29 Upper Extremity Injuries in Adults and Children: Evidence-Based Emergency Imaging

Kara Gaetke-Udager, Corrie M. Yablon, and Stefan Puig

Key Points

- Radiography is the initial imaging test of choice for upper extremity trauma (strong evidence).
- Wrist: Magnetic resonance imaging (MRI) has the best sensitivity and specificity to evaluate for *scaphoid fracture* and may be considered in the acute setting (strong evidence). Scaphoid fractures are often occult on radiographs, resulting in unnecessary immobilization (strong evidence). Bone scintigraphy is sensitive but not very specific for fracture; this can be useful for patients who cannot undergo MRI (moderate evidence). Computed tomography (CT) needs further study (insufficient evidence).
- Elbow: Radiographs are indicated as the first-line study in assessing for *elbow dislocation* (strong evidence). Vascular injury evaluation with CT angiography or conventional angiography must be considered if there is any suspicion of vascular injury (strong evidence): there is no evidence as to which of these methods is preferable. MRI provides excellent soft tissue evaluation in the acute or chronic setting (strong evidence). CT can be used in cases with complex fractures (moderate evidence).
- Shoulder: Radiographs are a necessary first-line study in the diagnosis of *glenohumeral dislocation* (strong evidence). MRI provides excellent soft tissue detail (strong evidence). MR arthrography is superior to MRI for evaluating labral, ligamentous, and cartilage injury (strong evidence). CT helps evaluate complex fractures (moderate evidence). CT arthrography can be useful in evaluating labral, ligamentous, and cartilage injury, although it is less useful for other soft tissue injuries compared to MR arthrography (moderate evidence).

(continued)

K. Gaetke-Udager (✉) · C.M. Yablon
Department of Radiology, Michigan Medicine, Ann Arbor, MI, USA
e-mail: kgaetke@umich.edu; cyablon@umich.edu

S. Puig
Department of Diagnostic, Interventional, and Pediatric Radiology, Inselspital, University Hospital Bern, University of Bern, Bern, Switzerland

Department of Radiology and Neuroradiology, Klinik im Park, Hirslanden AG, Zurich, Switzerland
e-mail: Puig1@mac.com

A. Kelly et al. (eds.), *Evidence-Based Emergency Imaging*, Evidence-Based Imaging,
https://doi.org/10.1007/978-3-319-67066-9_29

- Shoulder: Radiographs are a necessary first-line study in acromioclavicular joint (ACJ) separation (strong evidence). When unilateral radiographs are negative or equivocal, bilateral views are necessary (strong evidence), and weighted views are recommended (moderate evidence). MRI provides excellent soft tissue detail and can be useful in distinguishing low- from high-grade injuries (strong evidence).

Definitions and Pathophysiology

Injuries of the upper extremity are common and occur most frequently at home, with recreational/sports-related injuries being the next most common setting [1]. Risk factors for upper extremity injuries in adults include advanced age, female gender, participation in athletics, and work that entails heavy machinery or other mechanism for high-energy trauma. In children, several independent risk factors have been identified: genetic constitution, birth weight, poor nutrition, low socioeconomic status, participation in sports, obesity, and repetitive stress [2].

Emergency department (ED) visits for upper extremity injuries are common, and imaging is a key component of diagnosis and management. This chapter focuses on the use of imaging to evaluate injuries to the upper extremities, specifically scaphoid fracture, elbow dislocation, glenohumeral dislocation, and AC joint separation. While other types of upper extremity injuries are more common, including finger lacerations and contusions [1], the use of imaging is not necessarily needed for such superficial injuries. In addition, many fractures, both in adults and children, can be easily diagnosed with radiographs without the need for further imaging evaluation [3]. We will focus on those injuries in which imaging evaluation might require multiple modalities and in which the use of some types of imaging is controversial.

Epidemiology

A data analysis of the US National Electronic Injury Surveillance System revealed that, as of 2009, there were about 3.5 million estimated injuries to the upper extremity treated at EDs in the United States [1]. This corresponds to an incidence of 1130 upper extremity injuries per 100,000 persons per year. By anatomic site, the majority were finger injuries (38.4%), followed by shoulder (16.8%), lower arm (15.3%), wrist (15.2%), elbow (10.5%), and upper arm (3.7%) injuries.

The most common type of upper extremity injury seen in an ED is a fracture [1, 3]. Wrist fractures account for 40% of all wrist injuries. About one third of elbow injuries and nearly one fourth of shoulder injuries are fractures. Dislocations of the elbow and shoulder comprise over 10% of injuries to those joints [1].

Overall Cost to Society

The estimated total compensable cost for upper extremity cumulative trauma in the United States was $563 million based on data in 1992 [4]. There has been limited investigation into the cost of upper extremity trauma in the United States in recent years, with demand for more rigorous economic evaluation [5]. An investigation into the cost of trauma to the wrist, elbow, and shoulder in the Netherlands between 1986 and 2008 showed a total cost of 290 million euros, with wrist fractures overall being the most costly (83 million euros) [6].

Goals of Imaging

One of the primary goals of imaging in patients with upper extremity trauma is to identify acute injuries that require urgent attention, including closed reduction, or potential emergent surgical intervention. Another goal is appropriate triage of injuries that require clinical follow-up, including potential delayed/outpatient imaging studies such as MRI or CT.

Methodology

A comprehensive PubMed (US National Library of Medicine Database) search was performed for original articles published between 1966 and September 2015. The search strategy involved different combinations of the following terms: *scaphoid fracture*, *elbow dislocation*, *glenohumeral dislocation*, *acromioclavicular separation*, *Salter-Harris (or physeal) fractures*, *imaging*, *acute*, *radiography*, *MRI*, *CT*, *scintigraphy*, and *cost-effectiveness*. The search was limited to English language articles and human studies. Additional articles were identified by reviewing the references list of related articles. An initial review of articles' titles and abstracts were performed, followed by a review of the full text of selected articles.

Discussion of Issues

What Imaging Modalities Should Be Utilized to Diagnose Scaphoid Fractures?

Summary of Evidence Extensive research has been done to determine the optimal use of radiography, MRI, bone scintigraphy, and CT in diagnosing scaphoid fracture. Radiographs are typically the first-line study, but in at least 20% of cases, scaphoid fractures are radiographically occult (strong evidence). Standard practice is to apply a cast in those patients and repeat the clinical evaluation and radiographs in 10–14 days when resorption at the fracture line may make previously occult fractures visible. If the repeat radiographs are still normal or equivocal and the suspicion of scaphoid fracture continues to be strong, imaging with a second modality is indicated. A number of studies and several meta-analyses have shown that MRI has the best sensitivity and specificity for diagnosing fracture (strong evidence), and some groups recommend MRI on the day of injury to avoid unnecessary immobilization. Scintigraphy is very sensitive for fracture, and while not as specific as MRI, it is a reasonable alternative in patients who cannot undergo MRI (moderate evidence). CT is widely available and has excellent sensitivity for cortical fractures, but trabecular fractures are sometimes missed, and more evidence is needed to warrant the routine use of CT in the acute setting.

Supporting Evidence The scaphoid is the most commonly fractured carpal bone, and the injury occurs most often in males 15–30 years old; the relative weakness of the radius in pediatric and elderly patients makes a buckle or Colles fracture, respectively, more common in these age groups [7]. The most common mechanism of injury is a fall on an outstretched hand [8]. Because the potential complications of a scaphoid fracture are serious, including nonunion, avascular necrosis, and arthritis, early diagnosis is crucial. While immobilization has commonly been used for nondisplaced fractures, with subsequent surgery as needed for nonunion, recent investigation has shown that early surgical management provides a favorable outcome to immobilization for acute nondisplaced and minimally displaced fractures, especially related to functional outcome and decreased disability [9].

After the initial clinical assessment, radiographs are usually the first-line imaging study to evaluate for fracture [10, 11]. However, fractures can be radiographically occult in one-fifth to one-third of cases [12, 13]. Because negative radiographic findings do not exclude a scaphoid fracture, up to 75% of patients with negative initial radiographs but suspicious clinical findings are unnecessarily immobilized [14]. Imaging follow-up for these patients varies greatly by institution, although a repeat set of radiographs after 10–14 days is most commonly performed [15].

MRI

A number of studies have focused on the use of MRI versus radiographs as short-term follow-up (within a week) to assess a clinically-suspected scaphoid fracture [13, 16–20]. Although MRI sometimes leads to false-positive diagnoses [21, 22], it has a high sensitivity for detection of occult fractures (Fig. 29.4) [13, 16–20], in some cases even when only two sequences (T1 coronal and STIR coronal) are used [16]. In addition, MRI reveals other carpal fractures and soft tissue injuries that are not visible on radiographs [18, 19, 23]. Several reviews and meta-analyses have concluded that MRI is the imaging method of choice to evaluate scaphoid fracture [10, 22, 24], with an overall sensitivity of 96% and specificity of 99% [10].

Importantly, clinical management was changed for more than half of patients in one study who received an MRI after initial management based on radiographs [18]. One group showed that using MRI rather than repeat radiographs reduced immobilization time from 20 to 4 days and sick leave from 27 to 11 days; in-hospital costs were slightly reduced, while out-of-hospital costs were substantially reduced [25]. Another group showed that the costs of traditional work-up (i.e., initial radiographs, immobilization, and then repeat radiographs) were only about $100 less than using MRI as an initial screening tool for patients with suspected scaphoid fracture [14]. Many of these patients eventually needed an MRI, thus further increasing the cost of this common diagnostic algorithm.

Scintigraphy

Because not all patients are able to undergo an MRI due to lack of availability, implanted metallic devices, and/or claustrophobia, bone scintigraphy is an alternative for those patients needing additional imaging evaluation for suspected scaphoid fracture. Scintigraphy shows increased radiotracer uptake at the fracture site, although this can lead to false-positive diagnoses in cases of bone contusion [26]. The sensitivity and specificity of scintigraphy have been reported as 97% and 89%, respectively [10]. However, several reviews that compared the utility of MRI and scintigraphy showed that MRI was superior for diagnosing scaphoid fractures as well as other soft tissue injury [27, 28].

CT

CT is widely available, has a fast acquisition time compared to MRI and scintigraphy, and has fewer patient restrictions compared with MRI. In addition, CT shows excellent osseous detail and, in one small study, outperformed MRI in the identification of subtle cortical fractures [29]. However, CT has limited sensitivity for trabecular injury compared to MRI [29], and its overall sensitivity and specificity were 93% and 99%, respectively, in a large meta-analysis [10]. Another review concluded that while CT is cheaper and faster to obtain than MRI, CT should be used with caution due to its lower sensitivity.

What Imaging Modalities Are Appropriate to Evaluate Elbow Dislocation?

Summary of Evidence Radiographs are a necessary first step in the evaluation of elbow dislocation (strong evidence). There has been limited evaluation of the utility of CT in the acute setting, although CT is commonly used to evaluate complex fractures. MRI is the best modality for evaluating soft tissue injury, both in the acute and chronic setting, especially when surgical decision-making is based on the presence of ligamentous damage (strong evidence). Ultrasound offers the benefits of dynamic imaging and portability, but it is operator dependent and currently not widely used (limited evidence). A small but significant number of dislocations are associated with vascular injury, which is best assessed using either CT angiography or conventional angiography (strong evidence), depending on availability, with insufficient evidence to suggest one technique over the other.

Supporting Evidence The annual incidence of elbow dislocation in the United States is 5.2 per 100,000 person-years, with more than 40% of injuries occurring in patients 10–19 years of age, with a slight male predilection [30]. Elbow dislocations in adults are most commonly posterior [31]; anterior dislocations are rare and more commonly occur in children, while divergent dislocations, in which the distal humerus becomes interposed between the proximal radius and ulna, are also uncommon [32]. Most of the recent literature has focused on a mechanism of axial compression, supination, and valgus stress for posterior dislocations, which most commonly results from a fall on an outstretched hand [31].

There are a few instances in which acute surgical management is necessary for elbow dislocation: open dislocation and compartment syndrome require emergent surgery, and elbows with unstable fractures might also need urgent surgical fixation [33]. Vascular injury also requires urgent intervention. As a general rule, non-emergent surgical intervention is needed in elbow dislocations with intra-articular fractures [34]. Those dislocations without fracture (simple dislocations) but with ligamentous instability are often surgically repaired, and some studies that evaluated the use of surgery in these patients showed good outcomes [35]. In elbow dislocations without ligamentous instability, an early, aggressive, range-of-motion rehabilitation protocol has been shown to be effective [33]. Imaging can aid in determining the presence and extent of these different types of associated injuries.

Radiographs

Patients with clinically suspected elbow dislocation should undergo radiographs as the first-line imaging study [36]. Two standard views (anterior-posterior and lateral) can be supplemented with specialty views such as medial or lateral oblique views, a radial head view, a coronoid view, various axillary views, and/or a gravity stress view. Dislocations result in a variety of fractures seen on radiographs, including radial head and neck fractures in 5–10%, coronoid fractures in 10%, medial and/or lateral avulsion fractures in 12%, and overall periarticular fractures in up to 60% [37]. Radiographic evidence of these fractures can help direct the use of additional imaging. In addition, some radiographic signs can suggest possible elbow instability: one study assessed the ulnohumeral distance on lateral radiographs of 10 patients with dislocation versus 20 normal patients [38]. Those patients with increased ulnohumeral distance after reduction correlated with continued elbow instability.

MRI

Two review studies have shown that MRI is the best modality for evaluation of soft tissue injury, including ligament disruption, after elbow dislocation [32, 39]. The findings at MRI give some insight into the mechanism for posterior dislocation: an MRI study in 16 patients with posterior dislocation showed complete tears of medial elbow ligaments, while lateral ligament tears were sometimes partial [40]. This suggests a pattern of ligamentous failure beginning on the medial side. MRI is more commonly utilized in the subacute or chronic setting, although urgent MRI might be needed in cases in which the extent of instability prevents early mobilization, as these cases require surgical intervention [32].

CT

CT can be used to evaluate elbow fractures, especially when there is concern for intra-articular fracture and/or fracture fragments in the joint [39]. CT often provides a better evaluation of soft tissue calcification/ossification, fracture fragments, and intra-articular bodies than MRI. While CT is widely available and readily accessible, it also has the disadvantages of radiation exposure and poor visualization of soft tissues [32, 39]. There have been no studies to date directly comparing the utility of CT versus MRI for sequela of elbow dislocation, possibly due to the clear differences in the advantages and disadvantages of each modality. Despite the high rate of surgical intervention for elbow dislocation and fracture, elbow CT is relatively uncommonly performed [41].

Vascular Imaging

Approximately 5–13% of elbow dislocations have associated vascular injury [42]. Failure to recognize the signs and symptoms of vascular injury can lead to delay in diagnosis, thus putting the patient at risk for debilitating consequences [43]. Vascular injury usually occurs with open, rather than closed, dislocations, and vascular injury in closed dislocation can be challenging to diagnose due to collateral circulation that can mask symptoms [42]. If the clinical presentation is unclear, emergent imaging should be obtained either with CTA or conventional angiography [43]. One small study evaluated nine cases of posterior elbow dislocation, in which three patients had complete ischemia (no pulse) and six others had less severe findings [44]. Arteriogram was obtained in five of the six less severe cases, and all responded well to surgical intervention (brachial artery bypass with autologous vein in eight of nine cases). There are no studies directly comparing the use of CTA versus conventional angiography.

What Imaging Modalities Are Optimal to Evaluate for Acute Glenohumeral Dislocation?

Summary of Evidence Radiographs are the first-line imaging study in the emergency setting (strong evidence); special views might be necessary to assess for dislocation and/or associated fractures. Cross-sectional imaging might not be necessary in the ED setting, but it is frequently needed in the subacute setting to assess for the sequela of shoulder dislocation. CT is more sensitive than radiography, and sometimes superior to MRI, to evaluate for fractures that can occur with dislocation (moderate evidence). MRI provides excellent depiction of associated soft tissue injury, although MR arthrography is better than MRI for specifically assessing labral and cartilage injury (moderate evidence). CT arthrogram has been shown to be equivalent to MR arthrography in detecting labral, ligamentous, and cartilage defects by some studies (moderate evidence) and is a useful alternative, especially if the patient cannot have an MRI.

Supporting Evidence The prevalence of shoulder dislocations in the general population is as high as 2% [45]. The maximum incidence occurs between 20 and 29 years of age [46]. Recurrence is inversely related to age: more than 80% of patients with a first dislocation before the age of 20 will dislocate again, while only 16% of patients with a first dislocation after age 40 will dislocate again [47]. Repeated dislocation occurs three times more often in men than women [48].

The glenohumeral joint has the widest range of motion of any joint in the body; however, this attribute also predisposes the joint to instability and dislocation [49]. Dislocation is most commonly anterior, and the first dislocation results from trauma over 90% of the time, often from a fall on an outstretched hand or a direct blow during sports. Common associated injuries include Hill-Sachs lesions (superolateral humeral head impaction fracture), Bankart lesions (fracture of the anteroinferior glenoid rim), and tears of the labral-ligamentous complex [50]. Imaging plays a major role in evaluation of these injuries.

Radiographs

The American College of Radiology (ACR) appropriateness criteria recommend radiographs for acute shoulder pain, including either an axillary or scapular Y view to increase sensitivity for dislocation [51]. While Y views are easier to obtain and more comfortable for the patient [52], axillary views are more sensitive for dislocation and glenoid fractures [52, 53]. Additional views can be obtained to assess for fractures typically seen in dislocation, including a Stryker notch view for Hill-Sachs deformity and a West Point view to assess for Bankart or other glenoid fracture [54]. Postreduction radiographs are warranted in the acute setting to assess for fracture [49]. However, radiographs are less sensitive than MRI for subtle fractures, such as Hill-Sachs deformities, and soft tissue injury [55], and additional imaging is often warranted after the acute dislocation (Fig. 29.3).

MRI

MRI is considered the gold standard for assessing soft tissue injury related to shoulder dislocation [56]. While suspected injuries of the rotator cuff are the most common indication for MRI, injuries of other soft tissue structures such as the labrum, ligaments, and articular cartilage can also be evaluated with great accuracy. One study evaluated MRI versus arthroscopy for evaluation of osteochondral defects in 15 patients after dislocation; the sensitivity of MRI was 87% compared to 80% with arthroscopy, with the discrepancies thought to be due to the ability of either technique to show either intra-articular or extra-articular cartilage injury [57]. Another study evaluated the ability of MRI versus MR arthrography (MRA) to assess articular cartilage injury, Bankart lesions, and Hill-Sachs deformities, with MRI having similar sensitivity and specificity compared to MRA [58]. Some studies have even shown that non-arthrographic MRI can be quite useful for labral evaluation, with an accuracy of up to 95% [59].

MRI can be useful in the subacute setting (days to a week after injury) to help evaluate for bone marrow edema/occult fracture [49]. However, findings on MRI performed in the acute to subacute setting can sometimes resolve on follow-up studies, as shown by Liavaag et al., who found that the presence of a capsular injury within a week of injury had often resolved by 30 days [60]. Also, a joint effusion and/or hemarthrosis present after injury can act as a pseudo "contrast" agent on conventional MRI to better evaluate intra-articular structures [49].

Magnetic Resonance Arthrography

MRA has little or no role in the acute setting and is mostly used to assess intra-articular injuries before surgical planning. MRA is typically performed after the injection of a dilute gadolinium contrast solution into the joint. The use of saline only as a contrast agent has also demonstrated a high degree of accuracy for labral, ligamentous, and osseous injuries [61]. MRA is especially useful for the evaluation of labral-ligamentous injuries, for which it has a high (greater than 90%) sensitivity and specificity [62]. Overall MRA has been shown to be superior to MRI for evaluation of labral tears based on a number of direct comparison studies and reviews [63–65]. MRA has particularly good sensitivity for anterior labral tears, superior labral tear anterior posterior (SLAP) tears, and partial thickness, articular-sided supraspinatus tendon tears [63].

CT and CT Arthrography

CT can be useful in the acute setting after shoulder dislocation to evaluate for fractures [54], with glenoid fractures typically being the most important prognostic indicator for future dislocation [49]. From a surgical planning standpoint, CT is useful to show the size of Bankart lesions, the amount of glenoid bone stock, the percentage of the humeral head involved in a Hill-Sachs deformity, and the presence of small, intra-articular fracture fragments [54]. CT arthrography has been shown by Oh et al. to be a cost-effective, useful method for preoperative evaluation of labral and ligamentous injury and full-thickness rotator cuff tears, although it is not as sensitive as MRI in evaluating partial-thickness cuff tears [66]. A study by Lecouvet et al. showed that CT arthrography is accurate in detecting cartilage substance loss [67]. Another study showed that CT arthrography is slightly more accurate than MR arthrography for detecting cartilage substance loss [68]. However, CT arthrography results in suboptimal evaluation of associated soft tissue injury [53, 69].

What Imaging Modalities Are Useful in the Evaluation of Acromioclavicular Joint Separation?

Summary of Evidence Radiographs are the first-line imaging study to evaluate ACJ separation. The evidence favors the use of bilateral radiographs with and without weights (moderate to strong evidence). MRI is useful when radiographs and/or the clinical evaluation are discrepant, as it provides excellent evaluation of soft tissue structures, including ligaments (strong evidence). CT is not typically indicated to evaluate ACJ injuries, except perhaps in cases with complex fractures. The distinction of grade 2 vs. grade 3 ACJ injury was traditionally important to determine surgical management, although the evidence does not necessarily support surgery for grade 3 injuries (strong evidence).

Supporting Evidence ACJ separation accounts for approximately 10% of shoulder injuries, and it is most common among males aged 10–20 years [70]. The mechanism of injury usually involves either a direct blow with the arm in adduction or a fall on an outstretched hand [71]. The ACJ consists of two major ligaments: the acromioclavicular ligament and the coracoclavicular ligament. The coracoclavicular ligament has two main components, the lateral trapezoid ligament and the medial conoid ligament. One study evaluated the coracoclavicular ligament in cadavers; the conoid ligament always failed first under stress, which led to superior and posterior positioning of the clavicle on radiographs, while ligation of the trapezoid ligament led to superior displacement of the distal clavicle on radiographs [72].

The original, three-grade classification system of ACJ separation described by Tossy [73] was later expanded by Rockwood (Table 29.1). Grading depends on the degree of injury to the ligaments surrounding the ACJ, with varying imaging appearances resulting from the particular injury grade. Anatomic studies in cadavers have shown that radiographic findings correlate with the Rockwood grading system, with grade 1 and 2 injuries resulting from AC ligament ligation and grades 3–6 injuries occurring after ligation of the CC ligament [74]. The grade of injury has important treatment implications. While in the past, grade 1 and 2 injuries were typically managed conservatively with grade 3 and higher injuries treated surgically, a number of studies and at least one meta-analysis have shown that grade 3 injuries can be managed conservatively with good outcomes [75, 76].

Radiographs

Radiographs should be the first imaging study obtained in the ED setting for patients with suspected ACJ dislocation. Radiographic technique typically involves bilateral anteroposterior views for comparison of the injured and non-injured side, with Zanca views (10–15% cephalad angulation of the beam) thought to provide additional sensitivity for ACJ injury [77, 78]. Acromioclavicular distances of 6–7 mm or greater and coracoclavicular distances of 11–13 mm or greater are typically considered abnormal [71].

Weighted views, in which the patient has radiographs performed with and without a 10-pound weight affixed to the affected wrist, are commonly used to evaluate whether stress on the ACJ can "unmask" a ligamentous injury (Fig. 29.5a–c). Weights are either held or suspended from the wrist, with no apparent difference between these two methods [79]. The use of weighted views has been controversial. One recent study showed that bilateral weighted views can unmask otherwise undiagnosed grade V injuries [78]. Another study showed that only 3 cases in 84 resulted in a grade 3 injury unmasked by weights, although given that in some cases the use of weights decreased the coracoclavicular distance, the reliability of this study is somewhat questionable [80].

MRI

MRI allows excellent visualization of acromioclavicular soft tissue structures [81]. Special planes, specifically a coronal oblique plane, can be helpful for evaluating the ACJ, although even this plane can be limited when a clavicle fracture or other deformity is present [70, 81]. One study evaluated the correlation between MRI and radiographs in cadavers with ACJ injury and showed that while MRI allows excellent visualization of ligamentous structures, the ligamentous injuries seen on MRI did not necessarily correspond to the findings on radiographs [82]. Another study showed that MRI provides a better assessment than radiographs of the extent of degenerative changes of the ACJ [83]. A review article by Antonio et al. showed that ligamentous anatomy of the ACJ is best seen on T1-weighted images, although these sequences can sometimes obscure edema and hemorrhage [84].This group concluded that MRI should be used for grade 3 injuries or higher for better assessment of soft tissue injuries.

Which Specific Considerations Should Be Taken in Children Presenting with Upper Extremity Injuries?

Summary of Evidence Conventional radiography is the first-line imaging modality in pediatric upper extremity injuries and often the only imaging required (strong evidence). Views in at least two planes are required, with adequate coverage of the injured area. Knowledge of the specific structural and functional features of the immature skeleton is essential in interpreting radiographs correctly. Occasionally, radiography may be followed by advanced imaging modalities. Sonography plays a small role in the evaluation of those injuries (limited evidence).

Supporting Evidence The physis also known as the "growth plate" is a cartilaginous area unique to the pediatric growing bone. Physeal fractures account for about 20% of all pediatric fractures [85]. They are usually classified into five categories using the Salter-Harris classification system to indicate progressive risk of growth arrest with increasing fracture category. Salter-Harris fractures type II are the most common. Radiography is sufficient for imaging the vast majority of these injuries. However, type I (mild) and type V (severe impaction) fractures may not be radiographically apparent, except for showing nonspecific soft tissue swelling. In these cases, MRI or ultrasound may better delineate the bone marrow edema of the fracture adjacent to the physis. However, the use of ultrasound in traumatic injuries requires a level of expertise that is not typically available [11]. CT may be necessary to plan operative intervention for intra-articular displacements in physeal fractures.

As opposed to adults, elbow fractures in children are quite common and represent about 10% of all pediatric fractures [85]. Diagnosis may be challenging, as this requires distinguishing normal ossification centers from fractures in a radiograph. Applying the mnemonic CRITOE (see also Fig. 29.6), which refers to the age-related sequence of appearance of six secondary ossification centers at the elbow, is essential [2, 86]. The most frequent pediatric elbow fractures are supracondylar fractures [87].

Table 29.1 Rockwood grading system of acromioclavicular joint separation with radiographic findings

Grade	Soft tissue injuries	Radiographic findings
I	Sprain of AC ligament	None
II	AC ligament ruptured Sprain of CC ligament	Clavicle elevated but not above superior acromion
III	AC and CC ligaments ruptured	Clavicle elevated above superior border of acromion Coracoclavicular (CC) distance less than twice normal
IV	AC and CC ligaments ruptured Joint capsule ruptured Trapezius and deltoid muscles detached	Clavicle displaced posteriorly into trapezius
V	AC and CC ligaments ruptured Joint capsule ruptured Trapezius and deltoid muscles detached	Clavicle markedly elevated and coracoclavicular distance more than double normal Scapula droops inferiorly
VI	AC and CC ligaments ruptured Joint capsule ruptured Trapezius and deltoid muscles detached	Clavicle inferiorly displaced behind coracobrachialis and biceps tendons

Data from Mazzocca AD, Spang JT, Rodriguez RR, et al. Biomechanical and Radiographic Analysis of Partial Coracoclavicular Ligament Injuries. Am J Sports Med. 2008;36:1397–1402

Take Home Tables and Figures

Table 29.1 explains the Rockwood grading system of acromioclavicular joint separation, and Table 29.2 makes imaging recommendations for upper extremity injuries. Figure 29.1 presents an algorithm for imaging when a scaphoid fracture is suspected. In Fig. 29.2, an imaging algorithm for acute elbow dislocation is presented. Figure 29.3 presents an imaging algorithm for acute glenohumeral dislocation. In Fig. 29.4, an imaging algorithm for acromioclavicular joint separation is presented.

Table 29.2 Summary of imaging recommendations for specific upper extremity injuries

Injury	Population mostly affected	First-line imaging tool	Second-line imaging tools[a]
Wrist: scaphoid fracture	Adolescent and young adult males	Radiography; however, these fractures are radiographically occult in at least 20% of cases	• vRepeat radiography in 10–14 days If still negative or equivocal: • MRI (96%/99%) • Scintigraphy (97%/89%) • CT (93%/99%, but evidence for these values is insufficient)
Elbow dislocation	Adolescents	Radiography	• MRI: when ligament injury is suspected • CT: for evaluation of possible intra-articular fracture and/or fracture fragments • CTA: if vascular injury is suspected
Elbow fracture	Children and adolescents	Radiography	• MRI: to clarify radiographically equivocal fractures or for further evaluation of sports-related overuse injuries
Shoulder: glenohumeral dislocation	Young adults	Radiography	• MRI: for the evaluation of suspected rotator cuff or other soft tissue injuries • CT or CTA: to evaluate possible fractures for surgery planning
Shoulder: ACJ separation	Adolescent and young adult males	Radiography	• MRI: for better visualization of ligamentous structures in ACJ Rockwood grade III–VI injuries
Salter-Harris (growth plate) fracture	Children and adolescents	Radiography; Salter-Harris fracture types I and V may not be apparent on initial radiographs, except for nonspecific soft tissue swelling	• CT: for surgery planning in intra-articular displacements • MRI: if radiographic findings are equivocal

[a]In case of negative or equivocal results of first-line imaging and continued clinical suspicion, percentages in brackets are sensitivity/specificity values

Imaging Case Studies

Case 1

Figure 29.5a–c presents a 22-year-old man after a fall on an outstretched hand.

Case 2

In Fig. 29.6, the six ossification centers around the elbow joint are depicted.

Case 3

In Fig. 29.7a–c, a 42-year-old man presented with humeral head dislocation after an injury.

Case 4

In Fig. 29.8a, b, a 71-year-old woman is presented with a left ACJ injury after a biking accident.

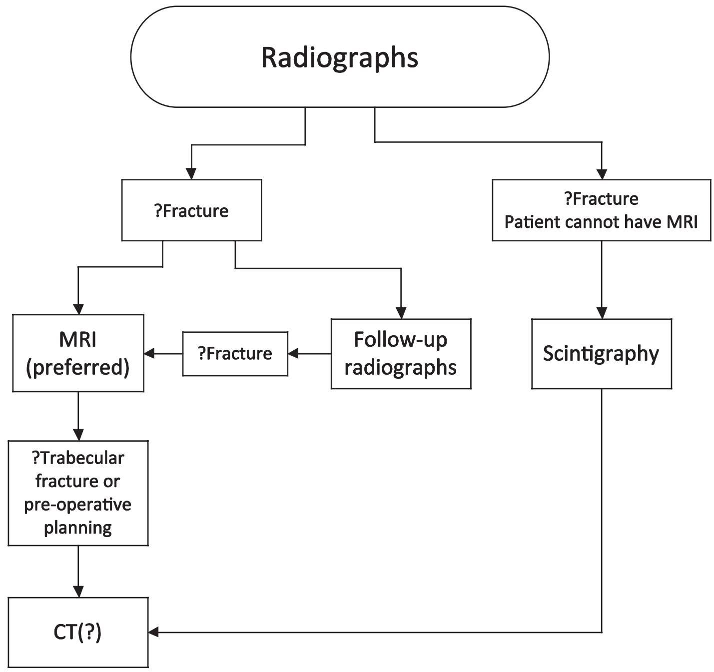


Fig. 29.1 Imaging algorithm for suspected scaphoid fracture

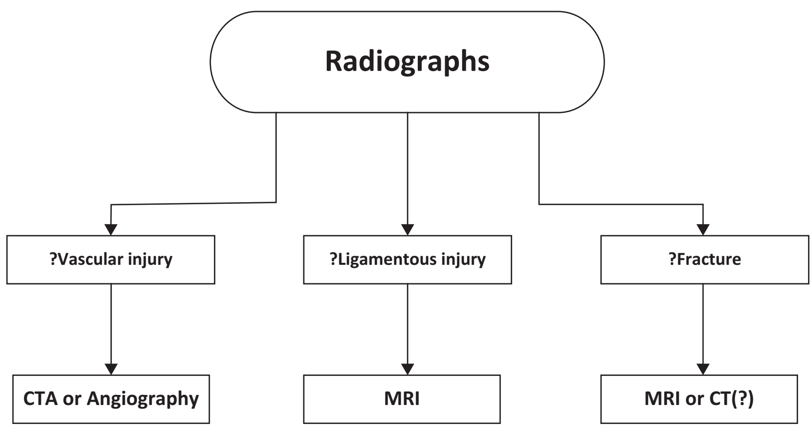


Fig. 29.2 Imaging algorithm for acute elbow dislocation

Suggested Imaging Protocols

Wrist Imaging for Scaphoid Fracture

1. Radiographs: anteroposterior, lateral, bilateral oblique views and scaphoid view (the latter usually not in children, unless requested, because scaphoid fractures do not occur in children under 6 years and are rare in children under age 10).
2. In case of negative radiographs and persistent clinical concern, obtain MRI including at least coronal T1-weighted and coronal T2-weighted fat-suppressed sequences, usually also with T1-weighted sagittal and axial STIR.

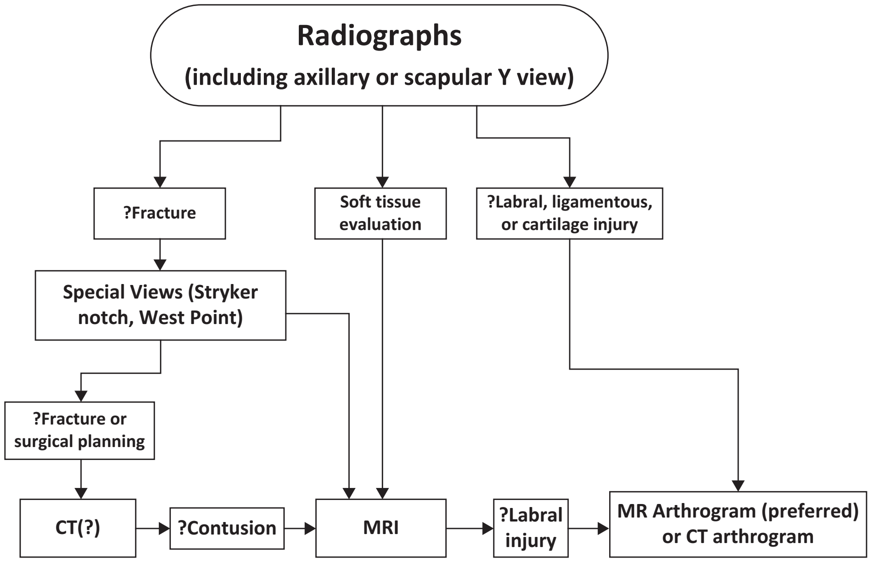
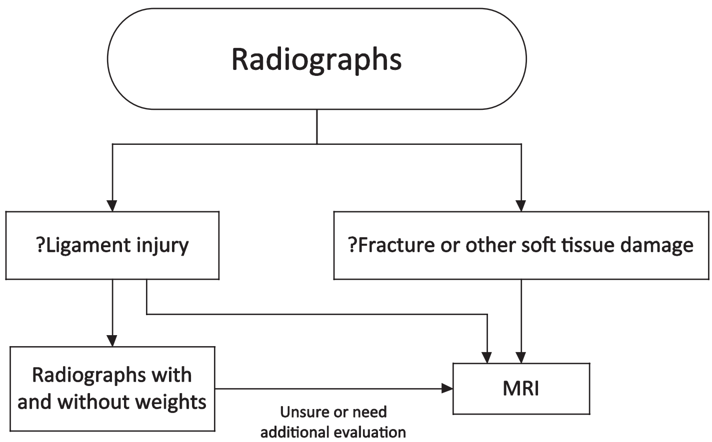


Fig. 29.3 Imaging algorithm for acute glenohumeral dislocation

Fig. 29.4 Imaging algorithm for acromioclavicular joint separation



Elbow Imaging for Dislocation (or Fracture-Dislocation)

1. Radiographs: anteroposterior, lateral.
2. If concern for vascular injury, obtain CTA: mid humerus to proximal radius/ulna including entire elbow joint, 0.625 mm axial acquisition with IV contrast administration, oblique coronal and sagittal reformats using thin (e.g., 2 mm) reformats. Depending on institution, conventional angiography might also be used.
3. If concern for ligamentous/soft tissue injury, obtain MRI including coronal T1-weighted and coronal T2-weighted fat-suppressed, sagittal and axial PD fat-suppressed.

Shoulder Imaging for Glenohumeral Dislocation

1. Radiographs: anteroposterior in internal and external rotation, axillary view (if possible) or

Fig. 29.5 (**a**)–(**c**) 22-year-old man with a radiographically occult scaphoid fracture after a fall on outstretched hand. Initial radiographs (**a**) were negative; the scaphoid view, shown here, does not demonstrate a fracture line. On MRI, a T2-weighted fat-suppressed image (**b**) shows bone marrow edema in the scaphoid (*arrowhead*). On the corresponding coronal T1-weighted image (**c**), a linear, low-signal fracture line (*arrow*) is seen

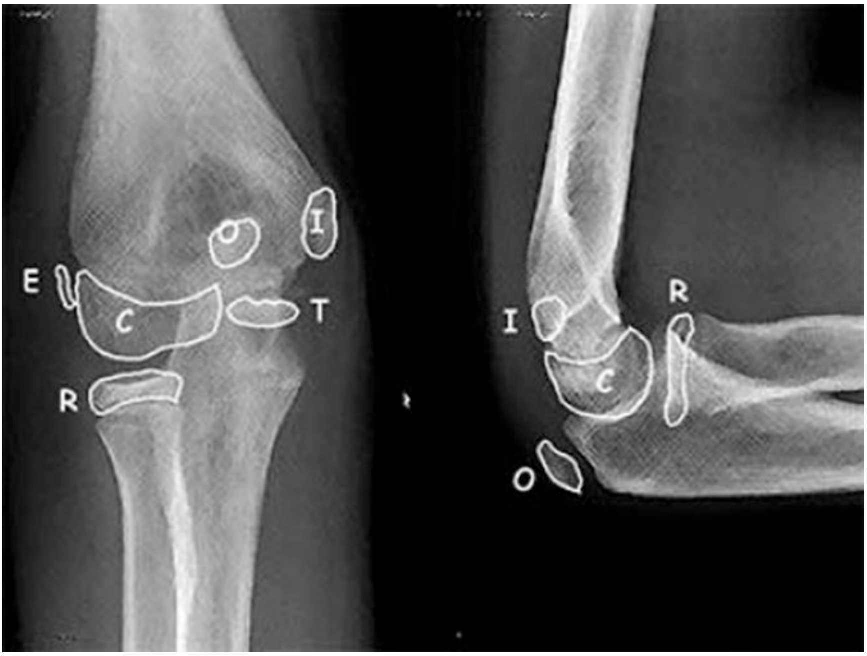


Fig. 29.6 There are six ossification centers around the elbow joint. They appear and fuse to the adjacent bones at different ages. This order of appearance is specified in the mnemonic C-R-I-T-O-E (Capitellum-Radius-Internal or medial epicondyle-Trochlea-Olecranon-External or lateral epicondyle). The ages at which these ossification centers appear are highly variable and differ between individuals. (Used with kind permission from Robin Smithuis: Elbow Fractures in Children. 2005. www.radiologyassistant.nl. http://www.radiologyassistant.nl/en/p420f0b3ef35c6/the-radiology-assistant.html)

scapular Y view if not; consider Stryker notch and/or West Point views if further evaluation is needed for Hill-Sachs or Bankart injuries, respectively.

2. If evaluation of soft tissue injury is necessary, obtain MRI including axial PD fat-suppressed, coronal and sagittal oblique PD fat-suppressed, and sagittal oblique T1-weighted.
3. If evaluation of labrum, intra-articular ligaments, and/or cartilage is needed, get MR arthrogram including arthrogram procedure followed by axial T1-weighted fat-suppressed, coronal oblique T1- and T2-weighted fat-suppressed, and sagittal T1-weighted fat-suppressed. If CT arthrogram is used, perform arthrogram procedure followed by 0.625 oblique axial slices through shoulder (perpendicular to glenoid) with oblique coronal and oblique sagittal reconstructions.

Acromioclavicular Imaging for Joint Separation

1. Radiographs: bilateral AP radiographs with Zanca view with and without 10-pound weights.
2. If ligamentous evaluation is needed, perform MRI with axial PD fat-suppressed, coronal and sagittal oblique PD fat-suppressed, and sagittal oblique T1-weighted sequences.

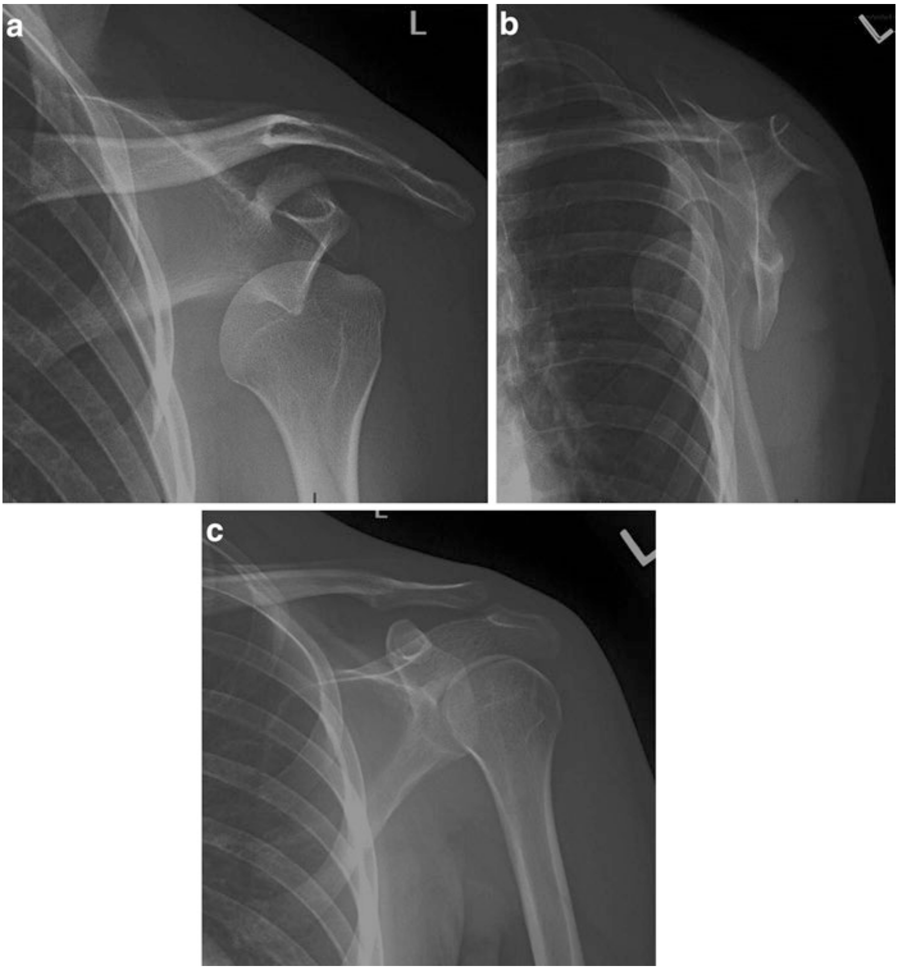


Fig. 29.7 (**a**)–(**c**) 42-year-old man with humeral head disloction after an injury. (**a**) AP radiograph of the shoulder shows the humeral head located medially compared to the glenoid fossa. (**b**) "Y" view confirms anterior dislocation of the glenohumeral joint with the humeral head located anteriorly compared to the glenoid. (**c**) Postreduction radiograph shows the humeral head in anatomic position, aligned with the glenoid fossa

Future Research

Future studies should address the following research questions:

- Is MRI cost-effective as first-line imaging modality in suspected scaphoid fracture?
- Is there a role for CT to diagnose scaphoid fracture when radiography is negative?
- What is the optimal timing of MRI to evaluate for ligamentous injury in elbow dislocation (presently, MRI is more commonly used in the subacute or chronic setting)?
- Should all patients with shoulder dislocation undergo MRI evaluation? What is the optimal timing for MRI after reduction of shoulder dislocation?

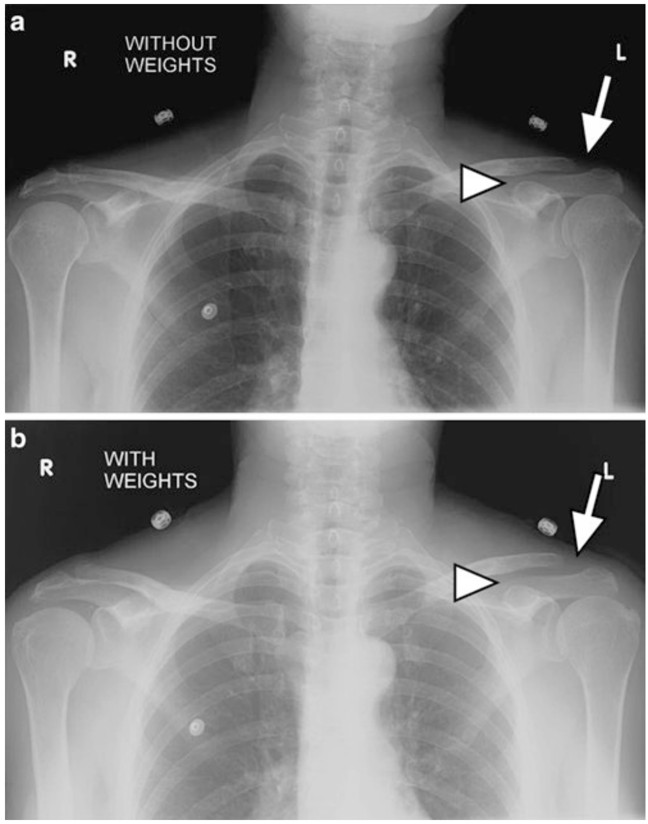


Fig. 29.8 (**a**) and (**b**) 71-year-old woman with left ACJ injury after a biking accident. Bilateral AP radiograph (**a**) of the clavicles without weights shows a left acromioclavicular interval of 7 mm (*arrow*) and a coracoclavicular interval of 10 mm (*arrowhead*), both of which are at the upper limits of normal. Right acromioclavicular and coracoclavicular distances are normal. On the radiograph with weights (**b**), there is increased left acromioclavicular distance to 15 mm (*arrow*) and increased coracoclavicular distance to 15 mm (*arrowhead*)

References

1. Ootes D, Lambers KT, Ring DC. Hand (N Y). 2012;7:18–22.
2. Arora R, Fichadia U, Hartwig E, et al. Pediatr Ann. 2014;43:196–204.
3. Karl JW, Olson PR, Rosenwasser MP. J Orthop Trauma. 2015;29:e242–4.
4. Webster BS, Snook SH. J Occup Med. 1994;36:713–7.
5. Kuye IO, Jain NB, Warner L, et al. J Shoulder Elbow Surg. 2012;21:367–75.
6. Polinder S, Iordens GI, Panneman MJ, et al. BMC Public Health. 2013;13:531.
7. Schubert HE. Can Fam Physician. 2000;46:1825–32.
8. Phillips TG, Reibach AM, Slomiany WP. Am Fam Physician. 2004;70:879–84.
9. Buijze GA, Doornberg JN, Ham JS, et al. J Bone Joint Surg Am. 2010;92:1534–44.
10. Yin ZG, Zhang JB, Kan SL, et al. Clin Orthop Relat Res. 2010;468:723–34.
11. Bruno M, Weissman B, Kransdorf M, et al. ACR Appropriateness Criteria: acute hand and wrist trauma. 2013. https://acsearch.acr.org/docs/69418/Narrative/.
12. Tiel-van Buul MM, van Beek EJ, Broekhuizen AH, et al. Injury. 1992;23:77–9.
13. Breitenseher MJ, Metz VM, Gilula LA, et al. Radiology. 1997;203:245–50.
14. Dorsay TA, Major NM, Helms CA. Am J Roentgenol. 2001;177:1257–63.
15. Groves AM, Kayani I, Syed R, et al. Am J Roentgenol. 2006;187:1453–6.
16. Bretlau T, Christensen OM, Edstrom P, et al. Acta Orthop Scand. 1999;70:504–8.
17. Lohman M, Kivisaari A, Vehmas T, et al. Acta Radiol. 1999;40:615–8.
18. Mack MG, Keim S, Balzer JO, et al. Eur Radiol. 2003;13:612–7.
19. Tibrewal S, Jayakumar P, Vaidya S, et al. Int Orthop. 2012;36:107–10.
20. Hunter JC, Escobedo EM, Wilson AJ, et al. Am J Roentgenol. 1997;168:1287–93.
21. de Zwart AD, Beeres FJ, Kingma LM, et al. J Hand Surg Am. 2012;37:2252–6.
22. Duckworth AD, Ring D, McQueen MM. J Bone Joint Surg Br. 2011;93:713–9.
23. Khalid M, Jummani ZR, Kanagaraj K, et al. Emerg Med J. 2010;27:266–9.
24. Blum A, Sauer B, Detreille R, et al. J Radiol. 2007;88:741–59.
25. Hansen TB, Petersen RB, Barckman J, et al. J Hand Surg Eur Vol. 2009;34:627–30.
26. Groves AM, Cheow HK, Balan KK, et al. Br J Radiol. 2005;78:791–5.
27. Foex B, Speake P, Body R. Emerg Med J. 2005;22:434–5.

28. Fowler C, Sullivan B, Williams LA, et al. Skeletal Radiol. 1998;27:683–7.
29. Memarsadeghi M, Breitenseher MJ, Schaefer-Prokop C, et al. Radiology. 2006;240:169–76.
30. Stoneback JW, Owens BD, Sykes J, et al. J Bone Joint Surg Am. 2012;94:240–5.
31. O'Driscoll S. Elbow dislocations. In: Morrey B, Sanchez-Sotelo J, editors. The elbow and its disorders. 4th ed. Philadelphia, PA: Saunders/Elsevier; 2009. p. 436–49.
32. Sheehan SE, Dyer GS, Sodickson AD, et al. Radiographics. 2013;33:869–88.
33. Kuhn MA, Ross G. Orthop Clin North Am. 2008;39:155–61, v.
34. Durig M, Muller W, Ruedi TP, et al. J Bone Joint Surg Am. 1979;61:239–44.
35. Micic I, Kim SY, Park IH, et al. Int Orthop. 2009;33:1141–7.
36. Crosby NE, Greenberg JA. J Hand Surg Am. 2014;39:1408–14.
37. Mezera K, Hotchkiss RN. Fractures and dislocations of the elbow. In: Rockwood CA, Green DP, Bucholz RW, editors. Fractures in adults. 5th ed. Philadelphia, PA: Lippincott, Williams, & Wilkins; 2001. p. 921–34.
38. Coonrad RW, Roush TF, Major NM, et al. J Shoulder Elbow Surg. 2005;14:312–7.
39. Stevens KJ, McNally EG. Clin Sports Med. 2010;29:521–53.
40. Schreiber JJ, Potter HG, Warren RF, et al. J Hand Surg Am. 2014;39:199–205.
41. Lumsdaine W, Enninghorst N, Hardy BM, et al. Injury. 2013;44:471–4.
42. Marcheix B, Chaufour X, Ayel J, et al. J Vasc Surg. 2005;42:1230–2.
43. Carter SJ, Germann CA, Dacus AA, et al. Am J Emerg Med. 2010;28:960–5.
44. Ayel JE, Bonnevialle N, Lafosse JM, et al. Orthop Traumatol Surg Res. 2009;95:343–51.
45. Kroner K, Lind T, Jensen J. Arch Orthop Trauma Surg. 1989;108:288–90.
46. Zacchilli MA, Owens BD. J Bone Joint Surg Am. 2010;92:542–9.
47. Rowe CR. J Bone Joint Surg Am. 1956;38-A:957–77.
48. Hovelius L. Clin Orthop Relat Res. 1982;166:127–31.
49. Bencardino JT, Gyftopoulos S, Palmer WE. Radiology. 2013;269:323–37.
50. Owens BD, Nelson BJ, Duffey ML, et al. J Bone Joint Surg Am. 2010;92:1605–11.
51. Wise J, Daffner R, Weissman B, et al. ACR Appropriateness Criteria: acute shoulder pain. 2010. https://acsearch.acr.org/docs/69433/Narrative/. Accessed 1 Aug 2015.
52. Silfverskiold JP, Straehley DJ, Jones WW. Orthopedics. 1990;13:63–9.
53. Sanders TG, Morrison WB, Miller MD. Am J Sports Med. 2000;28:414–34.
54. Dumont GD, Russell RD, Robertson WJ. Curr Rev Musculoskelet Med. 2011;4:200–7.
55. Workman TL, Burkhard TK, Resnick D, et al. Radiology. 1992;185:847–52.
56. Gyftopoulos S, Bencardino J, Palmer WE. Semin Musculoskelet Radiol. 2012;16:286–95.
57. Denti M, Monteleone M, Trevisan C, et al. Knee Surg Sports Traumatol Arthrosc. 1995;3:184–6.
58. Hayes ML, Collins MS, Morgan JA, et al. Skeletal Radiol. 2010;39:1199–204.
59. Gusmer PB, Potter HG, Schatz JA, et al. Radiology. 1996;200:519–24.
60. Liavaag S, Stiris MG, Svenningsen S, et al. Scand J Med Sci Sports. 2011;21:e291–7.
61. Willemsen UF, Wiedemann E, Brunner U, et al. Am J Roentgenol. 1998;170:79–84.
62. Palmer WE, Brown JH, Rosenthal DI. Radiology. 1994;190:645–51.
63. Magee T. Am J Roentgenol. 2009;192:86–92.
64. Major NM, Browne J, Domzalski T, et al. Am J Roentgenol. 2011;196:1139–44.
65. Smith TO, Drew BT, Toms AP. Arch Orthop Trauma Surg. 2012;132:905–19.
66. Oh JH, Kim JY, Choi JA, et al. J Shoulder Elbow Surg. 2010;19:14–20.
67. Lecouvet FE, Dorzee B, Dubuc JE, et al. Eur Radiol. 2007;17:1763–71.
68. Omoumi P, Rubini A, Dubuc JE, et al. Eur Radiol. 2015;25:961–9.
69. Saupe N, White LM, Bleakney R, et al. Radiology. 2008;248:185–93.
70. Alyas F, Curtis M, Speed C, et al. Radiographics. 2008;28:463–79; quiz 619.
71. Melenevsky Y, Yablon CM, Ramappa A, et al. Skeletal Radiol. 2011;40:831–42.
72. Mazzocca AD, Spang JT, Rodriguez RR, et al. Am J Sports Med. 2008;36:1397–402.
73. Tossy JD, Mead NC, Sigmond HM. Clin Orthop Relat Res. 1963;28:111–9.
74. Eschler A, Rosler K, Rotter R, et al. Arch Orthop Trauma Surg. 2014;134:1193–8.
75. Phillips AM, Smart C, Groom AF. Clin Orthop Relat Res. 1998;353:10–7.
76. Schlegel TF, Burks RT, Marcus RL, et al. Am J Sports Med. 2001;29:699–703.
77. Zanca P. Am J Roentgenol Radium Ther Nucl Med. 1971;112:493–506.
78. Ibrahim EF, Forrest NP, Forester A. Injury. 2015;46(10):1900–5.
79. Sluming VA. Br J Radiol. 1995;68:1181–4.
80. Bossart PJ, Joyce SM, Manaster BJ, et al. Ann Emerg Med. 1988;17:20–4.
81. Schaefer FK, Schaefer PJ, Brossmann J, et al. Eur Radiol. 2006;16:1488–93.
82. Barnes CJ, Higgins LD, Major NM, et al. J Surg Orthop Adv. 2004;13:69–75.
83. de Abreu MR, Chung CB, Wesselly M, et al. Clin Imaging. 2005;29:273–7.
84. Antonio GE, Cho JH, Chung CB, et al. Am J Roentgenol. 2003;180:1103–10.
85. Hambidge SJ, Davidson AJ, Gonzales R, et al. Pediatrics. 2002;109:559–65.
86. Iyer RS, Thapa MM, Khanna PC, et al. Am J Roentgenol. 2012;198:1053–68.
87. Carson S, Woolridge DP, Colletti J, et al. Pediatr Clin North Am. 2006;53:41–67, v.