Radiology

Elbow US: Anatomy, Variants, and Scanning Technique[1]

Alberto S. Tagliafico, MD
Bianca Bignotti, MD
Carlo Martinoli, MD

As with other musculoskeletal joints, elbow ultrasonography (US) depends on the examination technique. Deep knowledge of the relevant anatomy, such as the bone surface anatomy, tendon orientation, nerves, and vessels, is crucial for diagnosis. It is important to be aware of the primary imaging pitfalls related to US technique (anisotropy) in the evaluation of deep tendons such as the distal biceps and peripheral nerves. In this article, US scanning technique for the elbow as well as the related anatomy, primary variants, and scanning pitfalls are described. In addition, an online video tutorial of elbow US describes a possible approach to elbow evaluation.

Online supplemental material is available for this article.

Online SA-CME
See www.rsna.org/education/search/ry

Learning Objectives:

After reading the article and taking the test, the reader will be able to:

- Apply US technique to imaging the elbow
- Apply dynamic maneuvers to assess the ligaments, the tendons, and the nerves
- Describe the normal anatomic structures of the elbow at US

Accreditation and Designation Statement

The RSNA is accredited by the Accreditation Council for Continuing Medical Education (ACCME) to provide continuing medical education for physicians. The RSNA designates this journal-based SA-CME activity for a maximum of 1.0 *AMA PRA Category 1 Credit*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Disclosure Statement

The ACCME requires that the RSNA, as an accredited provider of CME, obtain signed disclosure statements from the authors, editors, and reviewers for this activity. For this journal-based CME activity, author disclosures are listed at the end of this article.

---

[1] From the Institute of Anatomy, Department of Experimental Medicine (DIMES) (A.S.T.), and Department of Health Sciences (DISSAL) (B.B., C.M.), University of Genoa, Largo Rosanna Benzi 8, 16132 Genoa, Italy. From the 2012 and 2013 RSNA Annual Meeting. Received August 28, 2014; revision requested October 6; revision received October 29; accepted November 26; final version accepted December 16. **Address correspondence to** A.S.T. (e-mail: *albertotagliafico@gmail.com*).

After the shoulder, the elbow is the second most commonly injured upper extremity joint in sporting activities. It has been estimated that elbow injuries account for approximately 20% of upper limb injuries in sports (1). Clinical examination and routine radiography are essential to initially evaluate the elbow. Recently, ultrasonography (US) has gained an important role in the evaluation of the soft tissues around the elbow. The recent Delphi-based consensus article by the European Society of Musculoskeletal Radiology found that US might be particularly useful to assess elbow disorders (2). In addition, for several elbow disorders such as lateral epicondylitis, effusions, bursitis, and nerve lesions, US is believed to be the first-choice assessment technique, and other more expensive techniques rarely provide more information (2). On the other hand, the evidence level (Oxford Centre for Evidence-based Medicine) related to the use of US is not a level A for every clinical indication (2,3). Accordingly, further diagnostic examinations such as computed tomography (CT) and magnetic resonance (MR) imaging are used to study the status of the joint cavity, the articular cartilage, and the bone. In recent years, the use of US has broadened to include the evaluation of US-visible articular cartilage in selected clinical conditions such as rheumatologic and hematologic disorders (eg, hemophilia) (4). It must be remembered that US has a low negative predictive value for cartilage assessment owing to the low contrast between cartilage and synovial fluid and the inability to visualize all surfaces.

Essentials

- High-resolution probes are mandatory for a comprehensive elbow assessment.
- Positioning the elbow appropriately along with correct transducer placement is an essential requirement in performing elbow US.
- At the anterior elbow, the distal biceps and the brachialis are identified by two tendons; US is able to help differentiate the two distinct components of the distal biceps tendon, which belong to the long and short heads of the biceps, respectively.
- Dynamic scans are helpful in evaluating ligaments and tendons; performing provocative maneuvers can be useful to accentuate a pathologic condition.
- Ulnar nerve evaluation should be done with both static and dynamic maneuvers; the ulnar nerve should be measured with the elbow fully extended to avoid dynamic compression of the nerve during flexion or displacement of the nerve over the medial epicondyle.

The elbow is well suited for US evaluation—the majority of structures are superficial, it is possible to obtain long- and short-axis images of almost every anatomic structure, and one can perform dynamic evaluations, which can be useful for some diagnoses.

As a general rule, image resolution improves as the frequency of the US beam increases, while the US beam penetration decreases with increased transducer frequency. A US probe of at least 10 MHz is sufficient if the patient has a normal body mass index. A US probe up to 20 MHz may be useful to depict very small and superficial nerves, such as the posterior interosseous nerve or the ulnar nerve at the cubital tunnel. Frequency and depth should be optimized in each individual. Elbow US is often performed as a targeted examination.

In this article we will review the relevant US elbow anatomy during a step-by-step description of how to evaluate the elbow systematically. Short movies showing a demonstration of elbow US (Movies 1–4 [online]) will be presented, divided into four parts for educational purposes.

Common and important pitfalls encountered during an elbow US evaluation will be described. Unlike the shoulder, which has normally a standard protocol, the elbow should be evaluated based on the site of clinical concern. From the US point of view, the elbow may be divided in four areas: anterior, lateral, posterior, and medial.

A possible checklist of structures to be evaluated with US is presented in the Table.

Anterior Elbow

In general, the US examination of the anterior elbow may begin with the upper limb resting in an extended and supinated position on the examination table. Placing a pillow under the elbow may be useful to obtain a full elbow extension. If the patient is not able to tolerate elbow extension, longitudinal scans are hampered.

The main anatomic structures to be evaluated anteriorly are as follows: the anterior synovial recess with the anterior fat pad and the radiocapitellar and trochlea-ulna joints, the distal biceps brachii muscle and tendon, the distal brachialis muscle and tendon, the median nerve, the radial nerve, and the brachial artery. The examination should include transverse, longitudinal, and oblique planes extending at least 5 cm proximal and 5 cm distal to the trochlea-ulna joint (5). Transverse US images are those perpendicular to the humeral shaft. Although the radiologic evaluation of articular cartilage mainly relies on MR imaging, which is often considered the reference standard, the role of US has been recently highlighted. Anterior transverse US images over the distal humeral extremity are able to demonstrate the wavy osteochondral surface of the convex capitellum and of the concave trochlea. The articular cartilage appears as a uniform hypoechoic band overlying the subchondral bone (Fig 1). Anterior sagittal or long-axis US images over the radiocapitellar joint are useful to study the radial fossa with the radial recess and

Content codes: MK US

Radiology 2015; 275:636–650

Conflicts of interest are listed at the end of this article.

the coronoid fossa with its respective coronoid recess. The radiocapitellar joint is located laterally and the trochlea-ulna joint is found medially. The anterior fat pads are evaluated superficially to the recesses. The US evaluation of the articular cartilage and recesses at the level of the elbow may be useful in several pathologic conditions for which both qualitative and quantitative evaluations are required (4).

Complete Checklist for Elbow US Evaluation

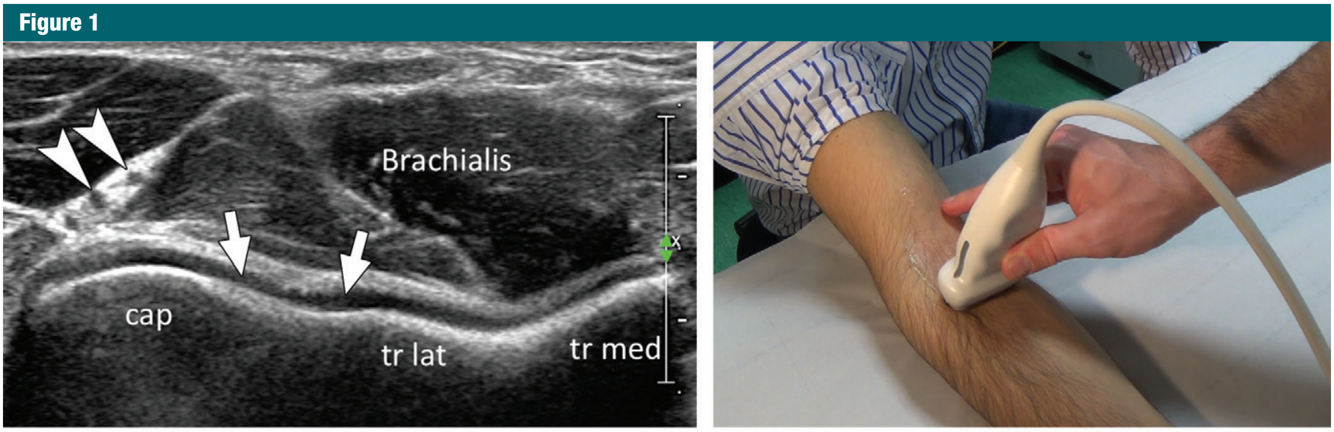
Anatomic Area	Site
Anterior elbow	Distal biceps tendon
	Brachialis tendon
	Median nerve and anterior interossesous nerve
Lateral elbow	Common extensor tendon origin
	Lateral collateral ligament
	Radial nerve and posterior interosseous nerve
Medial elbow	Common flexor tendon origin
	Medial collateral ligament (anterior band)
Posterior elbow	Triceps tendon
	Ulnar nerve (normal, anconeus epitrochlearis, and unstable)

Distal Biceps Tendon

The biceps brachii muscle is a flexor of the elbow but also a supinator. It is normally innervated by the musculocutaneous nerve, which arises from the fifth and sixth cervical nerves. The biceps brachii muscle is superficial to the brachialis and its long distal tendon is not surrounded by muscle, making it more susceptible to injury than the brachialis muscle. The tendon is approximately 7 cm long and inserts on the medial aspect of the radial tuberosity. Recently it has been demonstrated that in most individuals, the distal biceps tendon is made of two separate distal tendons—one belonging to the short head and one to the long head of the biceps brachii muscle (6–9). The tendon of the long head of the biceps inserts proximally while the tendon of the short head of the biceps inserts distally. The distal insertion of the tendon belonging to the short head of the biceps produces a more favorable lever than the long head. This is important, especially in starting the flexion from a fully extended position. In an alternative to MR imaging, US can be used to differentiate the two distinct components of the distal biceps tendon, which belong to the long and short heads of the biceps (Fig 2). In addition, US can be used to differentiate isolated lesions of one of the two components, which can modify the clinical management of young patients from surgical to conservative (6). The so-called lacertus fibrosus extends from the myotendinous junction of the distal biceps to the medial deep fascia of the forearm. The "lacertus fibrosus" covers the median nerve and the brachial artery and its function is to keep the biceps tendon in the appropriate position. The distal portion of the biceps tendon is covered by an extrasynovial paratenon and by the bicipitoradial bursa. This bicipitoradial bursa is normally not visible at US unless distended with fluid effusion. At US, the biceps tendon has a central hyperechoic lamina reflecting the aponeurosis (6–9). More distally, the distal biceps tendon appears generally as a hyperechoic oval structure that overlies the brachialis muscle. A careful scanning technique is necessary to study this difficult tendon with US. Different approaches have been proposed to study the distal biceps tendon:

Anterior approach.—With the arm extended and maximally supinated, the tendon may be found on short-axis im-

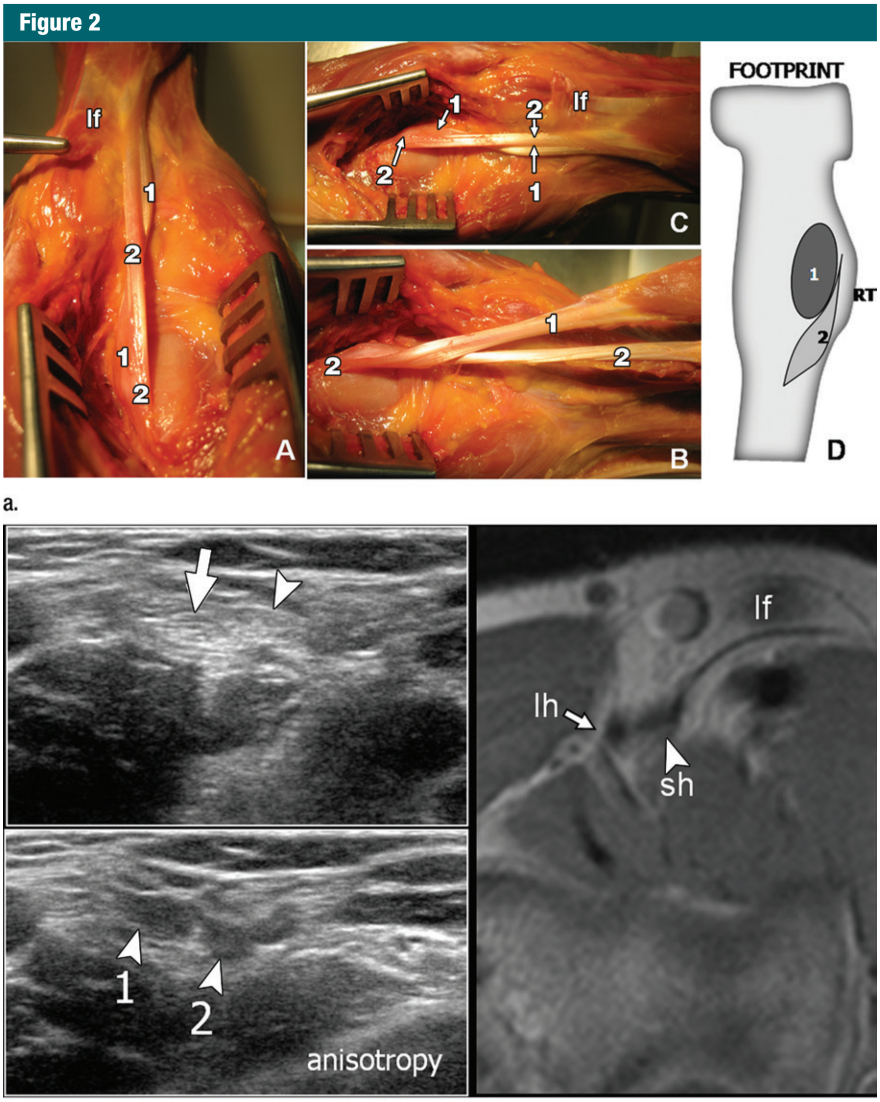
Figure 1



a. b.

Figure 1: **(a)** The osteochondral surface of the distal humeral extremity can be identified based on its wavy appearance and bilayered structure formed by a superficial hypoechoic band of articular cartilage and a deep linear echo related to the subchondral bone. Anterior transverse US image over the distal humeral extremity demonstrates a wavy osteochondral surface consisting of the convex capitellum *(cap)* and the concave trochlea that exhibits two facets, lateral *(tr lat)* and medial *(tr med)*. The articular cartilage appears as a uniform hypoechoic band (arrows) overlying the subchondral bone. Arrowheads = radial nerve. **(b)** Transducer placement is demonstrated.

Figure 2



a.

b.

Figure 2: **(a)** Anatomic demonstration of the distal bifurcation of the biceps brachii tendon after partial removal of the lacertus fibrosus *(lf)* and complete removal of the bicipitoradialis bursa. Note the separated course of the two distal tendons from the myotendinous junction to the radial tuberosity. *A–C* = anatomical cadaveric details, *D* = footprint insertion of both tendons on the radial tuberosity *(RT)* with long head inserting proximally and short head distally. *1* = Long head, *2* = short head. **(b)** US and MR images of normal anatomy demonstrate the two different tendons. Top left: Transverse 17–5-MHz US image (top) shows two oval fibrillar structures with different cross-sectional areas. The larger (arrow) belongs to the long head of the biceps and the smaller and flattened (arrowhead) to the short head. Bottom left: The anisotropy artifact obtained by changing the ultrasound beam angle makes the tendons hypoechoic (*1* = long head, *2* = short head). Right: Correlative axial MR image confirms the US findings. *lf* = lacertus fibrosus, *lh* = long head, *sh* = short head. Reprinted, with permission, from reference 6.

ages at the level of the elbow crease; next, rotate the probe 90°. It is possible to place the transducer longitudinally on the cubital fossa, find the brachial artery, and then move the probe laterally (Fig 3). Increasing the probe pressure over the distal part of the tendon reduces the anisotropy artifact at the insertion, because the tendon is more parallel to the ultrasound beam (Movie 1 [online]).

Lateral approach.—Place the probe longitudinally over the lateral aspect of the arm with the elbow 90° flexed and the forearm supinated. The brachioradialis serves as an acoustic window (10) (Fig 4). It is important to adjust the focal zone to better visualize the distal biceps near the insertion, because in this position the tendon seems to be very deep relative to the subcutaneous tissue and to the myotendinous junction. This position is helpful when employing dynamic imaging (Movie 2 [online]).

Medial approach.—Place the probe longitudinally and medially over the distal arm with the elbow 90° flexed and the forearm supinated. Use the flexor pronator muscle as an acoustic window (11) (Fig 5). In this position the brachial artery lies medial to the biceps tendon and it may be used to minimize beam attenuation and to enhance the echogenicity of the biceps tendon (11) (Movie 3 [online]).

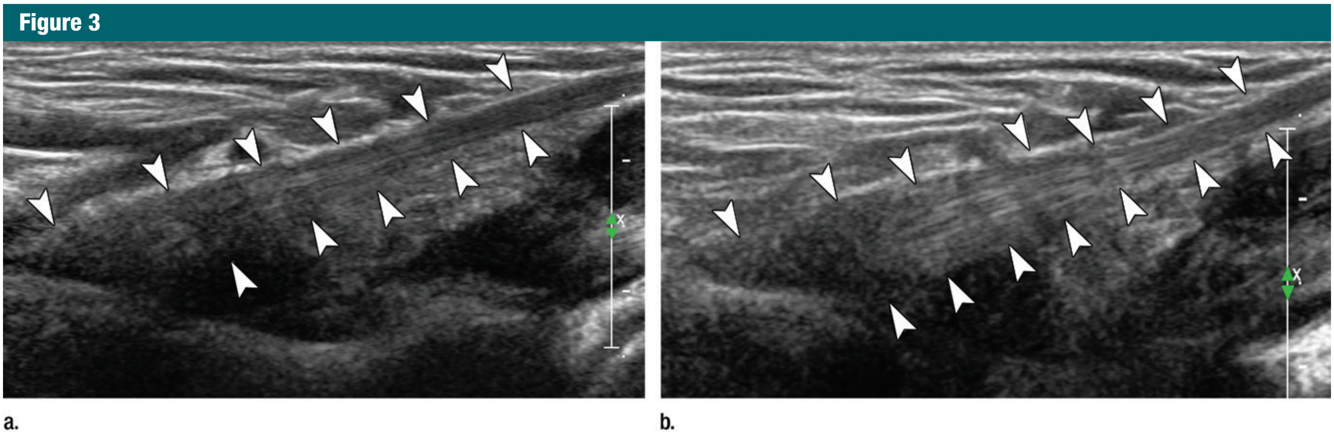
Posterior approach.—Place the transducer on a transverse plane over the proximal forearm at the level of the radial tuberosity with the elbow maximally flexed and the dorsum of the hand pointing toward the ceiling. The distal biceps is visible during pronation and supination movements (12) (Fig 6) (Movie 4 [online]).

These different approaches are complementary and may be performed together. No consensus exists to affirm what is the best approach to visualize the distal biceps tendon; however, we believe that the combined use of all approaches may enhance the diagnostic accuracy of US.

Brachialis Tendon

Located deep relative to the biceps brachii muscle, the brachialis muscle originates from the anterior surface of the distal humeral shaft and from the adjacent intermuscular septum to insert onto the anterior surface of the coronoid process of the ulna. Its tendon is thinner than the biceps tendon and it is surrounded by muscular tissue. The distal insertion of the brachialis on the ulnar tuberosity may be purely muscular, tendinous, or mixed (13). The brachialis muscle insertion is described

Figure 3



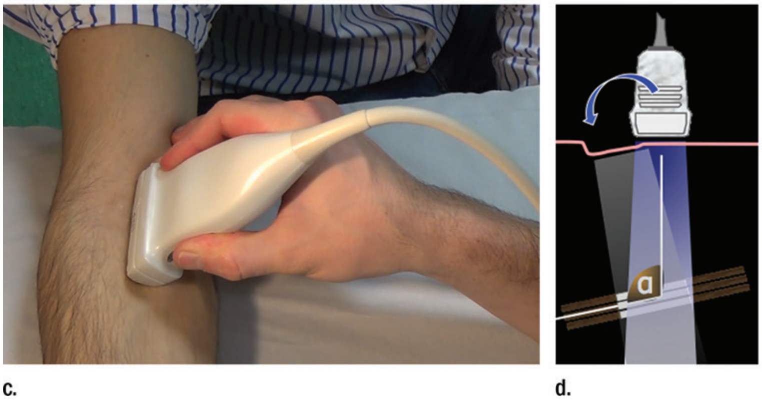


Figure 3: Anterior approach for distal biceps tendon evaluation. **(a)** The distal biceps is highlighted by arrowheads. **(b)** Increasing the probe pressure over the distal part of the probe reduces the anisotropy artifact at the insertion. **(c)** Transducer placement is demonstrated. **(d)** Schematic drawing for probe positioning: The alpha angle shows that probe angulation reduces anisotropy. The blue arrow depicts probe movements to keep the ultrasound beam as parallel as possible to the tendon.

Figure 4

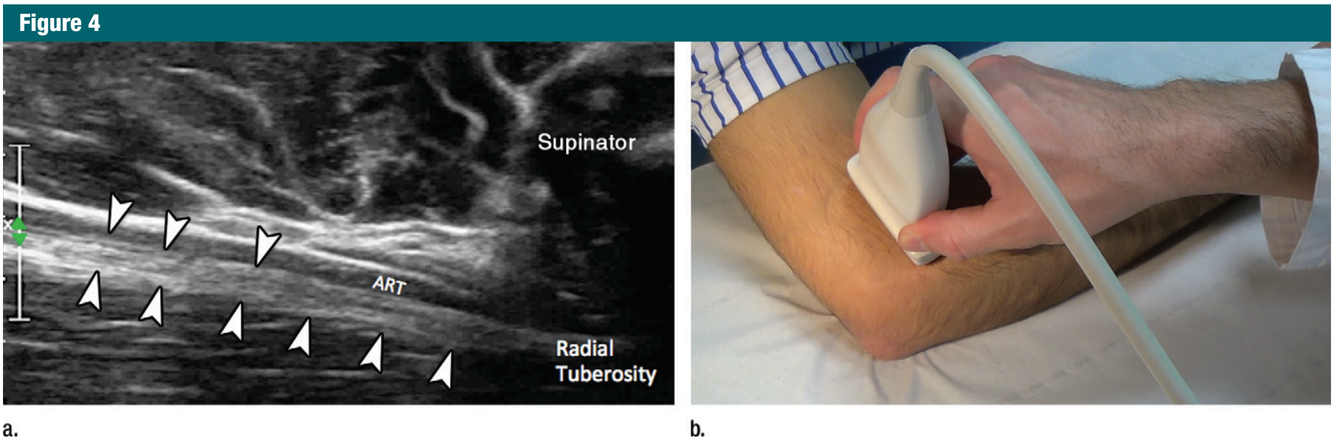


Figure 4: Lateral approach for distal biceps tendon evaluation. **(a)** The brachioradialis serves as an acoustic window. The distal biceps is highlighted by arrowheads. Note how the focal zone has been adjusted to better visualize the distal insertion. *ART* = artery. **(b)** Transducer placement is demonstrated.

as a single broad tendon or as having two heads, one with a tendinous and the other with an aponeurotic attachment (13). Two heads compose the distal attachment of the brachialis: a superficial head and a deep head. The larger, superficial head originates from the anterolateral aspect of the middle third of the humerus and the lateral intermuscular septum, whereas the smaller, deep head originates from the distal third of the anterior aspect of the humerus and the medial intermuscular septum (13).

The brachialis essentially acts as a flexor of the elbow regardless of the position of the forearm. It has a double innervation: It is innervated by the musculocutaneous and by the radial nerve (13). To evaluate the brachialis tendon with US, transverse and

Figure 5

Figure 5: Medial approach for distal biceps tendon evaluation. **(a)** The flexor pronator muscle is used as an acoustic window; the brachial artery may be used to enhance the biceps tendon's echogenicity as a supplemental acoustic window. The distal biceps is highlighted by arrowheads. **(b)** Transducer placement is demonstrated. **(c)** Corresponding schematic drawing.

longitudinal planes are useful; the anisotropy artifact and pronosupination movements are useful to identify the two separate tendinous components belonging to the superficial head and the deep head of the brachialis (Fig 7) (Movie 1 [online]). It has been proposed that US may be more suitable than MR imaging to evaluate the two tendons. In normal volunteers, with US the two tendons could be differentiated in 100% of cases, compared with 83% of cases with MR imaging (13). As for the distal biceps tendon, US may be used to distinguish isolated lesions of one of the two components of the distal brachialis muscle, possibly influencing the clinical management of the patient.

Median Nerve and Anterior Interosseous Nerve

At the elbow, the median nerve is medial to the brachial artery and can be followed distally in up to 80% of individuals, between the humeral and ulnar heads of the pronator teres. An atypical intermuscular course of the median nerve between the brachialis and pronator muscles may be present in up to 17% of subjects without contact with the brachial artery or, more distally, with the ulnar artery. Normally, the median nerve is close to the brachial artery. This atypical course of the median nerve is not the exclusive cause of pronator syndrome (14). The median nerve supplies the pronator teres, flexor carpi radialis, palmaris longus, and flexor digitorum superficialis muscles. At the elbow, the median nerve is easily evaluated with US on short-axis planes. It has the typical honeycomb appearance with hypoechoic nerve fascicles and intervening hyperechoic epineurium (Fig 8; Movie 1 [online]). The brachial artery is superficial and courses along the medial border of the biceps; then it passes between the median nerve (medial) and the biceps tendon (lateral) beneath the bicipital aponeurosis to divide, at the proximal forearm, into the radial and ulnar arteries. If the US examination is extended distally to the forearm, approximately 5–8 cm distal to the lateral epicondyle, it is possible to assess the anterior interosseous nerve (Fig 8), which is a purely motor nerve branching off the median nerve at the level of the deep head of the pronator teres. The US diagnosis of anterior interosseous neuropathy, the so-called Kiloh-Nevin syndrome, may be suggested by a loss in bulk and increased reflectivity of the innervated muscles—the flexor pollicis longus, the flexor digitorum profundus, and the pronator quadratus—more than on the direct evaluation of the anterior interosseous nerve (15).

Lateral Elbow

In general, the lateral aspect of the elbow is examined with the elbow in extension, thumb up or with the elbow in flexion (5). The radial head and the lateral epicondyle may be used as landmarks to start the examination (16). In this anatomic area, high-resolution US can be used to assess the common extensor tendon, the lateral collateral ligament complex, the radial nerve with its superficial and deep (posterior interosseous nerve) branches, and part of the radiocapitellar joint (Movie 2 [online]).

Common Extensor Tendon Origin

The common extensor tendon origin is a flattened tendon arising from the anterolateral surface of the lateral epicondyle. It consists of the tendons of four contributing muscles: the extensor carpi radialis brevis, extensor digitorum communis, extensor digiti minimi, and extensor carpi ulnaris. The extensor carpi radialis brevis is the deepest, and the extensor digitorum is the most superficial (16–18). The common extensor tendon origin is separated from the joint capsule by the lateral collateral ligamentous complex, including the annular ligament,

Figure 6

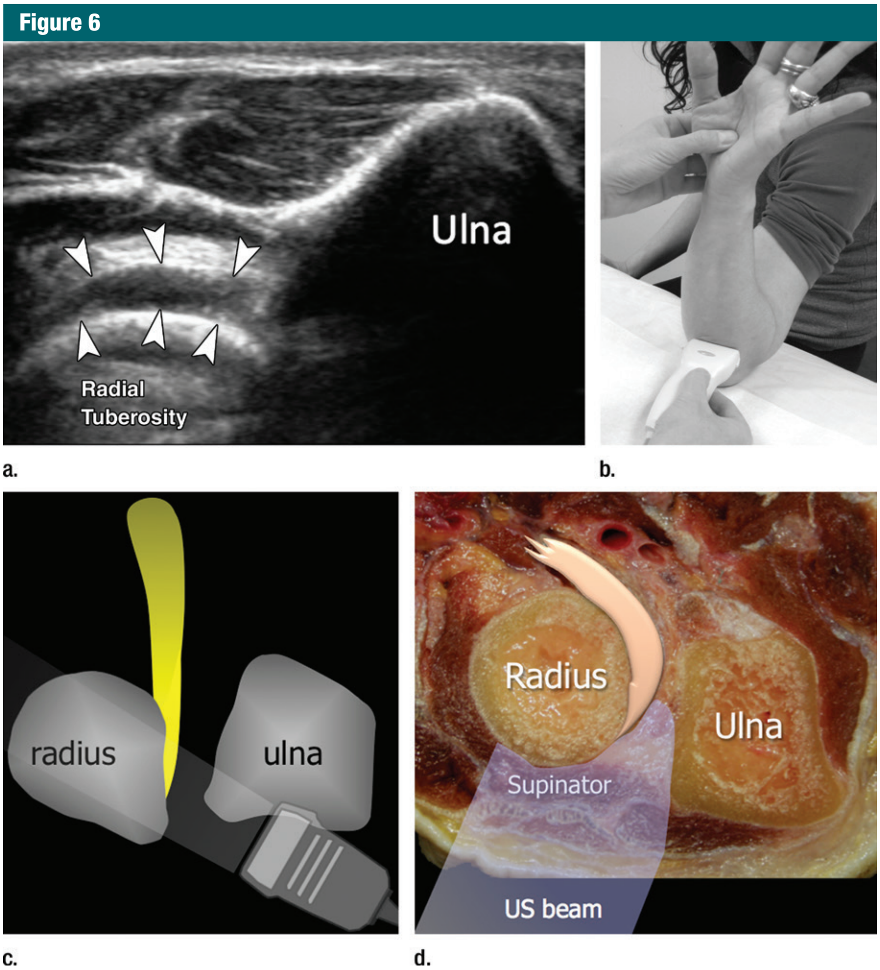


Figure 6: Posterior approach for distal biceps tendon evaluation. **(a)** The distal biceps (arrowheads) is visible during pronosupination movements and is better visible at dynamic US evaluation, as in Movie 4 (online). **(b)** Transducer placement is demonstrated. **(c)** Corresponding schematic drawing. **(d)** Correlative cadaveric view is shown.

the radial collateral ligament, and the lateral ulnar collateral ligament relative to the common extensor tendon origin. With regard to the anatomy of the lateral elbow, the common extensor tendon is located superficial to the radial collateral ligament. The radial collateral ligament attaches to the humerus at the superior aspect of the intertubercular sulcus and the inferior aspect of the superior tubercle and extends distally to the annular ligament (19). Longitudinal planes are the best to visualize the beak-shaped hyperechoic origin of the common extensor origin between the subcutaneous tissue and the radial collateral ligament. The lateral epicondyle appears as a smooth down-sloping hyperechoic structure (Movie 2 [online]). The single contributions from the extensor muscles to the common extensor tendon cannot be identified at US. On long-axis images it is possible to demonstrate the brachioradialis superficially to the common extensor origin and the radiocapitellar joint below the tendon. On short-axis images, the common extensor tendon origin appears oval superficially to the bone of the lateral epicondyle (Fig 9). The lateral synovial fringe (a synovial plica) is depicted as a triangular hyperechoic structure intervening between the capitellum and the radial head. The common extensor tendons are usually evaluated to assess the severity and extent of tendon abnormality with the potential to guide injection (20–26). The extensor carpi radialis brevis tendon is always involved, followed by the extensor digitorum communis (17). In addition, tendon abnormal compressibility called "tenomalacia" and US elastography (Fig 9c) has proved to be valuable in the detection of the intratendinous and peritendinous alterations of lateral epicondylitis to differentiate normal from pathologic tendons (18,27).

Lateral Collateral Ligament

The lateral collateral ligamentous complex is one of the elbow stabilizers. This complex consists of several components: the radial collateral ligament, the lateral ulnar collateral ligament, part of the annular ligament, and sometimes an accessory radial collateral ligament (20–26). The radial collateral ligament proper is a fan-shaped structure that arises from the anteroinferior aspect of the lateral humeral epicondyle and converges with the fibers of the annular ligament distally (19–26). The radial collateral ligament is thick. It appears hyperechoic and connects the lateral epicondyle with the bony surface of the radius and with the annular ligament. An important stabilizer of the elbow joint is the lateral ulnar collateral ligament. It prevents varus stress and posterolateral rotatory instability (17). To evaluate the lateral ulnar collateral ligament, the elbow should be with the hand supinated and pronated applying a varus stress to open the lateral elbow joint space in the case of ligamentous lesions (Fig 10). The lateral ulnar collateral ligament is a cordlike fibrillar structure covering the joint space visible when the superficial extensor carpi radialis brevis is torn (28). The contralateral normal elbow may be used for comparison. In children, US may help visualize an increased distance between the radial head and the humeral capitellum, probably due to the impingement of the annular ligament

Figure 7

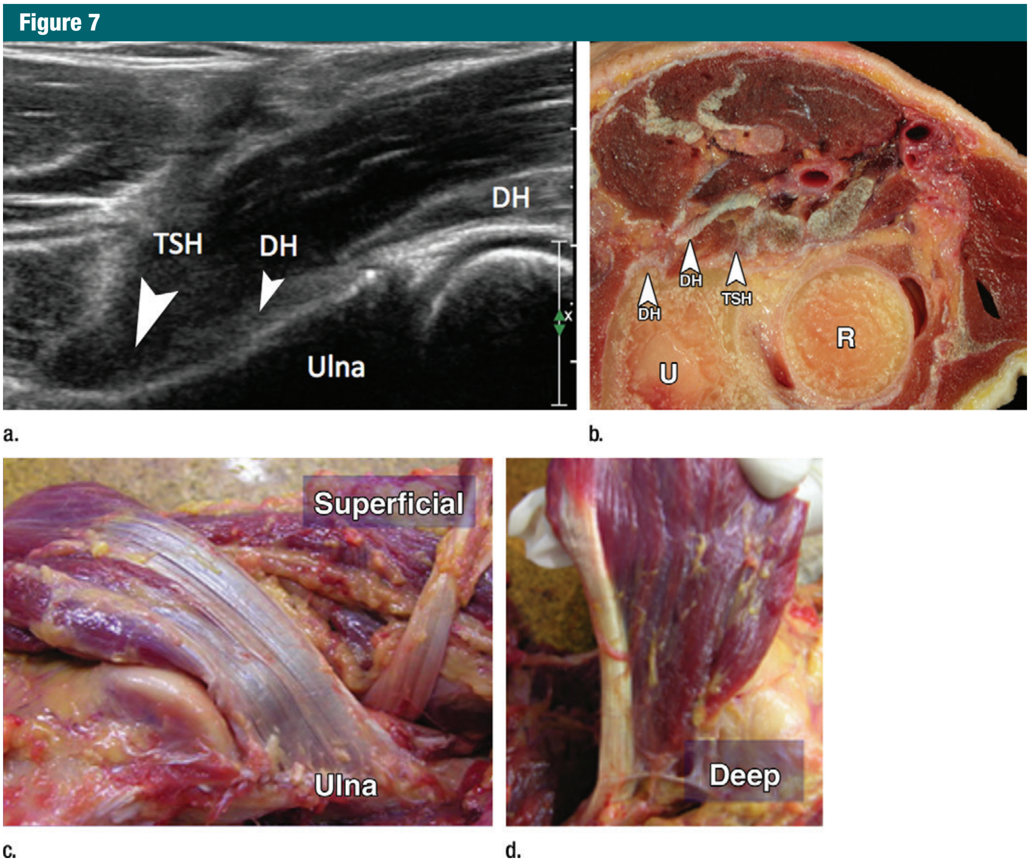


Figure 7: Distal brachialis evaluation. **(a)** US longitudinal view of brachialis insertion. **(b)** Cadaveric axial view of brachialis insertion. **(c)** Cadaveric view of the superficial head. **(d)** Cadaveric view of the deep head insertion. *DH* = deep head, *R* = radius, *TSH* = tendon of the superficial head, *U* = ulna. Images **c–e** reprinted, with permission, from reference 13.

(20–26). This condition is known as "pulled elbow" and it is due to the annular ligament slipping over the radial head following forceful pronation (28). MR imaging has to be considered the modality of choice to evaluate the lateral ulnar collateral ligament. No evidence and consensus exist to evaluate this ligamentous complex with US (2).

Radial Nerve and Posterior Interosseous Nerve

At the humeral diaphysis, the radial nerve has a curvilinear and deep course around the humeral shaft. Then, anterior to the lateral epicondyle, the radial nerve is located between the brachialis and the brachioradialis muscles. At this level, transverse US images are sufficient to demonstrate the nerve as a multifascicular nerve with hypoechoic fascicles surrounded by a hyperechoic epineurium (28). The recurrent radial artery is located near the nerve and color Doppler is useful to differentiate this vessel from a fascicle. More distally, the radial nerve divides into the superficial cutaneous sensory branch and the posterior interosseous nerve (Fig 11). To evaluate these very small nerves, dynamic transverse US images are used, because it is difficult to recognize small monofascicular nerves on static US images. The posterior interosseous nerve can be visualized with US as it pierces the supinator muscle and enters the arcade of Frohse, passing between the superficial and deep parts of it. After leaving the supinator tunnel, the nerve reaches the posterior compartment of the forearm (28). To evaluate this nerve, the elbow should be moved in semiflexion: Pronation movements may be responsible for an angulated course of the nerve at the proximal edge of the arcade of Frohse. This is a common pitfall, and the examiner should not interpret this aspect as pathologic. Distally, the posterior interosseous nerve divides into different branches directed to the muscles (Movie 2 [online]).

The normal mean cross-sectional area of the radial nerve has been estimated to be 7.2 mm^2 at the humeral shaft, 6.2 mm^2 at the intermuscular septum, and 2.3 mm^2 at the supinator area, which are the sites of common pathologic findings (29). When compared with the healthy contralateral side, it has been found that the minimum detectable difference for the radial nerve is up to 31% at the humeral shaft (29). The superficial cutaneous

Figure 8

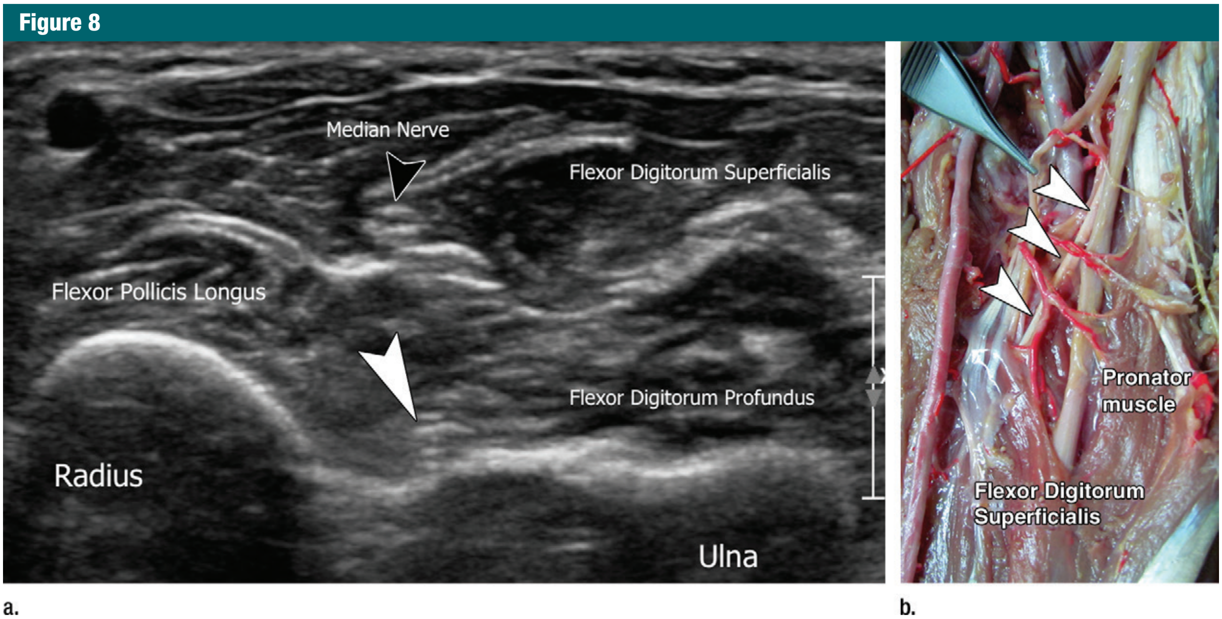


Figure 8: Anterior interosseous nerve. **(a)** Transverse 12–5-MHz US image obtained over the volar compartment at the middle forearm reveals the position of the median (black arrowhead) and anterior interosseous (white arrowhead) nerve relative to the flexor digitorum superficialis, the flexor digitorum profundus, and the flexor pollicis longus. Note the focal zone has been moved deep to highlight the anterior interosseous nerve (white arrowhead). **(b)** Cadaveric correlation. Arrowheads = anterior interosseous nerve.

sensory branch of the radial nerve runs into the anterior forearm. At the proximal forearm, it follows the radial artery and it can be demonstrated between the flexor carpi radialis and the brachioradialis. The brachioradialis may be used as a landmark to find the nerve at the distal forearm. Common pathologic conditions related to the superficial cutaneous sensory branch of the radial nerve are mainly located at the forearm or wrist (28).

Medial Elbow

The medial compartment of the elbow includes the pronator teres and the epicondylar muscles, the origin of which is known as the "common flexor tendon."

The common flexor tendon is made by the flexor carpi radialis, the palmaris longus, the flexor carpi ulnaris, and the flexor digitorum superficialis from anterior to posterior. The flexor digitorum profundus has a more distal origin from the anteromedial aspect of the ulna, the coronoid process, and the anterior surface of the interosseous membrane. Anatomic structures of interest at the medial elbow that are amenable to US examination are the common flexor tendon and the anterior band of the ulnar collateral ligament.

Common Flexor Tendon Origin

The common flexor tendon supports the ulnar collateral ligament in resisting valgus stress. To study the medial elbow, the forearm may be placed in forceful external rotation with the elbow extended or slightly flexed on the examination table. Coronal images with the proximal edge of the transducer over the medial epicondyle (epitrochlea) demonstrate the common flexor tendon in its major axis (Movie 3 [online]). The tendon appears larger but shorter than the common extensor tendon (Fig 12c). Deep to this tendon, the anterior band of the medial collateral ligament is visible.

Medial Collateral Ligament (Anterior Band)

The ulnar collateral ligament complex is composed of the anterior band, a posterior band, and a transverse band. The anterior and posterior bands arise from the inferior aspect of the medial humeral epicondyle. From the biomechanical point of view, the maximum tension on the ulnar collateral ligament occurs at elbow flexion. The anterior band inserts distally at the sublime tubercle of the ulna. The anterior band is the most important stabilizer against valgus stress. The posterior band inserts distally at the posteromedial margin of the trochlear notch of the ulna and acts against internal rotation. The transverse band does not cross the elbow joint; therefore, it may not have a relevant stabilizing function.

Overhead athletic activities such as seen in baseball, javelin throwing, volleyball, water polo, and tennis are recreational activities that predispose participants to injury of the ulnar collateral ligament complex (30). To evaluate the medial collateral ligament complex, a possible study position may be with the patient supine, keeping the shoulder abducted and externally rotated and the elbow in 90° of flexion. The anterior band of the medial collateral ligament is depicted as an elongated structure crossing the trochlea-ulna joint if the US image is obtained with

Figure 9

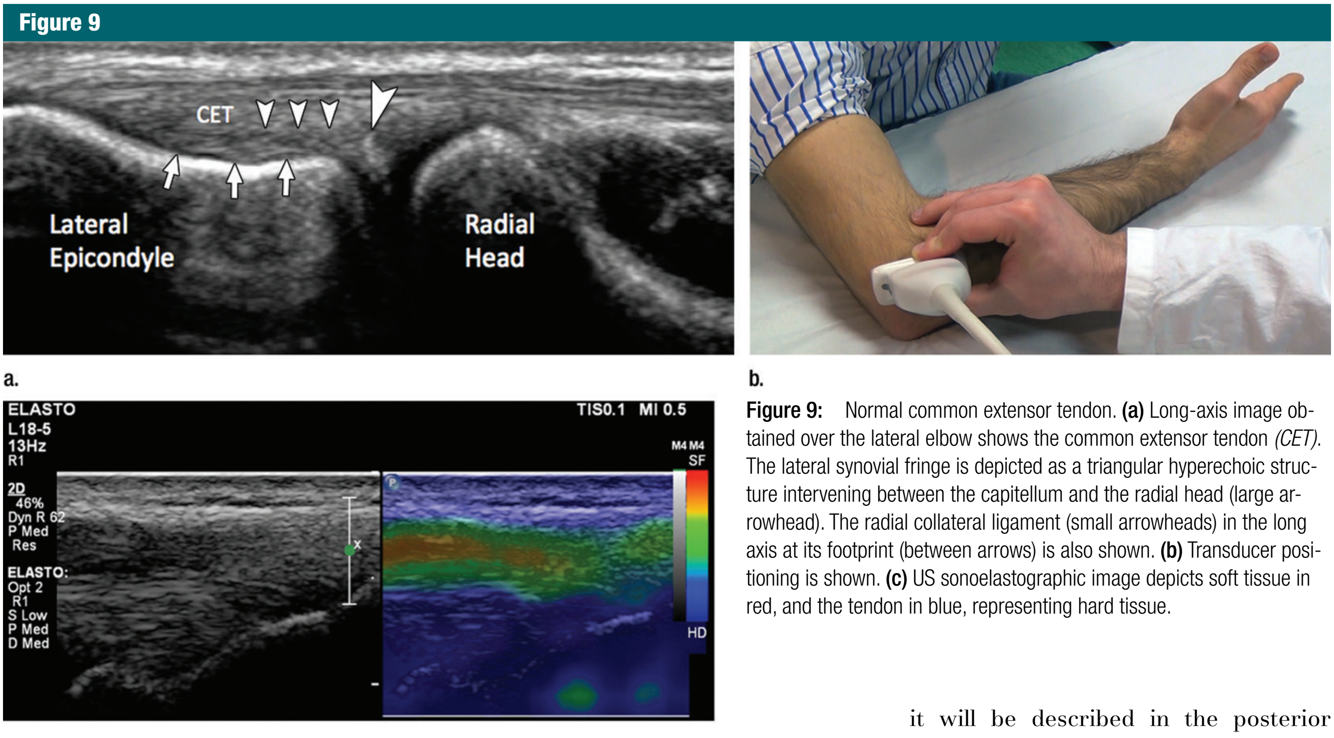


Figure 9: Normal common extensor tendon. **(a)** Long-axis image obtained over the lateral elbow shows the common extensor tendon *(CET)*. The lateral synovial fringe is depicted as a triangular hyperechoic structure intervening between the capitellum and the radial head (large arrowhead). The radial collateral ligament (small arrowheads) in the long axis at its footprint (between arrows) is also shown. **(b)** Transducer positioning is shown. **(c)** US sonoelastographic image depicts soft tissue in red, and the tendon in blue, representing hard tissue.

Figure 10

Figure 10: Probe positioning to evaluate the lateral ulnar collateral ligament, which is visible when the superficial extensor carpi radialis brevis is torn.

the elbow extended, whereas with the elbow flexed, the ligament is tense and its fibrillary pattern is better appreciated (Movie 3 [online]). In normal states, the ligament has a uniform thickness and echotexture (Fig 12). Dynamic scanning in valgus stress (to demonstrate joint space widening) may be useful to evaluate suspected partial tears, with the ligament continuous but elongated (28). The contralateral side is normally used for comparison.

Posterior Elbow

The posterior compartment of the elbow includes the triceps and the anconeus muscles. The ulnar nerve may be considered to be located in the posteromedial elbow, and in this review it will be described in the posterior elbow. In clinical practice, more than one compartment may require attention for a given clinical scenario. For example, ulnar neuropathy is frequently associated with medial epicondylitis, therefore both medial and posterior compartments should be scanned. In cases of inflammation, the olecranon bursa is located superficial to the olecranon process and it is visible with US by using a thick layer of gel and gentle transducer pressure not to displace the fluid inside the bursa. To evaluate the triceps, the posterior recess, and the olecranon bursa, the elbow may be flexed 90° with the palm resting on the table (5). For the evaluation of the cubital tunnel, the elbow may be fully extended and the arm internally rotated to avoid compression of the ulnar nerve at the cubital tunnel.

Triceps Tendon

The triceps is made up of three heads: medial, lateral, and long. The muscle bellies form a single thick tendon inserting on the proximal portion of the olecranon process of the ulna. The distal triceps brachii inserts as two tendons, a superficial tendon composed of the lateral and long heads, and a deeper medial head (28,30–32). Both tendons share a common insertion (28,30–32).

The radial nerve innervates all three heads of the triceps muscle. To increase the lever strength, the triceps tendon does not insert on the tip of the olecranon, but approximately 1 cm distal to it. The anconeus muscle is a small muscle located on the lateral side of the olecranon to assist the triceps in elbow extension. This muscle also provides dynamic support to the lateral ulnar collateral ligament in resisting varus stress (28).

US examination of the triceps tendon can be performed on transverse planes moving the transducer up and down from the olecranon to the myotendinuos junction and on longitudinal planes using a posterior approach (Fig 13) (31). Once the tendon is visually detected on the basis of the typical fibrillar echotexture, it has to be kept in the center of the field of view. Anisotropy, flexion-extension, and mediolateral movements are useful in identifying the tendinous components belonging to the medial/deep and lateral/superficial heads of the triceps (31).

On longitudinal scans, the distal triceps tendon is slightly hyperechoic with striations as it reaches the olecranon (Fig 13). These striations are believed to be made of fat between the tendon fibers and should not be misinterpreted as pathologic (28). Tendon laxity, especially in the elderly, should be considered normal. Extended field-of-view images obtained with the elbow

Figure 11

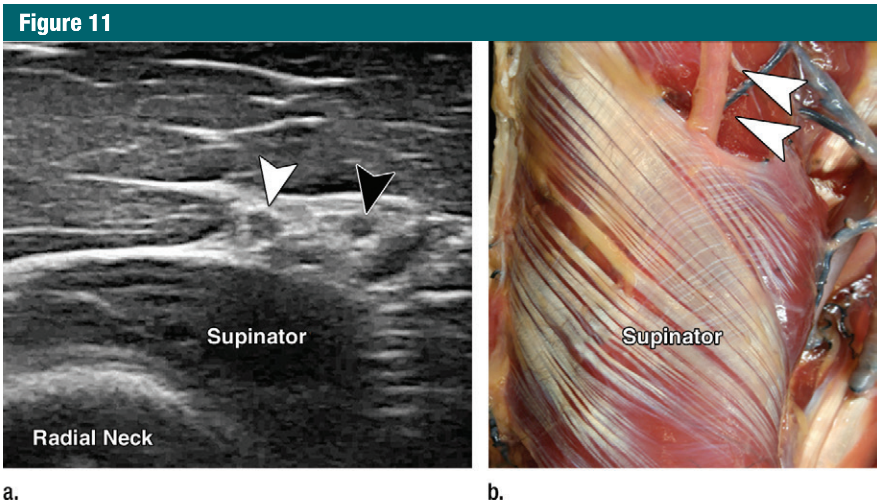


Figure 11: Radial nerve. **(a)** The cutaneous sensory branch (black arrowhead) and the posterior interosseous nerve (white arrowhead) can be appreciated over the supinator muscle as a result of bifurcation of the main trunk of the nerve. **(b)** Cadaveric correlation of the posterior interosseous nerve (arrowheads).

Figure 12

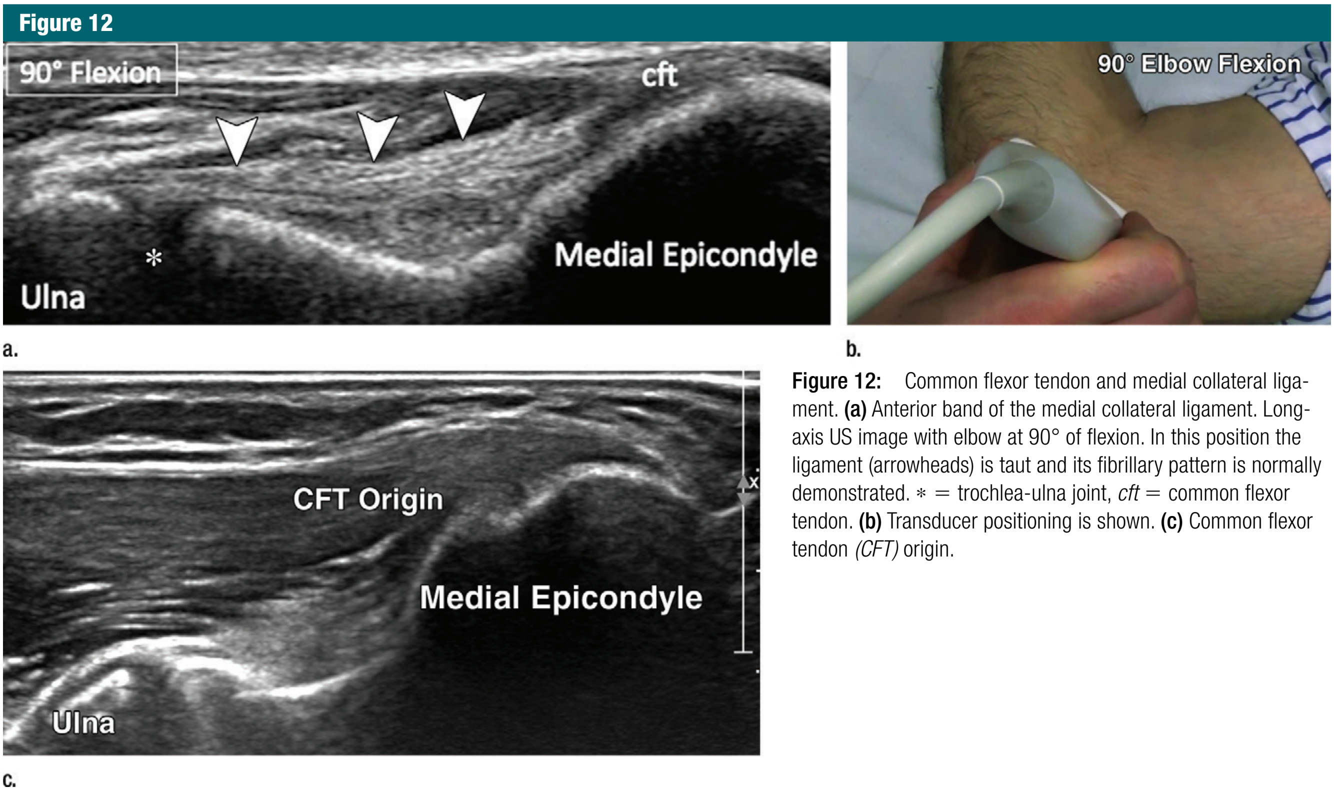


Figure 12: Common flexor tendon and medial collateral ligament. **(a)** Anterior band of the medial collateral ligament. Long-axis US image with elbow at 90° of flexion. In this position the ligament (arrowheads) is taut and its fibrillary pattern is normally demonstrated. ∗ = trochlea-ulna joint, *cft* = common flexor tendon. **(b)** Transducer positioning is shown. **(c)** Common flexor tendon *(CFT)* origin.

Figure 13

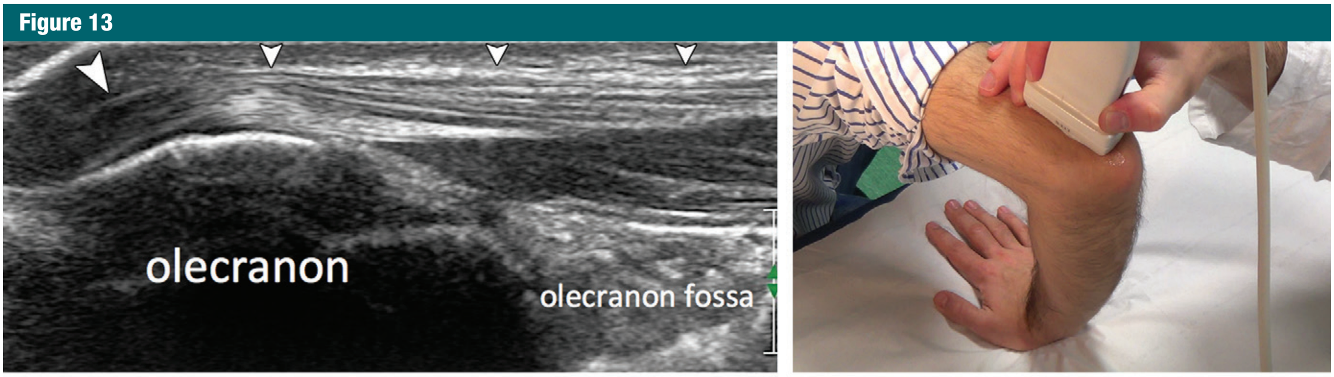


Figure 13: Normal distal triceps tendon. **(a)** Midsagittal or long-axis US image obtained over the olecranon process and the posterior aspect of the distal humerus. The distal triceps tendon (arrowheads) appears as a beak-shaped hyperechoic structure. **(b)** Transducer positioning is shown.

flexed over the olecranon process can show the distal triceps from the myotendinous junction to the olecranon. Preinsertional fibers of this tendon may appear hypoechoic owing to their oblique course and anisotropy artifact. It has been demonstrated that US can be used to differentiate between complete and partial triceps tendon tears and that it has the potential to identify isolated lesions of the lateral/superficial head of the triceps with an intact medial head (31). In addition, partial-thickness distal triceps brachii tendon tears have a characteristic appearance with selective superficial tendon retraction and olecranon avulsion fracture (32). Deep to the triceps, the olecranon fossa and the posterior olecranon recess are visible (Movie 4 [online]). In patients with small effusions, the joint may be examined at 45° flexion to move the intraarticular fluid from the anterior synovial space to the olecranon recess. To evaluate the superficial olecranon bursa, gentle probe movements with low pressure are necessary to detect even a small amount of fluid.

Ulnar Nerve

Normal.—At the medial side of the elbow the ulnar nerve is located in an osteofibrous ring called the condylar groove. This tunnel has a floor formed by the posterior band of the medial collateral ligament and a roof formed by the cubital tunnel retinaculum (Osborne ligament) connecting the olecranon process of the ulna and the medial epicondyle of the humerus.

Approximately 1 cm distal to the condylar groove, the ulnar nerve enters in the true cubital tunnel where the ulnar and humeral heads of the flexor carpi ulnaris muscle are connected by an aponeurotic arch (the "arcuate ligament") (33). When the elbow flexes and extends, the cubital tunnel changes shape and volume probably due to the eccentric origin of the retinaculum. During elbow movements, a 55% decrease in the nerve cross-sectional area and a sixfold increase in interstitial pressure of the cubital tunnel occur as a result of increasing tension of the retinaculum and bulging of the medial collateral ligament (20). For this biomechanical reason, it is possible that repetitive flexion-extension movements may contribute to the development or worsening of cubital tunnel syndrome. Inside the cubital tunnel there are also two small vessels—the posterior ulnar recurrent artery and vein. These vessels should be differentiated from ulnar nerve fascicles and not included in the ulnar nerve cross-sectional area evaluation. Color Doppler used with gentle probe pressure is useful to differentiate small vessels from the nerve.

Anconeus epitrochlearis.—In some individuals it is possible to find the anconeus epitrochlearis, an accessory muscle located between the posterior aspect of the medial condyle of the humerus and the medial aspect of the olecranon. This muscle has exactly the same course as the cubital tunnel retinaculum (Osborne ligament); for this reason, the retinaculum could represent a fibroaponeurotic remnant of this atavistic muscle, according to some authors (33). From the biomechanical point of view, the anconeus epitrochlearis shortens during elbow extension and therefore might be considered an accessory slip to the medial head of the triceps. Its prevalence has been reported to be from 1% to 34% (Fig 14). This muscle is too small to be palpated but it is visible with US as an isolated ovoid mass forming the roof of the condylar groove, just superficial to the ulnar nerve. Transverse planes across the cubital tunnel are helpful to assess that the muscle is a separate entity from the adjacent medial head of the triceps. In cases of ulnar neuropathy, a change in the nerve cross-sectional area is found between the anconeus epitrochlearis and the proximal edge of the arcuate ligament. US can show dynamic impingement of the muscle on the underlying nerve (34).

Stability.—Due to the particular anatomic location, the ulnar nerve at the elbow is prone to instability especially if the retinaculum is lax or absent. Dynamic US of the ulnar nerve should be performed to evaluate for subluxation or luxation with or without snapping triceps syndrome. With the

Figure 14

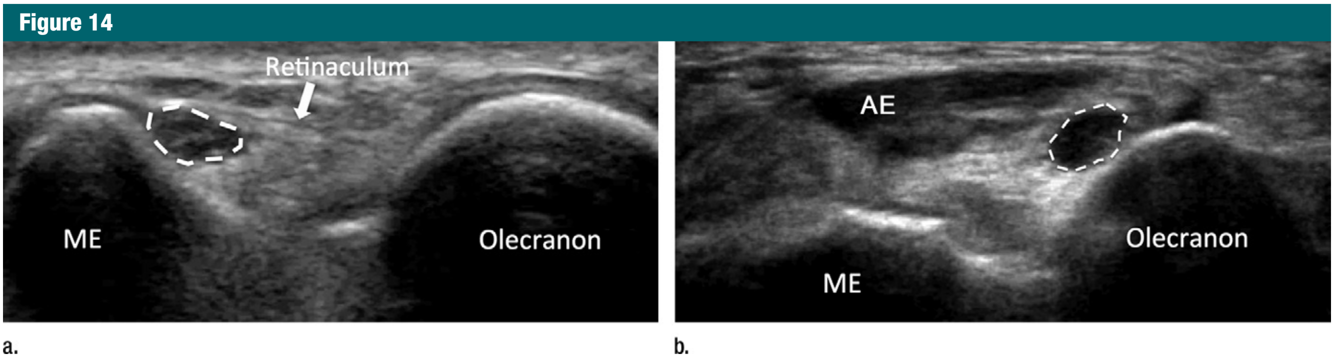


Figure 14: Normal ulnar nerve. **(a)** Transverse US image at the cubital tunnel level shows the normal relationship of the ulnar nerve (arrow) with the medial epicondyle *(ME)* in a patient with **(b)** an accessory muscle called anconeus epitrochelearis *(AE)*. The dotted circle highlights correct cross-sectional area measurement.

transducer in the transverse plane between the olecranon process and fixed at the medial epicondyle, the patient is asked to flex actively the elbow (Movie 4 [online]). This movement allows assessment of abnormal translation of the ulnar nerve over the medial epicondyle, with or without the medial head of the triceps muscle. Snapping triceps syndrome should be assessed with ulnar nerve subluxation and it is more common in young healthy adults with hypertrophic muscles. If a snapping triceps is not diagnosed and treated symptoms and nerve irritation may persist.

Pitfalls

Several scanning pitfalls have been introduced above, however some anatomic areas of the elbow are worthy of further emphasis due to deep positioning, difficult anatomy, scanning technique, and pathologic conditions related to these structures.

Distal Biceps Tendon Anisotropy

The distal biceps has the main problem of visualization related to anisotropy. In general, only 2°–3° of probe angulation will be sufficient to produce this artifact, as the ultrasound beam is reflected away from the transducer. This artifact is particularly problematic when assessing the distal biceps near the radial tuberosity. The artifact is a potential pitfall especially on transverse planes when the hypoechoic appearance of the distal tendon may mimic an absent retracted tendon (6). Longitudinal images with an accurate evaluation of the insertion on the radial tuberosity are important to avoid misinterpretation (Fig 3). We normally use an anterior approach with transverse and longitudinal scans to visualize the distal insertion of the distal biceps tendon (6). When using the anterior approach it is important to press the distal aspect of the probe into the forearm and use the radial neck and tuberosity as bony landmarks. This maneuver helps in keeping the tendon as parallel as possible to the US probe. Anisotropy artifact is useful at the level of the distal biceps tendon to differentiate the two distinct components. On dynamic US, pronosupination movements of the arm determine a change in the position of the two tendons; this action is important to separate the two components. Differentiation between the two separate tendinous components of the distal biceps is easier on short-axis planes, while on longitudinal planes the oblique course of the two tendons makes the visualization more difficult.

Pronator Quadratus Atrophy (Mimicker of Anterior Interosseous Nerve Neuropathy)

The anterior interosseous nerve may be damaged and compressed alone or together with the main trunk of the median nerve by fibrous bands arising from the pronator teres and the flexor digitorum superficialis, hypertrophied anomalous muscles (Gantzer muscle). The anterior interosseous nerve neuropathy is called Kiloh-Nevin syndrome and the flexor pollicis longus, the flexor digitorum profundus to the index finger (middle finger involved in 50% of cases), and the pronator quadratus are the main muscles involved. No sensory loss is present and difficulty in pinching movements is typical. Direct US evaluation of this nerve is very difficult due to the small size and deep position of the nerve. We suggest using the anterior interosseous artery as a landmark for the nerve and then to assess if a mass is visible following the artery from proximal to distal. An indirect sign of Kiloh-Nevin syndrome may be suggested evaluating the loss in bulk and increased reflectivity of the innervated muscles (the flexor pollicis longus, the flexor digitorum profundus, and the pronator quadratus). However, it is important to remember that finding an isolated atrophy of the pronator quadratus is not sufficient to make the diagnosis. Atrophy of the pronator quadratus may be present in patients with no anterior interosseous nerve syndrome in up to 7% of individuals. Some hypotheses have been made to explain this phenomenon: The first is that, in humans, the pronator quadratus plays only a minor role in pronation respect to the pronator teres. On the contrary, animals that live and travel in trees display a well-developed pronator quadratus to support travel and maintain balance on trees (15,35).

Ulnar Nerve Quantitative Measurements (Cubital Tunnel Syndrome Evaluation)

The addition of US in cubital tunnel syndrome increases the sensitivity and specificity of the diagnosis and it is recommended (36,37). Normally, ulnar nerve cross-sectional area is evaluated considering the threshold value for cubital tunnel syndrome to be an area of 7.5 mm^2 (38,39). In addition, the use of “ratios” such as the cubital-to-humeral nerve area ratio has been proposed to increase US diagnostic accuracy (40). Several pitfalls have to be taken into account when evaluating the ulnar nerve cross-sectional area at the elbow:

Measure the nerve with the elbow fully extended to avoid dynamic compression of the nerve that may mimic a compression or displace the nerve over the medial epicondyle.

Measure only the hypoechoic inner part of the nerve and do not measure the hyperechoic epineurium (Fig 14). The epineurium may be thickened in chronic subluxations or luxation and in some alterations of the connective tissue.

Consider that some systemic conditions such as diabetes and acromegaly may alter the normal cross-sectional area cut-off values (39).

Consider that side-to-side variability exists and it may reach values near 20% of the cross-sectional area (29).

If these pitfalls are taken into account, the reliability of the cross-sectional area measurement at the cubital tunnel is increased. Finally, although US has a great value for cubital tunnel assessment, correlation with clinical parameters and neurophysiologic examinations is essential to correctly diagnose and classify the cubital tunnel syndrome. MR imaging may also be used to assess the ulnar nerve at the cubital tunnel, but it is expensive, time consuming, and perhaps less reliable than US (41).

In conclusion, the keys to a successful US examination of the elbow include understanding the relevant anatomy, imaging the structures with the correct technique, eliminating common artifacts, and then evaluating for disease while being aware of the major pitfalls. The use of US for elbow evaluation enhances the clinical examination and it should be routinely proposed especially in cases with uncertain diagnoses.

Disclosures of Conflicts of Interest: A.S.T. disclosed no relevant relationships. **B.B.** disclosed no relevant relationships. **C.M.** disclosed no relevant relationships.

References

1. Yang NP, Chen HC, Phan DV, et al. Epidemiological survey of orthopedic joint dislocations based on nationwide insurance data in Taiwan, 2000-2005. BMC Musculoskelet Disord 2011;12:253.
2. Klauser AS, Tagliafico A, Allen GM, et al. Clinical indications for musculoskeletal ultrasound: a Delphi-based consensus paper of the European Society of Musculoskeletal Radiology. Eur Radiol 2012; 22(5):1140–1148.
3. Centre for Evidence-Based Medicine in Oxford in the UK. http://www.cebm.net. Published 2011. Accessed January 8, 2014.
4. Martinoli C, Della Casa Alberighi O, Di Minno G, et al. Development and definition of a simplified scanning procedure and scoring method for Haemophilia Early Arthropathy Detection with Ultrasound (HEAD-US). Thromb Haemost 2013;109(6):1170–1179.
5. Beggs I, Bianchi S, Bueno A, et al. Musculoskeletal ultrasound technical guidelines. II. Elbow. European Society of Musculoskeletal Radiology, http://www.essr.org/html/img/pool/elbow.pdf. Published 2006. Accessed January 2014.
6. Tagliafico A, Michaud J, Capaccio E, Derchi LE, Martinoli C. Ultrasound demonstration of distal biceps tendon bifurcation: normal and abnormal findings. Eur Radiol 2010;20(1):202–208.
7. Dirim B, Brouha SS, Pretterklieber ML, et al. Terminal bifurcation of the biceps brachii muscle and tendon: anatomic considerations and clinical implications. AJR Am J Roentgenol 2008;191(6):W248–W255.
8. Blasi M, de la Fuente J, Martinoli C, et al. Multidisciplinary approach to the persistent double distal tendon of the biceps brachii. Surg Radiol Anat 2014;36(1):17–24.
9. Cho CH, Song KS, Choi IJ, et al. Insertional anatomy and clinical relevance of the distal biceps tendon. Knee Surg Sports Traumatol Arthrosc 2011;19(11):1930–1935.
10. Kalume Brigido M, De Maeseneer M, Jacobson JA, Jamadar DA, Morag Y, Marcelis S. Improved visualization of the radial insertion of the biceps tendon at ultrasound with a lateral approach. Eur Radiol 2009;19(7):1817–1821.
11. Smith J, Finnoff JT, O’Driscoll SW, Lai JK. Sonographic evaluation of the distal biceps tendon using a medial approach: the pronator window. J Ultrasound Med 2010; 29(5):861–865.
12. Giuffre BM, Lisle DA. Tear of the distal biceps branchii tendon: a new method of ultrasound evaluation. Australas Radiol 2005;49(5): 404–406.
13. Tagliafico A, Michaud J, Perez MM, Martinoli C. Ultrasound of distal brachialis tendon attachment: normal and abnormal findings. Br J Radiol 2013;86(1025):20130004.
14. Husarik DB, Saupe N, Pfirrmann CW, Jost B, Hodler J, Zanetti M. Elbow nerves: MR findings in 60 asymptomatic subjects—normal anatomy, variants, and pitfalls. Radiology 2009;252(1):148–156.
15. Tagliafico A, Perez MM, Padua L, Klauser A, Zicca A, Martinoli C. Increased reflectivity and loss in bulk of the pronator quadratus muscle does not always indicate anterior interosseous neuropathy on ultrasound. Eur J Radiol 2013;82(3):526–529.
16. Miller TT. Elbow. In: Beggs I, ed.Musculoskeletal ultrasound. Philadelphia, Pa: Lippincott Williams & Wilkins, 2014; 49–72.
17. Konin GP, Nazarian LN, Walz DM. US of the elbow: indications, technique, normal anatomy, and pathologic conditions. RadioGraphics 2013;33(4):E125–E147.
18. De Zordo T, Lill SR, Fink C, et al. Real-time sonoelastography of lateral epicondylitis: comparison of findings between patients and healthy volunteers. AJR Am J Roentgenol 2009;193(1):180–185.
19. Jacobson JA, Chiavaras MM, Lawton JM, Downie B, Yablon CM, Lawton J. Radial collateral ligament of the elbow: sonographic characterization with cadaveric dissection correlation and magnetic resonance arthrography. J Ultrasound Med 2014;33(6):1041–1048.
20. Alcid JG, Ahmad CS, Lee TQ. Elbow anatomy and structural biomechanics. Clin Sports Med 2004;23(4):503–517, vii.
21. Capo JT, Collins C, Beutel BG, et al. Three-dimensional analysis of elbow soft tissue footprints and anatomy. J Shoulder Elbow Surg 2014;23(11):1618–1623.
22. Dugas JR, Ostrander RV, Cain EL, Kingsley D, Andrews JR. Anatomy of the anterior bundle of the ulnar collateral ligament. J Shoulder Elbow Surg 2007;16(5):657–660.
23. Farrow LD, Mahoney AJ, Stefancin JJ, Taljanovic MS, Sheppard JE, Schickendantz MS. Quantitative analysis of the medial ulnar collateral ligament ulnar footprint and its relationship to the ulnar sublime tubercle. Am J Sports Med 2011;39(9):1936–1941.
24. Floris S, Olsen BS, Dalstra M, Søjbjerg JO, Sneppen O. The medial collateral ligament

of the elbow joint: anatomy and kinematics. J Shoulder Elbow Surg 1998;7(4):345–351.

25. Morrey BF, An KN. Functional anatomy of the ligaments of the elbow. Clin Orthop Relat Res 1985 (201):84–90.

26. Morrey BF, An KN. Articular and ligamentous contributions to the stability of the elbow joint. Am J Sports Med 1983;11(5):315–319.

27. Khoury V, Cardinal E. "Tenomalacia": a new sonographic sign of tendinopathy? Eur Radiol 2009;19(1):144–146.

28. Bianchi S, Martinoli C. Elbow. In: Bianchi S, Martinoli C, eds. Ultrasound of the musculoskeletal system. New York, NY: Springer, 2007; 349–408.

29. Tagliafico A, Martinoli C. Reliability of side-to-side sonographic cross-sectional area measurements of upper extremity nerves in healthy volunteers. J Ultrasound Med 2013; 32(3):457–462.

30. Beltran LS, Bencardino JT, Beltran J. Imaging of sports ligamentous injuries of the elbow. Semin Musculoskelet Radiol 2013; 17(5):455–465.

31. Tagliafico A, Gandolfo N, Michaud J, Perez MM, Palmieri F, Martinoli C. Ultrasound demonstration of distal triceps tendon tears. Eur J Radiol 2012;81(6): 1207–1210.

32. Downey R, Jacobson JA, Fessell DP, Tran N, Morag Y, Kim SM. Sonography of partial-thickness tears of the distal triceps brachii tendon. J Ultrasound Med 2011; 30(10):1351–1356.

33. O'Driscoll SW, Horii E, Carmichael SW, Morrey BF. The cubital tunnel and ulnar neuropathy. J Bone Joint Surg Br 1991; 73(4):613–617.

34. Martinoli C, Perez MM, Padua L, et al. Muscle variants of the upper and lower limb (with anatomical correlation). Semin Musculoskelet Radiol 2010;14(2):106–121.

35. Larson SG, Stern JT Jr. Maintenance of above-branch balance during primate arboreal quadrupedalism: coordinated use of forearm rotators and tail motion. Am J Phys Anthropol 2006;129(1):71–81.

36. Beekman R, Schoemaker MC, Van Der Plas JPL, et al. Diagnostic value of high-resolution sonography in ulnar neuropathy at the elbow. Neurology 2004;62(5):767–773.

37. Silvestri E, Martinoli C, Derchi LE, Bertolotto M, Chiaramondia M, Rosenberg I. Echotexture of peripheral nerves: correlation between US and histologic findings and criteria to differentiate tendons. Radiology 1995;197(1):291–296.

38. Chiou HJ, Chou YH, Cheng SP, et al. Cubital tunnel syndrome: diagnosis by high-resolution ultrasonography. J Ultrasound Med 1998;17(10):643–648.

39. Tagliafico A, Resmini E, Nizzo R, et al. The pathology of the ulnar nerve in acromegaly. Eur J Endocrinol 2008;159(4):369–373.

40. Gruber H, Glodny B, Peer S. The validity of ultrasonographic assessment in cubital tunnel syndrome: the value of a cubital-to-humeral nerve area ratio (CHR) combined with morphologic features. Ultrasound Med Biol 2010;36(3):376–382.

41. Tagliafico AS. Ulnar neuropathy at the elbow: is MR imaging reliable? Radiology 2011;261(2):659–660; author reply 660.