed by the soft tissues.

PITFALLS

- Accepting a poorly located skin starting site will result in either an unacceptable lateral iliac bone insertion site or improper directional aim.
- In morbidly obese patients, standard cannulated screw system guide pins, measuring devices, and screw drivers may be of insufficient length. Special longer instrumentation is available and should be utilized.

CONTROVERSIES

- Controversy remains regarding the optimal iliosacral screw number, orientation, and length.
- Some surgeons use only the lateral sacral image for iliosacral screw insertion. This is controversial because it limits the surgeon to just one style of iliosacral screw use.

Step 3

- Depending on the planned pathway, the drill is either advanced into the vertebral body or across the contralateral ala and SI joint, exiting the lateral iliac cortical bone.
- If an oblique iliosacral screw is planned, the drill should not penetrate the anterior vertebral body cortical bone.
- The guide pin for the cannulated screw system is then inserted into the drilled pathway, and the depth is assessed using a measuring device or guide pin of the same length.
- The iliosacral screw and washer are inserted over the guide pin.
- The C-arm is used at frequent intervals during screw insertion to ensure that the guide pin is not being inadvertently advanced.
- At terminal tightening, the C-arm beam is oriented tangentially relative to the screw insertion site at the posterior lateral iliac cortical bone. The screw is tightened to approximate the washer against the lateral iliac cortical bone surface without intrusion.

CONTROVERSIES

- Controversy persists on the value of accurate anterior pelvic reduction prior to posterior.

PEARLS

- Using the cannulated drill to prepare the pathway first instead of completely inserting the guide pin allows a more precise pathway preparation. Thinner diameter guide pins often become misdirected, resulting in a poorly located screw.
- The posterior iliac tangential image demonstrates the washer as it contacts the bone surface. The washer is used to decrease the chance of unwanted screw intrusion through the lateral iliac cortical bone surface.

PITFALLS

- If the cannulated drill exits the anterior vertebral body, the guide pin can inadvertently advance and injure the local neurovascular structures.
- If the washer intrudes through the lateral iliac cortical bone, the iliosacral screw stability is compromised.

INSTRUMENTATION/IMPLANTATION

- Oblique iliosacral screws are more perpendicular to the SI joint surfaces than trans-sacral screws.
- The oblique iliosacral lag screw compresses residual SI joint distraction.
- Oblique iliosacral screws usually spare the majority of the SI joint articular surfaces, whereas trans-sacral screws penetrate the articular surfaces.

CONTROVERSIES

- Trans-sacral screws are controversial because they penetrate the uninjured SI joint and are riskier than oblique screws because they traverse the alar areas on both sides.
- Trans-sacral screws result in better biomechanical construct strength, although it is unclear if this results in superior clinical outcomes.

Step 4

- Adding additional iliosacral screws improves stability and is performed whenever possible.
- If the initial oblique screw is inserted in the caudal-anterior portion of the upper sacral safe osseus fixation pathway, the subsequent screw should be located slightly posterior and cranial to the initial screw in order to be properly contained.
- If the initial screw has provided sufficient compression, the subsequent screw can be a fully threaded screw to maintain the reduction.

PEARLS

- Safe and reliable iliosacral screw insertion occurs when the screw pathway is well planned, the osteology and its intraoperative imaging are completely understood, and the intraoperative imaging is high quality and consistent.

PITFALLS

- Locating the initial screw in the middle area of the osseus fixation pathway improves the safety for that screw, but that location then adds risk to subsequent screw placement.

CONTROVERSIES

- Using multiple screws (and/or trans-sacral screws) at multiple levels to further stabilize the SI joint injury remains controversial. No study has identified how much fixation is required to predictably provide durable stability until complete healing.

Step 5

- The overall fixation construct is strengthened when both the unstable SI joint and the anterior pelvic injured are stabilized and reduced.
- For more extensive injuries (e.g., "jumper's fractures"), lumbopelvic fixation is added to augment the posterior pelvic stability.
- Posterior trans-iliac screw and plating fixation techniques also have been described to supplement the iliosacral screw fixation.

PEARLS

- The lumbopelvic supplemental fixation procedure is performed with the patient positioned prone after the SI joint injury has been reduced and stabilized.
- Iliosacral screws are inserted before the lumbopelvic iliac bolts are placed. The LPF iliac bolts can be positioned to accommodate the iliosacral screws.

PITFALLS

- Failure to recognize, reduce, and stabilize the associated unstable anterior pelvic ring traumatic injury can result in posterior fixation failure.
- Applying LPF or other implants prior to iliosacral insertion can obstruct the iliosacral screw's optimal pathway.

INSTRUMENTATION/IMPLANTATION

- Malleable reconstruction plates and medullary ramus screws are used commonly to provide anterior pelvic fixation.
- Safe iliosacral screws have a limited bone pathway, especially when trans-sacral screws are used.
- LPF iliac bolts can be adjusted in position to avoid the iliosacral screws.

CONTROVERSIES

- Controversy remains concerning the number of iliosacral screws necessary to provide sufficient fixation

POSTOPERATIVE CARE AND EXPECTED OUTCOMES

- Rehabilitation is guided by a licensed physical therapist whenever possible.
- The patients use crutches or other assistive devices to unload the injured SI joint during gait. Protected weight bearing on the injured side is continued for 4 to 8 weeks after operation, depending on the injury and fixation details.

PITFALLS

- The fixation construct should be enhanced (i.e., more screws, more levels, trans-sacral screws) at surgery if patient noncompliance is anticipated prior to surgery.

CONTROVERSIES

- Noncompliant patients who exhibit early unprotected weight bearing have an increased risk of fixation failure.

EVIDENCE

Lucas JF, Routt Jr ML, Eastman JG. A useful preoperative planning technique for transiliac-transsacral screws. *J Orthop Trauma*. 2017;31(1):e25–e31.

This article is a well-illustrated technique guide describing "state-of-the-art" planning for the insertion of trans-iliac and trans-sacral screws.

Simonian PT, Routt Jr ML, Harrington RM, Mayo KA, Tencer AF. Biomechanical simulation of the anteroposterior compression injury of the pelvis. An understanding of instability and fixation. *Clin Orthop Relat Res.* 1994;309:245–256.

A biomechanical study using seven cadaveric pelvii showed that plate fixation of the symphysis pubis alone reduced symphysis pubis motion, but not sacroiliac motion. Use of sacroiliac fixation alone without a symphysis pubis plate did not affect symphysis pubis motion. Both single iliosacral screws and plates produced equivalent decreases in sacroiliac joint motion.

Keating JF, Werier J, Blachut P, Broekhuyse H, Meek RN, O'Brien PJ. Early fixation of the vertically unstable pelvis: the role of iliosacral screw fixation of the posterior lesion. *J Orthop Trauma*. 1999;13(2):107–113.

This paper describes the early results of 38 patients treated with iliosacral screw fixation for injuries of the SI joint. Nearly 44% of patients had some loss of reduction on final follow-up radiographs (malunion). It was recommended that iliosacral screw fixation be protected by anterior ring fixation.

Carlson DA, Scheid DK, Maar DC, Baele JR, Kaehr DM. Safe placement of S1 and S2 iliosacral screws: the "vestibule" concept. *J Orthop Trauma*. 2000;14(4):264–269.

This study attempted to determine the optimal starting points for placement of S1 and S2 iliosacral screws using normal subject study evaluating helical CT scans of 30 normal pelvic rings. Finding was that the transversely placed (horizontal) iliosacral screw was the least safe of the screws tested. The safest lateral ilium starting point for our entire population was at the posterior sacral body sagittally and at the inferior S1 foramen coronally. S2 iliosacral screws had less cross-sectional area for placement than S1 screws. Placement of the S2 screw slightly to the S1 foraminal side of the S2 vertebral body increased the safety of placement.

Sagi HC, Ordway NR, DiPasquale T. Biomechanical analysis of fixation for vertically unstable sacroiliac dislocations with iliosacral screws and symphyseal plating. *J Orthop Trauma*. 2004;18(3):138–143.

Anterior symphyseal plating for the vertically unstable hemipelvis significantly increases the stability of the fixation construct and restores the normal response of the hemipelvis to axial loading. A significant benefit to supplementary iliosacral screws, in addition to a properly placed S1 iliosacral screw, was not shown.

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PROCEDURE 2

Sternoclavicular Joint Open Reduction and Internal Fixation

Marissa Bonyun and Aaron Nauth

INDICATIONS

- Acute posterior injuries of the sternoclavicular (SC) joint having symptoms consistent with mediastinal compromise (~30%) representing a life-threatening emergency (e.g., dysphagia, dyspnea, limb tingling, feeling of choking or venous congestion in the neck or ipsilateral arm)
- Failed closed reduction of posterior SC dislocations
- Chronic recurrence of posterior SC dislocations
- Recurrent subluxation and/or dislocation of anterior SC dislocations

Examination/Imaging

- A careful examination should be performed to asses for neurovascular injuries in addition to examination of the chest to identify any associated injuries (e.g., rib fractures, pneumothorax).
- Initial imaging should consist of plain radiographs of the chest and clavicle (Fig. 2. 1).
- Computed tomography scan (with intravenous contrast to assess the vasculature) is the gold standard for assessing injuries to the SC joint (Fig. 2.1).

SURGICAL ANATOMY

- Important structures include the medial aspect of the clavicle, the sternum, the SC ligaments, the subclavian vessels, the great vessels of the neck, the brachial plexus, the trachea, the esophagus, the vagus nerve, and the superior aspect of the pleura (Fig. 2.2).
- The medial physis of the clavicle closes between the ages of 22 and 25, and injuries to the SC joint in patients below this age often represent physeal injuries as opposed to true dislocations.
- The closest structure at risk is the brachiocephalic vein (which can be as close as 1 mm from the SC joint in anatomic studies; the mean distance from the SC joint is 6 mm) (see Fig. 2.1).

POSITIONING

- For closed reductions, the patient is positioned supine with a 3 to 4 inch thick pad placed between the scapulae.
- For acute (<72 hours) anterior dislocations of the SC joint, closed reduction can be attempted by providing conscious sedation to the patient and applying abduction, extension, and longitudinal traction to the arm combined with gentle, posterolateral pressure on the medial clavicle.
- For acute (<72 hours) posterior dislocations of the SC joint, closed reduction can be attempted by providing general anesthesia (for pain and muscle spasm) and applying abduction, extension, and longitudinal traction to the arm.
- If this is unsuccessful, the area over the SC joint can be prepared, and the medial end of the clavicle can be grasped percutaneously with a sharp towel clip to allow direct anterolateral manipulation of the medial clavicle in combination with the above maneuvers.
- For open reductions, the patient is positioned in a similar fashion and the SC joint and entire chest, as well as the affected arm are free draped.

INDICATIONS PITFALLS

- A large proportion of SC joint injuries in young patients (below age 25) are physeal fractures or pseudosubluxations (Salter-Harris I or II).
- Posterior SC joint injuries are frequently missed owing to their rare nature, the difficulty to diagnose them on plain radiographs, and their frequent occurrence in association with other significant, distracting traumatic injuries.
- Unreduced posterior dislocations are associated with complications including thoracic outlet syndrome, vascular compromise, and erosion of the medial clavicle into posterior vascular structures.

INDICATIONS CONTROVERSIES

- Controversy exists regarding open versus closed management of acute posterior SC joint dislocations.
- There is also controversy regarding nonoperative treatment versus closed reduction versus open reduction of acute anterior SC joint dislocations.

TREATMENT OPTIONS

- Acute anterior dislocations of the SC joint can be managed nonoperatively but should probably be reduced in most patients, if logistically possible and the patient has no contraindications to surgery. Treatment is with initial closed reduction followed by open reduction in those patients with recurrent instability.
- Acute posterior dislocations **with** symptoms of mediastinal compromise should be treated **emergently** with closed ± open reduction.
- Acute posterior dislocations **without** mediastinal symptoms should be treated urgently with closed ± open reduction.
- For posterior dislocations of the SC joint that are more than 72 hours old, fail closed reduction, or are unstable despite closed reduction, open reduction ± stabilization is indicated.
- Surgical options for stabilization of **acute** SC dislocations once reduction has been performed include:
  - No stabilization (i.e., closed or open reduction only)
  - Transosseous sutures or mersilene tape
  - Plate and screw fixation across the SC joint (with subsequent removal)
- Surgical options for stabilization of **chronic** or **recurrent** SC dislocations once reduction has been performed include:
  - Plate and screw fixation across the SC joint (with subsequent removal)
  - SC ligament reconstruction using autograft or allograft tendon

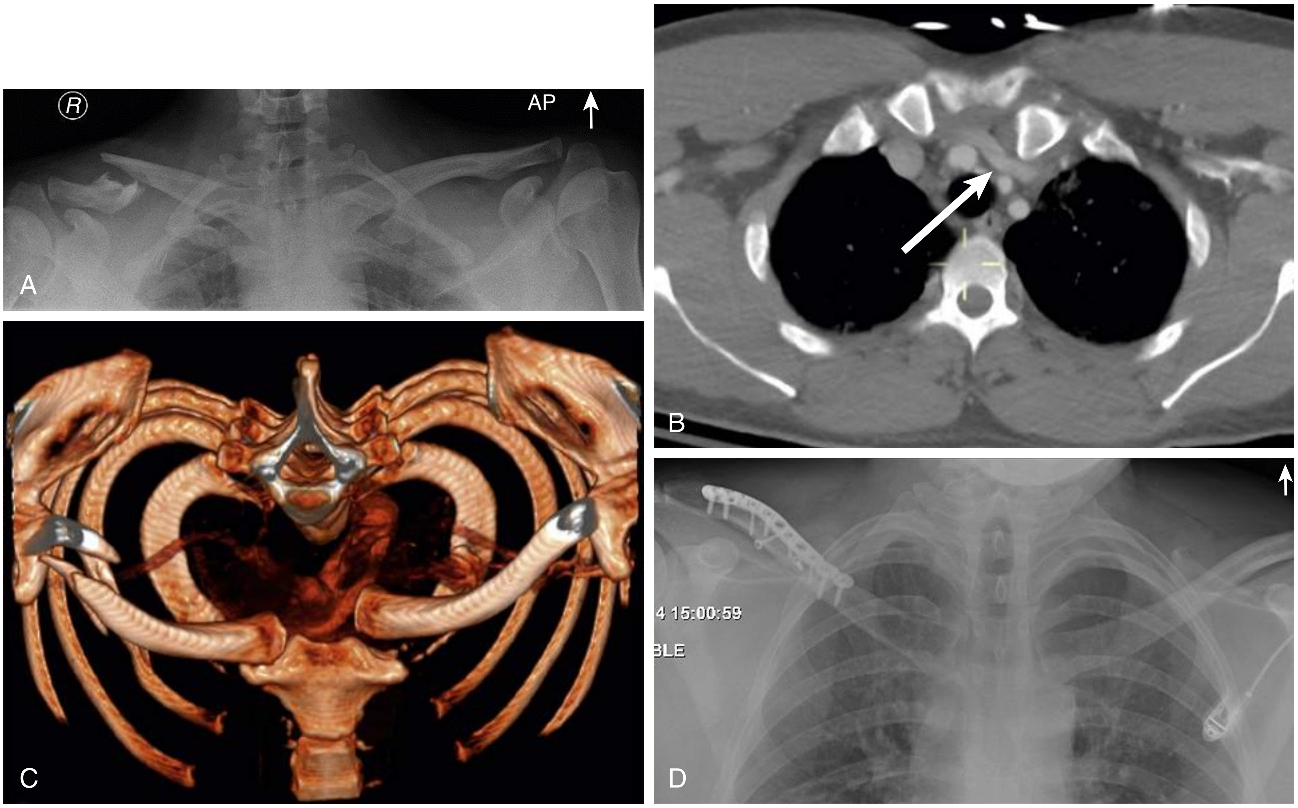


FIG. 2.1 AP chest radiograph, axial CT slice and 3D reconstruction of the thorax of a 32 year old male trauma patient involved in a motor vehicle accident. The images demonstrate a displaced right midshaft clavicle fracture and posterior dislocation of the left sternoclavicular joint (A-C). The white arrow demonstrates abutment of the posteriorly dislocated clavicle on the left brachiocephalic vein. Postoperative AP chest radiograph following ORIF of the right midshaft clavicle and open reduction and suture stabilization of the left posterior sternoclavicular dislocation (D). Prior to taking this patient to the operating room the on call cardiothoracic surgeon was notified about the procedure. The patient's surgery was uncomplicated and he had an excellent clinical outcome. Used with permission from Nauth A and McKee MD. Humerus and shoulder: fractures and nonunions. In Grauer J.N. and Ring D., Eds. *Orthopaedic Knowledge Update 12* (pp. 299–320), 2017. Rosemount, IL: AAOS.

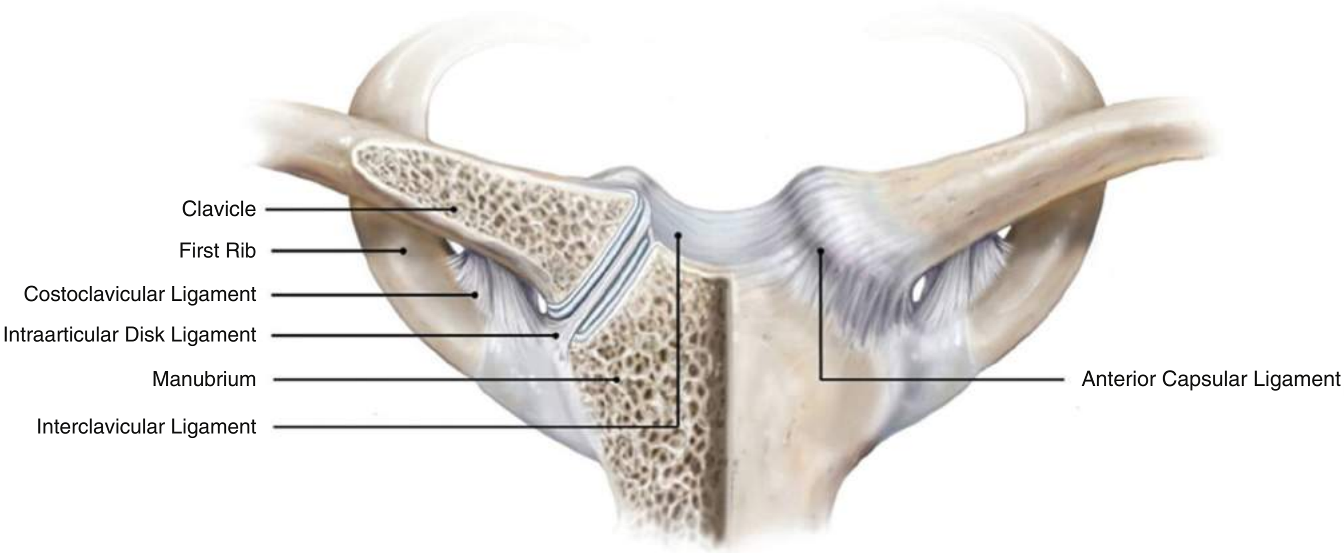


FIG. 2.2 Osseoligamentous anatomy of the sternoclavicular joint. Used with permission from Martetschlager F, Warth RJ, Millett PJ. Instability and degenerative arthritis of the sternoclavicular joint: a current concepts review. *Am J Sports Med.* 2014;42(4):999–1007.

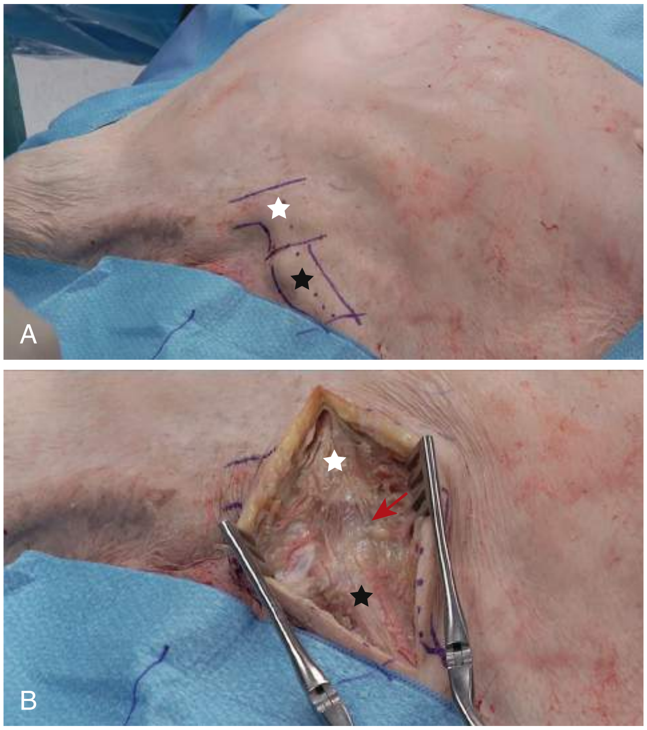


FIG. 2.3 Cadaveric photograph of the bony landmarks for exposure of the right SC Joint (A). For all cadveric photographs the right SC joint is viewed from the patient's right side with patient's head to the left of the photograph and their feet to the right. Cadaveric photograph of the exposed SC joint (B). White star = manubrium, black star = medial end of clavicle, red arrow = SC joint capsule.

PORTALS/EXPOSURES (VIDEO 2-1)

- For open reductions, mark out bony landmarks including the medial clavicle, sternal border, and SC joint (Fig. 2.3).
- A 5- to 10-cm skin incision is made directly over the medial clavicle, SC joint, and sternum.
- Often significant soft-tissue damage is seen in the vicinity of the SC joint; this should be identified and incorporated into the surgical approach.
- The SC joint capsule is exposed using electrocautery (**Fig. 2.3**).
- The periosteum and sternocleidomastoid muscle are dissected from the medial clavicle together as a continuous soft-tissue sleeve.
- A longitudinal split in the SC joint capsule is made and reflection superiorly and inferiorly is performed using electrocautery, thus allowing exposure of the SC joint.
- The intraarticular disk (which is usually torn or damaged in this setting) can be removed with careful sharp dissection.
- Further exposure of the medial clavicle and sternum can be carried out to allow the placement of malleable retractors or a Cobb elevator posterior to the sternum and clavicle to allow for safe suture/graft passage if a stabilization procedure is to be performed (Fig. 2.4).

PROCEDURE (VIDEO 2.1)

Step 1: Open Reduction of the SC Joint

- For posterior dislocations, the medial end of the clavicle will be seen to be displaced posteriorly and medially behind the sternum once the anterior capsule is reflected (Figs. 2.5 and 2.6).
- Reduction is performed by grasping the medial end of the clavicle with a small reduction forceps and applying traction and an anteriorly directed force (Figs. 2.5 and 2.6).
- Once reduction has been performed, stability of the SC joint should be assessed with a dynamic examination by moving the free-draped arm through a full range-of-motion.

POSITIONING PEARLS

- It is **critically important** to have a cardiothoracic surgeon notified and available prior to any attempt at closed or open reduction of a posterior SC joint dislocation.
- Draping of the entire chest is a necessary precaution should any cardiothoracic intervention be required.
- Free draping of the involved extremity allows for the application of traction to assist with reduction and dynamic intraoperative examination of SC joint stability once reduction ± stabilization has been performed.

PORTALS/EXPOSURES PEARLS

- The incision should be made parallel to the superior border of the medial clavicle, extending over the sternum.
- **Extreme care** should be carried out with any retrosternal dissection and/or instrument placement to avoid injury to the major vascular structures that are in close proximity to the SC joint.
- In the setting of a physeal injury (patients <25 years), take care to preserve the epiphysis, which will be retained within the SC joint.
- Careful repair of the anterior capsule can aid in maintaining stability of the SC joint.
- In the setting of chronic SC joint instability and painful degenerative changes, medial clavicle resection may be performed.

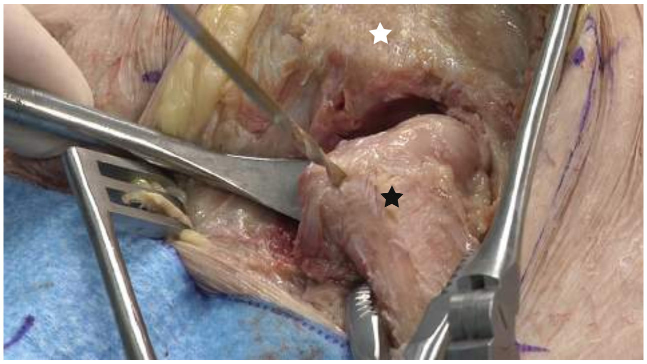


FIG. 2.4 Cadaveric photograph of the right SC Joint demonstrating placement of a cobb elevator posterior to the medial aspect of the clavicle to allow safe drilling of anterior to posterior bone tunnels. White star = manubrium, black star = medial end of clavicle.

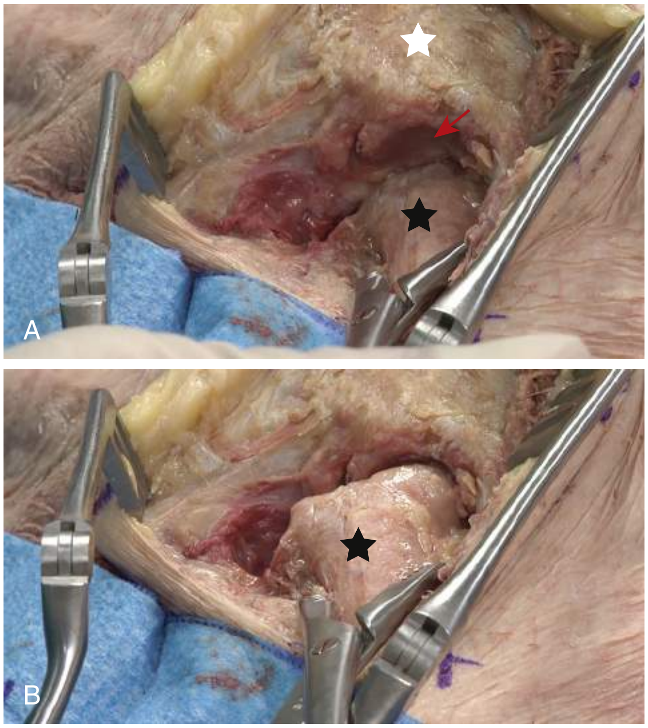


FIG. 2.5 Cadaveric photograph of the right SC Joint demonstrating posterior dislocation (A). Subsequent reduction of the SC joint using a small fragment reduction forcep to apply traction and anterior force to the medial aspect of the clavicle (B). White star = manubrium, black star = medial end of clavicle, red arrow = empty articular facet of the manubrium.

STEP 1 PITFALLS

- If there has been erosion or injury to any of the major vascular structures posteriorly, this is likely to become dramatically apparent at the time of reduction (although this is exceedingly rare, it is important that both the surgical and anesthetic teams are prepared for this potential life-threatening complication).

STEP 1 INSTRUMENTATION/ IMPLANTATION

- Small fragment reduction forceps

- If there is any instability of the SC joint, a stabilization procedure of some type should be carried out.

STEP 1 CONTROVERSIES

- There is relative controversy and a lack of high-level evidence regarding the need for surgical stabilization once an open reduction has been performed.
- One retrospective study showed a strong trend toward superior outcomes when open reduction was combined with a stabilization procedure.
- The preference of the authors is to perform a stabilization (most commonly with transosseous suture) in most cases once an open reduction has been performed.

Step 2: Technique 1: Suture or Autograft/Allograft Tendon Stabilization of the SC Joint

- Stabilization of the SC joint can be carried out by placing transosseous sutures or autograft/allograft tendon.
- A variety of suture/tendon configurations have been described; the authors prefer a figure-of-eight configuration using either mersilene tape suture (in the acute setting) or a combination of high tensile suture and autograft tendon (for reconstruction of the SC ligaments in the chronic setting):
  - If an autograft construct is planned, harvest the graft in a typical fashion using either semitendinosis autograft (authors' preference) or palmaris longus tendon (Fig. 2.7).
  - Two bone tunnels (2.5 mm for suture or 3.5 mm for tendon autograft) are drilled from anterior to posterior in the manubrium, medial to the sternal articular facet (Figs. 2.8–2.10).
  - Two bone tunnels (2.5 mm for suture or 3.5 mm for tendon autograft) are drilled at the medial end of the clavicle at the level of the condylar flare from anterior to posterior (see Figs. 2.8–2.10).
  - Suture and/or tendon autograft are passed through the holes in sequential fashion creating a figure-of-eight construct using either a blunt needle (mersilene) or a Hewson suture passer (tendon autograft) (see Figs. 2.8–2.10).

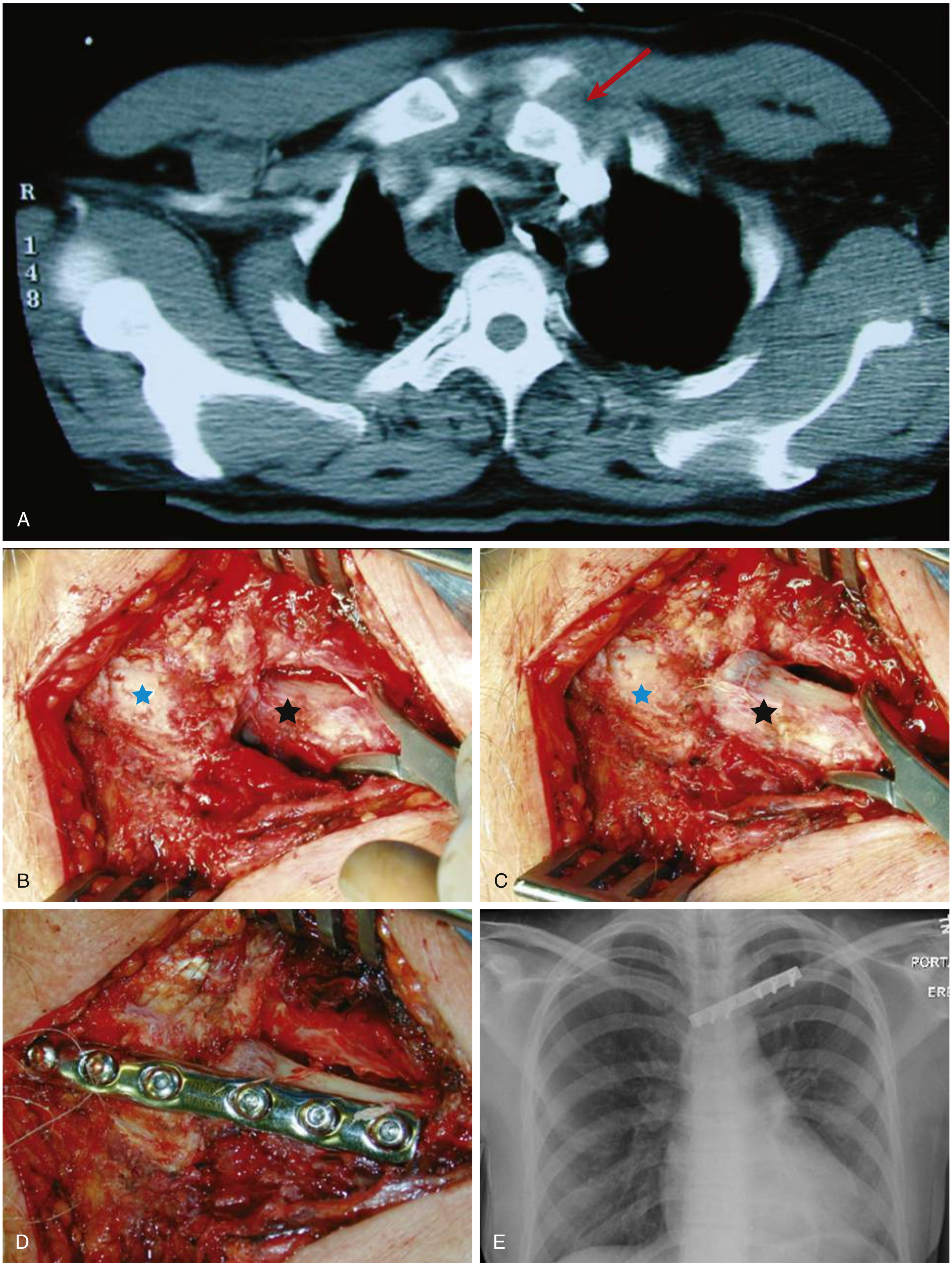


FIG. 2.6 Pre-operative CT scan of a 28 year old male demonstrating posterior dislocation of the left SC joint (red arrow) (A). Intra-operative photographs demonstrating posterior dislocation of the left SC joint (B), subsequent reduction with a small fragment reduction forcep (C), and stabilization with 1/3 tubular plate fixation across the SC joint (D). In all photographs the patient's head is at the superior aspect of the photograph (Images courtesy of Michael D. McKee). Blue star = manubrium, black star = medial end of clavicle. Post-operative AP chest radiograph in a different patient demonstrating the identical construct of a six hole 1/3 tubular plate fixation across the left SC joint (E).

FIG. 2.7 Cadaveric photograph demonstrating preparation of the tendon autograft for stabilization of the SC joint.

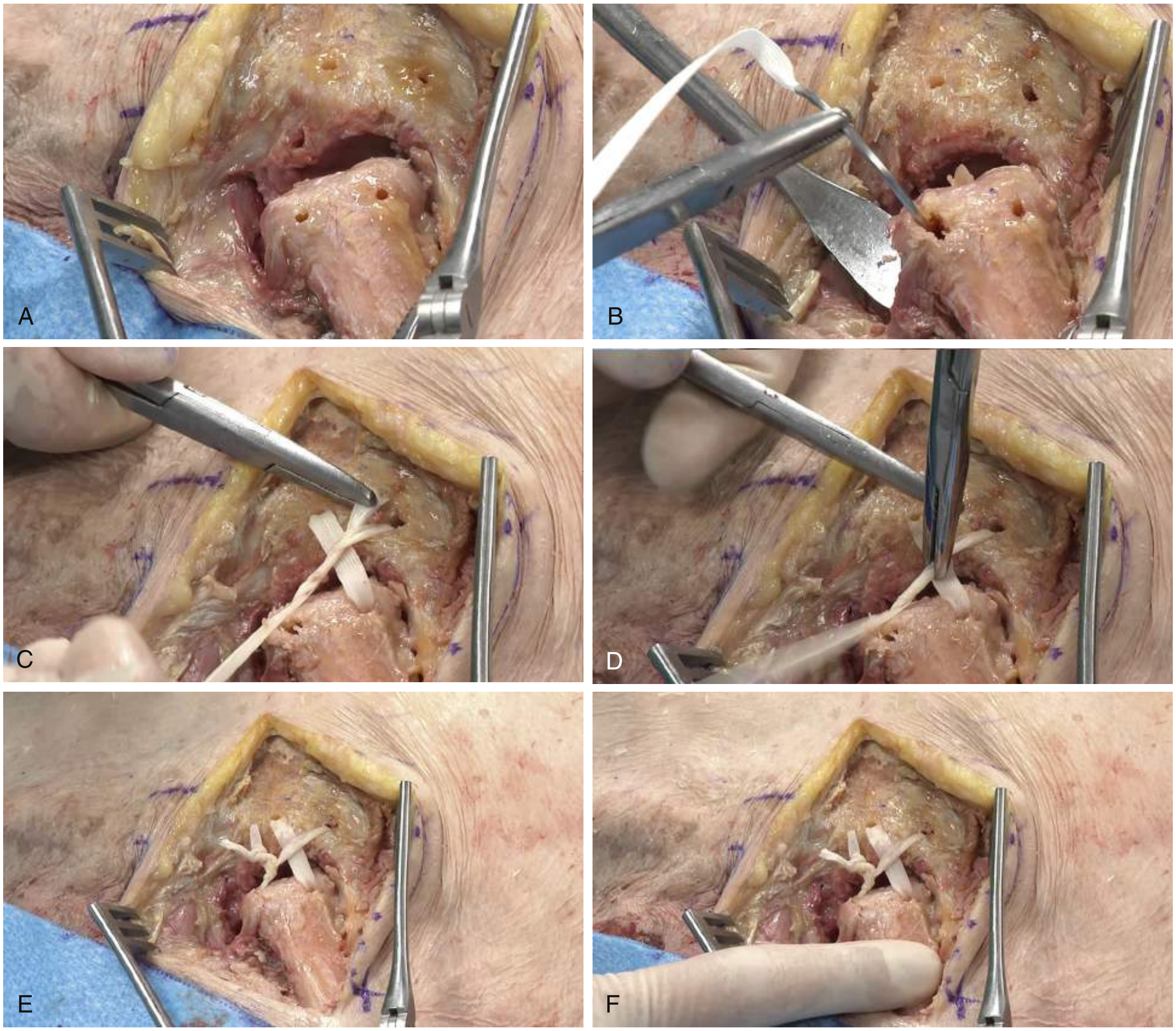


FIG. 2.8 Cadaveric photograph of the left SC Joint demonstrating 2 drill holes (2.5 mm) placed in the clavicle and 2 drill holes placed in the manubrium for transosseous figure-of-eight suture stabilization of the SC joint (A). Passage of mersilene tape suture through one of the drill holes is shown (B). Tying of the subsequent figure-of-eight construct is shown (C and D). Final construct and testing of stability with posteriorly directed force on the medial clavicle (E and F).

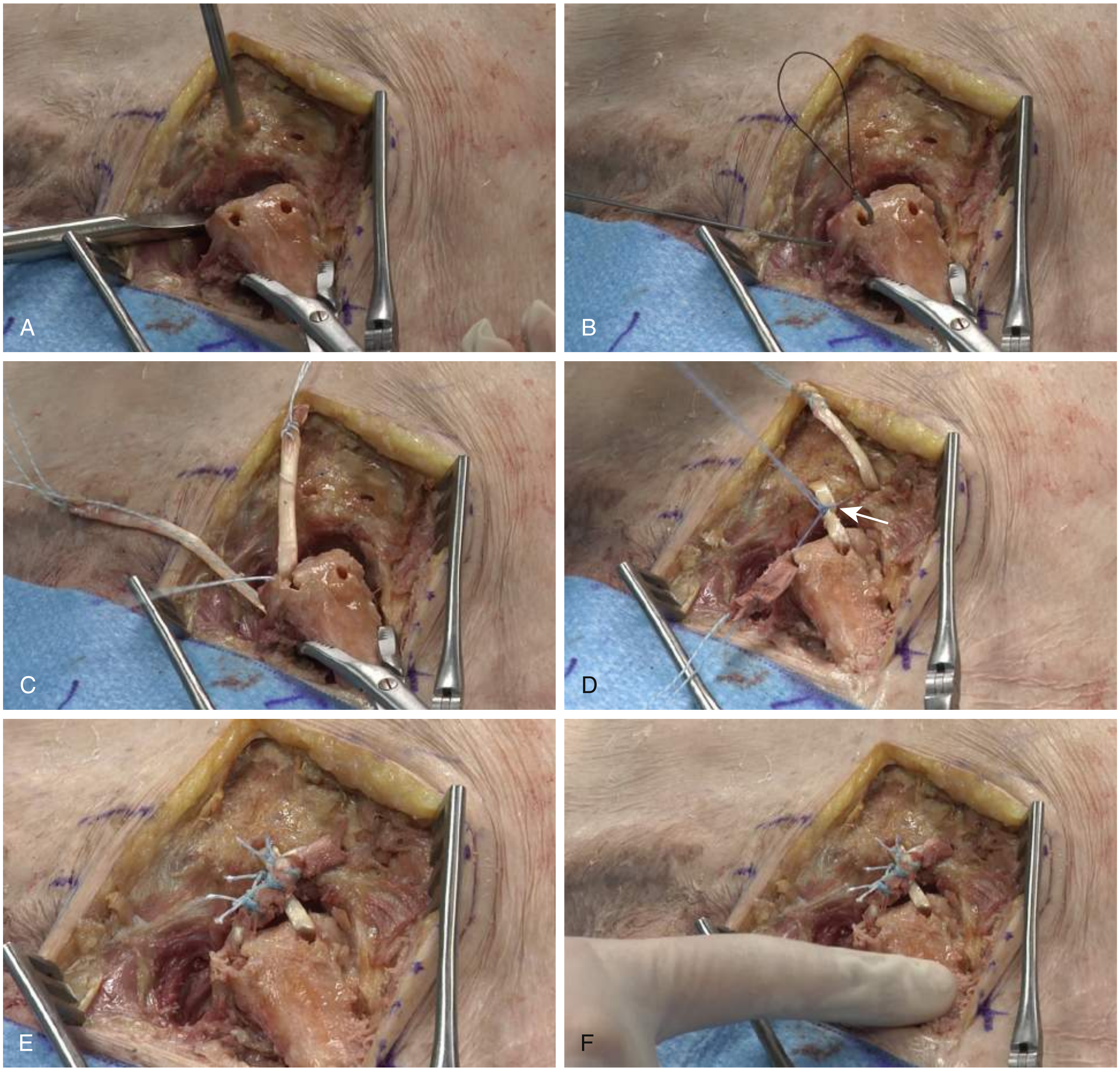


FIG. 2.9 Cadaveric photograph of the left SC Joint demonstrating drilling of 3.5 mm holes to allow for autograft tendon passage for figure-of-eight reconstruction of SC joint (A). Use of a Hewson Suture Passer to pass the tendon autograft and high tensile suture (B and C). Prior to securing the autograft tendon figure-of-eight construct, a high tensile suture is tied to stabilize the SC Joint while the autograft is healing (white arrow) (D). Final construct and testing of stability with posteriorly directed force on the medial clavicle (E and F).

STEP 2 PEARLS

- In younger patients (<22–25 years), clavicular tunnels should be placed further lateral to avoid the open physis.
- Keep the parallel limbs of the suture and/or tendon autograft posterior and oblique limbs anterior, forming the 'X' of the construct anterior (Figs. 2.8–2.10).
- Following fixation, stability of the SC joint should be tested under both direct visualization and dynamic evaluation (Figs. 2.8 and 2.9).

STEP 2 PITFALLS

- Space tunnels appropriately to avoid inadvertent fracture.
- Place a Cobb or malleable retractor posterior to the clavicle and manubrium to protect the posterior vascular structures when drilling or passing sutures (see Figs. 2.8–2.10).

STEP 2 INSTRUMENTATION/ IMPLANTATION

- 2.5-mm or 3.5-mm drill
- Mersilene tape
- High-tensile suture
- Hewson suture passer
- Cobb elevator or malleable retractor
- Tendon stripper for graft harvest

STEP 2 CONTROVERSIES

- SC ligament reconstruction with autograft (hamstring or palmaris longus tendon grafts) using a figure-of-eight construct has been shown to be a biomechanically superior construct.

STEP 3 PITFALLS

- It is critical to avoid plunging with the drill bit while drilling for screw placement given the proximity of the posterior vascular structures.
- Fixation with smooth Kirschner wires (K-wires) is contraindicated owing to the risk of catastrophic complications with wire migration.

STEP 3 INSTRUMENTATION/ IMPLANTATION

- Small fragment set
- Clavicle locking plate set

STEP 3 CONTROVERSIES

- High-level evidence is lacking that compares clinical outcomes across the variety of stabilization techniques that have been described in the literature.

FIG. 2.10 Illustration of the figure-of-8 graft reconstruction technique. Used with permission from Martetschlager F, Warth RJ, Millett PJ. Instability and degenerative arthritis of the sternoclavicular joint: a current concepts review. *Am J Sports Med.* 2014;42(4):999–1007.

- Suture and/or tendon is tied anteriorly ± securing of the autograft tendon with high tensile suture (see Figs. 2.8–2.10).

Step 3: Technique 2: Plate and Screw Fixation across SC Joint (Transarticular Plating)

- Alternatively, following reduction, the SC joint can be stabilized by placing plate and screw fixation across the joint (Fig. 2.6).
- A six- or seven-hole small fragment one-third tubular plate is placed across the joint with three screws of fixation placed in the clavicle and manubrium each (the use of precontoured distal clavicle locking plates or distal radius locking plates has also been described).
- Contouring of the plate is often required.
- There is some residual motion of the reduced SC joint and the screws may loosen with the passage of time. For this reason the plate should be removed at approximately 6 months postoperatively.

Step 4: Closure

- The anterior joint capsule is repaired with interrupted sutures.
- Further layered closure is performed in a standard fashion.

POSTOPERATIVE CARE AND EXPECTED OUTCOMES

- The shoulder is immobilized in a simple sling for 6 weeks postoperatively.
- Gentle range-of-motion exercises are begun at 2 weeks postoperatively.
- Progressive range-of-motion exercises and strengthening are begun at 6 weeks postoperatively.
- Sports, impact activities, and heavy lifting are avoided for 3 months postoperatively.

EVIDENCE

Bak K, Fogh K. Reconstruction of the chronic anterior unstable sternoclavicular joint using a tendon autograft: medium-term to long-term follow-up results. *J Shoulder Elbow Surg*. 2014;23:245–250.

This case series of 27 patients reported on the use of autologous tendon autograft (palmaris longus or gracilis tendon) for the reconstruction for chronic symptomatic anterior SC joint instability. At a minimum of 2 years follow-up shoulder scores had improved significantly, although 7.4% of patients required revision surgery and 40% reported some degree of donor site “discomfort” at final follow-up.

Glass ER, Thompson JD, Cole PA, Gause TM, Altman GT. Treatment of sternoclavicular joint dislocations: a systematic review of 251 dislocations in 24 case series. *J of Trauma, Injury, Infection and Critical Care*. 2011;70(5):1294–1298.

A systematic review of case series (with a total number of 251 dislocations) examining both anterior and posterior dislocations of the SC joint and their outcomes following nonoperative and/or operative management. Overall, 80% of patients had excellent or good outcomes. Most anterior SC joint dislocations were treated nonoperatively and had satisfactory outcomes. For posterior dislocations, most were treated with attempted closed reduction, and outcomes remained stable whether treated by closed reduction or open reduction after failed closed reduction. Of note, up to 30% of patients with a posterior dislocation presented with symptoms indicative of mediastinal compression.

Gardeniers JWM, Burgemeester J, Luttjeboer J, Rijnen WHC. Surgical technique: results of stabilization of sternoclavicular joint luxations using a polydioxanone envelope plasty. *Clin Orthop*. 2013;471:2225–2230.

This retrospective review and technique guide reported on 39 patients treated with a modified figure-of-eight construct using polydioxanone (PDS) ligament for SC joint instability. The investigators reported excellent results in the majority of patients with an average Constant score of 90, although 13% of patients had postoperative subluxations. This construct is very similar to the authors’ construct of choice using figure-of-eight mersilene tape for the stabilization of acute posterior SC joint dislocations.

Kirby JC, Edwards E, Kamali Moaveni A, et al. Management and functional outcomes following sternoclavicular joint dislocation. *Injury*. 2015;46(10):1906–1913.

This retrospective case series examined 22 patients sustaining an SC joint dislocation (77% posterior, 23% anterior or superior). Functional outcomes following open reduction internal fixation versus closed reduction were assessed. Approximately 50% of patients managed with initial closed reduction for posterior dislocation failed that treatment and required open reduction. The majority of patients ultimately experienced good or excellent results.

Laffosse JM, Espie A, Bonnevialle N, et al. Posterior dislocation of the sternoclavicular joint and epiphyseal disruption of the medial clavicle with posterior displacement in sports participants. *J Bone Joint Surg [Br]*. 2010;92:102–109.

This retrospective case series reported on the management of athletes with posterior SC joint injuries and minimum follow-up of 1 year. The authors reported improved functional scores in patients undergoing associated stabilization procedures rather than reduction alone.

Martetschlager F, Warth RJ, Millet PJ. Instability and degenerative arthritis of the sternoclavicular joint: a current concepts review. *Clin Sports Medicine Update*. 2013;42:999–1007.

This current concepts article provides a succinct review of the literature on the diagnosis and management of SC joint instability. Particularly, the authors summarize relevant biomechanical evidence to be considered when deciding on management for SC joint instability.

Nauth A, McKee MM. Shoulder and humerus fracture nonunions. In: Grauer JN, ed. *Orthopaedic Knowledge Update*. 2017:12.

A comprehensive review article on this topic with a discussion of imaging, surgical techniques, and clinical results with an expanded reference list.

Singer G, Ferlic P, Kraus T, Eberl R. Reconstruction of the sternoclavicular joint in active patients with the figure-of-eight technique using hamstrings. *J Shoulder Elbow Surg*. 2013;22:64–69.

This small retrospective series of six patients reported on the use of hamstring autograft for reconstruction owing to chronic instability following either anterior or posterior dislocations of the SC joint. The authors reported that all patients returned to full activity levels (including high impact sports) postoperatively, with significant improvement in the DASH scores.

Spencer EE, Kuhn JE. Biomechanic analysis of reconstructions for sternoclavicular joint instability. *J Bone Joint Surg [Am]*. 2004;86(1):98–105.

This biomechanical study demonstrated that figure-of-eight constructs are biomechanically superior for SC joint reconstruction.

Tepolt F, Carry PM, Heyn PC, Miller NH. Posterior sternoclavicular joint injuries in the adolescent population: a meta-analysis. *Am J Sports Med*. 2014;42:2517–2524.

This meta-analysis examined 140 cases and showed equal rates of return of full shoulder function for both closed and open reduction (92.31% vs. 95.83%, respectively) in adolescents sustaining a posterior SC joint dislocation. The success rate of closed reduction within 48 hours of injury was 56% versus 31% after 48 hours.

PROCEDURE 3

Fractures of the Clavicle

Michael D. McKee

CONTRAINDICATIONS

- Undisplaced or minimally displaced clavicle fracture
- Poor soft-tissue coverage or active infection in the anticipated surgical area
- Patient with compliance/mental health issues or substance abuse issues (alcohol, illicit drugs, prescribed opiates)
- Patients with medical comorbidities (i.e., diabetes) or medical contraindications to anesthesia
- Sedentary patients unlikely to benefit from rapid rehabilitation or who would tolerate malunion/nonunion well

INDICATIONS CONTROVERSIES

- Adolescents with displaced fractures
- Older, sedentary patients may not benefit from operative intervention
- Fractures displaced less than 1.5 to 2.0 cm may not benefit from fixation
- Intramedullary nailing for simple pattern fractures is preferred over plate fixation in some centers

TREATMENT OPTIONS

- Nonoperative treatment:
  - Over 200 methods of “closed reduction” of clavicle fractures have been described: none have been shown to reliably maintain reduction or improve clinical outcome.
  - Multiple studies comparing a regular sling versus figure-of-eight bandage have shown no difference in pain, functional outcome, or radiographic result.
  - The simplest treatment possible with a sling is recommended. Range-of-motion exercises are instituted when pain subsides, followed by strengthening when union is established.
- Surgical fixation:
  - The goal of surgery is to reduce and stabilize the clavicle fracture sufficiently to allow early motion and a rapid return to activity.
  - Multiple surgical options are available. The standard fixation is with a small fragment precontoured plate.
  - Other options include mini-fragment plates and screws, large caliber nails (some with locking capability), and small diameter titanium elastic nails (popular in Europe).
  - Intermedullary (IM) fixation may be best for simple pattern fractures with intrinsic axial and rotational stability.
  - Small displaced fragments can be “teased” into position then fixed with small or mini-fragment lag screws.
  - It is important to preserve any soft-tissue attachment to comminuted fragments.

INDICATIONS

- Completely displaced fractures with 2.0 to 2.5 cm of displacement/shortening
- Healthy, active patient aged 16 years to 65 years
- Associated scapular winging (from anterior rotation of distal fragment of clavicle)
- Associated neurovascular injury
- Open fractures
- Associated displaced scapular neck/glenoid fracture (floating shoulder)
- Associated scapulothoracic dissociation
- Requirement for rapid return to function (athlete, manual worker, self-employed professional)

EXAMINATION/IMAGING

- Examine the overlying skin and soft tissues for deficits, old scars, or previous incisions.
- Measure the length of the injured clavicle measured from the sternoclavicular joint to the acromioclavicular joint and compare with the opposite uninjured side both clinically and radiographically.
- Perform a carefully documented neurovascular examination of the upper extremity to exclude preoperative injury.
- Obtain anteroposterior and 20 degree cephalad upshot views of the clavicle to assess fracture configuration.
- Fig. 3.1 is an anteroposterior radiograph of a completely displaced midshaft clavicle fracture with significant displacement and rotation at the fracture site. There is an anterior butterfly fragment *(arrow)*.

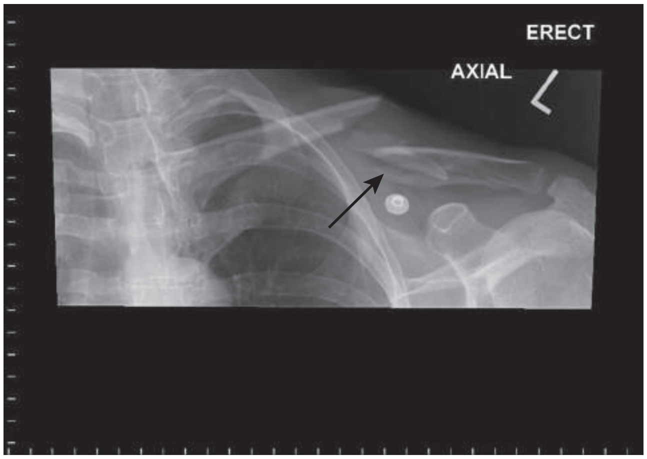


FIG. 3.1

SURGICAL ANATOMY

- The clavicle forms an anterior strut to maintain the position of the shoulder on the thoracic cage.
  - It is an S-shaped bone with a cephalad-to-caudad bow.
  - The subclavian vessels and brachial plexus pass posterior/posteroinferior to the clavicle before passing inferior to the coracoid and into the arm.
  - The apex of the lung lies posterior/posteroinferior to the clavicle.
  - Superficially, cutaneous braches of the intermediate supraclavicular nerve fan out over the anterosuperior region of the middle third of the clavicle.
  - The sternoclavicular joint is a diarthrodial joint allowing movement in both the horizontal and vertical planes, as well as 20 to 40 degrees of rotation relative to the manubrium, and is stabilized by the joint capsule.
  - The acromioclavicular joint is a planar joint allowing approximately 20 degrees of rotation relative to the acromion. This joint is stabilized by the capsule and intracapsular ligaments, as well as the conoid and trapezoid coracoclavicular ligaments.
  - Together these joints allow movement of the clavicle of up to 60 degrees in the vertical plane and 20 degrees in the horizontal plane and up to 40 degrees of rotation.
  - Fig. 3.2 is an artist's rendition of the pertinent neurovascular structures: the subclavian artery and associated brachial plexus are posterior to the clavicle in the proximal third and then passes inferior to the clavicle in the middle third. The apex of the lung lies posterior to the midclavicular portion. It is important not to plunge with the drill in these areas.

POSITIONING PEARLS

- A complicated positioning apparatus is not typically required for clavicular fixation.
- It is not usually necessary to free-drape the involved arm; it may be padded and tucked into the side in most cases.
- A midline pad or bump will help in reducing the distal fragment as it falls backward from its usually anteriorly displaced position.
- However, this maneuver may bring the neurovascular bundle closer to the inferior/posterior clavicle and care should be taken not to injure these structures during reduction and drilling.
- If an associated scapular/glenoid fracture is to be fixed through a posterior approach, a "sloppy lateral" position with a beanbag can facilitate fixation of both clavicle and scapular fractures without repeating prepping and draping.

POSITIONING PITFALLS

- The head should be turned and taped to the opposite side to allow for easy superior access with drills and instrumentation.
- The endotracheal tube or laryngeal mask should be positioned to the opposite side of the fracture.

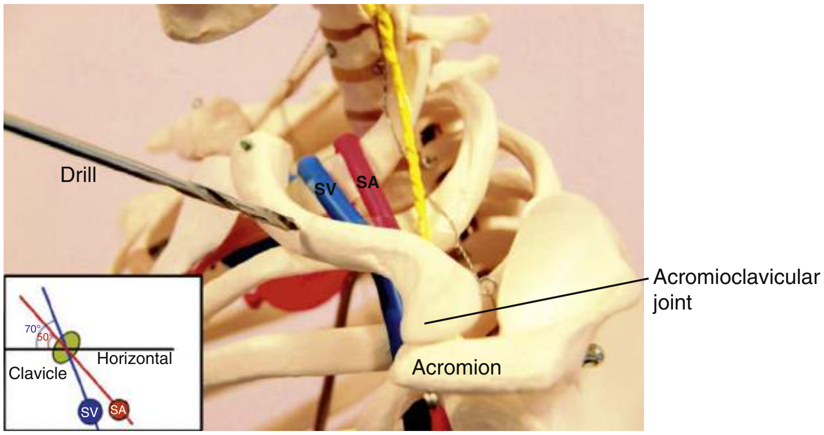


FIG. 3.2

POSITIONING

- Patient is positioned in the beach chair position with the head on a support.
- The arm is typically tucked in at the side; it is not usually necessary to have the arm free-draped in most situations.
- A radiographic plate can be placed behind the shoulder preoperatively to allow an intraoperative radiograph to be taken.
- If desired, a radiolucent table may be used to allow intraoperative imaging of the fracture site and fixation: the image intensifier can be brought in from the ipsilateral side. This is especially important if intramedullary fixation, with the requirement for image intensifier control, is chosen (Fig. 3.3).

FIG. 3.3

POSITIONING EQUIPMENT

- A regular operating room table with a pad for the head is sufficient for most cases.
- Commercially available head and neck frames/supports may be used: they are advantageous if image intensification is anticipated.
- Additionally, a radiolucent table is recommended if image intensification is anticipated (i.e., for intramedullary nailing).

POSITIONING CONTROVERSIES

- Some surgeons prefer anterior plating of the clavicle: if this is the case, then the patient may be placed in the supine position.

EXPOSURES

- The operative method described pertains to superior plating of the clavicle with a small fragment precontoured plate.
- The fractured clavicle is prepared and square draped as outlined above. The entire clavicle should be accessible, from sternoclavicular joint to acromioclavicular joint.
- A longitudinal incision is made directly over the fracture site. For a simple fracture pattern (i.e., transverse or short oblique), a 5- to 6-cm incision, with mobilization of the skin, subcutaneous, and muscular tissues, is sufficient to apply a precontoured six-hole plate. Incision length should decrease as surgeon experience increases.
- Typically two main branches of the supraclavicular nerves cross the surgical field: these should be identified and protected. Although this is usually possible for simple pattern cases, it may be difficult for complex fractures or revision cases. It is therefore prudent to warn patients preoperatively that they may experience some numbness distal to the incision. This is typically limited and improves with time.

PORTALS/EXPOSURES PEARLS

- A superior approach allows for excellent fracture visualization with minimal additional soft-tissue disruption.
- A two-layer closure provides better soft-tissue coverage of the fracture site and implant and reduces deep infection rate.

PROCEDURE

Step 1

- The surgical approach to be used is performed and the fracture site and fragments clearly identified.

STEP 1 PEARLS

- Identify and protect branches of the supraclavicular nerves.
- Carefully develop two soft-tissue layers: skin/subcutaneous tissue and the deep fascial/muscular layer.

STEP 1 INSTRUMENTATION/IMPLANTATION

- A precontoured plating system that allows the surgeon the choice of different contours, superior or anterior fixation, midshaft or distal plate options, and the ability to "bridge" comminuted areas is advantageous.

STEP 1 CONTROVERSIES

- An anterior approach and plating are preferred by some surgeons, with the theoretical advantages of decreased incidence of soft-tissue injury, the ability to insert longer screws (in the anteroposterior plane of the clavicle), and decreased soft-tissue irritation and subsequent hardware removal.

Step 2

- Fig. 3.4A Identify the fracture site, clear it of debris and hematoma, and thoroughly irrigate the area.
- Fig. 3.4B Carefully assess the fracture pattern and number of fragments and formulate a strategy for fixation. Here the forceps hold an anterior butterfly fragment.

STEP 2 PITFALLS

- Take care not to perform excessive stripping of the soft-tissue of the main fracture fragments.
- Do not completely denude smaller fragments in order to reduce them: it is better to accept some malreduction than to devascularize the fragments.
- Avoid dissection underneath the clavicle given the proximity of the lung and neurovascular bundle.

- Fig. 3.4C Reduce smaller fragments, if present, and then lag to the primary proximal or distal fragment with lag screws. Take care to preserve inferior soft-tissue attachments to this fragment. Reduce the anterior fragment and fix it to the distal fragment with a 2.7-mm screw inserted in lag fashion.
- Fig. 3.4D Then reduce the main fracture line and then either hold it provisionally with a K-wire, or, if the fracture pattern permits, with a lag screw. Care should be taken if a lag screw is used to countersink the head so as not to interfere with eventual definitive plate placement. In this case, another 2.7-mm screw is used to lag the distal fracture assembly (distal fragment with lagged anterior butterfly fragment) to the shaft fragment.

Step 3

- Fig. 3.4E Choose a precontoured plate of appropriate length and curvature. The plate should be long enough to allow the placement of three bicortical screws on either side of the fracture. Additionally, because there is some inherent variability in

STEP 2 INSTRUMENTATION/ IMPLANTATION

- Appropriate reduction forceps are required to hold fracture fragments reduced: a forceps with a low profile inferior tine (to slide underneath the clavicle without injuring the subclavican vessels) is very useful in this setting.
- It is recommended that a fixation system with both mini- (2.0 mm or 2.7 mm) and small (3.5 mm) screws is available so that small fragments can be fixed with screws of the appropriate caliber.

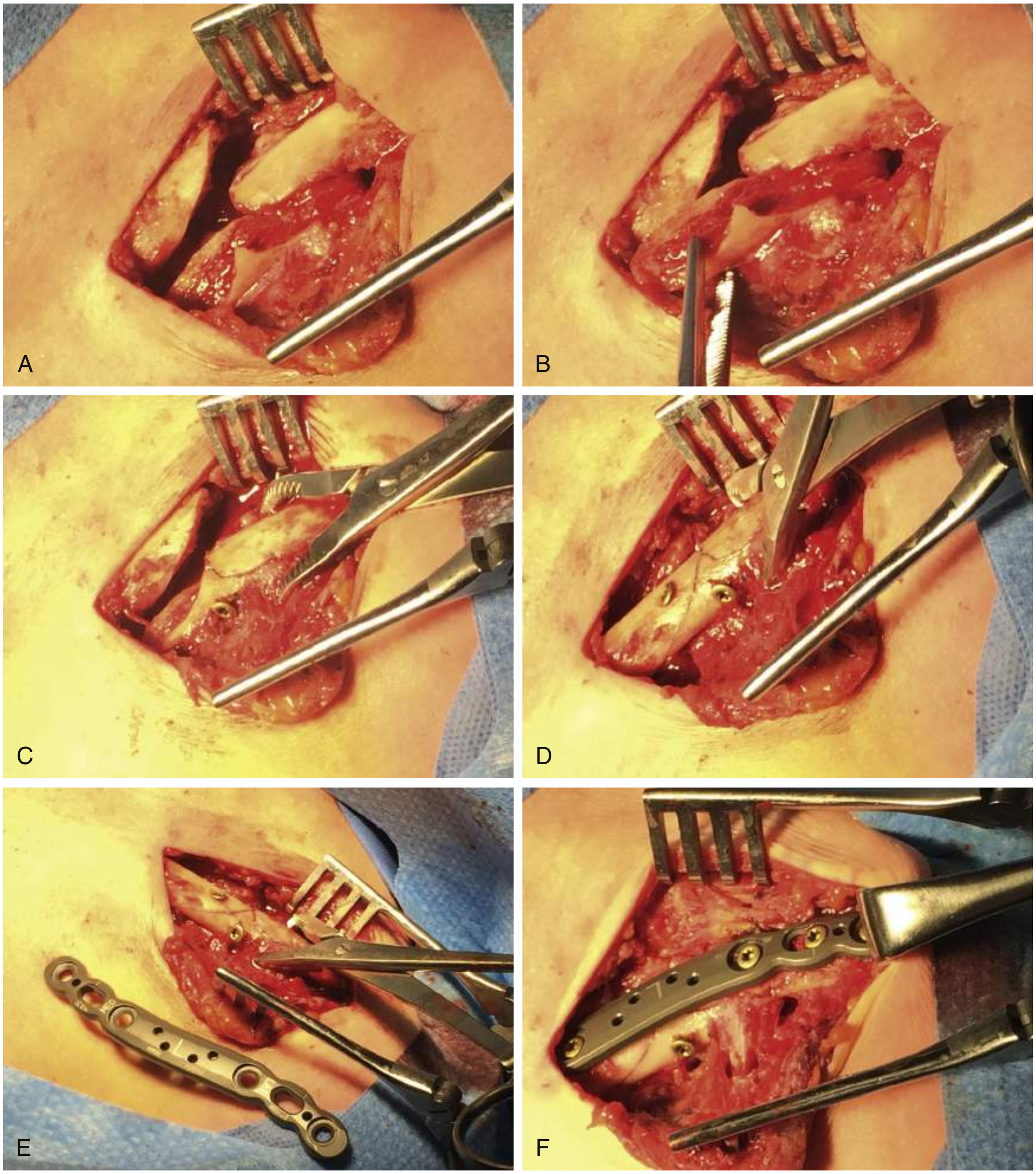


FIG. 3.4

the contour and curve of an individual's clavicles, a plating system with multiple curvature options is optimal.

- Fig. 3.4F Apply the plate to the superior surface of the clavicle in a neutralization mode with nonlocking cortical screws, and check the entire fracture construct for reduction accuracy and quality of fixation.

Step 4

- Following the completion of fracture fixation, perform a two-layer closure.
- The first layer is the reapproximation and closure of the deep layer of the detached deltotrapezial muscle and fascia. This is performed with interrupted #1 absorbable sutures.
- Close the skin and subcutaneous tissue with interrupted 3-0 nonabsorbable monofilament sutures.
- The two-layer closure is very important: if there is any superficial skin infection/dehiscence/necrosis, the deep layer protects the implanted hardware and fracture site.
- Closure of the skin/subcutaneous tissue with a nonabsorbable suture eliminates the need for 2-0 subcutaneous sutures: in this superficial location these can develop as stitch abscesses that can be problematic.
- Apply a standard dressing and a sling for patient comfort.
- Fig. 3.5 If no intraoperative images have been taken, a postoperative radiograph is taken to confirm reduction of the fracture and position of the plate and screws.

FIG. 3.5

POSTOPERATIVE CARE AND EXPECTED OUTCOMES

- The fixation of an isolated clavicle fracture is typically performed as an out-patient procedure.
- The postoperative dressing is removed 48 hours following the surgery, and the patient is then allowed to bathe or shower. Following this, wound coverage is optional.
- A standard sling is worn for 10 to 14 days, at which time the patient is seen in the clinic and the sutures are removed. The sling is discontinued, and unrestricted active and passive range-of-motion exercises are then instituted.
- At 6 weeks postoperatively, if radiographs demonstrate fracture union, strengthening and resisted exercises are initiated.
- At 12 weeks postoperatively, return to full activities, including contact or collision sports, is allowed.

STEP 3 PEARLS

- Choose a precontoured plate: this improves operating efficiency, helps restore clavicular anatomy, and decreases hardware removal rates.
- Obtain at least three bicortical screws in both the proximal and distal fragments.

STEP 3 PITFALLS

- Avoid plunging with the drill into the neurovascular bundle.
- If a vascular injury does occur, urgent action is required. In general, packing with sustained pressure over/around the area of the laceration is sufficient to control bleeding.
- Alert the anesthetist to the complication, and initiate fluid resuscitation. Consult a vascular surgeon urgently.
- If the injury is venous, beware of air embolism. This can occur if the vessel lumen is open to air, blood pressure is low, and the patient is in the sitting or beach chair position.
- Maintain manual pressure on the injury, return the OR table to the supine position, and blood pressure is improved. Then the vascular injury can dealt with definitively with repair, ligation, or packing.

STEP 3 CONTROVERSIES

- Some experts prefer anterior plate placement. This may be advantageous in certain situations where associated injures (e.g., spine fracture) preclude sitting the patient up, or where the fracture pattern is more amenable to fixation through an anterior plate (e.g., a long coronal plane fracture line).
- Additionally, a theoretical advantage is the possibility of a lower hardware removal rate with anterior plating.

STEP 4 PEARLS

- A two-layer soft tissue closure (deep muscle/fascial and superficial subcutaneous tissue/skin) is important.
- Use nonabsorbable skin sutures for the superficial layer.
- Long-acting anesthetic can be injected into the superficial layer prior to closure to minimize postoperative pain and discomfort.

STEP 4 PITFALLS

- Prominent subcutaneous knots can become infected or irritated and should be avoided.
- A Valsalva maneuver performed by the anesthetist prior to closure can help detect any potential pleural injury or pneumothorax (air is seen bubbling up through the saline-filled wound). If this is positive (a rare complication), a chest tube or drain may be required if respiration/ventilation problems are encountered.

POSTOPERATIVE PEARLS

- Following stable fixation, many patients accelerate the postoperative timetable on their own.

EVIDENCE

Canadian Orthopaedic Trauma Society. Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures: a multicenter, randomized clinical trial. *J Bone Joint Surg [Br]*. 2007;89:1–10.

This prospective, randomized multicenter study compared sling treatment with open reduction and internal fixation of completely displaced middle-third clavicle fractures. The authors concluded that operative treatment in young, active individuals provided improved functional outcome and a lower symptomatic malunion and nonunion rate, with a low incidence of operative complication. (Grade A recommendation.)

Ferran NA, Hodgson P, Vanett N, Williams R, Evans RO. Locked IM fixation versus plating for displaced and shortened mid-shaft clavicle fractures: a randomized clinical trial. *J Shoulder Elbow Surg*. 2010;19:783–789.

This small randomized trial comparing plating versus locked IM nails demonstrated 100% union in both groups but a high rate of hardware removal, regardless of the implant chosen.

Hill E, McGuire M, Crosby L. Closed treatment of displaced middle-third fractures of the clavicle gives poor results. *J Bone Joint Surg [Br]*. 1997;79:537–539.

This prospective cohort study evaluated the outcomes of 242 consecutive fractures of the clavicle treated nonoperatively; 66 were displaced middle-third clavicle fractures; of these, 52 patients were available for review. Radiographic and patient-oriented outcomes were reported, showing a 15% nonunion rate and a 31% unsatisfactory result in patients with completely displaced middle-third clavicle fracture. (Grade B recommendation.)

McKee MD, Wild LM, Schemitsch EH. Midshaft malunions of the clavicle. *J Bone Joint Surg [Am]*. 2003;85:790–797.

This case series reported 15 patients with middle-third symptomatic clavicle malunions who underwent clavicular osteotomy and fixation. Radiographic and patient-oriented outcomes were collected pre- and postsurgery. Postoperatively, the mean clavicular shortening improved from 2.9 to 0.4 cm, and the mean DASH score improved from 32 to 12 points, suggesting clavicle fracture malunions that cause significant residual morbidity can be ameliorated with surgical correction. (Grade C recommendation.)

Robinson CM, Court-Brown CM, McQueen MM, Wakefield AE. Estimating the risk of nonunion following nonoperative treatment of a clavicular fracture. *J Bone Joint Surg [Am]*. 2004;86:1359–1365.

This prospective observational cohort study evaluated the prevalence of nonunion after nonoperatively treated clavicle fractures. The authors reported an overall nonunion rate of 6.2%; however, completely displaced fractures with comminution had a higher risk of nonunion. (Grade B recommendation.)

van der Meijden OA, Houwert RM, Hulsmans M, et al. Operative treatment of dislocated midshaft clavicular fractures: plate or intramedullary nail fixation? A randomized controlled trial. *J Bone Joint Surg (Am)*. 2015;97(8):613–619.

This large randomized trial demonstrated superior early function in the plate group but no difference by 6 months. Complications were rare, but there was a high incidence of hardware removal in both groups.

Intramedullary Fixation of Clavicle Shaft Fractures

Paul R. King, Carl J. Basamania, Ajmal Ikram, and Robert P. Lamberts

INDICATIONS PITFALLS

- Clavicle shaft fracture comminution extending to within 50 mm of the medial end of the clavicle bone
- Clavicle shaft fracture comminution extending lateral to the coracoid process or conoid tubercle
- Fractures extending more medially or laterally would be difficult to bridge adequately with the intramedullary (IM) device, which will compromise construct stability
- Comminuted or complex fracture patterns that have little intrinsic axial stability

INDICATIONS CONTROVERSIES

- Implant choice remains controversial. Numerous intramedullary options are available: unlocked and locked, as well as rigid and flexible. Flexible devices have the advantage of being able to follow the S-shaped curvature of the clavicle in the axial plane, allowing a longer segment of the clavicle to be instrumented. Locked IM devices have yielded promising preliminary results and have some advantages owing to length and rotational stability, but further research is needed to confirm this.

TREATMENT OPTIONS

- Nonoperative management in a shoulder sling
- Traditional plating using precontoured locked or unlocked plates
- IM fixation: numerous options available

INDICATIONS

Absolute indications:

- Absolute indications include open fractures, overlying skin compromise, neurological deficit or associated vascular injury

Relative indications:

- Relative indications include multisystem traumatized patients, painful malunions and non-unions and a floating shoulder. Relative indications have also been expanded to include fractures with 15-20mm of shortening, complete displacement and comminution.

Examination/Imaging

- Anteroposterior radiograph of fractured clavicle (Fig. 4.1)
- 15-degree cephalad tilt radiograph of fractured clavicle (Fig. 4.2)
- 45-degree cephalad tilt image may be helpful in certain cases to better visualize comminuted fragments (Fig. 4.3).

FIG. 4.1

FIG. 4.2

FIG. 4.3

SURGICAL ANATOMY

- Branches of the supraclavicular nerves are at risk. Injury to these nerves causes an area of abnormal sensation on the anterior chest wall, which carries a degree of morbidity (Fig. 4.4).
- Subclavian vein and artery posterior and inferior to the clavicle (Fig. 4.5)

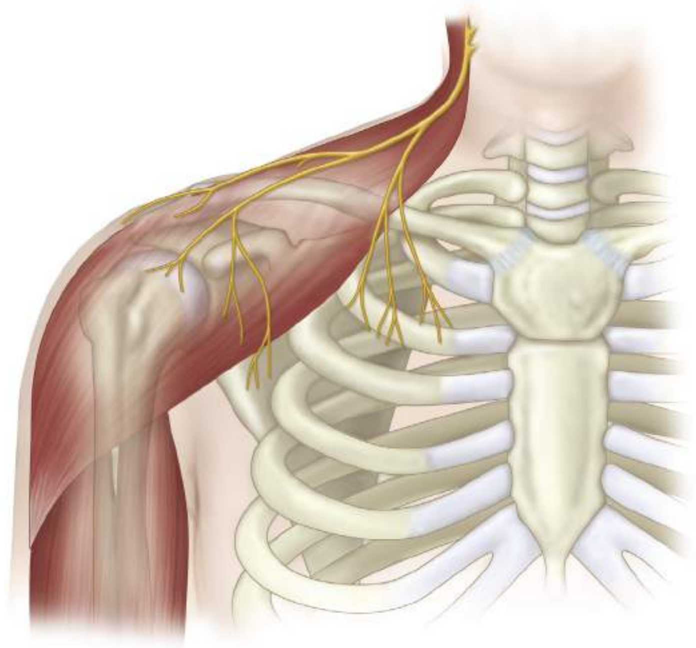


FIG. 4.4 Courtesy AO Foundation. www2.aofoundation.org

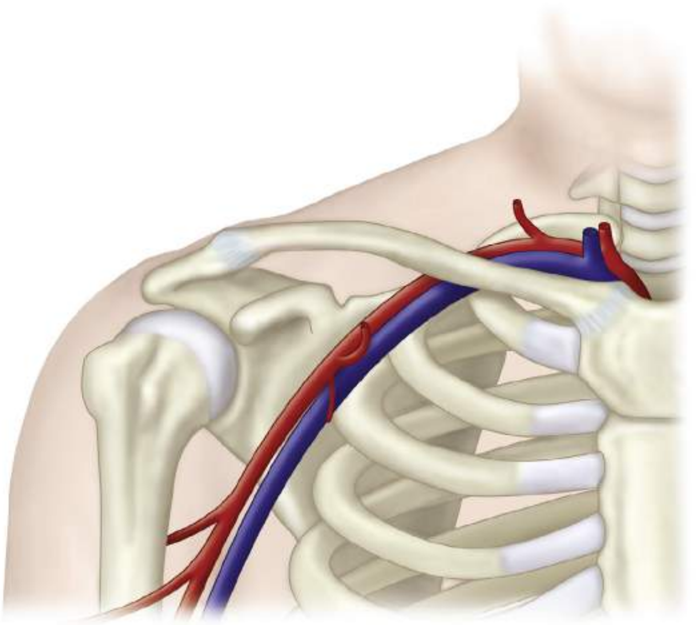


FIG. 4.5 Courtesy AO Foundation. www2.aofoundation.org

POSITIONING

- Traditional "beach chair" position with the upper body 45 degrees to the horizontal: head and neck secured in a neutral position (Fig. 4.6)
- Drape the arm on the fractured clavicle side free, so that you can flex and extend the shoulder. This will allow you to position the clavicle in such a way that a caudal tilt view and an axial view of the clavicle can be seen with fluoroscopy without having to change the position to the C-arm. Place the fluoroscopy machine in line with the patient, with the C-arm over the patient's shoulder and fractured clavicle (Fig. 4.7).

POSITIONING PEARLS

- Make sure the patient is secured in the desired position before draping.
- The sternal end of the clavicle, as well as the acromial end, must be clearly visible with fluoroscopy; make sure of this before securing and draping the patient.
- Infiltrate the incision site over the fracture with epinephrine and local anesthetic to reduce bleeding at the incision site. The dosage of the epinephrine and local anesthetic is patient mass specific. Confirm the concentration and volume with the anesthesist before administration. Intravenous administration of the mixture must be avoided.

POSITIONING PITFALLS

- Loss of patient positioning intraoperative can make the procedure very difficult as well as endanger the patient.
- The "beach chair" position is a position with significant anesthetic risks, requiring an experienced anesthetist.

FIG. 4.6 Courtesy Dr. Carl Bassamania.

FIG. 4.7 Courtesy Dr. Carl Bassamania.

PORTALS/EXPOSURES

- Option 1: Transverse incision from the tip of the medial fragment extending lateral for a 2- to 3-cm incision size, which is dictated by fracture configuration and amount of comminution (Fig. 4.8).
- Option 2: Oblique incision along Langer's lines over the distal tip of the medial fragment. If the incision needs to be extended medially or laterally, it can be extended in a "Z" pattern by extending the inferomedial aspect of the incision medially and the superolateral aspect laterally.

PORTALS/EXPOSURES PEARLS

- The incision should allow adequate access to the less mobile lateral fragment's (secured by the corocaclavicular ligaments) medullary canal. This medullary canal is more difficult to access owing to its inability to be lifted out of the incision. The medial fragment is easy to manipulate and lift out of the wound to gain access to the canal.
- Avoid stripping the periosteum and muscle attachments around the fracture site because this will compromise the blood supply to the fracture site and healing potential.

FIG. 4.8

PROCEDURE

STEP 1: Preparing the Medial Fragment

- The preparation of the medial fragment is of the utmost importance, as the IM device should be placed as far as possible into the medial fragment of the clavicle to provide the most stability at the fracture site. The medial end of the clavicle is lifted out of the wound and its medullary canal opened with a sharp awl. The utmost care is taken to ensure that the medullary canal is entered and not breached by the sharp awl to avoid injury to the subclavian vasculature. The medullary canal is then enlarged with hand reamers as far medially as possible (Fig. 4.9).

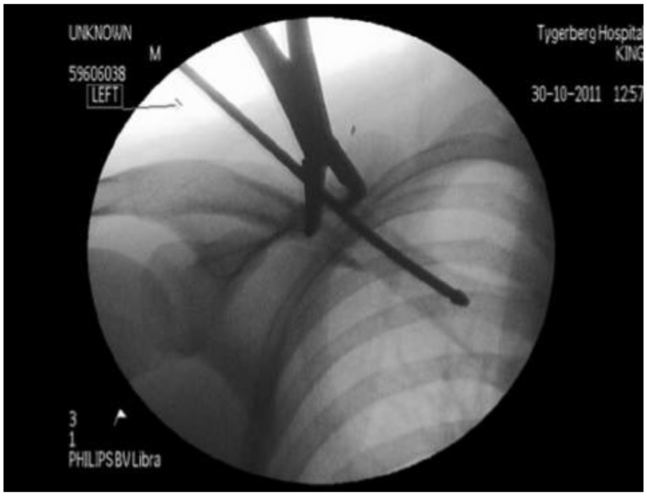


FIG. 4.9

STEP 1 PEARLS

- The canal must be prepared to at least 5 cm medial to the medial end of the fracture.
- The awls must be manipulated gently and the curvature of the awls must be used to follow the curvature of the clavicle in the axial plane to avoid breaching the medullary canal.

STEP 1 PITFALLS

- Breach of the medullary canal can result in neurovascular injury or misplacement/migration of instrumentation.
- If the canal cannot be prepared 5 cm medial to the fracture then traditional plating should be performed. Fracture stability would be compromised if the fracture site cannot be bridged adequately.

STEP 1 INSTRUMENTATION/IMPLANTATION

- 3-mm sharp awl curved to follow the curvature of the clavicle
- 4.5-mm blunt reaming awl

STEP 2: Preparing the Lateral Fragment

- The canal is located and opened in the same fashion as the medial fragment. An aiming device is placed in the lateral fragment used to direct a Kirschner wire (K-wire) from medial to lateral to exit the lateral fragment halfway between the conoid tubercle and the acromioclavicular joint at the equator of the clavicle (Fig. 4.10).
- A skin incision is made where the K-wire exits the skin posterior to the acromioclavicular joint. The entry point for the nail is then opened with a cannulated drill over the K-wire (Fig. 4.11).

STEP 2 PEARLS

- Flexing and extending the affected shoulder allows AP and axial views of the lateral fragment. This will ensure creating the ideal entry point for the nail—midway between the acromioclavicular joint and the conoid tubercle on the axial view and at the equator of the clavicle on the anteroposterior view.
- Exiting too high will cause apex superior angulation at the fracture site; exiting too low will cause apex inferior angulation.

STEP 2 PITFALLS

- The medullary canal is generally more difficult to enter on the lateral side and can only be prepared for a short distance lateral to the fracture. The aiming device should be held in place securely while advancing the K-wire to avoid misplacement of the entry point.

STEP 2 INSTRUMENTATION/ IMPLANTATION

- 3-mm sharp straight awl
- 4.5-mm blunt reaming awl
- 4.5-mm straight cannulated aiming awl to place K-wire.

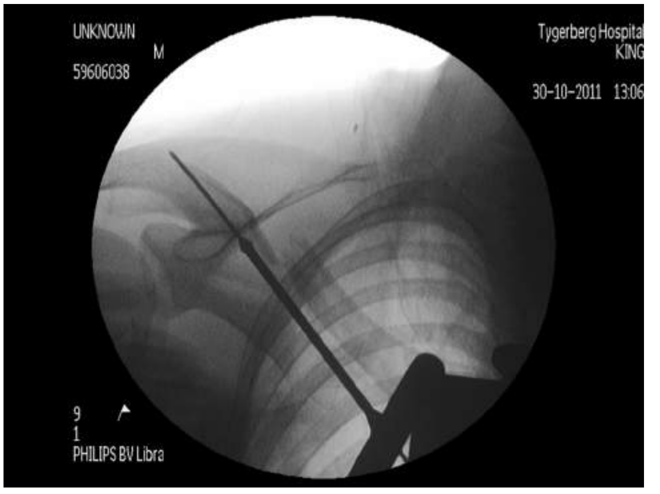


FIG. 4.10

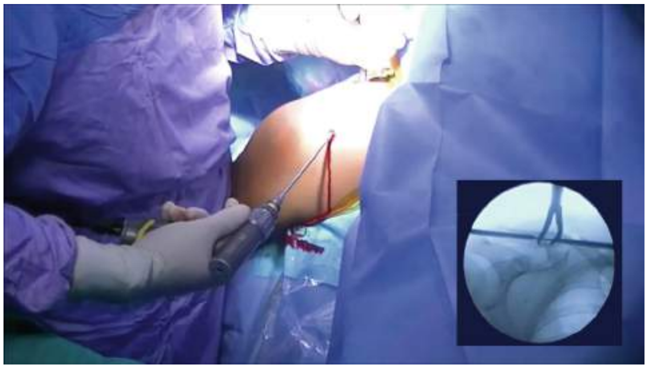


FIG. 4.11

STEP 3 PEARLS

- Reduction of the fracture can easily be achieved by flexing the patient's shoulder to counteract the effect of gravity on the lateral fragment while depressing the medial fragment. This can be done while the reduction is fine-tuned with reduction clamps.
- The length of implant must be determined while keeping the fracture out to length.
- Use the longest possible implant that the prepared medullary canal will accommodate.

STEP 3 PITFALLS

- It is paramount to ensure the guidewire is in the medial fragment's medullary canal before reaming. Obtaining fluoroscopic images in two orientations—an AP view and an axial view—accomplishes this.

STEP 3 INSTRUMENTATION/ IMPLANTATION

- Flexible guidewire
- Flexible 4.5-mm cannulated reamer

STEP 3: Reduction and Final Preparation of the Canal

- Using reduction clamps, hold the fracture reduced and out to length. A flexible guidewire is then inserted from the lateral entry point of the nail, over the fracture and into the medial fragment. The desired length of implant is then determined. The medullary canal can then be further prepared using flexible reamers over the guidewire (Fig. 4.12).

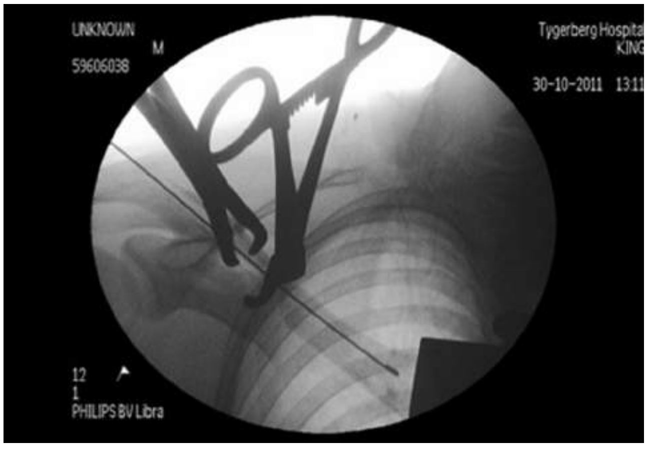


FIG. 4.12

STEP 4: Placement of the Intramedullary Device

- The desired length of implant is assembled to the standard jig. The guidewire is removed and while the fracture is held reduced and the clavicle is held out to length, the device is inserted from lateral to medial over the fracture and into the medial canal. The device must be inserted right up to where the medial canal was prepared (Fig. 4.13).

FIG. 4.13

STEP 4 PEARLS

- The medial end of the implant must be inserted at least 5 cm past the most medial end of the fracture to ensure stability.
- Do not insert the device too deep; the lateral end of the device should protrude slightly from the lateral entry point to facilitate removal of the device if required later.

STEP 4 PITFALLS

- Make sure under direct vision as well as with fluoroscopic guidance that the nail enters the medullary canal of the medial fragment and does not pass posterior to the medial fragment to endanger neurovascular structures.

STEP 4 INSTRUMENTATION/ IMPLANTATION

- 4.2-mm flexible intramedullary nail
- Insertion jig

STEP 5: Securing the Device

- The device is activated with a torque-limiting actuation driver inserted in the lateral end of the nail. This deploys the grippers securing the device in the medial fragment as well as making the flexible portion of the device rigid. The locking screw is placed using the jig secured to the nail. It requires making a third small incision to allow the screw to be placed (Fig. 4.14).

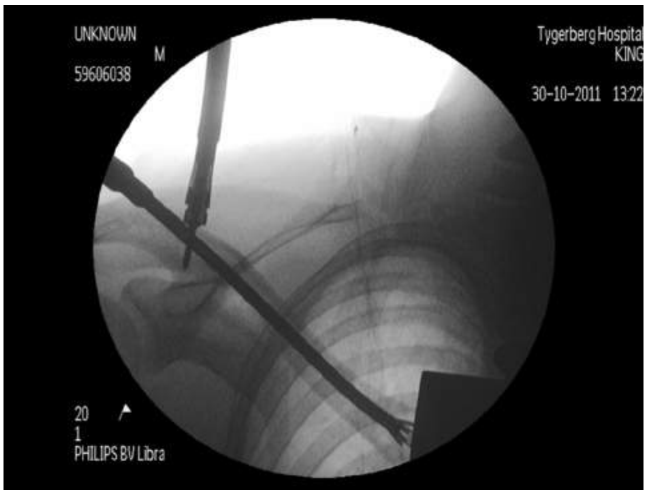


FIG. 4.14

STEP 5 PEARLS

- Comminuted fractures can be held out to length while the medial grippers are deployed and the lateral locking screw is placed, which ensures that the fractured clavicle's length is restored.
- The lateral locking screw should engage both the superior and inferior cortexes of the lateral fragment to ensure that no rotation is possible.
- Once the locking screw has been placed, the actuation driver can be replaced. If the driver engages the nail, the locking screw has been misplaced and should be repositioned.

STEP 5 PITFALLS

- The lateral locking hole is fairly small. The locking screw can easily miss the hole in the implant if soft tissue deflects the drill. Missing the hole will cause rotational instability at the fracture site.

STEP 5 INSTRUMENTATION/ IMPLANTATION

- Actuation driver
- Locking screw insertion jig
- Lateral 2-mm locking screw

Step 6: Management of Comminuted Fragments

- Although controversial, comminuted fractures are not necessarily a contraindication to the use of locked intramedullary devices because they can be reduced by the nail and secured using cerclage sutures. Hold the comminuted fracture out to length before the device is activated and the locking screw is placed; this ensures that length is preserved.
- While avoiding stripping periosteum and soft-tissue attachments, larger fragments can be held by passing cerclage absorbable sutures around the nail and fragments. Smaller fragments can be sutured back onto the strut provided by the nail (Fig. 4.15).

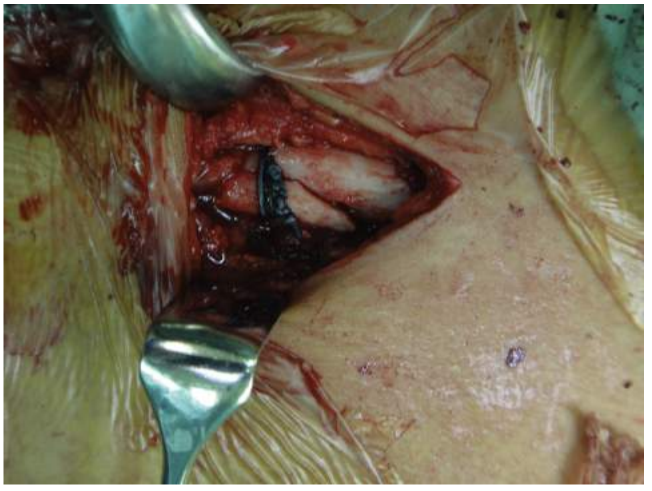


FIG. 4.15

POSTOPERATIVE CARE AND EXPECTED OUTCOMES

- Immobilization in a broad arm sling for 6 weeks
- Pendulum exercises of affected shoulder 6 times a day
- Ipsilateral elbow range-of-motion exercises 6 times a day
- Full mobilization 6 weeks postoperative
- Return to sporting activities 3 months postoperative with radiographic evidence of progression to union

EVIDENCE

Calbiyik M, Ipek D, Taskoparan M. Prospective randomized study comparing results of fixation for clavicular shaft fractures with intramedullary nail or locking compression plate. *Int Orthop*. 2017;41(1):173–179.

Study comparing locked intramedullary fixation with locked plating. This is the first study comparing the conventional plating technique for clavicle shaft fractures with intramedullary fixation that is locked at its medial and lateral end.

Hussain N, Sermer C, Prusick PJ, Banfield L, Atrey A, Bhandari M. Intramedullary nailing versus plate fixation for the treatment of displaced midshaft clavicular fractures: a systematic review and meta-analysis. *Sci Rep*. 2016;20(6):34912.

This meta-analysis and systematic review found no statistically significant difference between extra- and intramedullary fixation of clavicle shaft fractures in terms of functional outcome and union rate. There is a difference in wound size and surgical time, as would be expected, but functional outcomes are the same.

Lenza M, Faloppa F. Surgical interventions for treating acute fractures or non-union of the middle third of the clavicle. *Cochrane Database Syst Rev*. 2015;7(5):CD007428.

This Cochrane review found little evidence to suggest that any form of surgical technique used in the treatment of clavicle shaft fractures and non-unions is superior to another. Further research is definitely needed to determine the most effective surgical technique.

King PR, Ikram A, Lamberts RP. The treatment of clavicular shaft fractures with an innovative locked intramedullary device. *J Shoulder Elbow Surg*. 2015;24(1):e1–e6.

This was the first paper published describing the results of locked intramedullary fixation. This paper showed that the procedure is safe, but highlighted that further research is needed.

King PR, Basamania C, Robert PL. A novel intramedullary locked fixation device for treatment of clavicle shaft fractures. *JBJS Essent Surg Tech*. 2016;6(1):e8(1–11).

This paper provided a detailed description of the surgical technique used to implant a locked intramedullary device.

King PR, Eken MM, Ikram A, Lamberts RP. The effectiveness of a flexible locked intramedullary nail and an anatomically contoured locked plate to treat clavicle shaft fractures – a one year randomized control trial. *J Bone Joint Surg Am*. 101(7):628–634.

Randomized controlled trial comparing the 1 year outcomes of patients treated with anatomically contoured locked plates with an intramedullary locked device. Cohen effect sizes suggest better clinical outcomes in patients treated with the intramedullary nail compared to plating.

Wang XH, Cheng L, Guo WJ, et al. Plate versus intramedullary fixation care of displaced midshaft clavicular fractures: a meta-analysis of prospective randomized controlled trials. *Medicine (Baltimore)*. 2015;94(41):e1792.

This meta-analysis concluded that extra- and intramedullary fixation of clavicle shaft fractures provides comparable results. Extra-medullary fixation has a longer surgical time and earlier functional improvement, but functional outcome is similar from 6 months postoperatively onward.

Wright J, Aresti N, Heuveling C, Di Mascio L. Are standard antero-posterior and 20° caudal radiographs a true assessment of mid-shaft clavicular fracture displacement? *J Clin Orthop Trauma*. 2016;7(4):221–224.

A paper showing that normal anteroposterior (AP) and 20-degree cephalad tilt views are adequate to measure displacement of clavicle shaft fractures. The authors compared radiographs with computer tomography images of the same fractures.

Zehir S, Zehir R, Şahin E, Çalbıyık M. Comparison of novel intramedullary nailing with mini-invasive plating in surgical fixation of displaced midshaft clavicle fractures. *Arch Orthop Trauma Surg*. 2015;135(3):339–344.

The first randomized trail comparing plating with locked intramedullary fixation. Although traditional plating was not used in this study, which used a minimally invasive approach, it does provide further evidence of the efficiency of locked intramedullary fixation.

PROCEDURE 5

Glenoid Fracture

Pierre Guy

CONTROVERSIES

- Anterior rim fractures may be treated *nonoperatively* if the glenohumeral joint remains concentric.
- No clear evidence is available comparing operative and nonoperative treatment. Indications are relative and are based on principles of articular injury treatment, not on high evidence-level comparative trials.

OPEN REDUCTION AND INTERNAL FIXATION AND ARTHROSCOPICALLY ASSISTED FIXATION

PITFALLS

- Prioritize commonly associated life-threatening injuries: head, spine/spinal cord, chest, brachial plexus, vascular.
- Indication individualized to injury, patient health, and functional demand.
- Contraindications to open reduction and internal fixation: infections, preexisting shoulder arthritis, or severe comminution not allowing stable fixation.

TABLE 5.1 Indications for Glenoid Fracture ORIF: Glenoid Fossa and Glenoid Neck fractures

Fracture Site	Indication	Displacement	Quantity	Assessment	Comment
Glenoid Fossa	Incongruity	Articular Step	≥ 5mm (consideration) ≥10mm (definitive)	AP Xray (True AP of glenoid) AP Xray with passive external rotation CT +/- scapular plane coronal recosntructions	Majority of "steps" follow a transverse fracture
		Concentricity	Loss of congruity (Absence of 2° congruence)	AP Xray Axillary view Xray CT axial + scapular coronal planes	
	Instability	Subluxation	Humeral head fails to lie in middle of glenoid	Axillary Xray (AP Xray, Transcapular lateral) CT axial plane	Indication stands for Glenoid fossa and glenoid rim fractures
		Articular involvement	>1/4 anterior wall >1/3 posterior wall	Axillary Xray CT axial plane	
	Non-union Risk	Gap / Space between fragments	≥10mm	All Xrays CT All planes	Concerns that a large space between fragments would prevent callus formation and union
Glenoid Neck	Angulation (Instability)	Transverse or Coronal angulation	40 degrees		Severe angulation may cause Impingement, Subluxation, Dislocation
	Translation	Medial A-P	≥1 cm (relative) ≥ 2cm (considered)	AP Xray + CT: medial displ. Axillary + CT: A-P displacement	Severe translation may cause impingement and abductor weakness

TABLE 5.1 Indications for Glenoid Fracture ORIF: Glenoid Fossa and Glenoid Neck fractures—Cont'd

Fracture Site	Indication	Displacement	Quantity	Assessment	Comment
Adjacent structures	Instability Non-union	Associated clavicle #: "Floating shoulder"	Not yet determined	AP Xray	Controversial indication Conflicting reports Comparative study shows better Forward Elevation and Ext rotation with surgery
	Instability Non-union	Associated suspensory ligament injury	Not yet determined		Associated injuries (≥2 involved) to: the glenoid process, the coracoid process, the coracoclavicular ligament, the distal clavicle, the AC joint, or the acromion process may be an indication for repair.

*Other indications include: Open fractures, Associated vascular injuries

INDICATIONS

- General indications
  - Open fractures
  - Neurovascular injuries that need exploration
  - Symptomatic pseudoarthrosis or malunion
- Specific indications: relative to the portion of the glenoid involved (see Table 5.1)
  - Glenoid fossa fractures (intraarticular glenohumeral joint)
    - Articular step 4 mm or more
    - Articular gap more than 10 mm (risk of nonunion)
    - Glenoid rim fracture involving greater than one-fourth of fossa anteriorly, greater than one-third posteriorly
    - Associated with persistent dislocation or subluxation of the humeral head
  - Glenoid neck fractures (extraarticular fractures)
    - Translational displacement greater than 2 cm
    - Significant angulation: transverse or coronal plane greater than 20° to 40° or glenopolar angle (GPA) less than 20° (normal, 30°–45°) (Romero et al., 2001) The GPA is measured on an anteroposterior radiograph as the angle between the line connecting the most cranial with the most caudal point of the glenoid cavity and the line connecting the most cranial point of the glenoid cavity with the most caudal point of the scapular body (the lateral border of the scapula; Fig. 5.1)
  - Combined injuries: scapula body/glenoid fracture will occur, with the following injuries prompting a relative indication for fixation:
    - Associated displaced clavicle fracture (>2 cm) shortening or comminution
    - Associated acromioclavicular, coracoacromial, or coracoclavicular injury
    - Associated double disruption of the superior shoulder suspensory complex

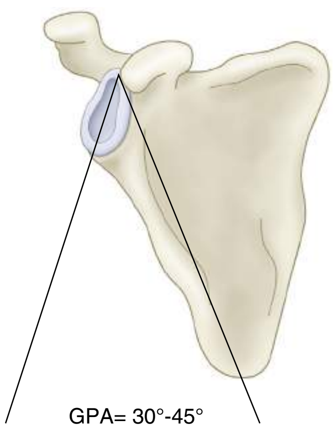


FIG. 5.1

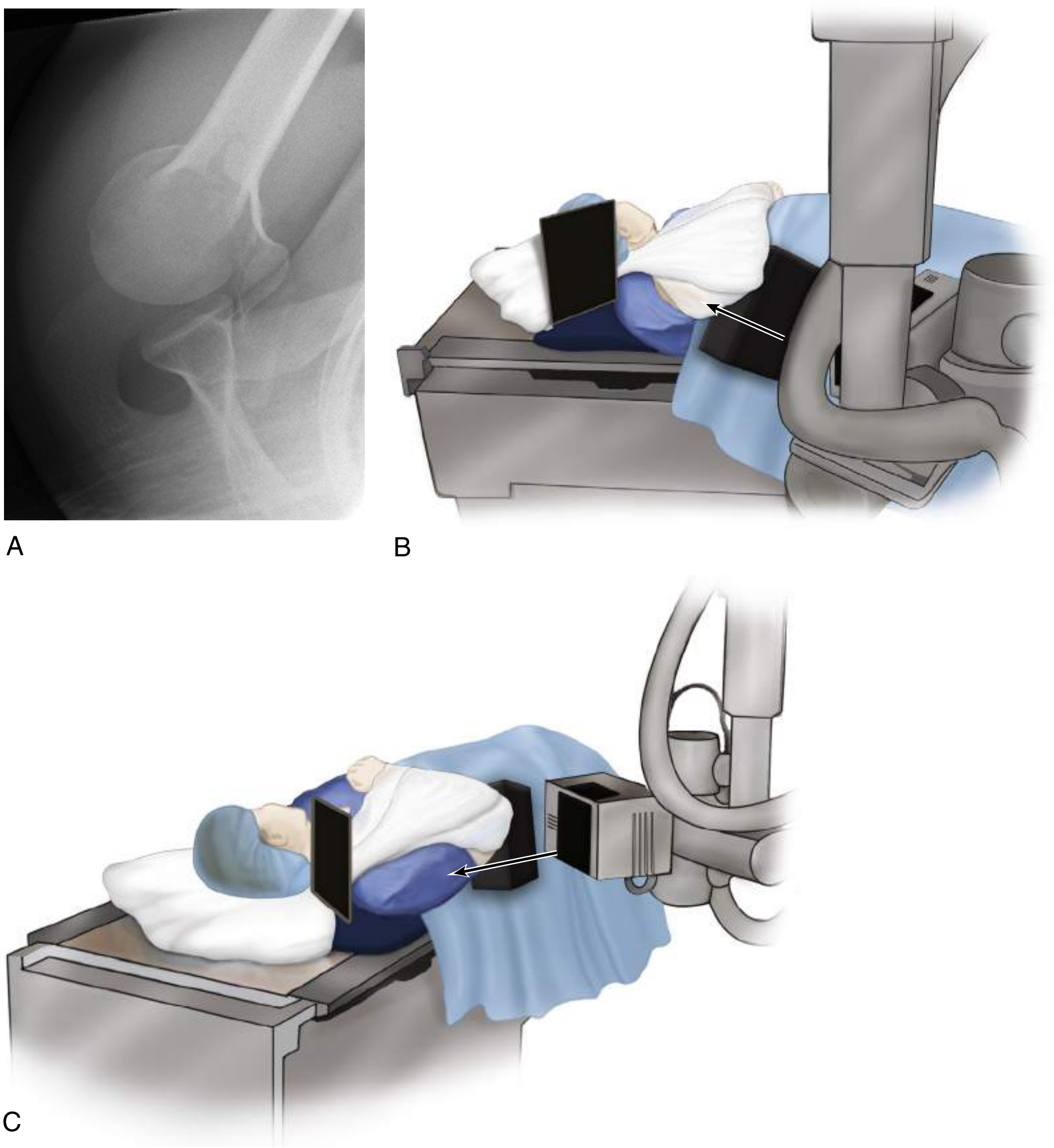
EXAMINATION/IMAGING

Physical Examination

- Goals: Identify/rule out associated injuries and characterize the scapular injury.
- Assess for concurrent:
  - Neurologic injury: head, spine/spinal cord, brachial plexus
  - Vascular injury
    - Inspection and palpation for pulse and perfusion signs
    - Side-to-side comparison of blood pressure (particularly in presence of first rib fracture); if abnormal, consider angiography/computed tomography (CT) angiography
  - Open fracture and/or ipsilateral limb–shoulder girdle injury: to define timing of care
  - Other system injury: primary and secondary surveys
- Assess shoulder injury: inspection, palpation, range of motion (ROM), shoulder muscle exam

Plain Radiography

- Chest radiograph
  - Important in assessing commonly associated chest trauma.
  - May represent the first chance to identify scapular fracture or scapulothoracic dissociation.
  - Not sufficient for assessment and preoperative planning for scapular fractures.
- Cervical spine imaging: radiography or CT as per center's protocol
- Shoulder trauma series
  - Obtain anteroposterior (Grashey view: x-ray beam tangential to glenoid/perpendicular to the plane of the scapular body), transscapular lateral, and transaxillary views.
  - Consider a "bumped-up view" (modified Velpeau view) if a standard axillary view with the arm abducted is not clinically feasible (Fig. 5.2A–C).
- Assess scapula-glenoid fractures and detect associated shoulder girdle injuries: clavicle; proximal humerus; disruptions of the acromioclavicular, glenohumeral, sternoclavicular, and scapulothoracic articulations; suspensory ligamentous complex injury.
- It is important to differentiate true fossa fractures from anterior and posterior rim fractures (see Fig. 5.16).
- Anterior and posterior rim fractures (type I; see Surgical Anatomy) are larger than Bankart "bony avulsions," which occur when the humeral head loses its congruity as it dislocates anterior to the glenoid. Rim fractures result from a lateral to medial compression force that drives the humeral head against the anterior or posterior portion of the glenoid fossa depending on arm position.
  - Fig. 5.3A–C shows an anterior rim fracture with maintained concentric glenohumeral alignment in a 63-year-old female accountant (Case 1) who can be treated nonoperatively with expected good functional outcome (Maquieira et al., 2007).



A B C

FIG. 5.2 A–C

- Fig. 5.4A–C shows an anterior rim fracture with loss of glenohumeral alignment in a 36-year-old male who sustained this injury while skimboarding, when he noticed his shoulder dislocate and self-reduce (Case 2).
- In contrast to type I, true glenoid fossa fractures (types II–VI; see Surgical Anatomy) follow a more centrally applied lateral force producing, in most cases, a transverse fracture of the glenoid, which then extends in one of several directions depending on the direction of the load (see Fig. 5.16).
  - Fig. 5.5A–C shows a displaced extraarticular fracture of the scapula in a 31-year-old overhead worker (electrician) who sustained this injury while mountain biking (Case 3). He has a significant past history of an acromioclavicular joint injury treated with late distal clavicle resection.
  - Fig. 5.6A–C shows a displaced comminuted, intraarticular fracture of the scapula (glenoid fossa type Va) in a 39-year-old male who sustained this injury catching his front wheel and falling from his bicycle (Case 4).
  - Fig. 5.7 shows a displaced intra-articular transverse fracture of the glenoid fossa (type III) with associated clavicle and first-rib fractures in a 36-year-old male triathlete who sustained this injury while road cycling (Case 5). He was neurovascularly intact with symmetric blood pressure in both upper extremities.

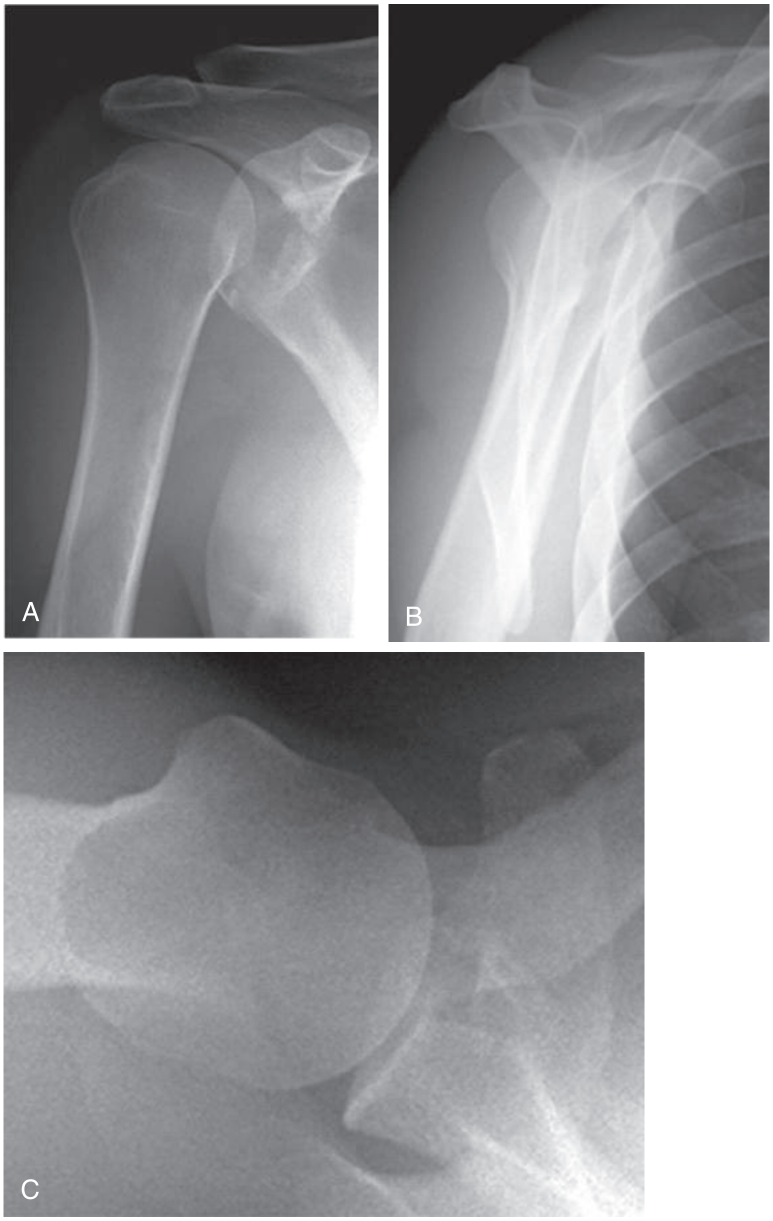


FIG. 5.3 A–C Case 1: Anterior rim fracture with concentric reduction treated nonoperatively.

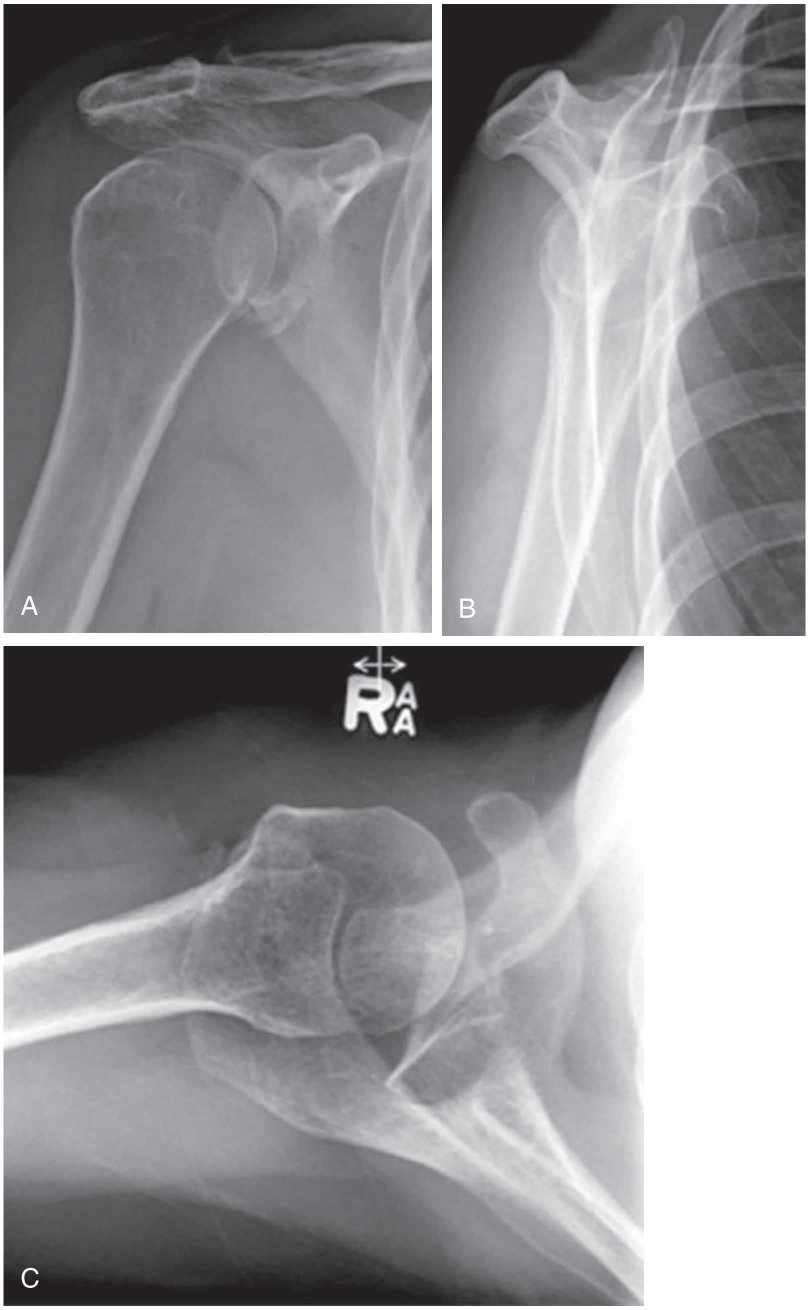


FIG. 5.4 A–C Case 2: Anterior rim fracture with persistent subluxation.

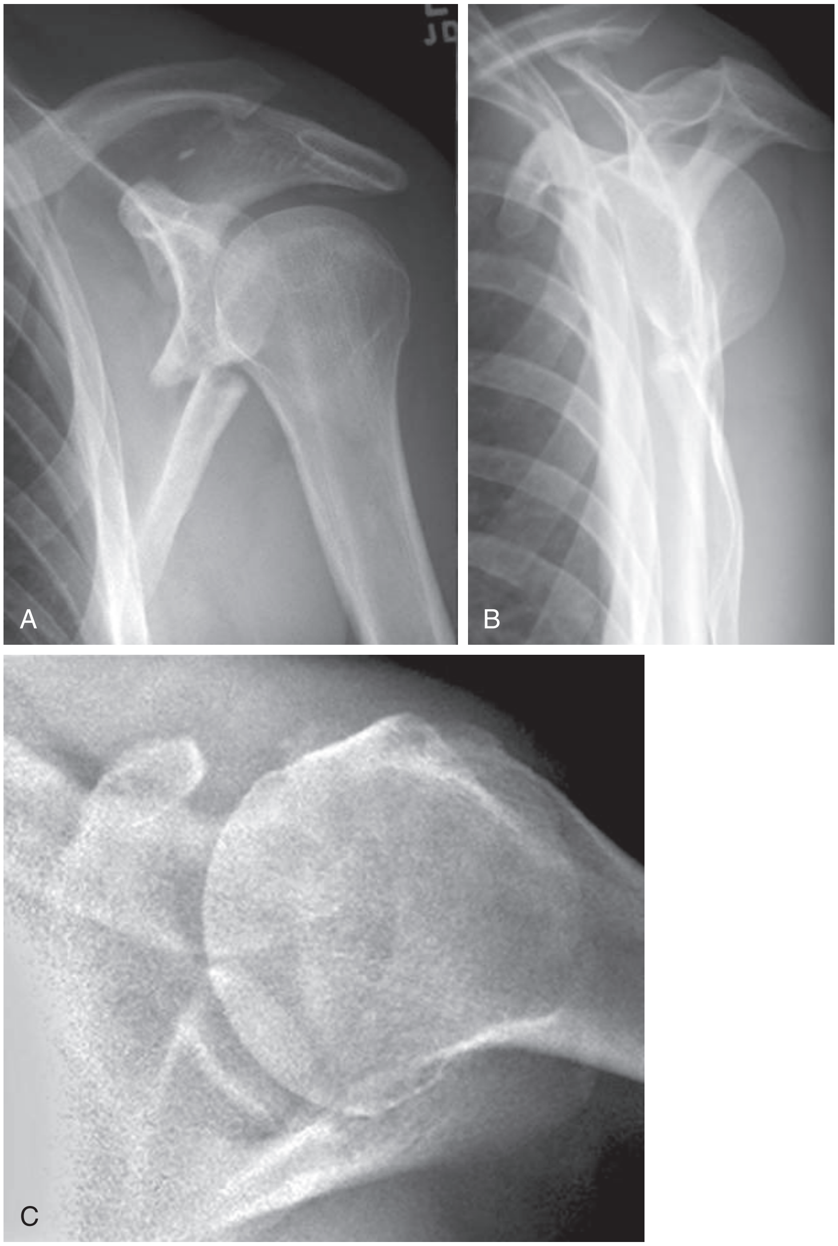


FIG. 5.5 A–C Case 3: Glenoid neck fracture with medialization and angulation. Previous AC joint injury with distal clavicle resection.

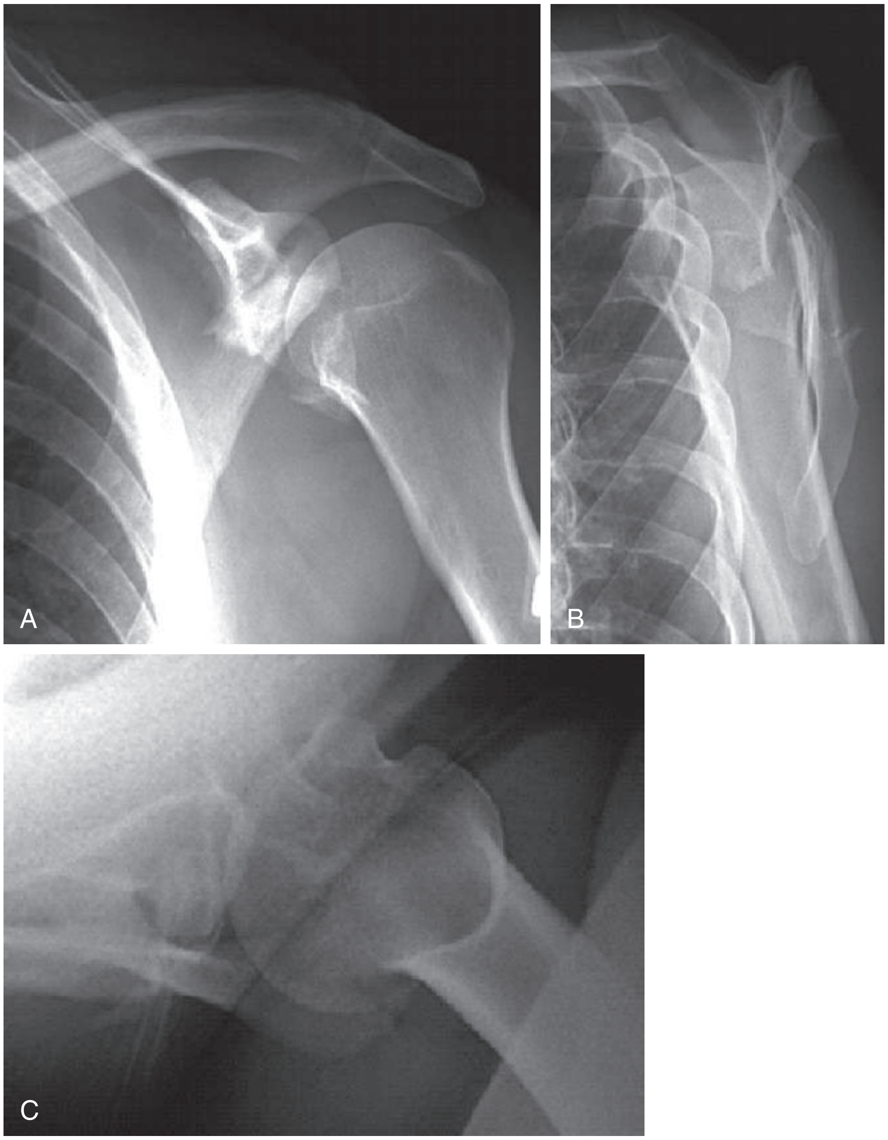


FIG. 5.6 A–C Case 4: Intraarticular glenoid fracture (type Va), which does not involve the scapular body.

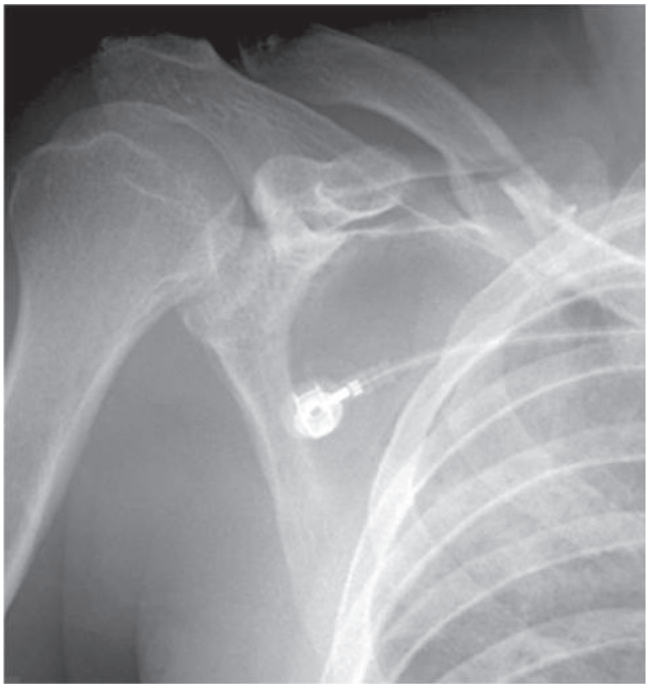


FIG. 5.7 Case 5: Type III glenoid fracture: transverse glenoid fracture involving superior glenoid fragment attached to the coracoid process. Associated clavicle fracture.

Computed Tomography and Magnetic Resonance Imaging

- Two-dimensional CT reconstruction may be useful in preoperative assessment if done in orthogonal planes to the glenoid to assess fragments and their relative displacement.
  - Fig. 5.8A–C shows two-dimensional CT views in sagittal and coronal planes of the large anterior rim injury sustained by the skimboarder in Case 2.
  - Fig. 5.9A–D shows two-dimensional CT views in axial and sagittal planes of the type III injury sustained by the triathlete in Case 5.
- Axial CT slices with three-dimensional reconstruction are the most useful modality in fracture assessment and preoperative planning. Health care centers could decide to make these part of chest trauma CT studies (time, resource utilization, radiation minimization).
  - Fig. 5.10A–B shows three-dimensional CT views of the small anterior rim injury sustained by the 63-year-old accountant in Case 1.
  - Figs. 5.11–B shows three-dimensional CT views of the large anterior rim injury sustained by the skimboarder in Case 2.
  - Fig. 5.12 shows a three-dimensional CT view of the extraarticular glenoid neck/body fracture sustained by the mountain biking electrician in Case 3.
  - Fig. 5.13 shows three-dimensional CT views of the type Vc injury sustained by the bicyclist. Note the separation between the inferior and superior glenoid fragments and the separate scapular spine and lateral clavicle fractures.
- Magnetic resonance imaging may be of value in detecting associated rotator cuff tears or ligament injuries; however, it is often not practical in an acute trauma setting.

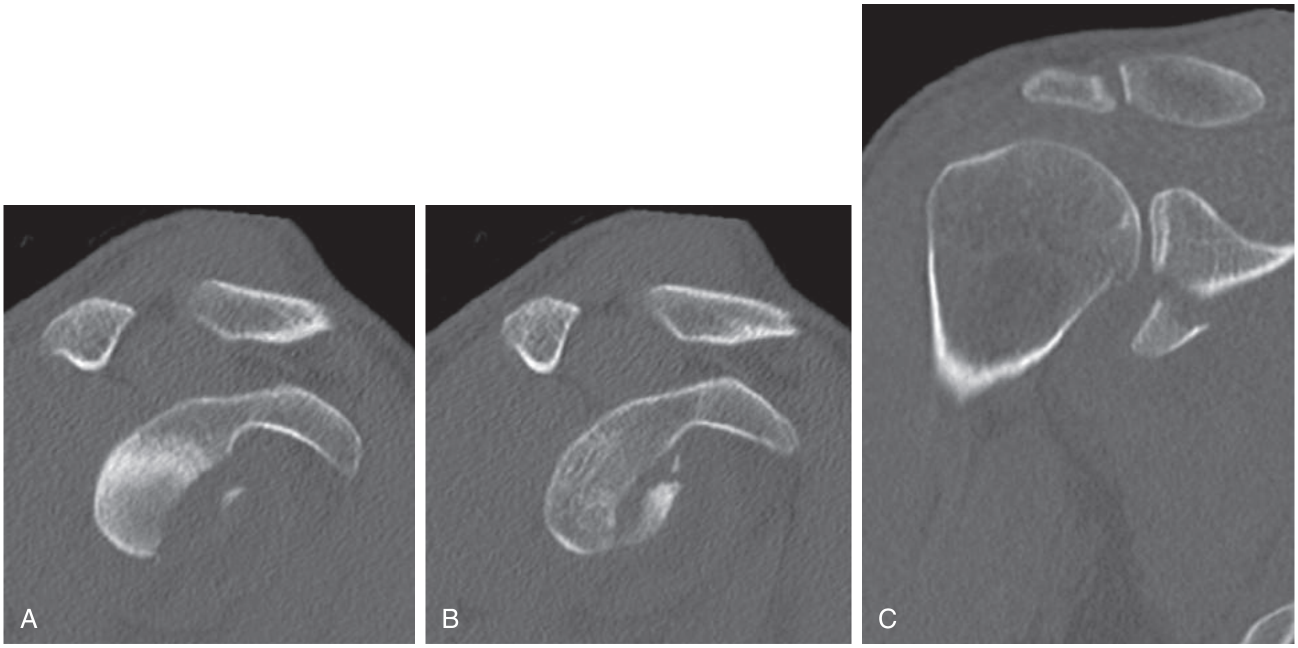


FIG. 5.8 A–C

FIG. 5.9 A–D

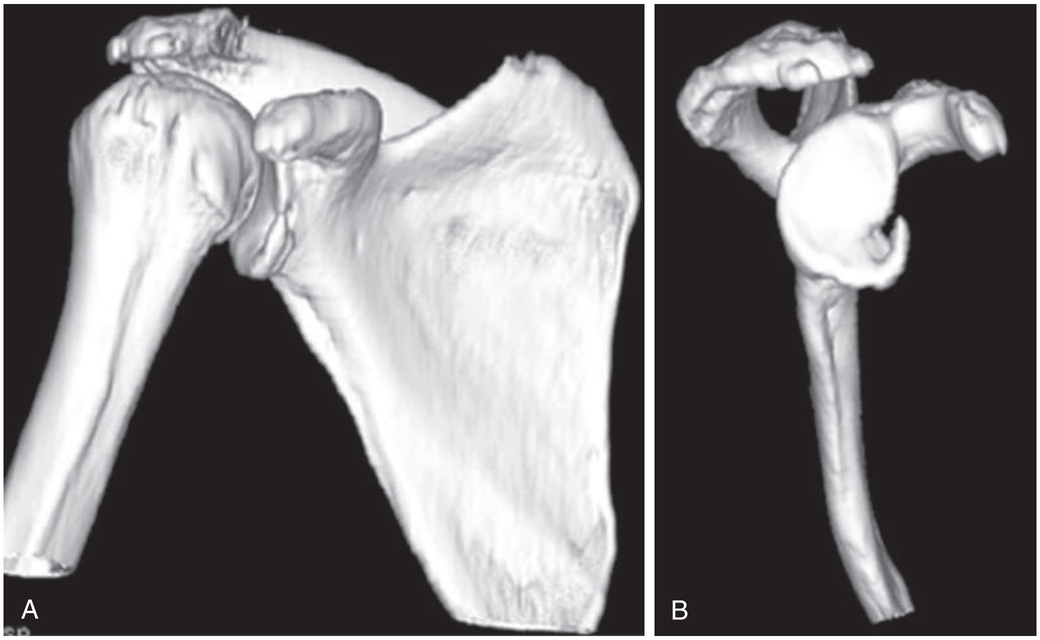


FIG. 5.10 A–C

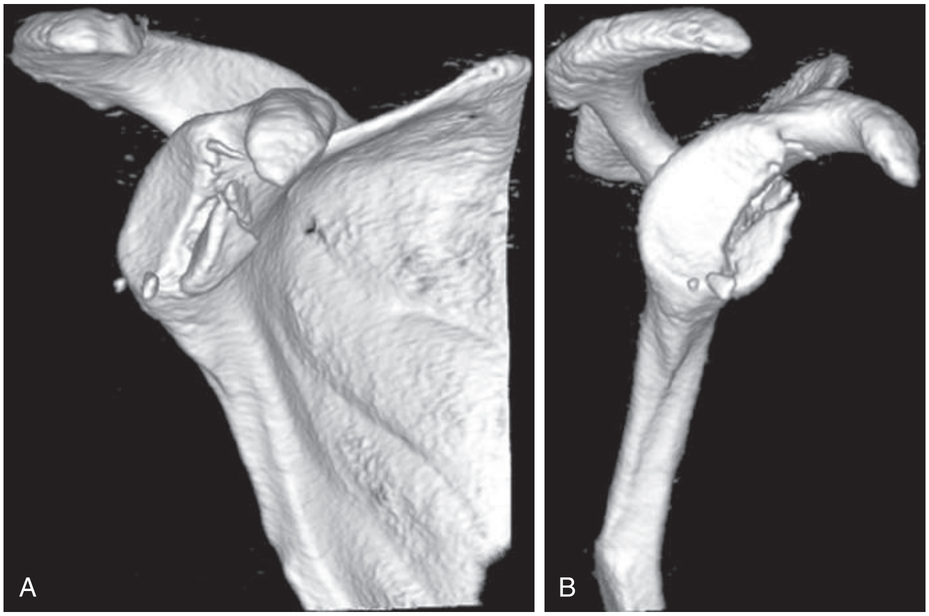


FIG. 5.11 A–B

FIG. 5.12

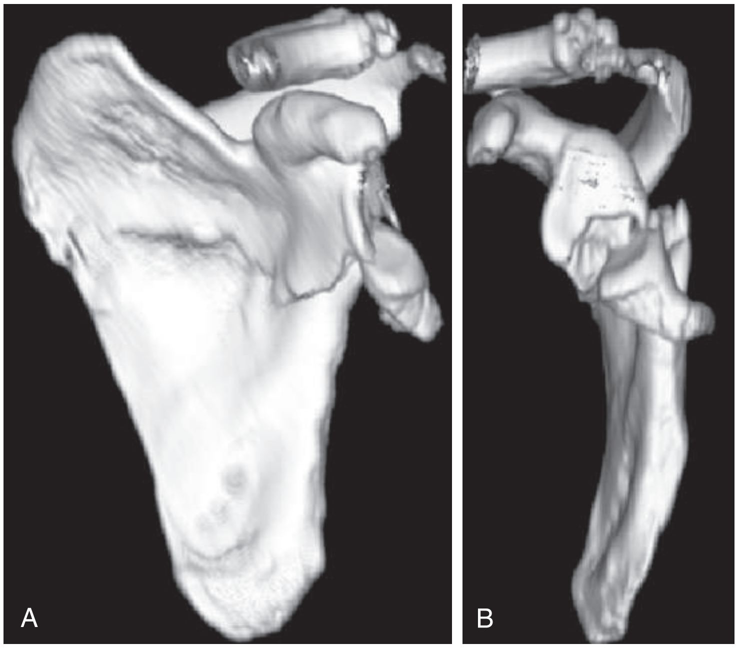


FIG. 5.13 A–B This shows three-dimensional CT views of the type Vc injury sustained by the bicyclist. injury sustained by the bicyclist.

FIG. 5.14 Modified from Mallon WJ et al. Radiographic and geometric anatomy of the scapula. *Clin Orthop Relat Res.* 1992;(277):142–154.

Classification of Glenoid Fractures

- Important for surgical decision making
- Scapular fractures can reliably be divided into three segments: fossa, body, and processes (Harvey et al., 2012) with body fractures to include "scapular neck" fractures. Typical patterns combining these segments are subclassified by groupings defined by Goss (1992, 1994).

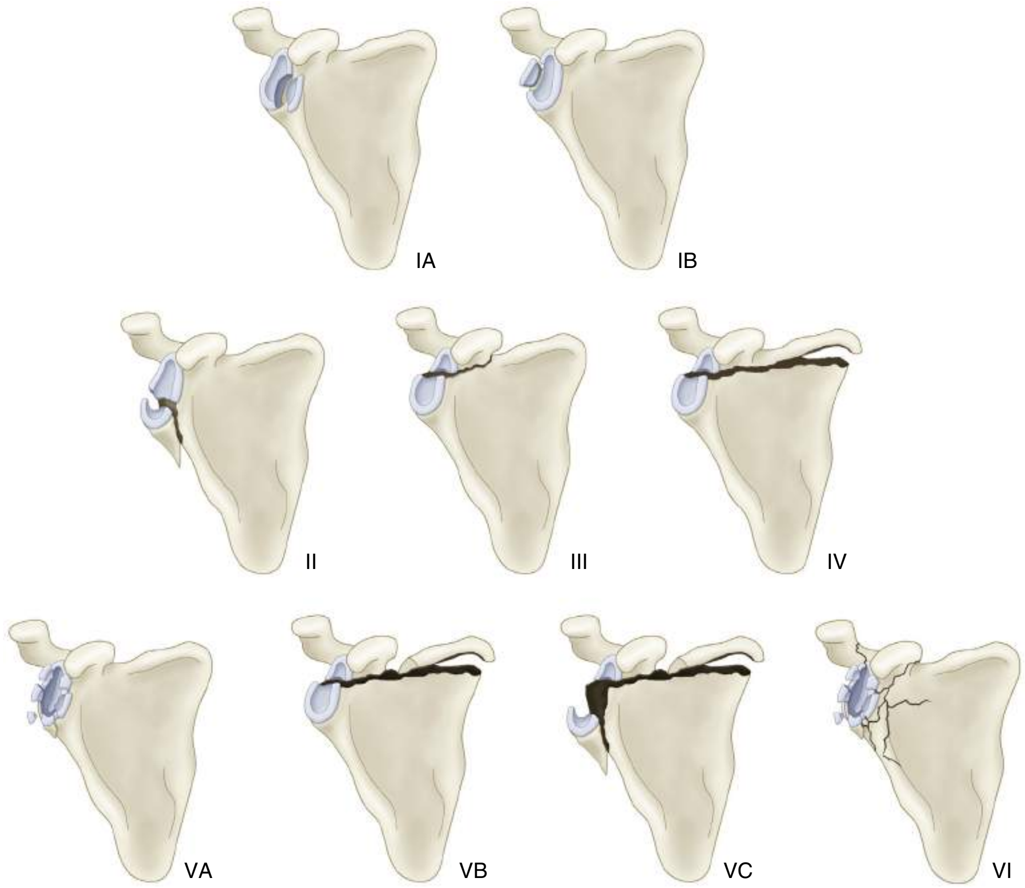


FIG. 5.15 Fossa fractures. Modified from Goss TP. Fractures of the glenoid cavity, *J Bone Jont Surg [Am]*, 1992; 74:299–305.

- Glenoid fossa fractures (intraarticular)
  - Goss (1992, 1995) modified the original Ideberg classification, which is useful in planning approaches.
  - Types of glenoid fossa fractures (Fig. 5.15):
    - Glenoid fossa fractures (Fig. 5.15)
    - IA—anterior rim fracture; IB—posterior rim fracture
    - II—fracture line through the glenoid fossa exiting at the lateral border of the scapula
    - III—fracture line through the glenoid fossa exiting at the superior border of the scapula
    - IV—fracture line through the glenoid fossa exiting at the medial border of the scapula
    - Va—combination of types II and IV; Vb—combination of types III and IV; Vc—combination of types II, III, and IV. Note the separation of superior and inferior components in type Vc.
    - VI—extensively comminuted fracture

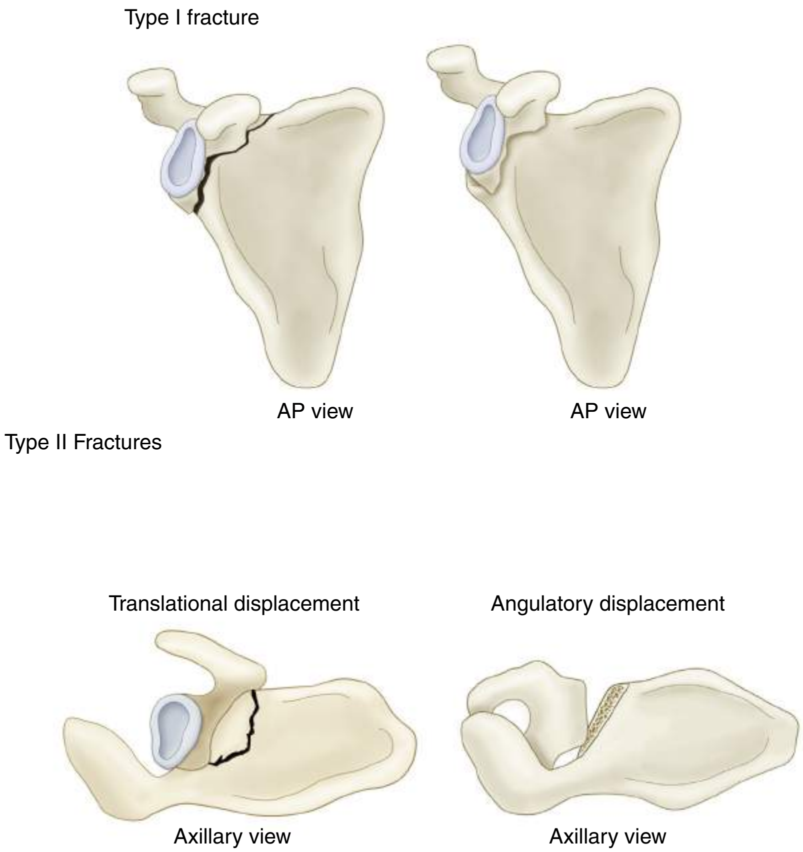


FIG. 5.16 Neck fractures. Modified from Goss TP. Fractures of the glenoid cavity, *J Bone Jont Surg [Am]*, 1992;74:299–305.

- Glenoid neck/body fractures (extraarticular) (Fig. 5.16)
  - Their typical displacement is translation of the glenoid toward the midline (or relative lateralization of the scapular body) with angulation in the transverse and coronal planes of the articular segment.
  - Indications for open reduction and internal fixation (ORIF) are based on Ada and Miller's (1991) recommendations and follow Goss's classification (1994) of glenoid neck fracture displacement (translation and angulation).
    - Type I includes all minimally displaced fractures.
    - Type II includes all significantly displaced fractures (translational displacement ≥ 1 cm; angulatory displacement ≥ 40°).
  - Of note, some relative lateral translation of the lateral border of the scapula to the glenoid may contribute to the apparent medial translation of the glenoid (Patterson et al., 2012; Zuckerman et al., 2012).
- Process fractures
  - These fractures occur on their own or in combination with fossa and body fractures.
  - Most isolated process fractures are treated nonoperatively. Note that isolated coracoid fractures are frequently associated with a glenohumeral dislocation.
  - Acromion fractures, when significantly displaced, can be treated operatively to avoid abduction impingement (Fig 5.26 A–B (Case 6)

TREATMENT OPTIONS

- Nonoperative treatment is advocated for undisplaced/minimally displaced fractures when the humeral head preserves its concentric alignment with the glenoid fossa (Maquieira et al., 2007). Additionally, severely comminuted unreconstructible fractures (when stable fixation cannot be expected) and cases in which no functional use of the limb is expected can be treated nonoperatively.
- Operative care includes open techniques, closed reduction and percutaneous fixation techniques, and arthroscopically assisted techniques.

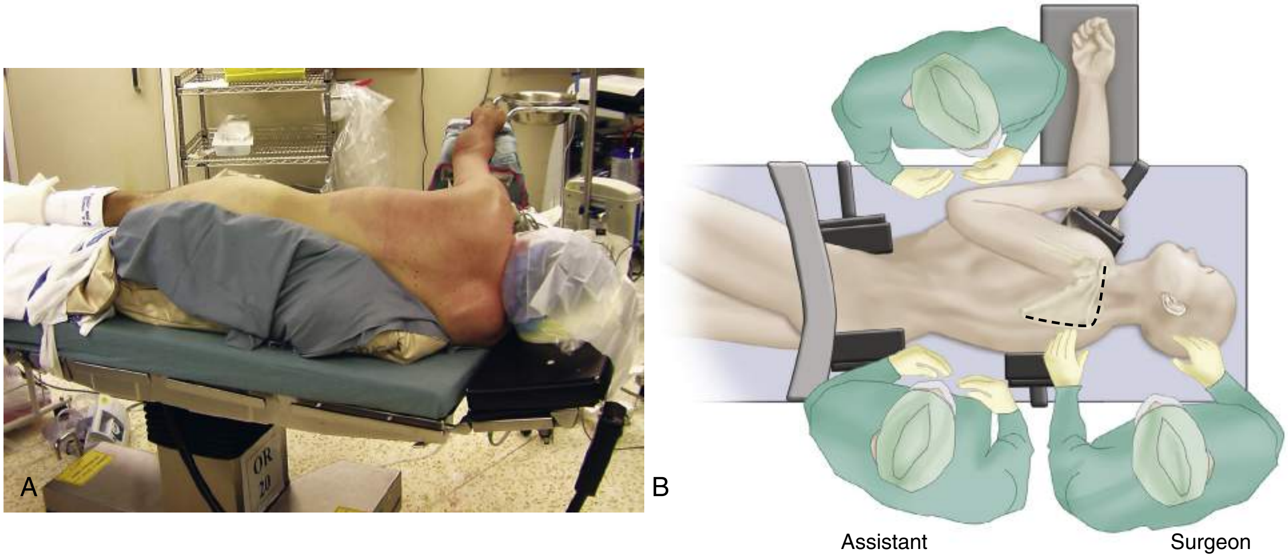


FIG. 5.17 A–B

SURGICAL ANATOMY

- Bony anatomy
  - Internal fixation is limited by the osseous anatomy of the scapula, which is mostly thin.
  - The thick regions suitable for internal fixation are the glenoid process, coracoid process, acromion/scapular spine, and lateral border of the scapular body (Fig. 5.14).
- Soft-tissue anatomy
  - The scapula is covered by muscle and surrounded by nervous and vascular structures. These must be avoided, protected, and/or mobilized during the surgical dissection.
- Associated injuries to the acromioclavicular joint (acromioclavicular ligament, coracoclavicular ligaments) may require repair. Associated injuries to the rotator cuff should be suspected in older patients with an associated glenohumeral dislocation.

POSITIONING

- Posterior approach
  - The prone or lateral decubitus position with the operative side up may be used.
  - The lateral decubitus position is favored in most trauma patients.
    - Fig. 5.17A shows a patient in the lateral decubitus position on a beanbag for a planned posterior approach and the use of a Mayo stand to support the operated arm.
    - Fig. 5.17B shows the use of table-based positioners and the position of the surgical team.
- Anterior approach: beach chair position
  - Arthroscopic surgery: beach chair or lateral decubitus position with traction and slight shoulder abduction and flexion

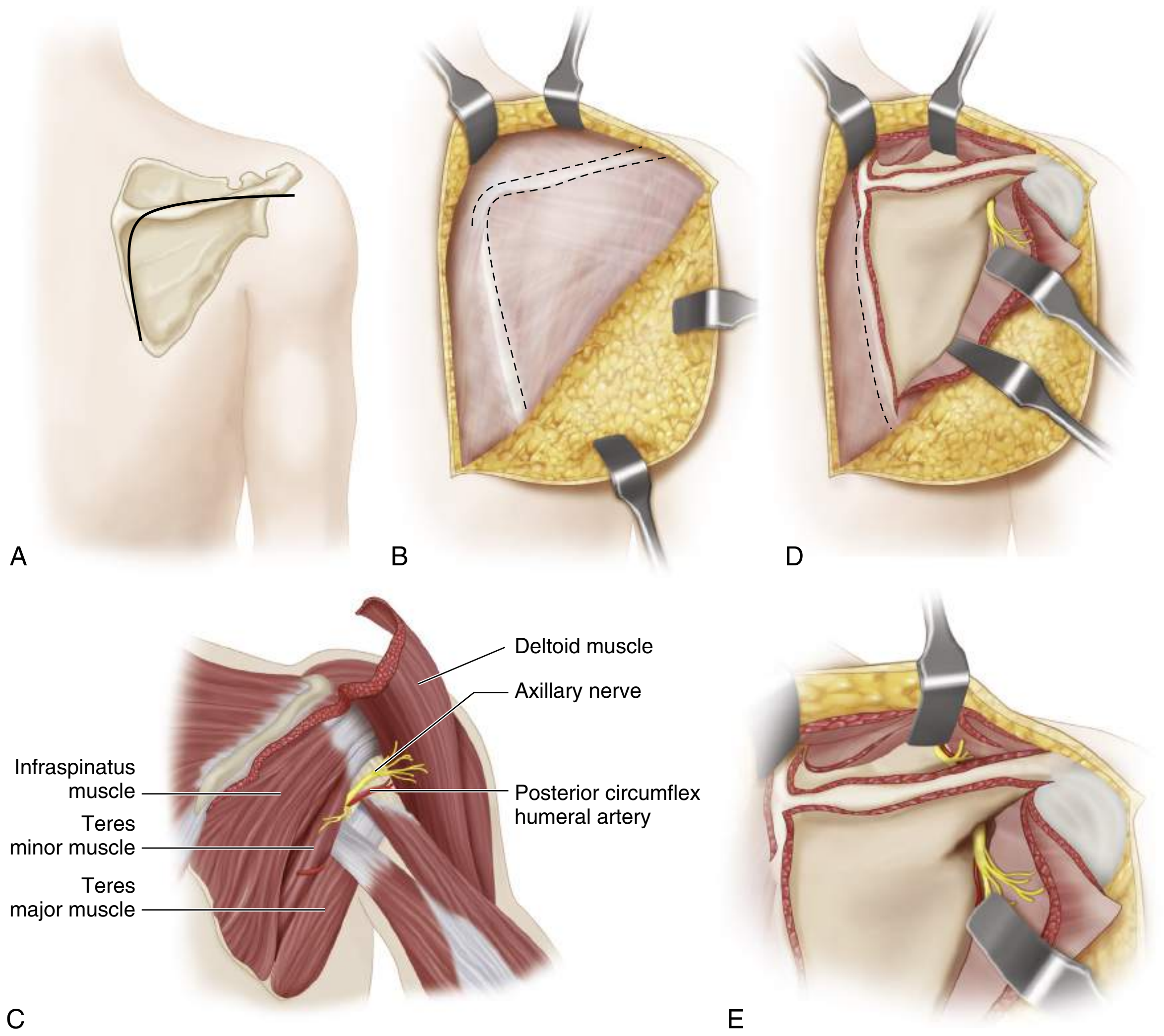


FIG. 5.18 A–E

PORTALS/EXPOSURES

- The choice of the approach depends on the type of fracture.
  - Type IA fractures may be approached anteriorly or arthroscopically.
  - The other glenoid fossa fracture types and operatively treated glenoid neck fractures are preferably approached posteriorly, supplemented by a superior approach for lag screw fixation for transverse fossa fractures as needed.
  - Isolated type III fractures may be reduced indirectly percutaneously and fixed by percutaneous superior-to-inferior screw placement (see Fig. 5.20 in the following ORIF procedure).
  - Process fractures: Acromion fractures are easily approached from the lateral decubitus. If treated operatively, isolated coracoid fractures are best approached anteriorly (see Fig. 5.26 Case 6).
- Posterior approach
  - Two posterior surgical approaches have been described for ORIF of glenoid fractures.
    - Extensile exposure described by Judet (author's preferred approach; see Video 1)
      - The skin incision extends from the posterolateral acromion angle along the whole length of scapular spine to the superomedial corner, then curves distally along the medial border of the scapula (Fig. 5.18A).

PEARLS

- Final position should allow safe access to the approached side (posterior or anterior) and the injuries planned for fixation (e.g., scapula alone vs. scapula + clavicle), allow limb mobilization and adequate intraoperative imaging, and should be decided in concert with other consultants (anesthesiologists, spine surgeons, neurosurgeons, and general surgeons) given the frequent associated additional injuries.

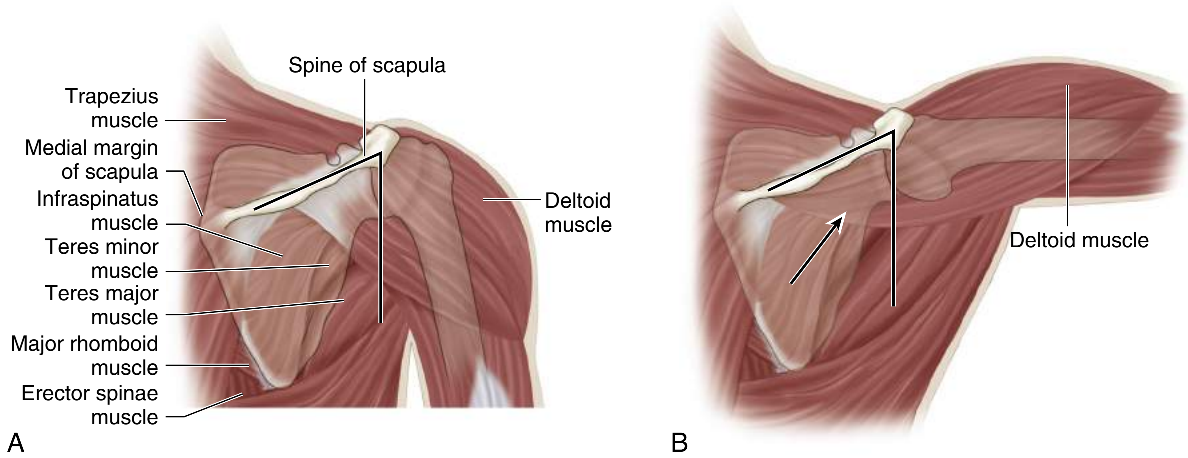


FIG. 5.19 A–B

- A skin flap is then elevated, exposing the posterior deltoid and infraspinatus muscles (Fig. 5.18B).
- The deltoid-infraspinatus muscle interval is then developed and the posterior deltoid is sharply detached from the lateral scapular spine to its tip (Fig. 5.18C; see also Video 1).
- The safe infraspinatus–teres minor interval (respectively supplied by the suprascapular and axillary nerves) can then be developed, exposing the lateral border of the scapula to the inferior aspect of the glenoid and safely freeing the infraspinatus for further dissection (Zuckerman et al., 2012) (Fig. 5.18D–E).
- The infraspinatus and teres minor muscle bellies are then detached from the medial border of the scapula and from the infraspinatus fossa (author's preferred approach; Fig. 5.18D-E).
- The infraspinatus is carefully reflected laterally and superiorly, keeping it moist and avoiding traction to its neurovascular pedicle originating from the spinoglenoid notch (Fig. 5.18E). Also, note that the supraspinatus should be elevated carefully.
- A posterior arthrotomy can help in monitoring articular reduction.

- The limited posterior approach (popularized by van Noort) (Fig. 5.19).
  - An alternative to Judet's exposure, avoiding elevation of the infraspinatus, was described by van Noort et al. (2004): "An angular incision is made, starting medially along 2⁄3 of the scapular spine, then curving 2 cm medial from the posterior edge of the acromion and proceeding caudad for 10 cm . . . By abducting the arm 90 deg, the inferior border of the deltoid is raised, which allows easy retraction" (Fig. 5.19A–B).
  - Minimal release of its medial attachment to the scapular spine may be needed.
  - The plane between the infraspinatus and teres minor muscles, respectively supplied by the suprascapular and axillary nerves, is developed, exposing the lateral border of the scapula to the inferior aspect of the glenoid.
  - A small posterior glenohumeral vertical arthrotomy is then made to allow joint visualization.
  - A retractor is inserted into the joint to retract the humeral head anteriorly.

EQUIPMENT

- A conventional operating table with beanbag stabilization is suitable for management of most fractures, allowing surgical access to all injuries and intraoperative imaging (see Fig. 5.17).
- A well-padded Mayo stand is used as a mobile adjustable armrest for the operated limb (see Fig. 5.17).

PITFALLS

- Care must be taken to avoid nerve injuries: the suprascapular, axillary, and XIth cranial accessory nerve in a posterior exposure and the brachial plexus and artery axillary in an anterior exposure. Converting to a more extended approach may be necessary to relieve nerve tension.
- One concern with the more limited posterior approach, which abducts the arm at 90°, is that this places the axillary nerve more lateral and closer to the surgical site.
- Fluid extravasation during arthroscopically assisted procedures should be monitored closely.