Multimodality Elbow Imaging with Emphasis on Magnetic Resonance Imaging

Michael J. Tuite and Laura W. Bancroft

Introduction

The elbow is a complex joint that may be affected by overuse, acute trauma, arthritis, inflammation and infection. When imaging is warranted for evaluation of pathology, radiographs are essential in the initial workup and cross-sectional imaging may be helpful for further evaluation depending on the suspected pathology. Sonography is particularly useful in assessing ligament and tendon injuries, identifying effusions or synovitis, and guiding percutaneous therapeutic injections. Computed tomography (CT) may be indicated in evaluating complex osseous injury after initial radiographs, and CT arthrography is an alternative to MRI in assessing tendons and ligaments when contraindications exist. For the purpose of this discussion, the normal and pathologic imaging characteristics of osseous and soft tissue elbow disorders will be focused on trauma, with an emphasis on magnetic resonance imaging (MRI) and MR arthrography.

Bones and Cartilage

Normal Anatomy

The elbow is composed of three individual joints, all within a single synovial-lined joint capsule [1–4]. The largest of these is the ulnotrochlear joint, where the trochlea (or medial condyle of the humerus) articulates with the sigmoid notch of the proximal ulna. The sigmoid notch forms a 190° arc when viewed from the side, and its distal margin is the coronoid process and its proximal margin the olecranon process. The trochlea is covered with articular cartilage throughout its 330° arc when viewed from the side. Above the trochlea anteriorly is the coronoid fossa, into which the coronoid process sits in full flexion. Above the trochlea posteriorly is the olecranon fossa into which the olecranon process sits in full extension.

Some of the stability of the elbow joint results from the shape of the trochlear and sigmoid notch articular surfaces. The sigmoid notch has medial and lateral surfaces that both slope upward to meet in the middle to form a longitudinally-oriented ridge (Fig. 1). The trochlea has corresponding medial and lateral surfaces that slope downward to form a longitudinally-oriented trough. This trough-like shape of the trochlea has been described as being like the groove in a pulley, and it provides medial-lateral stability to the elbow joint.

The second largest articulation in the elbow joint is the radiocapitellar joint. This joint does not contribute as much to the stability of the elbow because the radial head has a shallow articular surface, but the joint surfaces allow for forearm pronation-supination. The capitellum (or lateral condyle of the humerus) is covered by articular cartilage along its anterior and distal surfaces, but not posteriorly because the relatively small radial head does not contact the posterior capitellum even in full extension. This can be a source of confusion on coronal MR images because the posterior capitellum can appear irregular like an osteochondritis dissecans (OCD) lesion, when in fact this is the "bare area" where there is no articular cartilage (Fig. 2).

The third and smallest articulation in the elbow is the proximal radioulnar joint. This joint is between the peripheral margin of the radial head, and a small concavity in the lateral coronoid process termed the semilunar (or lesser sigmoid) notch. The semilunar notch is lined with articular cartilage, as is a variable portion of the medial radial head. This allows the joint surfaces to slide on each other during pronation and supination [1, 4].

M.J. Tuite (✉)
Department of Radiology, University of Wisconsin, 600 Highland Ave, Madison, WI 53792, USA
e-mail: mjtuite@wisc.edu

L.W. Bancroft
Department of Radiology, Florida Hospital, 601 E. Rollins, Orlando, FL 32803, USA
e-mail: Laura.bancroft.md@flhosp.org

J. Hodler et al. (eds.), *Musculoskeletal Diseases 2017-2020*, DOI 10.1007/978-3-319-54018-4_5

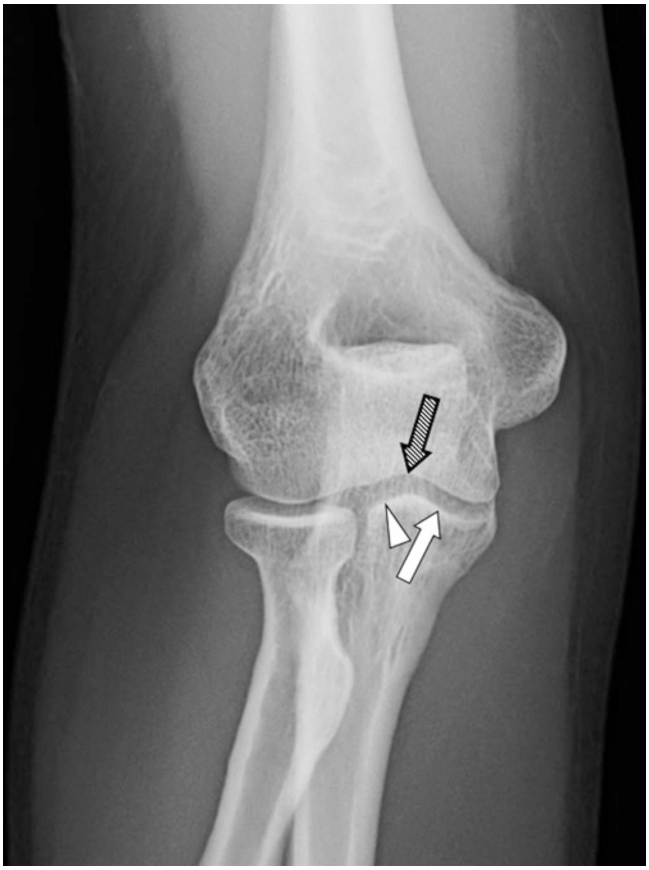

Fig. 1 Normal elbow. AP radiograph shows the medial (*white arrow*) and lateral (*arrowhead*) articular surfaces in the sigmoid notch that angle up to form a longitudinally-oriented ridge. The trochlea has corresponding sloped articular surfaces that angle down to meet in a longitudinally-oriented trough (*striped arrow*), that has been likened to the groove in a pulley

Above the elbow joint on the medial and lateral surfaces of the humerus sit the larger medial, and smaller lateral epicondyles. The medial epicondyle is the origin of the common flexor/pronator tendons, and the anterior and posterior bundles of the ulnar collateral ligament. The lateral epicondyle is the origin of the common extensor/supinator tendons, the radial collateral ligament, and the lateral ulnar collateral ligament (LUCL).

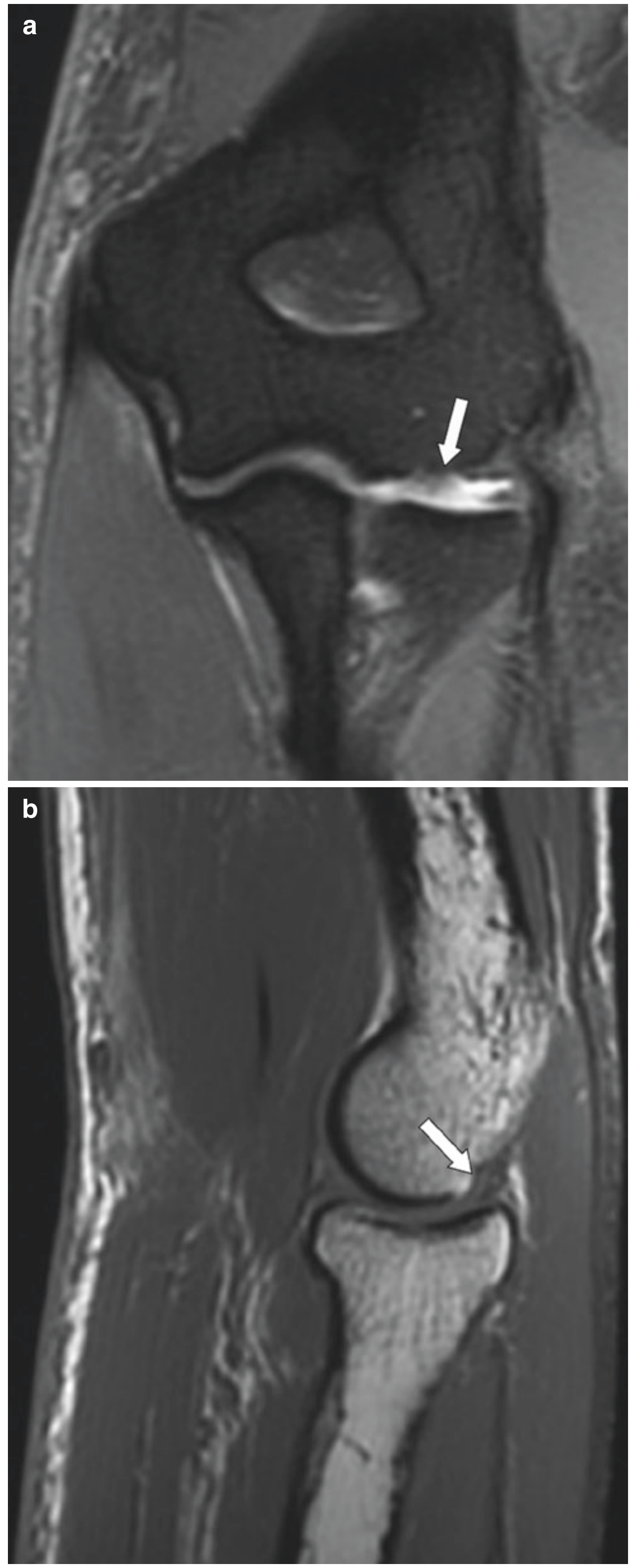

Fig. 2 (**a**–**b**) Pseudo-OCD of the capitellum. (**a**) Coronal fat-suppressed (FS) intermediate-weighted image shows apparent irregularity of the articular surface, or "pseudo-OCD" (*arrow*) of the capitellum. (**b**) Sagittal proton density image shows the normal bare area of the posteroinferior capitellum (*arrow*). The radial head articulates anterior to the bare area even when the elbow is fully extended

Bones and Cartilage: Normal Variants

There are several normal osseous variants of the elbow [3, 4]. Some individuals can have a ridge that runs transversely across the middle of the sigmoid notch dividing it into proximal and distal halves (Fig. 3). This ridge is variable in size and can be absent. The thickness of the articular cartilage on the ridge can be very thin, knowing this helps avoid confusing the ridge with a central osteophyte. At the medial and/or lateral margins of this ridge, there can be a small groove, which should not be confused with an osteochondral lesion (Fig. 4). Another osseous normal variant is when there is no osseous separation between the olecranon and coronoid fossae, called an olecranon foramen.

Fig. 3 Normal transverse sigmoid ridge. Sagittal reformatted CT image shows a normal variant transverse sigmoid ridge (*arrow*). This can be covered with imperceptibly-thin articular cartilage, and should not be confused with a pathologic central osteophyte

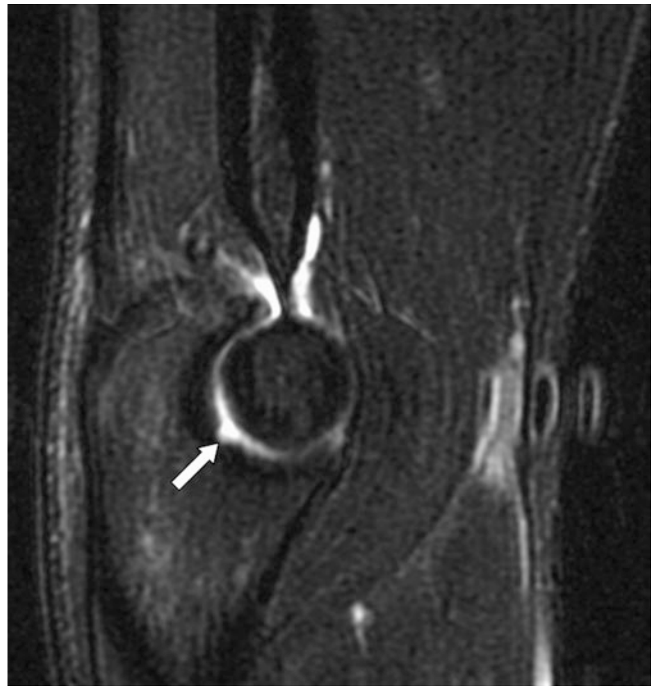

Fig. 4 Normal sigmoid groove. Sagittal T2-weighted FS image shows a normal variant sigmoid groove. These occur at the site of the fused olecranon physis, and should not be confused with a pathologic osteochondral defect

Bones and Cartilage: Pediatric Throwing Injuries

Because the ligaments and tendons in children are relatively strong relative to bone, pediatric throwers tend to get more osseous overuse elbow injuries compared to adult throwing athletes. The two main injuries in young throwers are therefore capitellar osteochondritis dissecans (OCD), and Little Leaguer's Elbow. The OCD in pediatric throwers typically involves the anterolateral aspect of the capitellum [5–8]. Although it usually occurs in the dominant throwing arm of 12–17 year old boys who are baseball pitchers, it can also be seen in young gymnasts and in other overhead sports such as tennis (Fig. 5). The OCD in gymnasts is often bilateral, and is felt to be due to similar repetitive shear forces to the elbow during hand springs or walking on their hands.

Most authors stress the difference between OCD and Panner disease. Panner disease is typically found in younger boys under 10 years old, and there is rarefaction and fragmentation of the entire capitellum rather than only the anterolateral portion. The condition is treated conservatively with rest, and is usually self-limited with reconstitution of

Fig. 5 (**a**–**d**) Bilateral osteochondritis dissecans in 12-year-old female gymnast. AP radiographs of the *left* (**a**) and *right* (**b**) elbow show bilateral osteochondritis dissecans (OCD) lesions (*arrows*) of the capitellum. On the *right elbow*, sagittal T2-weighted FS (**c**) and coronal intermediate-weighted FS (**d**) images show high signal at the interface (*arrows*) of the OCD fragment with the adjacent epiphysis. Because the capitellar physis is fused, this high signal indicates that the OCD is unstable

the capitellum and no long term sequelae. Although some authors report no history of trauma, others believe Panner disease is probably a similar manifestation of repetitive valgus load onto the capitellum, but in younger boys with an open capitellar physis [9].

Capitellar OCD can appear on radiographs as either a subtle area of osteopenia in the capitellum, flattening of the subchondral bone plate, or fragmentation. The subtle focal osteopenia of early OCDs can be difficult to see on radiographs, with some authors reporting that only about 1/2–2/3 are seen prospectively [7]. There are several radiographic, MR and arthroscopic grading systems for capitellar OCD that are used to separate early lesions from more advanced disease. The most important imaging determinant for the surgeon, however, is whether the OCD is stable or unstable. This is best determined with MR, and can often be done on routine T2-weighted images without intravenous or intraarticular contrast [1, 5, 8, 10]. Unstable capitellar OCD lesions will have linear increased T2 signal along most of the interface between the OCD fragment and the underlying epiphysis, or have cysts at this interface [6, 8]. If the increased signal involves only a portion of the interface in a child with an open capitellar physis, it may be stable [1, 8]. A full thickness articular cartilage fissure around the circumference of the OCD fragment is sometimes considered an additional sign of an unstable OCD.

Most capitellar OCD lesions do not heal with conservative management. Several authors have found that conservative treatment should only be pursued on patients who meet all three of the following criteria: (1) stable OCD on MR, (2) open capitellar physis, and (3) near-normal elbow motion [10, 11]. Because the majority of capitellar OCD lesions do not meet all three criteria, most either need surgery or will have a poor long term prognosis. About half of patients with a capitellar OCD will go on to have pain, reduced range of motion, or elbow degenerative change [11, 12].

Another injury in skeletally immature baseball pitchers is medial epicondyle apophysitis, also known as Little Leaguer's elbow [13, 14]. This is felt to be a chronic stress injury to the medial epicondylar physis from repetitive traction on the apophysis by the common flexor tendons and UCL from the valgus stress during throwing. The radiographic finding is abnormal widening of the physis, usually greater than 3 mm. The size of the apophysis is also often larger than that in the contralateral non-throwing elbow, probably from chronic hyperemia. On MRI in patients with Little Leaguer's elbow, the physis is wide and higher signal than normal, and there is typically adjacent bone marrow edema (Fig. 6).

Fig. 6 (**a**, **b**) Little Leaguer's elbow in 13-year-old right-handed baseball pitcher with medial epicondyle pain. Coronal intermediate-weighted FS (**a**) and axial T2-weighted FS (**b**) images show increased high signal at the physis (*arrows*) and apophyseal marrow edema (*arrowhead*) consistent with little leaguer's elbow or medial apophysitis

Bones and Cartilage: Other Osseous and Chondral Abnormalities

The most common sites for fractures around the elbow after acute trauma are the radial head/neck and the olecranon process in adults, and supracondylar fractures in children [1]. MR can be helpful in imaging some patients with acute elbow trauma, particularly if a fracture is suspected clinically but the radiographs only show an effusion (Fig. 7). Radiographically, occult fractures will appear as linear low signal on T1-weighted images, with a variable signal-intensity fracture line on T2-weighted images with surrounding marrow edema.

Fig. 7 (**a**–**d**) Radial head fracture in 33-year-old woman with elbow pain after fall. (A) Anteroposterior (**a**), lateral (**b**), and radial head (**c**) radiographic views show the anterior fat pad (*striped arrow*) becomes obscured distally (*arrowheads*) by an effusion. No fracture was seen. (**d**) Axial T2-weighted FS image 1 month later shows a subacute minimally-displaced radial head fracture (*arrow*)

Elbow dislocations can also result in fractures, often involving the coronoid process. Isolated coronoid process fractures can be small yet the patients can have significant ligamentous injuries [15]. Although patients with a small isolated coronoid process fracture after elbow dislocation may do well with casting and conservative management, those that demonstrate a "drop sign" on lateral radiographs often require surgery [16]. The injury of a coronoid process fracture, radial head fracture, and posterior dislocation is called the elbow "terrible triad," and these patients are at high risk for chronic instability [15]. Another osteochondral injury that can be seen after elbow dislocation is the Osborne-Cotterill lesion, an osteochondral fracture of the posterolateral capitellum with or without an impaction defect of the radial head. These patients often do not heal their LUCL and thus have posterolateral rotary instability.

MR can also be helpful in patients with degenerative change who have pain and restricted range of motion. MR is more sensitive for detecting loose bodies within the elbow, which can be removed arthroscopically to give patients improved range of motion.

Muscles and Tendons

Normal Anatomy

The muscles and tendons around the elbow can be divided into four main groups [2]. Medially, many of the wrist and hand flexors and pronators make up the common flexor-pronator tendon which arises from the medial epicondyle [17]. The flexor carpi ulnaris, and to a lesser extent the flexor digitorum superficialis, overlie the anterior bundle of the ulnar collateral ligament and provide secondary dynamic stabilization against varus stress.

The lateral tendon origins are more complex. The extensor carpi radialis brevis, extensor carpi ulnaris, and extensor digitorum superficialis arise from the lateral epicondyle as the common extensor/supinator tendon. The extensor carpi radialis longus and the brachioradialis arise from the anterolateral aspect of the distal humerus, anterior to the lateral epicondyle proper. The supinator muscle also has part of its origin from the lateral epicondyle, although portions also arise more distally including from the lateral proximal crest of the ulna. The supinator muscle wraps around, and then inserts broadly onto the ulna.

The main anterior muscles/tendons are the biceps and the brachialis. The deeper brachialis inserts onto the proximal ulna including at the base of the coronoid process. The more superficial biceps tendon dives lateral to the brachialis to insert onto the bicipital tuberosity located along the posteromedial aspect of the radius distal to the radial head. The two heads of the biceps sometimes have well defined continuations distally. In these cases, the tendinous continuation of the long head inserts more proximally onto the bicipital tuberosity and has a broad attachment. The short head of the biceps inserts more distal and posteriorly, so has greater mechanical advantage as a supinator of the forearm. The bicipitoradialis bursa separates the distal tendon from the anteromedial radius. The lacertus fibrosis (or bicipital aponeurosis) is a thickening of the anteromedial fascia of the biceps muscle that then courses superficial to the brachial artery and median nerve to insert onto the deep fascia of the anterior forearm.

The main posterior muscles/tendons are the triceps and the anconeus. The triceps is comprised of the long, medial, and lateral heads, and has a broad insertion onto the olecranon process. The long head originates from the infraglenoid tubercle of the scapula, while the medial and lateral heads originate from the humerus. The long head has the longest tendon distally before inserting onto the olecranon process, while the medial and lateral heads remain as muscles fairly distally with short tendons forming just proximal to their insertions. The anconeus is a small muscle that arises posterior to the lateral epicondyle and inserts onto the lateral aspect of the olecranon process. The anconeus muscle is superficial to the annular ligament and therefore may help stabilize the radial head.

Muscles and Tendons: Normal Variant

A muscle normal variant is an absent palmaris longus tendon. This variant can be important to note on MR images because the palmaris longus tendon is often used in surgical reconstructions of the wrist and hand.

Muscles and Tendons: Muscle Injuries

Muscle injuries about the elbow are uncommon, but range from delayed-onset muscle soreness (DOMS), strain, and ultimately rupture at the extreme end of the spectrum [18]. Patients with delayed-onset muscle soreness typically present with muscle pain hours to days after eccentric muscle contractions, with maximal symptoms 2 days after imaging. Consideration for imaging after overuse does not usually occur unless there is a diagnosis of rhabdomylosis or other complicating features. Abnormalities will be evident as enlarged, edematous muscles on MRI of the affected muscle groups, usually in the anterior compartment (Fig. 8).

Muscle strain is most common along the myotendinous junction, but can also occur peripherally within the muscle belly. Of note, peripheral strains typically result in extended time until return to play. Frank muscle rupture about the elbow is very rare, and is often secondary to traumatic elbow dislocation (Fig. 9) or crush injury. MRI is useful in delineating the extent of involvement, providing quantitative measurement of muscle tearing for treatment decisions, and assessing healing on subsequent followup.

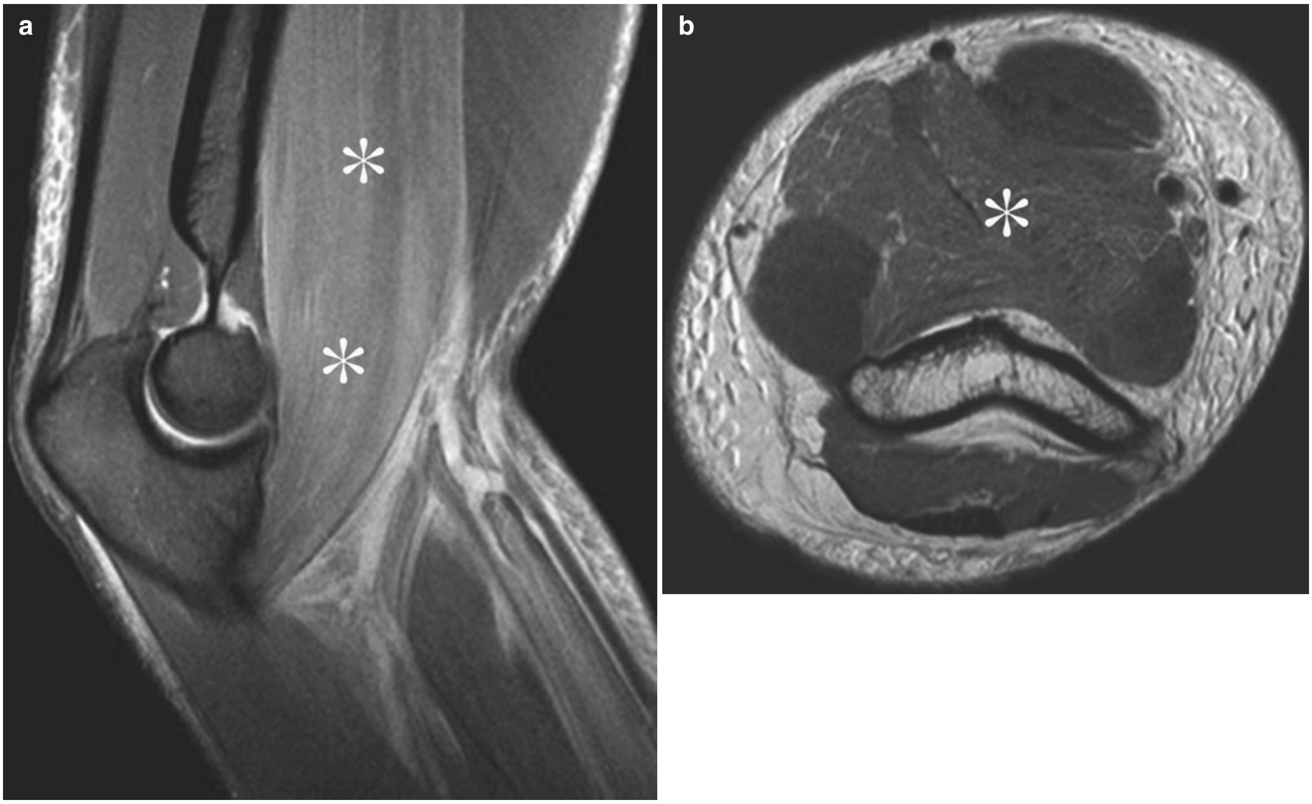

Fig. 8 (**a**–**b**) Brachialis rhabdomyolysis in 25-year-old man with arm pain and swelling 2 days after crossfit workout. Sagittal (**a**) and axial. (**b**) PD images demonstrate increased signal intensity within the enlarged brachialis muscle (*asterisks*) and subcutaneous edema-like signal changes. Patient had an elevated creatine kinase level of 33,840 units/l

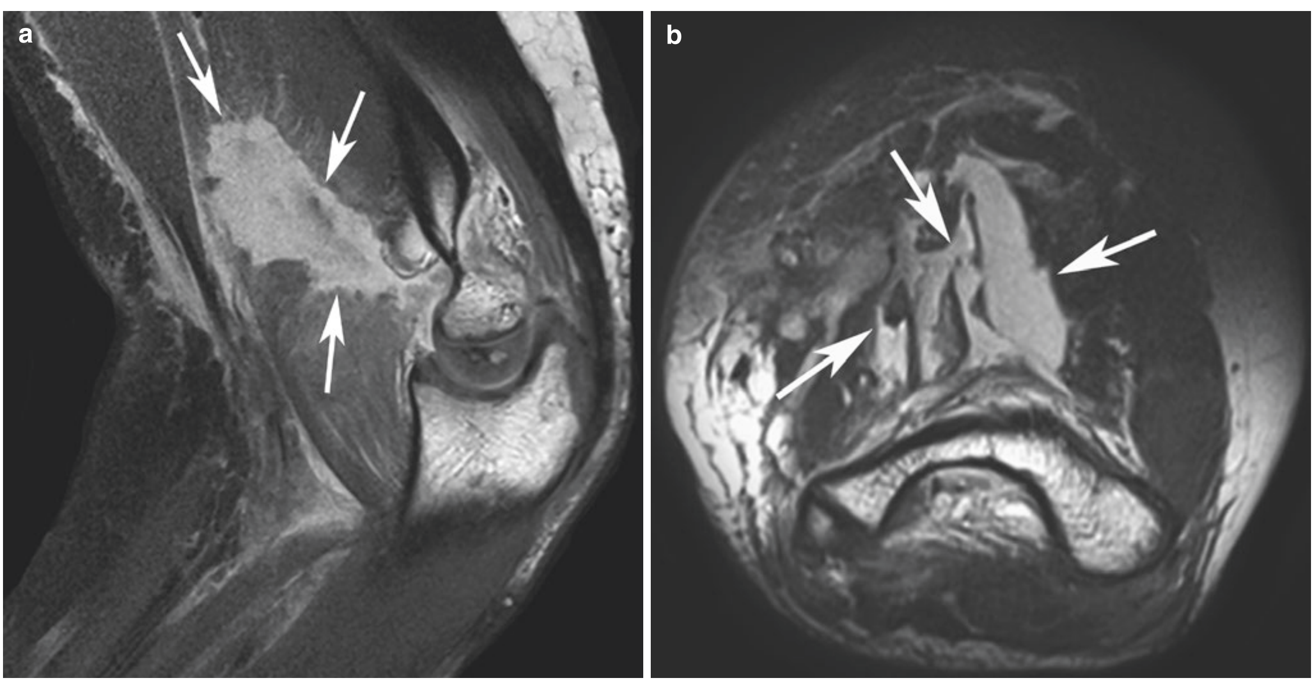

Fig. 9 (**a**–**d**) Brachialis muscle tear and brachial artery occlusion in 13-year-old boy after elbow dislocation. Sagittal (**a**) and axial (**b**) PD images show rupture of nearly the entire distal brachialis muscle (*arrows*). (**c**) Coronal 2D reconstruction from computed tomographic arteriogram (CTA) shows occlusion of the brachial artery (*arrowhead*) and adjacent hemorrhage (*asterisk*) in the brachialis defect. (**d**) 3D maximum intensity projection (MIP) from CTA shows occlusion of the brachial artery (*arrowhead*), with distal reconstitution (*arrow*)

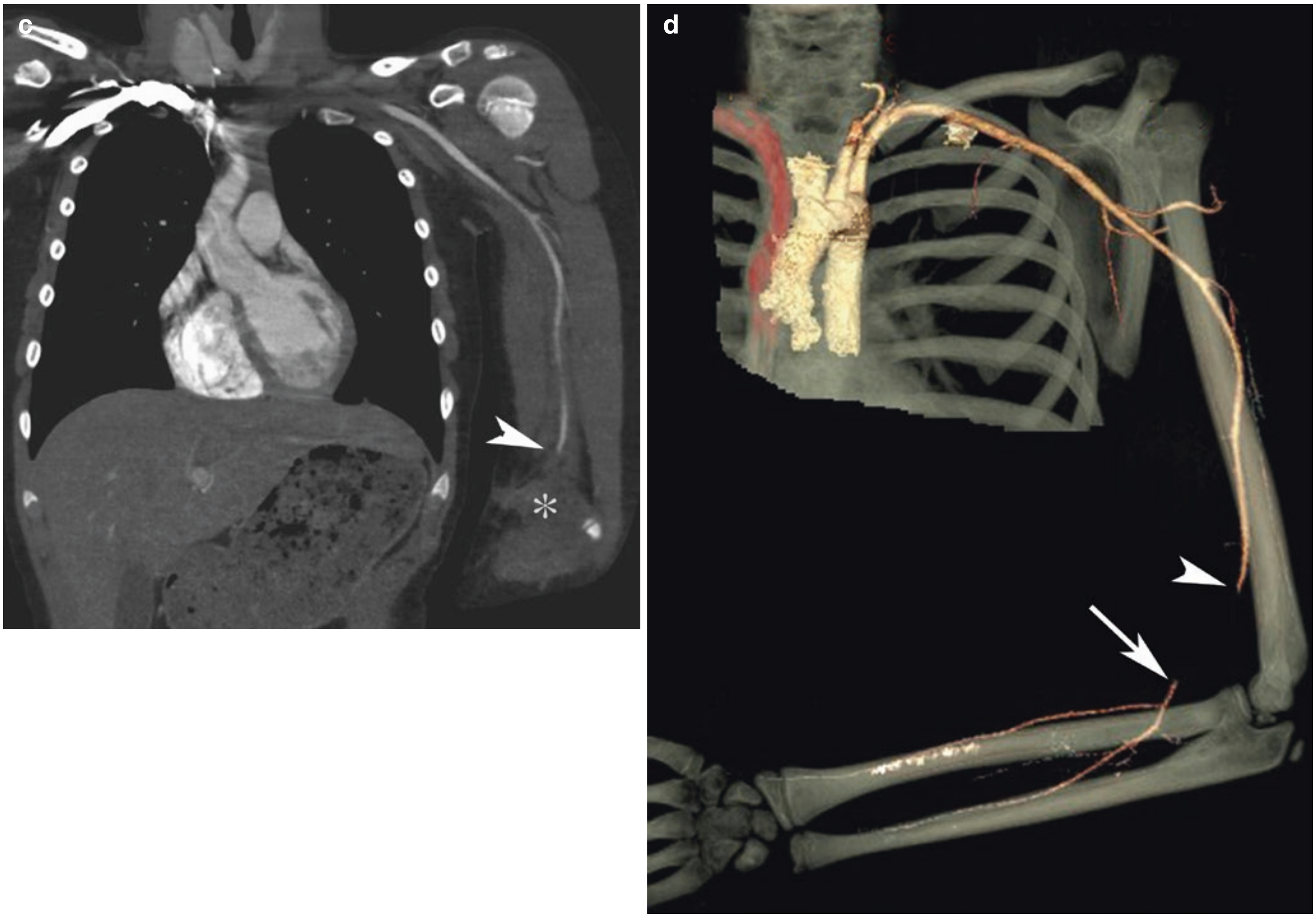

Fig. 9 (continued)

Muscles and Tendons: Tendon Injuries

Common Extensor Tendon Origin

The most common cause of elbow pain is "tennis elbow," otherwise known as "lateral epicondylitis." Common extensor tendon origin pathology classically presents in patients in the 4th or 5th decades with pain and point tenderness overlying the lateral epicondyle and pain with resisted wrist extension [19–22]. This degenerative process caused by repetitive microtrauma and is typically diagnosed clinically. If imaging is performed in equivocal or recalcitrant cases, findings include thinning, partial-thickness tearing or rupture of the common extensor tendon origin. Tendinosis will be evident as either tendon thickening or thinning, and intermediate T1- and T2-weighted signal intensity on MRI.

Partial- or full-thickness tears will demonstrate fluid signal within the discontinuous portion of the tendon [19–22]. Of importance, MRI or sonography may be helpful to exclude concomitant lateral ulnar collateral ligament complex tears, which can result in persistent instability and pain.

Common Flexor-Pronator Tendon Origin

Common flexor-pronator tendon origin pathology is also called "golfer's elbow." Repetitive overuse and microtearing of the flexor-pronator tendons in middle-aged and older individuals can result in progressive degeneration [17, 20]. Medial sided tendon injury is far less common than lateral sided pathology, and can occur in golfers, bowlers, swimmers, tennis players, and throwing athletes. Clinically, patients present with gradual onset of medial elbow pain and weakened grip. MRI or sonography may be warranted in patients with refractory medial elbow pain, and can exclude other etiologies.

Biceps Tendon

Biceps tendon injuries can be caused by caused by overuse from repetitive throwing, overhead activities or forced elbow flexion. Football players, weight-lifters and bodybuilders have the highest reported distal biceps tendon injuries, and risk further increases in men who smoke or use anabolic steroids [17, 23]. Injuries of the distal biceps are much less common than those involving the proximal biceps, and usually occur near the insertion onto the radial tuberosity. Partial-thickness tears are more common than full-thickness rupture, and tears can involve either the long or short head of the biceps. MRI and sonography are useful in presurgical planning of full-thickness tears, and imaging reports should include the degree of proximal retraction and the quality of the tendinous remnant (Fig. 10).

Triceps Tendon

Injuries of the triceps tendon are very rare, are often caused by a fall on an outstretched hand and usually occur near the olecranon insertion. Triceps tendon rupture can be partial or complete, can range from millimeters to centimeters in width, and almost always involve the lateral head insertion. Triceps tendon rupture will have adjacent soft tissue swelling, and may have olecranon bursal fluid and/or an associated small olecranon tip avulsion fracture, (Fig. 11). MRI is useful in excluding concomitant radial head fracture, capitellar fracture and ulnar collateral ligament rupture that can be associated with triceps tendon injuries [17, 20].

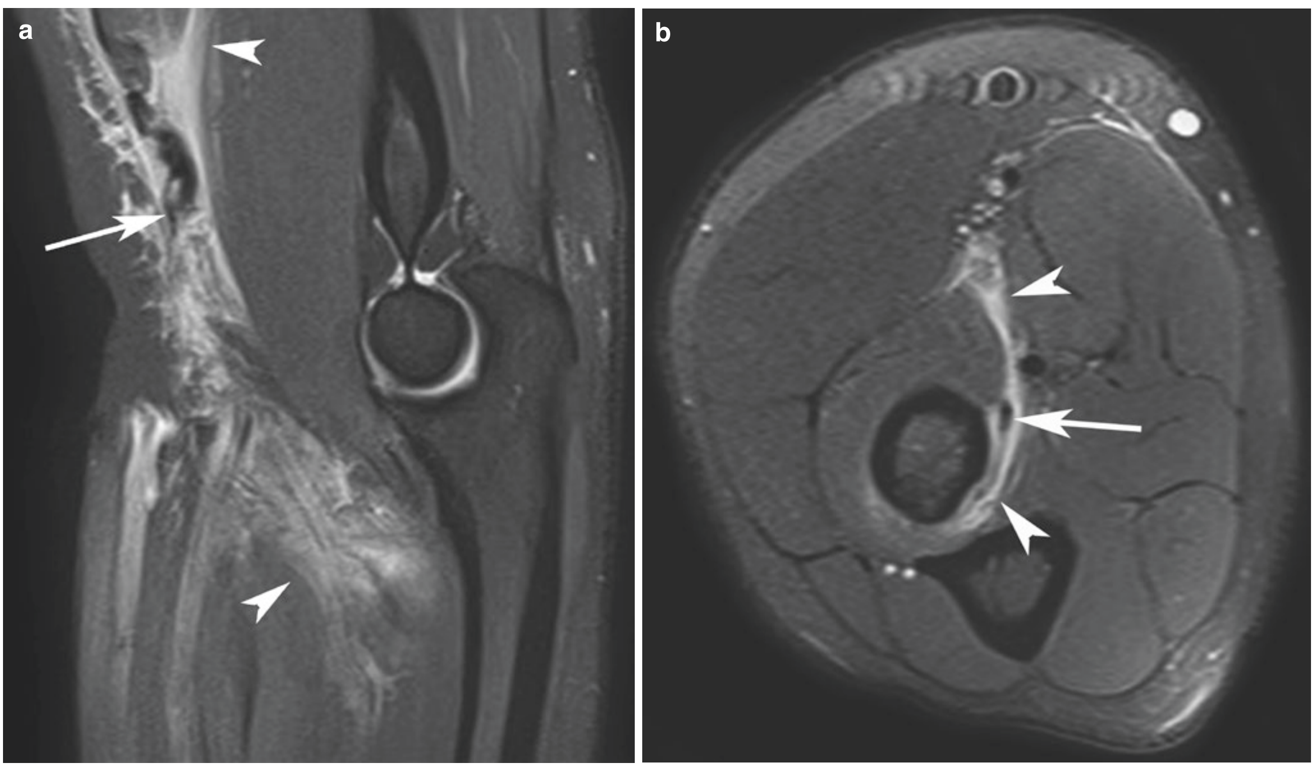

Fig. 10 (**a**, **b**) Distal biceps rupture in 44-year-old man after lifting heavy couch. (**a**) Sagittal PD FS image shows proximal retraction of both heads of the ruptured biceps tendon (*arrow*) and hyperintense hemorrhage (*arrowheads*) throughout the anterior arm and elbow soft tissues. (**b**) Axial PD FS image shows the distal biceps remnant (*arrowhead*) near its attachment onto the bicipital tuberosity and surrounding hemorrhage (*arrowheads*)

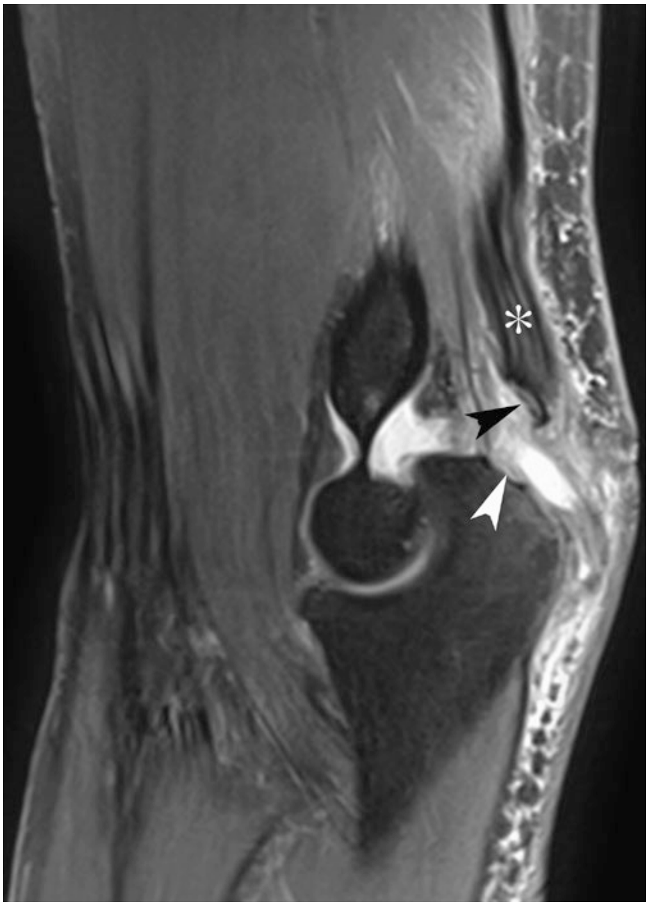

Fig. 11 Triceps tendon rupture and avulsion fracture in 54-year-old woman after fall. Sagittal PD FS image demonstrates small olecranon avulsion fracture (*arrowheads*) at the attachment of the triceps (*asterisk*)

Ligaments

Normal Anatomy

On the medial side of the elbow joint, the ulnar collateral ligament is comprised of three bundles—the anterior, posterior and transverse bundles. The anterior bundle originates from the undersurface of the medial epicondyle and inserts onto the sublime tubercle of the ulna. The anterior bundle can be separated into two bands which are taut during different portions of flexion/extension. The anterior band of the anterior bundle is the main static stabilizer of the elbow against valgus and internal rotation stress. The posterior bundle originates from the posterior aspect of the medial epicondyle and inserts on the medial aspect of the olecranon process, and forms the floor of the cubital tunnel. The transverse bundle originates from the medial tip of the olecranon process and inserts along the medial aspect of the coronoid process. Because the transverse bundle connects two points on the ulna and does not cross the elbow joint, it plays a minor role in stabilizing the elbow.

On the lateral side of the elbow joint, the lateral collateral ligament complex is made up of the radial collateral, the LUCL, and the annular ligaments [24]. The radial collateral ligament arises from the lateral epicondyle and inserts on the anterolateral aspect of the annular ligament. The annular ligament originates from the anterior margin of the semilunar notch, encircles the periphery of the radial head, and inserts onto the supinator crest of the ulna. The LUCL originates with, and is indistinguishable from, the lateral epicondylar origin of the radial collateral ligament, and inserts with the annular ligament onto the supinator crest of the ulna (Fig. 12). Although these three components of the lateral collateral ligament complex are described separately, studies show that they function as a continuous sheet to resist excessive varus and external rotational stress [24].

Fig. 12 Normal lateral ulnar collateral ligament. Coronal intermediate-weighted FS image shows the distal portion of the lateral ulnar collateral ligament (LUCL) (*arrow*) as it wraps around the posterior aspect of the radial neck (*arrowhead*) and inserts onto the supinator crest of the ulna (*striped arrow*)

Ligaments: Normal Variants

There are several ligament normal variants around the elbow [25]. Twenty-three percent of people have an accessory ulnar collateral ligament which originates on the posterior joint capsule and inserts onto the transverse bundle. Laterally in the elbow, one third of individuals have an accessory lateral collateral ligament which runs from the annular ligament to the supinator crest of the ulna. Also, some people may lack a LUCL. In addition, there is often a synovial fold (also called a plica or synovial fringe) in the posterolateral portion of the joint [4]. This is thickened in some people, and a subset of patients can have posterolateral elbow pain.

Ligament Injuries

Radial Collateral Ligament

Injuries to the radial collateral ligament complex can occur in conjunction with advanced cases of tennis elbow or trauma leading to posterolateral rotary subluxation. Tears can involve one or more of the three bundles (Fig. 13), but the lateral ulnar collateral ligament (LUCL) is the most important in terms of stability [14]. LUCL tears usually involve the humeral origin, and failure to recognize radial collateral ligament tears (particularly the LUCL) prior to surgical treatment of tennis elbow will lead to persistent postoperative symptoms (Fig. 14).

Fig. 13 Radial collateral ligament (RCL) and common extensor tendon rupture in 41-year-old man. Coronal PD FS image shows avulsion of the common extensor tendon origin (*arrow*) and the distal remnant of the ruptured RCL proper (*arrowhead*)

Fig. 14 Ulnar collateral ligament (UCL) rupture in 48-year-old woman with severe elbow pain and decreased range of motion. Coronal PD FS image shows distal avulsion of the anterior band of the UCL (*arrow*) and contusions (*arrowheads*) of the capitellum and radial head

Ulnar Collateral Ligament

Overhead throwing sports can result in medial elbow tension overload, lateral compression and extension overload. Medial elbow pain caused by excessive valgus forces and high pitching velocities can occur in overhead throwing athletes of all ages, and have been reported with baseball, football, javelin throwing, volleyball, golf and polo [14]. Injury to the ulnar (medial) collateral ligament is a common cause of medial elbow pain and valgus instability in athletes. Sonography may demonstrate hypoechoic and thickened ligaments with tendinosis, as well as classic findings for partial or complete ligamentous disruption. MRI may demonstrate increased T2-weighted signal within the ligament, most commonly the anterior band. Articular sided tears may occur anywhere along the tendon, and stripping of the distal ligamentous attachment may result in a "T sign" with contrast extension between the sublime tubercle and UCL [14, 20]. Complete rupture will show discontinuity of the ligament and extravasation of joint fluid or contrast through the ligamentous defect (Fig. 12).

Ligaments: Postoperative

Ligaments that have been either primarily repaired with sutures, reattached with bioabsorable or metallic suture anchors, or reconstructed with cadaveric or autologous grafts will not have the normal imaging appearance as native ligaments. It is important to recognize that intact postoperative ulnar and lateral collateral ligaments may be thicker and more heterogeneous in signal intensity than native ligaments, but tears can be detected by the same criteria of partial or complete ligamentous discontinuity (Fig. 15). High-level athletes with ulnar collateral ligament insufficiency may undergo "Tommy Johns" surgery or UCL reconstruction (Fig. 16). In a study of 51 patients who underwent MRI after UCL reconstruction, Wear and colleagues found that the normal intact UCL graft was thickened (because of double-bundle grafts and suturing of the graft to the native ligament) and variable in signal, but almost three fourths of the graft were homogeneously low signal on both T1- and T2-weighted images [26]. Intact grafts should be taut, and wavy grafts may be torn or insufficient. The Birmingham group

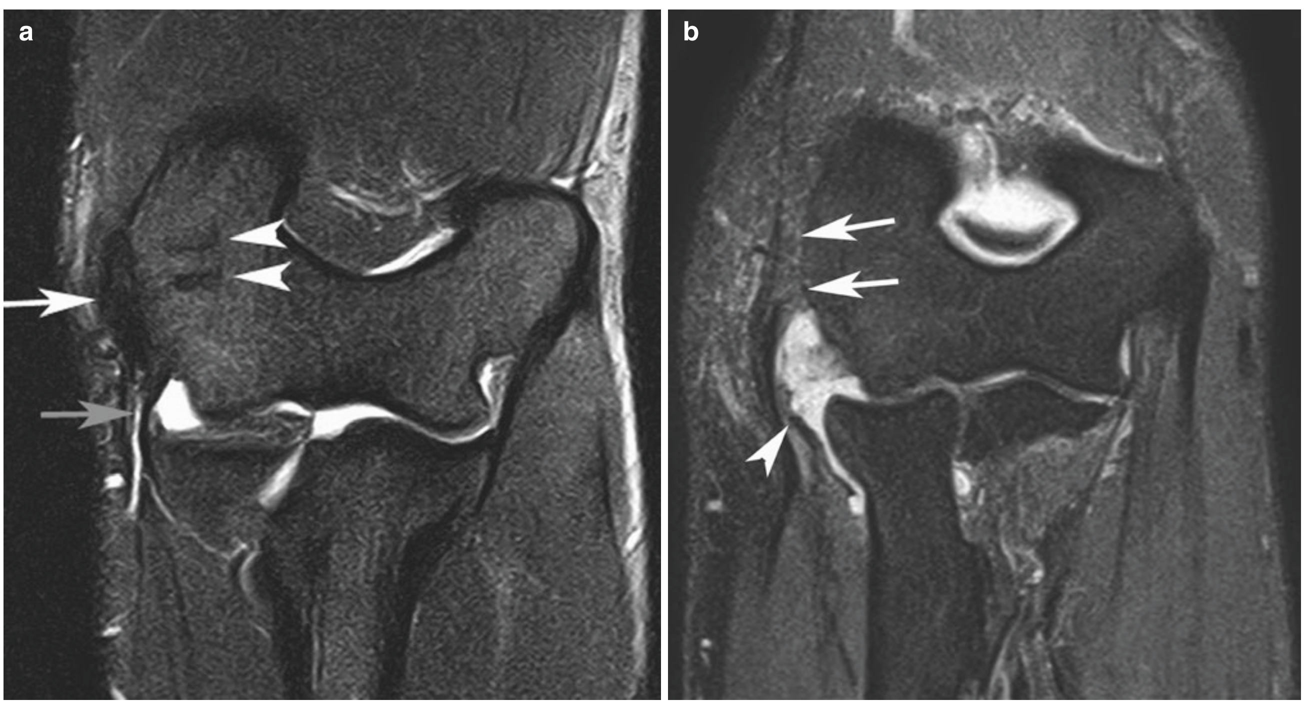

Fig. 15 (**a**, **b**) Intact common extensor tendon repair in two patients. (**a**) Coronal PD FS shows mild thickening of the intact, reattached common extensor tendon origin (*white arrow*) and underlying bioabsorbable suture anchors (*arrowheads*). Note the intact radial collateral ligament proper (*gray arrow*). (**b**) Coronal PD FS image in a 60-year-old man shows an intermediate signal but intact common extensor tendon (*arrows*) and torn underlying RCL complex (*white arrowhead*). Patient had recurrent pain and instability after undergoing fasciotomy, debridement and repair of the common extensor tendon 10 months previously

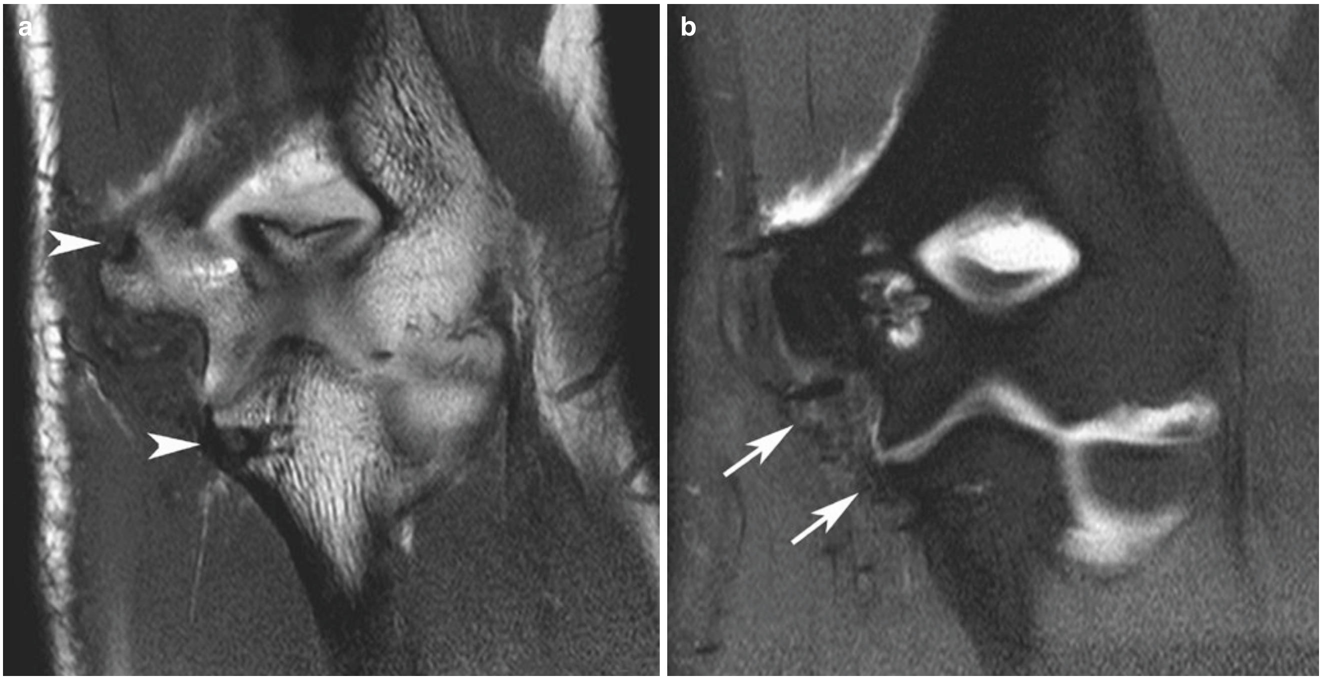

Fig. 16 Intact UCL reconstruction in 27-year-old professional baseball pitcher. (**a**, **b**). Coronal T1-weighted arthrographic images without (**a**) and with fat suppression (**b**) show the osseous tunnels (*arrowheads*) and intact UCL ligament graft (*arrows*). Grafts are thicker and typically more heterogeneous than native ligaments, and are anchored slightly distal to the sublime tubercle

prefers MR arthrographic evaluation of grafts since it can detect extension of contrast through discontinuous grafts. Of note, contrast may extend between the distal reconstructed UCL and the sublime tubercle due to distal attachment of the graft compared with the native ligament, and should not be interpreted as partial thickness tearing [26].

Nerves

Normal Anatomy

The three major nerves that course near the elbow are the ulnar, radial and median nerves. The ulnar nerve passes by the elbow joint within the cubital tunnel, which is posterior to the medial epicondyle. The floor of the cubital tunnel is made up of the posterior cortex of the medial epicondyle and the posterior bundle of the UCL. Most people have a retinaculum that covers the cubital tunnel and the ulnar nerve, and extends between the tip of the medial epicondyle and the medial aspect of the olecranon process.

The radial nerve at the level of the elbow runs within the radial tunnel, which is a space bounded mainly between the brachioradialis and brachialis muscles. Within the radial tunnel it passes by the fascial edge of the brachioradialis muscle, the tendinous edge of the extensor carpi radialis brevis muscle, and recurrent radial artery branches (the Leash of Henry). Just distal to the elbow the nerve divides into two branches, a motor branch which then dives deep to the superficial head of the supinator muscle which is called the posterior interosseous nerve (PIN), and a sensory branch called the superficial radial nerve. Proximal to the supinator muscle, motor branches arise to innervate the brachioradialis and supinator muscles, and sometimes the extensor carpi radialis longus and brevis muscles [27]. After passing the superficial head of the supinator muscle, the PIN typically innervates the extensor digitorum, extensor carpi ulnaris, anconeus, extensor pollicis longus and brevis, extensor indicis, and abductor pollicis longus muscles. The superficial radial nerve provides sensation to the dorsal forearm distal to the lateral epicondyle, as well as the back of the hand.

The median nerve runs deep to the lacertus fibrosis and medial to the brachial artery and biceps brachii muscles in the antecubital fossa. The nerve gives off motor branches to multiple muscles at the level of the elbow before it gives off the anterior interosseous nerve (AIN), a motor branch like the PIN. The AIN innervates the flexor pollicis longus muscle and the lateral portion of the flexor digitorum profundus muscle.

Nerves: Normal Variants

A small percentage of patients do not have a cubital tunnel retinaculum. Not having a retinaculum can allow the ulnar nerve to sublux out of the cubital tunnel, although this is typically asymptomatic [28]. The accessory anconeus (or anconeus epitrochlearis) muscle is a normal variant that is present in 3–28% of people. It replaces the cubital tunnel retinaculum, and originates from the posterior aspect of the medial epicondyle of the humerus and inserts onto the medial aspect of the olecranon process.

In addition to asymptomatic subluxation of the ulnar nerve, another normal variant for nerves around the elbow is where the median nerve distal to the elbow courses posterior to the brachial (ulnar) artery instead of running alongside it, although still between the pronator teres and brachialis muscles [4].

Non-Throwing Nerve Abnormalities

Ulnar Nerve

Cubital tunnel syndrome is the second most common neuropathy in the upper extremity, after carpal tunnel syndrome. In cubital tunnel syndrome, the patient has pain with or without muscle weakness due to irritation or compression of the ulnar nerve within the cubital tunnel. The irritation can be from overuse as is seen in overhead throwers and certain occupations, or entrapment due to structures that decrease the cross sectional area of the cubital tunnel. Entrapment can be from medial osteophytes, which is not only seen in overhead throwers with posteromedial impingement but also in people with osteoarthritis. Entrapment can also result from ganglia, inflamed synovium, or from an accessory anconeus muscle. An accessory anconeus muscle can be diagnosed if there is a thick, muscle signal intensity mass replacing the normal medial flexor retinaculum. In patients with a normal retinaculum there should be at least one axial image through the cubital tunnel below the triceps muscle and proximal to the medial flexor muscles where there is no muscle overlying the ulnar nerve. This axial section with no muscle in the cubital tunnel is lost in patients with an accessory anconeus muscle.

Ulnar neuropathy can also result from direct trauma. The ulnar nerve is particularly exposed to trauma at the cubital tunnel because the nerve is not protected by overlying muscles. Ulnar neuropathy is diagnosed on MR imaging by either size and signal-intensity changes of the nerve, or evidence of denervation edema of the innervated muscles. It is important to recognize that the ulnar nerve can normally be higher signal intensity on T2-weighted images within the cubital tunnel compared to that of the nerve just proximal or distal to the tunnel. Several authors have found that ulnar neuropathy should be considered only if the T2 signal intensity is twice that of the nerve outside the tunnel. Ulnar neuropathy should also be considered if the cross sectional area of the nerve is greater than 8 mm^2. Because the ulnar nerve has motor branches in the forearm to the flexor carpi ulnaris and flexor digitorum profundus muscles, edema within these muscles may also be seen on elbow MR images in patients with ulnar neuropathy (Fig. 17). If chronic, there may be atrophy and fat replacement of these two muscles.

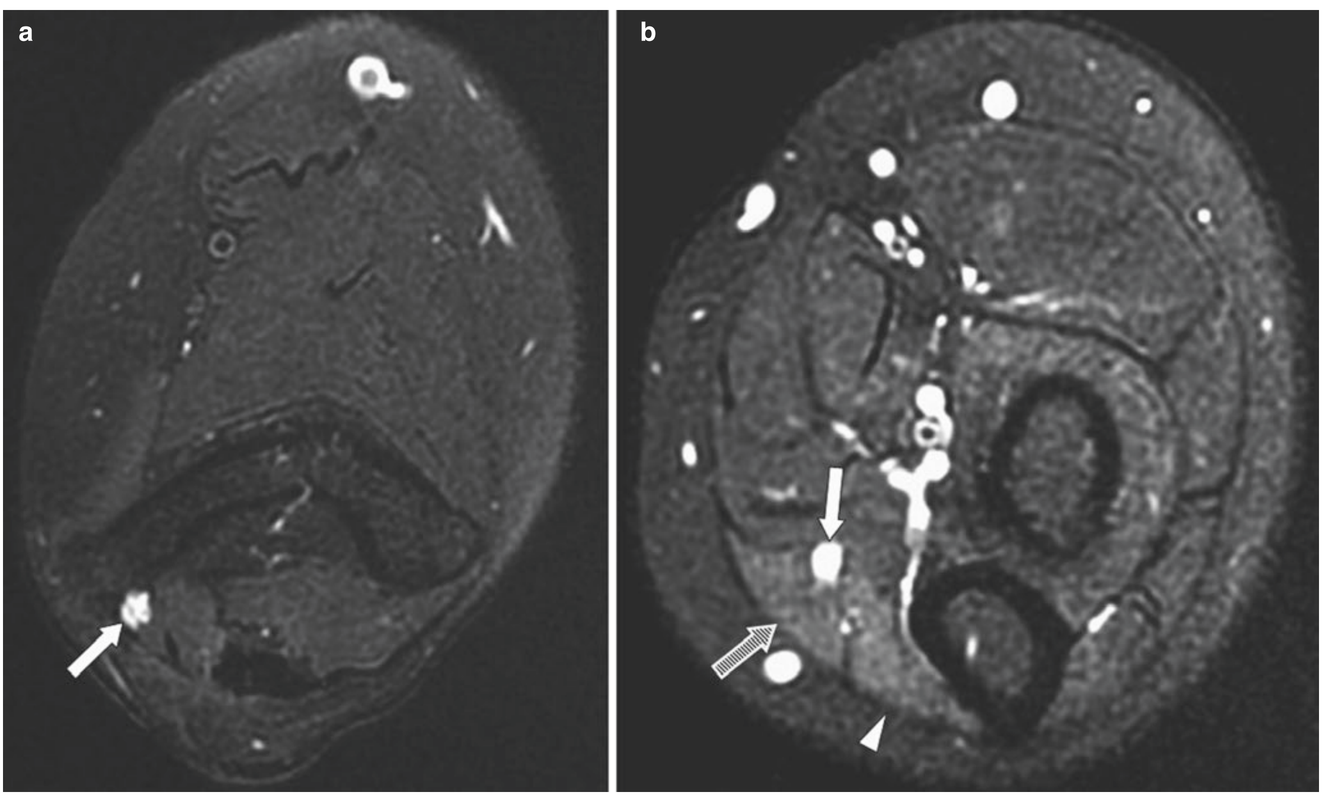

Fig. 17 (**a, b**) Ulnar neuritis in 16-year-old woman with numbness of the 5th and ulnar-aspect of the 4th fingers and hand weakness. Patient is active in martial arts and was lifting heavy boxes the prior day. Axial T2-weighted FS images through the elbow (**a**) and the proximal forearm (**b**) show a large and abnormally high signal ulnar nerve (*arrow*) and mild edema of the flexor digitorum profundus (*arrowhead*) and flexor carpi ulnaris (*striped arrow*) muscles. The symptoms resolved with physical therapy

Subluxation and dislocation of the ulnar nerve can be seen in up to 15% of individuals, and are usually asymptomatic. Dislocation out of the cubital tunnel usually occurs in individuals with an absent retinaculum and is worse in flexion. In patients with symptomatic ulnar nerve dislocation, there are typically signs of ulnar neuropathy with an enlarged and T2 high signal ulnar nerve.

Radial Nerve

There are two main entrapment neuropathies of the radial nerve at the elbow—*radial tunnel syndrome* and *posterior interosseous nerve* (PIN) syndrome [14]. Radial tunnel syndrome can be due to entrapment of the nerve at any point within the radial tunnel, and is typically due to repetitive rotatory movement of the forearm in individuals working in certain occupations. The symptoms are usually pain without much muscle weakness, as the sensory fibers tend to be effected worse than the motor fibers. The pain is in the dorsolateral aspect of the proximal forearm, several centimeters distal to the lateral epicondyle which helps distinguish it from lateral epicondylitis. The MR appearance of the radial nerve in the tunnel is often normal in these patients. It should be noted that the normal radial nerve is more difficult to see on MR images than the ulnar nerve because the radial nerve is not surrounded by fat.

The proximal edge of the superficial head of the supinator muscle is called the "Arcade of Frohse," particularly when it is fibrous and somewhat rigid as occurs in 30% of individuals [29]. The posterior interosseous branch of the radial nerve (PIN) passes adjacent to this proximal edge when it dives deep to the superficial head of the supinator muscle, and can be a site of nerve entrapment. Posterior interosseous nerve syndrome typically presents with weakness of the extensor muscles of the wrist and fingers. The posterior interosseous nerve is a purely motor nerve, so pain is less common. The most common cause of PIN syndrome is compression of the PIN as it dives deep past the proximal edge of the superficial head of the supinator muscle. PIN syndrome is more common in individuals with an Arcade of Frohse fibrous proximal edge of the superficial head of the supinator muscle [29]. Just proximal to the supinator muscle, the motor nerve branch to the supinator muscle can also be compressed, and this is sometimes also considered part of PIN syndrome. PIN syndrome can not only cause muscle weakness, but can cause denervation changes on MR images. This is seen as either edema within the supinator muscle, or within the extensor muscles such as the extensor digitorum, the extensor carpi ulnaris, the extensor pollicis longus and brevis, and the extensor indicis muscles (Fig. 18). For the supinator muscle, it is important not to overcall the slight increased signal seen normally in some individuals [30].

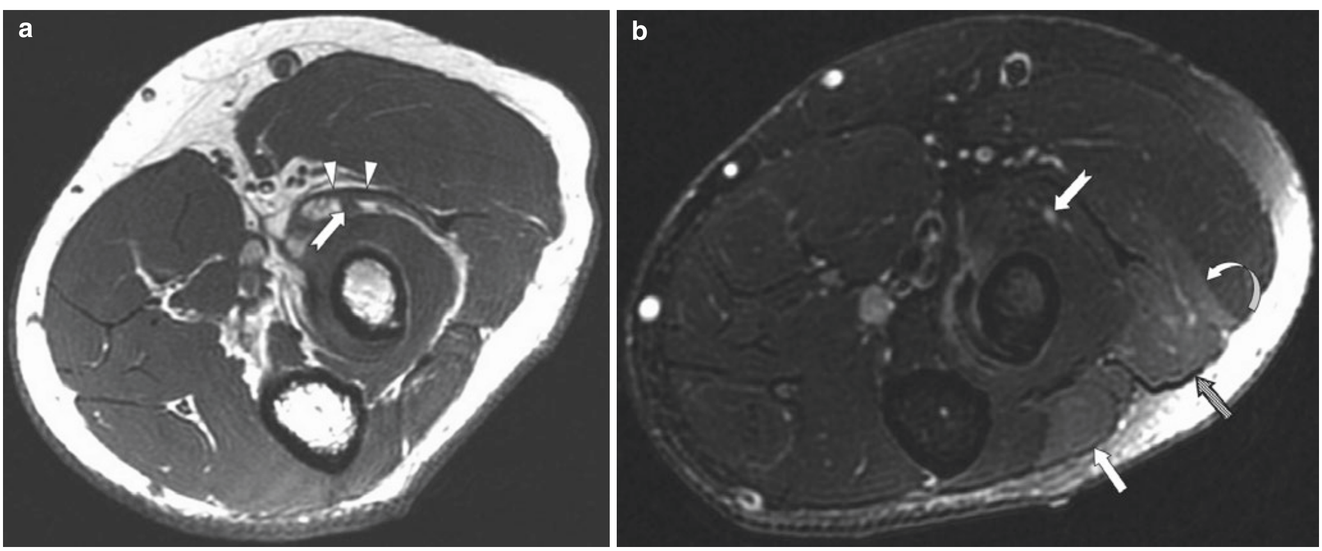

Fig. 18 (**a**, **b**) 46-year-old woman with "wrist drop" on exam and posterior interosseous nerve (PIN) abnormality on nerve conduction study. (**a**) Axial T1-weighed image shows the "Arcade of Frohse" fibrous proximal edge of the superficial head of the supinator muscle (*arrowhead*), and the PIN (*notched arrow*). (**b**) Axial T2-weighted FS image slightly more distal shows edema within the extensor carpi ulnaris (*white arrow*), extensor digitorum (*striped arrow*), and extensor carpi radialis brevis (*curved arrow*) muscles consistent with PIN syndrome. The PIN (*notched arrow*) is again seen between the superficial and deep heads of the supinator muscle

Median Nerve

There are two main entrapments that can affect the median nerve—*pronator syndrome* and *anterior interosseous nerve* (AIN) syndrome. Pronator syndrome refers to compression of the median nerve either where it crosses between the superficial and deep heads of the pronator teres muscle, or caused by a fibrous arch at the proximal margin of the flexor digitorum superficialis muscle. Like radial tunnel syndrome, this is seen usually in certain occupations with repetitive pronation/supination. People with pronator syndrome usually complain of pain in the volar aspect of the forearm, with motor weakness less common.

Anterior interosseous nerve syndrome is uncommon, and results from compression of the AIN typically by fibrous bands deep to the ulnar head of the pronator teres muscle or at the origin of the flexor digitorum superficialis muscle. The AIN is a purely motor nerve, so patients with AIN syndrome will have weakness of the flexor pollicis longus, the flexor digitorum profundus, and pronator quadratus muscles. On MR imaging, there will be denervation edema of these muscles, or atrophy and fatty replacement of the muscles.

References

1. Kijowski R, Tuite M, Sanford M (2004) Magnetic resonance imaging of the elbow. Part I: normal anatomy, imaging technique, and osseous abnormalities. Skelet Radiol 33(12):685–697
2. Morrey B (1993) Anatomy of the elbow joint. In: Morrey B (ed) The elbow and its disorders. Saunders, Philadelphia, pp 16–52
3. Sampaio ML, Schweitzer ME (2010) Elbow magnetic resonance imaging variants and pitfalls. Magn Reson Imaging Clin N Am 18(4):633–642
4. Stein JM, Cook TS, Simonson S et al (2011) Normal and variant anatomy of the elbow on magnetic resonance imaging. Magn Reson Imaging Clin N Am 19(3):609–619
5. Bancroft LW, Pettis C, Wasyliw C et al (2013) Osteochondral lesions of the elbow. Semin Musculoskelet Radiol 17(5):446–454
6. Bowen RE, Otsuka NY, Yoon ST et al (2001) Osteochondral lesions of the capitellum in pediatric patients: role of magnetic resonance imaging. J Pediatr Orthop 21(3):298–301
7. Kijowski R, De Smet AA (2005) Radiography of the elbow for evaluation of patients with osteochondritis dissecans of the capitellum. Skelet Radiol 34:266–271
8. Kijowski R, De Smet AA (2005) MRI findings of osteochondritis dissecans of the capitellum with surgical correlation. AJR Am J Roentgenol 185(6):1453–1459
9. Singer KM, Roy SP (1984) Osteochondrosis of the humeral capitellum. Am J Sports Med 12:351–360
10. Jans LB, Ditchefield M, Anna G et al (2012) MR imaging findings and MR criteria for instability in osteochondritis dissecans of the elbow in children. Eur J Radiol 81(6):1306–1310
11. Baker CL 3rd, Romeo AA, Baker CL Jr (2010) Osteochondritis dissecans of the capitellum. Am J Sports Med 38(9):1917–1928
12. Takahara M, Ogino T, Fukushima S et al (1999) Nonoperative treatment of osteochondritis dissecans of the humeral capitellum. Am J Sports Med 27:728–732
13. Hang DW, Chao CM, Hang YS (2004) A clinical and roentgenographic study of little league elbow. Am J Sports Med 21:79–84
14. Kijowski RM, Tuited M, Sanford M (2005) Magnetic resonance imaging of the elbow. Part II: abnormalities of the ligaments, tendons, and nerves. Skelet Radiol 34(1):1–18
15. Pierce JL, McCrum EC, ROzas AK et al (2015) Tip-of-the-iceberg fractures: small fractures that mean big trouble. AJR Am J Roentgenol 205(3):24–32
16. Sheehan SE, Dyer GS, Sodickson AD et al (2013) Traumatic elbow injuries: what the orthopedic surgeon wants to know. Radiographics 33(3):869–888
17. Chung CB, Chew FS, Steinbach L (2004) MR imaging of tendon abnormalities of the elbow. Magn Reson Imaging Clin N Am 12(2):233–245
18. Evans GF, Haller RG, Wyricks PS et al (1998) Submaximal delayed-onset muscle sorenesss: correlations between MR imaging findings and clinical measures. Radiology 208:815–820
19. Kotnis NA, Chiavaras MM, Harish S (2012) Lateral epicondylitis and beyond: imaging of lateral elbow pain with clinical-radiologic correlation. Skelet Radiol 41(4):369–386
20. Anderson MW, Alford BA (2010) Overhead throwing injuries of the shoulder and elbow. Radiol Clin N Am 48(6):1137–1154
21. Hayter CL, Adler RS (2012) Injuries of the elbow and the current treatment of tendon disease. AJR Am J Roentgenol 199(3):546–557
22. Frick MA, Murthy NS (2010) Imaging of the elbow: muscle and tendon injuries. Semin Musculoskelet Radiol 14(4):430–437
23. Brigido MK, De Maeseneer M, Morag Y (2013) Distal biceps brachii. Semin Musculoskelet Radiol 17(1):20–27
24. Seki A, Olsen BS, Jensen SL et al (2002) Functional anatomy of the lateral collateral ligament complex of the elbow: configuration of Y and its role. J Shoulder Elb Surg 11(1):53–59
25. Beckett KS, McConnell P, Lagopoulos M et al (2000) Variations in the normal anatomy of the collateral ligaments of the human elbow joint. J Anat 197(Pt 3):507–511
26. Wear SA, Thornton DD, Schwartz ML et al (2011) MRI of the reconstructed ulnar collateral ligament. AJR Am J Roentgenol 197(5):1198–1204
27. Andreisek G, Crook DW, Burg D et al (2006) Peripheral neuropathies of the median, radial, and ulnar nerves: MR imaging features. Radiographics 26(5):1267–1287
28. O'Driscoll SW, Horli E, Carmichael SW et al (1991) The cubital tunnel and ulnar neuropathy. J Bone Joint Surg Br 73(4):613–617
29. Posner MA (1990) Compressive neuropathies of the median and radial nerves at the elbow. Clin Sports Med 9(2):343–363
30. Gyftopoulos S, Rosenberg ZS, Petchprapa C (2010) Increased MR signal intensity in the pronator quadratus muscle: does it always indicate anterior interosseous neuropathy? AJR Am J Roentgenol 194(2):490–493