Traumatic Shoulder Injuries: A Force Mechanism Analysis of Complex Injuries to the Shoulder Girdle and Proximal Humerus

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OBJECTIVE. Acute shoulder trauma can result in complex injuries to the bone and soft-tissue structures of the shoulder girdle with the associated risk of development of shoulder girdle instability. Destabilizing injuries to the shoulder girdle and fractures of the proximal humerus can occur in predictable patterns based on the injury mechanism. The objectives of this article are to illustrate the relevant anatomy of the shoulder, use 3D modeling and animation to aid in a mechanistic understanding of some of the most common injury patterns, discuss the most relevant radiologic findings that determine the ultimate treatment approach, and discuss an approach to imaging diagnosis with attention to the common treatment strategies.

CONCLUSION. Understanding the force mechanisms responsible for the most common patterns of traumatic shoulder girdle injuries and proximal humeral fractures can improve detection of associated clinically significant secondary injuries, increase the effectiveness of injury classification, and ultimately direct appropriate and timely intervention.

Traumatic shoulder injuries are commonly encountered, and initial imaging of these injuries should primarily be aimed at identification of findings that may necessitate emergency surgical intervention. Equally important is the recognition of injuries that may result in functional instability and that may predispose the patient to delayed complications in the absence of timely and appropriate intervention. Injuries to the bone and soft-tissue structures of the shoulder girdle and proximal humerus can result in substantial functional impairment. Many of these injuries occur in consistent and recurrent patterns that correlate with the mechanism of injury. Understanding these mechanisms and injury patterns can improve the radiologist’s awareness of possible associated injuries, resulting in a more clinically effective imaging diagnosis and appropriate therapeutic strategy.

Radiographs are routinely obtained in the acute evaluation of shoulder trauma and can be supplemented with cross-sectional modalities such as CT and MRI in the acute and subacute phases. Knowledge of the most common injury mechanisms and their corresponding injury patterns may enable the radiologist to more appropriately direct timely follow-up cross-sectional imaging. This article serves to illustrate the relevant anatomy of the shoulder with an emphasis on the stabilizing structures of the shoulder girdle, describe the most commonly encountered mechanisms of injury and associated injury patterns seen in traumatic shoulder girdle injuries and proximal humeral fractures through the use of 3D modeling and animation, describe the findings and patterns of injuries identified with the various imaging modalities, and discuss how timely detection of these associated injuries may guide the optimal therapeutic strategy in preventing long-term disability.

Shoulder Girdle Stability

The shoulder is composed of the glenohumeral articulation and the shoulder girdle, which is made up of the scapula and clavicle and multiple ligaments (Figs. 1 and 2). Stability of the shoulder girdle is provided by a group of structures termed the superior shoulder suspensory complex (SSSC), which comprises two bony struts, the clavicle, and the lateral scapula linked by suspensory ligaments to form a bony and soft-tissue ring [1]. Instability most commonly results from damage to the scapular neck and lateral body, the coracoid and acromion processes, the distal clavicle, and the intervening acromioclavicular and coracoclavicular ligaments [1–3] (Fig. 3). Single disruptions of the SSSC ring are usually well tolerated and can be treated conservative-
ly, but injuries to two or more structures can have varying degrees of instability, often requiring surgical treatment [1]. Double disruptions can occur in the form of two fractures, two ligamentous injuries, or a combined fracture and ligamentous injury. For example, secondary stabilization of the shoulder girdle can be provided by the coracocromial ligament in the case of isolated fractures of the coracoid or acromion processes, but double disruptions involving either both processes or a single process with coracocromial ligament injury will result in instability [1, 3].

Injuries to the shoulder girdle can have multiple mechanisms but are most commonly caused by a direct lateral compressive impact, typically from falling onto the shoulder with the arm adducted [4–6]. In a lateral impact, the shoulder girdle is subjected to a compressive force that is transmitted medially through the acromioclavicular joint, the shaft of the clavicle, and finally to the sternoclavicular joint [7] (Fig. 4). With sufficient lateral compression, the integrity of the clavicle and its articulations at the acromioclavicular and sternoclavicular joints may be compromised, resulting in injury. Indirect or complex mechanisms can also produce shoulder girdle and proximal humerus injuries. These mechanisms can result from strong contractions of the shoulder musculature and from axial, rotational, or translational momentum of the body about the shoulder, typically occurring during a fall onto an outstretched hand (FOOSH). What follows is a discussion of specific injuries grouped according to the most common mechanisms.

**Lateral Impact Injuries**

**Shoulder Separation and Acromioclavicular Dislocation**

Anatomy and mechanism of injury—The acromioclavicular joint is a synovial joint between the lateral surface of the clavicle and the medial surface of the acromion. The joint is stabilized by the acromioclavicular and coracoclavicular ligaments, the latter of which comprises the conoid and trapezoid ligaments, and is reinforced by the deltoid and trapezius muscles. The distal end of the clavicle normally exhibits slight superior displacement relative to the acromion [8]. Direct lateral impact on the acromion with the shoulder adducted produces a medially directed compressive force that tends to push the acromion inferiorly and anteriorly relative to the clavicle owing to the natural angulation of the joint [4, 9] (Fig. 5). (Fig. S5, a video, can be viewed by clicking “Supplemental” at the top of this article and then clicking the figure number on the supplement page.) This compression stresses the acromioclavicular and coracoclavicular ligaments in proportion to the force of the lateral impact, potentially resulting in acromioclavicular joint separation. Less common mechanisms of acromioclavicular joint separation include direct inferiorly oriented impact on the clavicle with resulting inferior clavicular displacement with respect to the acromion [10]. Indirect mechanisms relating to a FOOSH type injury are less typical [4].

Classification and management—Acromioclavicular joint injuries are categorized most commonly according to the Rockwood classification system, which is based primarily on the degree of damage to the acromioclavicular and coracoclavicular ligaments and the corresponding direction and magnitude of clavicular displacement [5] (Fig. 6). The choice of treatment strategy relies in part on correct classification. Uncomplicated type I and II injuries can be treated conservatively with nonoperative management [11, 12]. Type IV–VI injuries typically require operative management because of substantial dislocation and associated soft-tissue injuries [11, 13, 14].

The management of type III injuries remains controversial. Though primary surgical repair has been reported to benefit younger patients with high functional demands, such as athletes [13], studies have shown similar success with conservative treatment of these patients [15]. Meta-analyses have concluded that a lack of well-designed studies precludes de-
Definitive treatment recommendations for type III acromioclavicular dislocations. The available data suggest that compared with nonsurgical treatment, surgical repair results in greater duration of sick leave and increased risk of complications with no appreciable functional or symptomatic improvement aside from cosmetic results [16–19]. Surgery may benefit patients with persistent pain or disability after a trial of conservative management [11, 15, 20].

Imaging—Initial imaging should be optimized to identify or infer acromioclavicular and coracoclavicular ligament injury and clavicle position to determine classification and subsequent treatment strategy. Radiography with frontal views obtained at 10°–15° cephalic angulation is usually sufficient for first-line imaging of suspected acromioclavicular joint injuries [5, 9]. The normal acromioclavicular joint width is 1–3 mm with a tendency to decrease with age. A width greater than 7 mm in men and greater than 6 mm in women is generally accepted as pathologic [5, 21]. The coracoclavicular space, the distance from the superior aspect of the coracoid to the inferior margin of the clavicle, is normally approximately 11–13 mm; however, this measurement can vary with projection and positioning. Use of bilateral views can help differentiate pathologic from anatomic variation: A coracoclavicular space difference of 25–100% between the symptomatic and contralateral asymptomatic side corresponds with disruption of the coracoclavicular ligament [5, 22].

Type I injuries have essentially normal radiographic findings but with possible soft-tissue swelling. Type II injuries exhibit widening of the acromioclavicular distance compared with the contralateral unaffected side but normal and symmetric coracoclavicular spaces. In type III injuries, there is widening of the acromioclavicular distance and a 25–100% increase in the coracoclavicular space compared with the unaffected contralateral side with apparent relative superior displacement of the clavicle (Fig. 7). However, with respect to the contralateral shoulder, the clavicles are at the same level; inferior displacement of the scapula and the entire upper extremity on the injured side causes the apparent relative superior displacement of the clavicle [5].

Weight-bearing views are likely of limited utility in differentiating type II and III injuries [23]. Fractures of the distal clavicle or the medial acromion process can occur in lieu of torn coracoclavicular ligaments and thus warrant scrutiny in patients with acromioclavicular distance widening with an apparently normal coracoclavicular space. These fractures are clinically equivalent to type III injuries in their contribution to SSSC instability [1, 5, 24]. Coracoid process fractures are often radiographically occult.
The diagnosis of type IV injury requires widening of the acromioclavicular distance with variable coracoclavicular space widening but notable posterior clavicular displacement. Posterior displacement is often best seen on axillary radiographs or on cross-sectional images. Type V injuries are diagnosed if there is gross widening of the acromioclavicular and coracoclavicular spaces with a coracoclavicular space increase of 100–300% relative to the contralateral unaffected side and increased inferior scapular displacement due to tearing of the deltotrapezius fascia [14]. Diagnosis of type VI injury requires acromioclavicular distance widening with a relative decrease in the coracoclavicular space and apparent inferior displacement of the distal clavicle.

Although not typically indicated for acromioclavicular joint injuries, CT may be helpful for assessment of a possible occult fracture and for evaluation of radiographically ambiguous clavicle positioning [25, 26]. Use of MRI improves visualization of acromioclavicular and coracoclavicular ligament injury through direct identification of ligament disruption, identification of related blood or edema, or identification of a radiographically occult clavicle or coracoid process fracture [9, 24] (Fig. 8). MRI can thus potentially be used to differentiate type II from type III injuries in patients with an indeterminate radiographic diagnosis and can improve the

![Fig. 6](image)

**A.** Type I, acromioclavicular ligament sprain.
**B.** Type II, acromioclavicular ligament tear with coracoclavicular ligaments intact.
**C.** Type III, acromioclavicular and coracoclavicular ligament tears with mild relative superior clavicular displacement.
**D.** Type IV, acromioclavicular and coracoclavicular tears with posterior displacement of clavicle, which is commonly trapped in deltotrapezius fascia and is irreducible.
**E.** Type V, acromioclavicular and coracoclavicular tears with marked superior displacement of clavicle.
**F.** Type VI, acromioclavicular and coracoclavicular tears with inferior displacement of clavicle, which comes to rest in subcoracoid or subacromial position.

![Fig. 7](image)

**Fig. 7**—33-year-old woman after fall. Bilateral frontal radiographs of shoulders show normal-appearing right acromioclavicular joint (yellow arrow) with no gross widening of coracoclavicular interval (yellow dashed line). In contrast, there is moderate widening of left acromioclavicular joint (red arrow) with 50–100% superior displacement of left clavicle and concomitant widening of left coracoclavicular interval (red dashed line), findings consistent with type III acromioclavicular separation.
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diagnosis of fracture equivalents to the type III injury pattern that may similarly destabilize the SSSC. Additional soft-tissue injuries, such as puncturing or tearing of the trapezius or deltoid muscles in type III and more severe injuries are also well visualized on MR images, but the utility of routine imaging of these structures has not been established [24].

Clavicular Fractures

Anatomy and mechanism of injury—The clavicle serves as the primary osseous strut between the sternum and the scapula, articulating medially with the sternal manubrium and laterally with the acromion of the scapula [6, 7]. The clavicle also serves as the attachment sites of the trapezius, deltoid, sternoclavicular, sternohyoid, and pectoralis major muscles and the coracoclavicular ligament. The clavicle improves the power and stability of the arm and shoulder, particularly in overhead motion. Serious functional deficits from clavicular injury or surgical removal of the clavicle have been reported [27].

Clavicular fractures account for approximately 2–4% of all fractures and 35–45% of shoulder girdle injuries [28, 29]. Clavicular fractures most often follow a lateral impact on the shoulder, where an axial compressive force acts along the shaft of the clavicle. The fractures occur in multiple locations along the shaft [4, 6] (Fig. 9). (Fig. S9, a video, can be viewed by clicking “Supplemental” at the top of this article and then clicking the figure number on the supplement page.) Distal fracture fragment displacement is most commonly inferior owing to downward pull from the weight of the shoulder and simultaneous upward pull on the proximal fragment by the sternoclavicular ligament [7]. Less common mechanisms of clavicular fractures are direct impact on the shaft and indirect FOOSH mechanisms [4, 6].

Classification and management—Clavicular fractures are classified according to the Allman system, in which injury regions are divided into thirds. Group I fractures involve the middle third of the clavicle and comprise approximately 80% of clavicle fractures. Group II fractures involve the distal clavicle, beginning at the medialmost attachment of the coracoclavicular ligaments. Group III fractures involve the proximal third of the clavicle, beginning at the mediallymost attachment of the coracoclavicular ligaments. Group III fractures are divided into five subtypes according to the Neer classification with the Craig modification and are based on degree of comminution and the integrity of the coracoclavicular ligaments and the acromioclavicular joint [31, 32] (Fig. 11).

General indications for primary surgical reduction and fixation include fractures with frag-
ment displacement greater than 100% of the clavicular width with unopposed fracture fragments, tissue interposition that prevents closed reduction, greater than 2 cm foreshortening, open or impending open fractures, neurovascular compromise, severe deformity, the presence of associated complete compromise of the acromioclavicular and coracoclavicular ligaments, and unstable scapular fractures [7, 27, 33, 34]. For fractures not meeting the general surgical criteria, treatment strategy depends in part on classification.

Group I fractures are traditionally treated conservatively. Meta-analyses have shown higher than expected rates of nonunion and symptomatic malunion with conservative treatment and a more rapid course of functional improvement with primary surgical treatment but no evidence of clinically significant long-term functional deficit with primary conservative therapy [29, 35]. However, patients with group I fractures with marked displacement or comminution gain the earliest symptomatic benefit from primary surgical fixation [33, 36].

Management of group II fractures depends in part on appropriate subtype classification (Fig. 11). Critical factors in determining treatment strategy include the degree of fracture displacement and comminution, and the integrity of the coracoclavicular ligaments [27]. If the conoid and trapezoid ligaments are intact and are attached to the medial and lateral fragments (type 1), or if the fracture is longitudinal (type 3) or takes the form of a periosteal sleeve fracture (type 4), the fracture tends to be stable with opposed fracture fragments. However, fracturing near the medial conoid margin (type 2A) and fracture with conoid disruption (type 2B) result in drooping of the scapula with apparent superior displacement of the medial fragment and poor fragment opposition [27].

Fig. 11—Computer-generated images show subclassification of group II distal clavicular fractures according to specific morphologic features. Yellow border indicates nonoperative treatment is most likely indicated but surgical repair may be warranted; red border, surgical treatment is indicated.

A, Type 1, nondisplaced interligamentous fracture without ligamentous injury.
B, Type 2A, fracture medial to coracoclavicular ligament with conoid and trapezoid ligaments intact and attached to distal fragment with possible displacement of medial fragment.
C, Type 2B, fracture on medial margin of coracoclavicular ligament with conoid disrupted but trapezoid ligament intact and attached to distal fragment with possible displacement of medial fragment.
D, Type 3, articular surface fracture with acromioclavicular joint involvement.
E, Type 4, periosteal sleeve fracture with ligaments attached to sleeve fragment.
F, Type 5, comminuted fracture with ligaments attached to inferior fragment.

Early surgical fixation of type 2 fractures has been advocated because of the reported high incidence of nonunion and functional deficits with nonsurgical or delayed surgical treatment [37–39]. Some investigators, however, question the long-term functional differences, noting relatively high operative complication rates compared with the incidence of nonunion with conservative therapy [34, 40]. Severely comminuted fractures (type 5) are also unstable and most commonly treated as type 2 injuries because of similar concern for symptomatic nonunion [33, 34]. Except for type 2 and 5 injuries, distal clavicular fractures are generally nondisplaced, stable, and treated conservatively with good functional outcome [27, 28].

Group III fractures are rare, but most are nondisplaced and traditionally respond well to conservative treatment [7, 27, 28, 30, 41]. Posteriorly displaced proximal clavicu-
lar fractures and associated posterior sternoclavicular dislocation can damage mediastinal structures, such as the great vessels and airway, and open reduction is often indicated for these rare injuries [28]. Surgical repair and resection are otherwise reserved for failed closed reduction or cases of delayed nonunion or poor functional status.

**Imaging**—Frontal and apical oblique views (up to 45° cephalic tilt) are typically sufficient for the diagnosis and classification of clavicular fractures [7]. Fracture location and degree of displacement or comminution are the most important features with regard to classification and subsequent treatment strategy. Characterization of the coracoclavicular ligament status is especially important (Fig. 12). Fractures distal to the conoid tubercle of the clavicle are likely associated with coracoclavicular ligament disruption with widening of the coracoclavicular space and fracture displacement [27]. Displaced fractures proximal to the conoid tubercle suggest ligament detachment from the medial fragment [27]. MRI can be used to detect coracoclavicular ligament injuries [14]. CT may be needed to assess proximal clavicular fractures for sternoclavicular dislocation and to evaluate the underlying structures of the neck and chest [7, 27].

**Combined-Mechanism Injuries**

**Scapular Fractures**

The scapula is a complex bone connecting the axial skeleton with the upper extremity. The 18 muscle insertions on the scapula allow six different movements about the shoulder joint. Scapular fractures are rare, accounting for 3–5% of shoulder girdle fractures and 1% of all fractures [3]. Scapular fractures generally result from injury force through either...
Fig. 14—Computer-generated images show mechanisms of intraarticular glenoid fractures. 
A, General mechanisms can be represented as force vectors (yellow arrows) producing axial loading of humerus with energy transmitted through humeral head into glenoid (red arrows) to produce fractures along incident line of force. Axial loading of humerus can occur as result of fall onto outstretched hand, among other mechanisms. More tangentially oriented vectors are thought to cause rim fractures and possible dislocation. More centrally oriented vectors are more likely to cause glenoid fossa fractures.
B, Alternative mechanism is that lateral fall (yellow arrow) onto shoulder can cause lateral compression at glenohumeral joint (red arrow) with humeral head impaction into glenoid and potential fracture.

Fig. 15—Computer-generated images show intraarticular glenoid fracture classification according to Ideberg system with Goss modification. Yellow border indicates nonoperative treatment is most likely indicated but surgical repair may be warranted; red border, surgical treatment is indicated.
A, Type Ia, fracture of anterior glenoid rim.
B, Type Ib, fracture of posterior glenoid rim.
C, Type II, transverse or oblique fracture through glenoid fossa and scapular neck with displaced inferior triangular fragment in articulation with humeral head.
D, Type III, fracture through glenoid fossa and superior scapular margin, often with associated acromioclavicular dislocation.
E, Type IV, horizontal fracture extending through glenoid fossa, scapular blade, and medial border.
F, Type Va, separation of inferior glenoid fossa from superior scapula with transverse fracture through superior scapular margin.

(Fig. 15 continues on next page)
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Direct impact or lateral compressive injury. Scapular fractures can also be caused by indirect forces via axial transmission through the humerus or secondary to muscular or ligamentous traction [2]. Scapular fractures most commonly result from high-impact trauma and are associated with serious bony or soft-tissue injuries in 80–95% of cases, including pneumothorax, hemothorax, pulmonary injuries, and spinal injuries [3].

The complex anatomy of the scapula makes a simple unified classification scheme difficult to define. Fractures are thus generally classified according to anatomic area and force through the humeral head to the glenoid cavity. Injuries are located along the course of this incident force vector [2, 3, 43] (Fig. 14). Glenoid fractures are classified according to the Ideberg system with the Goss modification, which includes six fracture types [2, 3, 43] (Fig. 15). Type I fractures are true glenoid rim fractures, but types II–VI are glenoid fossa fractures with varying extension through the scapular body. Glenoid fractures are treated conservatively in 90% of cases, which have minimal displacement and angulation [43]. Type I fractures are most common, and though glenoid rim injuries are most commonly caused by low-energy capsulolabral avulsion due to anterior or posterior glenohumeral dislocation, these fractures result from violent impact of the humeral head on the glenoid [43]. Type I fractures are often treated surgically when marked instability is present, correlating with fracture fragment size greater than 25% of the anterior and 33% of the posterior glenoid rims and with greater than 10-mm fragment displacement [42, 44]. Types II–IV fractures are treated surgically if they are unstable, exhibit greater than 5 mm of articular displacement, or destabilize the SSSC owing to failure of the acromioclavicular strut [3, 42] (Fig. 16). The surgical indications for type V injuries are similar to those for types II–IV. Most type V injuries, however, often ultimately require surgery because they are associated with higher-impact mechanisms, severe displacement, and in a large number of cases neurovascular injuries [2, 3, 43, 45]. Type VI fractures are severely comminuted, but surgery is generally contra-
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Extraarticular glenoid neck fractures—Glenoid neck fractures are extraarticular but the mechanism is similar to that of intraarticular glenoid fractures, most commonly involving humeral head impact on the glenoid after direct lateral impact or a FOOSH injury [2, 3]. These fractures are classified into two main categories: Type I fractures are nondisplaced and respond well to nonsurgical treatment. Type II injuries involve greater than 1 cm of translational fragment displacement or more than 40° of angular displacement and most often require surgical repair [3, 46, 47] (Fig. 16). Displaced fractures are commonly associated with high-grade acromioclavicular separation or clavicular fracture, which destabilizes the SSCS [2, 3, 42]. Fractures are also described relative to the coracoid process. A fracture line lateral to the coracoid defines an anatomic neck fracture, whereas a fracture line medial to the coracoid defines a surgical neck fracture [48]. Anatomic neck fractures are inherently unstable and require surgical repair because they reflect effective detachment of the glenohumeral articulation from the SSCS. Surgical neck fractures can be unstable if associated with a clavicular fracture or with coracoclavicular and coracoacromial ligament disruption, termed floating shoulder, which requires surgical repair [48]. It is therefore critical to identify associated injuries to the SSCS structures when a glenoid neck fracture is detected.

Acromion fractures—Fractures of the acromion process are classified with the Kuhn system into three types: type I fractures are nondisplaced; type II fractures are displaced laterally, superiorly, or anteriorly without narrowing of the subacromial space; and type III fractures are inferiorly displaced with reduction of the subacromial space [49]. These fractures are most often due to a lateral impact, a direct strike to the top of the shoulder, or, rarely, impact after superior humeral subluxation [2]. Type I and minimally displaced type II fractures that do not encroach on the subacromial space can be managed with immobilization. Surgical fixation is recommended for markedly displaced type II and type III fractures to reduce the acromioclavicular joint and prevent nonunion, malunion, impingement, or rotator cuff injury [2, 42, 49, 50] (Fig. 17).

Coracoid fractures—Coracoid fractures are classified into two types with the Ogawa system. Type I fractures are proximal and type II fractures are distal to the coracoclavicular ligament insertion (Fig. 13). Injury mechanisms include a direct blow to the shoulder from a lateral impact, muscle avulsion, direct humeral head impact during anterior shoulder dislocation, and a variant of acromioclavicular joint separation [2]. There is no clear consensus on the treatment of coracoid process fractures, but nondisplaced and minimally displaced fractures are most commonly type II and can be treated conservatively [50] (Fig. 18). Type I fractures are more likely to be markedly displaced owing to associated acromioclavicular

Fig. 17—35-year-old man with fracture of acromion process and concern for associated rotator cuff injury. Red border indicates surgical treatment is indicated.

A and B, Frontal (A) and scapular-Y (B) radiographs of shoulder show isolated depressed acromion process fracture (arrow) with reduction of subacromial space (type III).

Fig. 18—33-year-old woman with subtle coracoid process fracture. Green border indicates conservative treatment is most often recommended.

A, Anterosuperior shoulder radiograph shows fracture (arrow).

B, Coronal T2-weighted MR image of shoulder better shows fracture (red arrow), which is minimally displaced and lateral to attachment of intact coracoclavicular ligaments (yellow arrow), representing Ogawa type II injury.

Fig. 19—55-year-old woman with comminuted fracture of body of scapula. Scapular-Y radiograph shows fracture (arrows) with greater than 10 mm of fragment displacement.
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Fig. 20—Computer-generated image shows forward fall onto outstretched hand (1) with slight lateral momentum produces external rotation of body axis (relative internal rotation of humerus) (2) with resulting force vector producing oblique or spiral fracture of proximal humerus (3).

Fig. 21—Computer-generated image shows lateral fall (1) onto outstretched hand with arm extended and abducted results in hyperabduction (2) and impaction of greater tuberosity on acromion with subsequent shear fracture of greater tuberosity (3).

Fig. 22—Computer-generated image shows humeral head fractures are commonly classified as one to more than four parts, fracture lines most commonly occurring along physeal lines with potential anatomic neck, surgical neck, greater tuberosity, and lesser tuberosity fracture parts.

separation, displaced acromial fracture, clavicular fracture, or glenoid fracture. These injuries compromise SSSC stability in combination and most commonly require surgical treatment [1, 2, 42, 50, 51].

Scapular body fractures—Approximately 50% of scapular fractures involve the scapular body. The mechanisms include direct impact onto the scapula and sudden muscular contraction, as in seizures and electric shock [2]. Most scapular body fractures respond well to conservative management and are usually treated nonsurgically in the acute phase [3]. Nonunion or malunion are uncommon but may require delayed surgical fixation if symptomatic, particularly with fragment displacement of greater than 10 mm or if impingement symptoms are suspected [3, 52] (Fig. 19).

Imaging—Chest radiographs are generally the first imaging modality available for evaluating the scapula during trauma management. The sensitivity, however, is only 50–60% for detection of scapular fractures, which are often overlooked because of extensive associated chest injuries [2, 53]. A three-view scapular trauma series that includes anteroposterior, scapular-Y, and axillary views is usually sufficient for detection of most fractures. The coracoid process may require Stryker notch or cephalic tilt views for fracture visualization [2]. CT is generally reserved for subtle glenoid or coracoid fractures, scapular fractures with multiple fracture lines, fractures with marked displacement or angulation on radiographs, and evaluation of the glenohumeral articulation [2, 54]. MRI is not specifically indicated for scapular fractures, but the findings can suggest occult fracture if bone marrow edema is present and can delineate damage to surrounding soft-tissue structures of the SSSC if shoulder girdle instability is suspected [9, 24]. MRI can also be used to evaluate for rotator cuff tears in patients with symptomatic type III acromion fractures, particularly if the humeral head is markedly elevated on radiographs [2].

Proximal Humeral Fractures

Approximately 5% of all fractures are fractures of the proximal humerus [55]. The mechanisms of these fractures can be classified as direct or indirect. Direct fractures involve a direct impact along the shaft of the humerus in a traditionally high-energy nonaxial force vector [55, 56]. Indirect fractures usually involve a number of different mechanisms whereby the humerus is subjected to excessive but relatively lower-energy loading without a direct incident impact at the point of fracture. The indirect mechanism predominates. Fractures are most commonly sustained from a FOOSH mechanism in an attempt to arrest a fall from standing height [4, 57–59]. Indirect fractures occur most commonly in the elderly, likely owing to a higher prevalence of predisposing factors, such as osteoporosis and increased predisposition to recurrent falls [56, 60, 61]. Younger patients sustain a higher proportion of direct fractures, as in high-impact sports and automobile accidents [55, 56, 59, 61]. Less common mechanisms include excessive muscular contraction about the shoulder, as in seizures and electric shocks [62].

In a FOOSH injury, fractures can occur from a combination of movements best described as an attempted arrest of an uncontrolled crash, a fall direction favoring obliquely forward or sideward movement [58]. The mechanism often involves relative translational or rotational motion of the body mass about the pivot point of an extended and planted hand, producing an abduction or adduction moment on the proximal humerus [63–65] (Fig. 20). Fractures at the anatomic neck can result from posterior dislocations [66], and greater tuberosity fractures and Hill-Sachs lesions occur with anterior or dislocations. Both dislocation mechanisms...
Proximal humerus fractures are most commonly described in terms of displaced fracture parts with implications in method of treatment.

**A**, Computer-generated image of one-part fracture shows minimal displacement (< 0.5 cm for greater tuberosity and less than 1 cm for other fracture locations) and less than 45° of fragment angulation. Green border indicates conservative treatment is most often recommended.

**B–D**, Computer-generated images show examples of two-part fractures of surgical neck (B), lesser tuberosity (C), and greater tuberosity (D). Yellow border indicates nonoperative treatment is most likely indicated but surgical repair may be warranted. Dashed red border indicates likely need for surgical repair because of clinical unlikelihood of adequate closed reduction stabilization.

**E–H**, Computer-generated images show examples three-part fractures (E), four-part fractures (H), displaced anatomic neck fractures (F), and split fractures of humeral head (G). Red border indicates likely need for surgical repair.
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are seen in FOOSH injuries [4, 64, 67]. Greater tuberosity fractures can also occur without dislocation, possibly because of impingement of the greater tuberosity on the acromion with the arm in extension and abduction [67] (Fig. 21). Proximal humeral fractures can also be caused by arm hyperabduction whereby wedging of the greater tuberosity on the acromion produces leverage, which can fracture the surgical neck or produce an inferior glenohumeral dislocation, depending on the strength of the underlying ligaments [68]. Finally, a FOOSH mechanism can cause axial impact of the elbow or lateral impact of the shoulder onto the ground if the fall is not successfully halted, resulting in an injury force mechanism similar to that of intraarticular glenoid fractures (Fig. 14). This mechanism results in impact of the humeral head onto the glenoid, potentially producing a variety of injuries to the shoulder girdle, including proximal humeral fractures and humeral head split fractures [4, 67, 69, 70].

Classification and management—Fractures most commonly occur along physesal lines, as emphasized in the widely adopted Neer classification system, which categorizes fractures according to number of fracture parts [71] (Fig. 22). The Association for Osteosynthesis/Association for the Study of Internal Fixation system is also commonly used, though both systems have been reported to have questionable interobserver and intraobserver reliability [72]. Because of its simplicity and familiarity to orthopedists, fractures are most commonly described with the Neer terminology.

Approximately 80% of fractures are traditionally treatable by nonsurgical means [71]. When surgical therapy is considered, early intervention can minimize the development of functional deficits [33], though the decision for surgical repair is not strictly based on imaging findings. Factors such as patient age, bone quality, rotator cuff status, fracture severity, preexisting illness, and baseline functional demands are important factors in surgical evaluation [55, 59].

The Neer classification system defines a fracture fragment as a part if it is displaced 1 cm or more or angulated at least 45° [71]. Fractures in which there is no fragment fulfilling these criteria can be referred to as nondisplaced or one-part fractures [73] and are most commonly treated conservatively [33, 59] (Fig. 23).

Two-part fractures involving the surgical neck and lesser tuberosity can be treated conservatively if displaced less than 66% with acceptable functional angulation but are otherwise often best treated surgically [33, 55, 74] (Fig. 24). Treatment of two-part greater tuberosity fractures is often more aggressive because of poor outcomes with conservative management above specific thresholds. Surgery is usually recommended for fragment displacement greater than 5 mm in nonathlete adults and elderly patients and for displacement of greater than 3 mm in active younger patients, athletes, and people who engage in routine overhead activity [70, 75, 76] (Fig. 24). Greater tuberosity fractures are often associated with anterior glenohumeral dislocations [59], and marked greater tuberosity fracture fragment displacement can indicate an associated rotator cuff tear [68]. Three- and four-part fractures are most commonly treated with open fixation if surgery is appropriate for the patient [33, 55, 74].

Displaced fractures of the anatomic neck increase the risk of humeral head ischemia. Factors predictive of ischemia include an anatomic neck fracture with medial metaphyseal extension of less than 8 mm and medial hinge disruption of greater than 2 mm, thought to reflect increased risk of devascularized calcar periosseum [77]. Although anatomic neck fractures most commonly require operative treatment, if the risk of ischemia is determined to be low, surgical techniques that spare the humeral head can be used [74]. Cortical thickness around the fracture should be reported because a thickness greater than 4 mm is required for internal screw fixation techniques [74].

Fig. 24—Frontal radiographs of four 40- to 65-year-old patients shows multiple forms of proximal humeral fractures.
A, 54-year-old woman with transverse impacted 2-part surgical neck fracture. Yellow border indicates nonoperative treatment is most likely indicated but surgical repair may be warranted.
B, 52-year-old man with moderately displaced greater tuberosity fracture. Dashed red border indicates likely need for surgical repair because of clinical unlikelihood of adequate closed reduction stabilization.
C, 40-year-old man with markedly displaced greater tuberosity fracture with associated rotator cuff tear. Red border indicates surgical treatment is indicated.
D, 65-year-old woman with three-part surgical neck and greater tuberosity fracture. Red border indicates surgical treatment is indicated.
Imaging—Radiographs in the anteroposterior, scapular-Y, and axillary views are generally sufficient for detection of proximal humeral fractures [78]. However, significant interobserver and intraobserver variability confounds evaluation, classification, and selection of treatment modality [79]. CT generally adds limited value in classification [80, 81] but can help in delineation of the morphologic features and degree of displacement of complex proximal humeral fractures detected on initial radiographs and in evaluation for concomitant glenoid and scapular injuries [59, 78, 82]. CT may depict characteristic fracture morphologic features predictive of humeral head ischemia [77] and assist with preoperative planning.

Greater tuberosity fractures can be notoriously occult on radiographs and are often associated with rotator cuff tears [68, 83]. MRI is useful in detecting these occult fractures if clinical suspicion is high in the treatment of patients with apparently normal radiographic findings. These fractures are often identified during imaging for suspected rotator cuff tears [83–85]. Given the unpredictable outcomes associated with complex proximal humeral fractures complicated by rotator cuff tears, MRI or direct arthroscopic visualization of the rotator cuff is recommended for three- and four-part fractures and for displaced greater tuberosity fractures [86], though there is a risk of over-diagnosis of subtle rotator cuff tears among patients with fracture-related edema if images are obtained in the acute phase [87]. Advanced imaging such as Doppler ultrasound or angiography is also indicated if there is clinical suspicion of neurovascular compromise in the acute phase, most commonly seen with markedly displaced fractures [59].

Summary
Injuries to the SSSC and proximal humerus can result in chronic functional impairment and instability if not appropriately treated. Knowledge of the most common force mechanisms of shoulder injuries can improve detection of subtle associated injuries that occur in predictable combinations and can guide the use of additional advanced imaging. Early detection of these injuries will enable more accurate classification and can thus direct appropriate and timely intervention, minimizing the risk of delayed complications.

References
Traumatic Shoulder Injuries

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