Authors:

Henry L. Lew, MD, PhD
Carl P. C. Chen, MD
Tyng-Guey Wang, MD
Kelvin T. L. Chew, MD

Affiliations:

From the Division of Physical Medicine and Rehabilitation, Stanford University School of Medicine/VA Palo Alto Health Care System, Palo Alto, California (HLL); Sports Medicine Center, Department of Orthopaedic Surgery, Alexandra Hospital, Singapore (KTLC); Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Linkou, Taiwan; School of Medicine, Chang Gung University, Taiwan; King's College, London, United Kingdom (CPCC); and National Taiwan University Hospital, School of Medicine, Department of Physical Medicine and Rehabilitation, Taiwan (T-GW).

Correspondence:

All correspondence and requests for reprints should be addressed to Tyng-Guey Wang, MD, Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital, School of Medicine, National Taiwan University, Taiwan.

0894-9115/07/8604-0310/0
American Journal of Physical Medicine & Rehabilitation
Copyright © 2007 by Lippincott Williams & Wilkins

DOI: 10.1097/PHM.0b013e31803839ac

INVITED REVIEW

Introduction to Musculoskeletal Diagnostic Ultrasound

Examination of the Upper Limb

ABSTRACT

Lew HL, Chen CPC, Wang T-G, Chew KTL: Introduction to musculoskeletal diagnostic ultrasound: examination of the upper limb. Am J Phys Med Rehabil 2007;86:310–321.

With recent advances in computer technology and equipment miniaturization, the clinical application of diagnostic ultrasonography (U/S) has spread across various medical specialties. Diagnostic U/S is attractive in terms of its noninvasiveness, lack of radiation, readiness of use, cost-effectiveness, and its ability to make dynamic examinations possible. Dynamic imaging deserves special emphasis because it is useful in differentiating full-thickness from partial-thickness tendon tears, muscle tears, and tendon and nerve subluxations or dislocations. It is also a quick and easy avenue for side-to-side comparisons. When appropriately used, diagnostic U/S can be considered as an extension of one's physical examination. However, there are limitations of U/S, which will be discussed in this review article. This is part 1 of two articles; this first part will focus on the ultrasound examination of the upper extremity, using selected examples relevant to musculoskeletal medicine. Part 2 will cover common pathologies of the lower extremity.

Key Words: Musculoskeletal, Ultrasound, Upper Limb

Ultrasonography (U/S) is an imaging modality that uses sound waves in the higher frequency range of >20,000 Hz, which normally cannot be heard by human beings. Ultrasound travels as a longitudinal wave, and images are generated when pulses of ultrasound from the transducer produce echoes at tissue or organ boundaries.[1] Some of the waves are absorbed by the tissues, and the extent to which the ultrasound is absorbed or reflected gives information about the structures scanned, as illustrated in Figure 1. Resolution is defined as the smallest distance that can be discriminated in the image. Better resolutions are attained with higher frequencies. But, in doing so, signals are attenuated, decreasing the depth of field.[2] For example, a 7.5-MHz transducer would produce imaging depths of up to 8 cm with an average resolution of 0.20 mm, whereas a 10.0-MHz transducer would produce imaging depths of 6 cm or less, with a sharper resolution of 0.15 mm.

Between pulse transmissions, the transducer serves as a detector of echoes, which are processed to form an anatomic image. For most musculoskeletal diagnosis, the most useful frequency ranges for the transducer are between 7.0 and 12.0

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

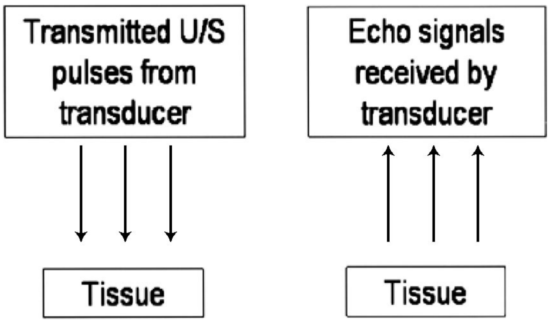

FIGURE 1 *Ultrasound pulse transducer.*

MHz. This article will review the ultrasound appearance of normal tissues in the upper limb and will use clinical examples to demonstrate pathologic changes as they appear on ultrasound.

TERMINOLOGY AND EQUIPMENT CONSIDERATIONS

Interpretation of ultrasound images depends on the echogenicity: the brightness of the image, depending on the degree of reflection of the ultrasound waves. Terms used include hyperechoic, isoehoic, hypoechoic, and anechoic. The images are also described in terms of the plane on which the sonogram is viewed, which is usually longitudinal or transverse in relation to the structure scanned. Common terminology used in musculoskeletal ultrasound is defined in Table 1. Correct selection and configuration of equipment is critical for musculoskeletal U/S. The choice of transducer used depends on the size and location of the musculoskeletal structure to be imaged. Generally, linear transducers are used with high-frequency transducers (7.5–20 MHz) that have higher-resolution imaging but poorer tissue penetrance, making them ideal for small, superficial structures. Low-frequency transducers (<7.5 MHz) have poorer resolution but excellent tissue penetrance; these are preferable for larger, deeper structures. Images in this review were attained from the HDI 5000 (Advanced Technology Laboratories, Bothell, WA) and Xario (SSA 660A, Toshiba Corporation, Japan) with variable-frequency transducer probes between 5 and 20 MHz.

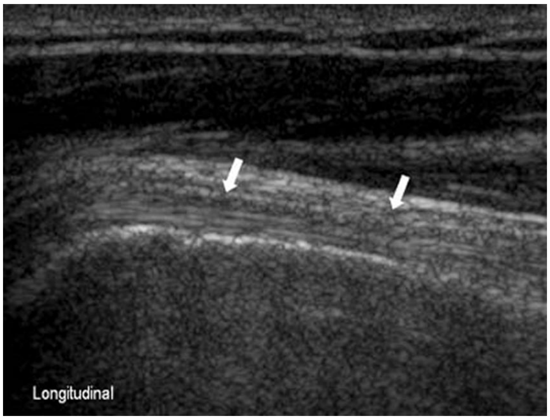

FIGURE 2 *Normal biceps tendon. The ultrasound scan longitudinal to the biceps tendon shows normal, hyperechoic, parallel fibrillar pattern (arrows).*

NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE TENDON

Assessment of tendon integrity is one of the best applications of musculoskeletal U/S.[3–5] Tendons are recognized by parallel and fine fibrillar patterns on U/S in the longitudinal view, as shown in Figure 2. The parallel fascicles of collagen fibers produce hyperechoic lines, whereas the interfascicular ground substance produce anechoic lines in between.[6] In the transverse view, tendons appear as round or oval hyperechoic structures. Anisotropy is a characteristic feature of U/S of tendons and ligaments, where echogenicity of the structure changes depending on the angle of the U/S beam, as illustrated in Figure 3. The image appears hyperechoic when the beam is perpendicular to the tendon and hypoechoic when the beam is oblique, which may lead to misinterpretation.[7] This characteristic is useful in identifying the scanned structure as either a tendon or ligament.

TABLE 1 Terminology in musculoskeletal ultrasound

Term	Definition
Echogenicity	Capacity of a structure in the path of an ultrasound beam to reflect back sound waves.
Hyperechoic	The structure examined in the ultrasound image shows a high reflective pattern and appears brighter than the surrounding tissue.
Isoechoic	The structure demonstrates the same echogenicity as the surrounding soft tissues.
Hypoechoic	The structure examined in the ultrasound image shows a low reflective pattern, manifesting as an area where the echoes are not as bright as the surrounding tissue.
Anechoic	The image of the structure shows no internal echoes (e.g., simple fluid).
Longitudinal	Scan is lengthwise and parallel to the long axis of the structure, organ, or body part.
Transverse	Scan is crosswise and at right angles to the long axis of the structure, organ, or body part.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

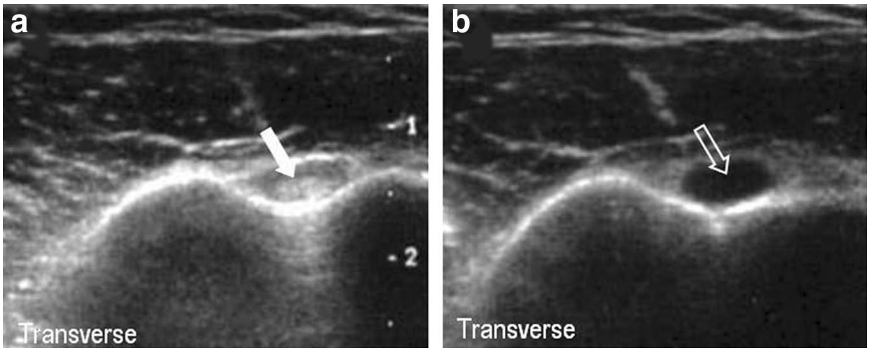

FIGURE 3 *Anisotropy of normal biceps tendon.* a, *Transverse sonogram of hyperechoic biceps tendon (*arrow*) when the ultrasound beam is perpendicular to the tendon.* b, *Hypoechoic biceps tendon (*open arrow*) when the ultrasound beam is not perpendicular to the tendon.*

The extent and mechanisms of tendon injury can be demonstrated by U/S through passive or resisted dynamic examination.[8] Tendon degeneration on ultrasound is seen as irregularities of fibrillar appearance, such as thickening and fragmentation, focal hypoechoic areas, and calcifications.[2,9,10] In tendons with synovial sheath, chronic tendinosis is characterized by widening of the tendon sheath, loss of normal fibrillar echotexture, and loss of definition of tendon margins. In tendons without synovial sheath, the pathology is characterized by focal or diffused thickening of the tendon, with loss of fibrillar echotexture and patches of hypoechogenicity. Tendon ruptures, which can range from partial to complete to massive, appear as fragmented, contiguous fibrils. It is difficult to draw the distinction between tendon degeneration and intrasubstance tears in the absence of hematoma. This is especially so because the two conditions are not mutually exclusive. Complete tears of the tendon are characterized by retraction of torn edges, with hypoechoic hematoma or granulation tissue.[11] Passive movement to accentuate the tendon interruption is a useful maneuver in U/S examination of a suspected tendon tear.[12] In tendons with synovial sheath, fluid can collect in the space between the retracted ends of the tendon.[13] Partial-thickness tears present with a combination of intact and retracted ruptured portions of the tendon, often accompanied by hematoma.[5]

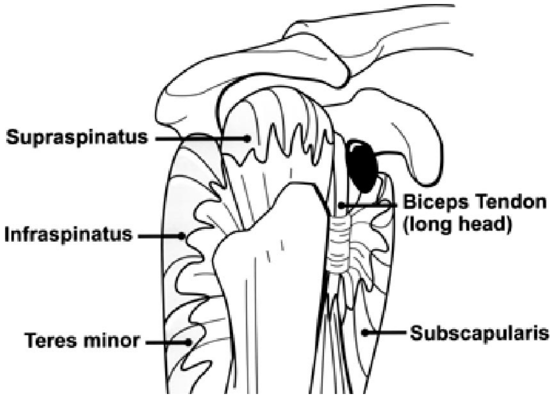

FIGURE 4 *Lateral view of the right shoulder, showing the rotator cuff muscles.*

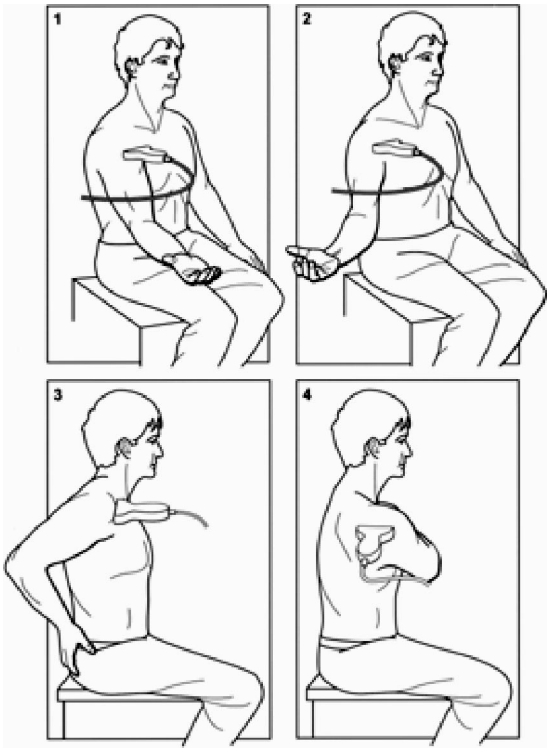

FIGURE 5 *Sequence for rotator cuff ultrasound. 1) Ultrasound transducer placement for imaging the biceps tendon, with the forearm resting in a supinated position on the thigh. 2) Ultrasound transducer placement for imaging the subscapularis, with the arm externally rotated. 3) Ultrasound transducer placement for imaging the supraspinatus, with the hand in a back pocket, palm toward the gluteal muscles, and the elbow directed posteriorly. 4) Ultrasound transducer placement for imaging the infraspinatus, teres minor, and posterior glenohumeral joint, with an arm across the chest and the hand on the opposite shoulder.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

ROTATOR CUFF U/S

Rotator cuff disease is common and is one of the most common reasons for using U/S. Matsen and coworkers[14] have suggested diagnostic U/S as a primary imaging technique for soft-tissue injuries of the shoulder. The main advantages are its ability to perform dynamic examinations and to conduct side-to-side comparisons on the spot. Many studies report excellent sensitivity and specificity of ultrasound in diagnosing rotator cuff tears.[15–20] U/S diagnosis of full-thickness rotator cuff tears has an overall accuracy of up to 96%.[21] Recently, Teefey and colleagues[22] found comparable accuracy of diagnostic ultrasound and magnetic resonance imaging for diagnosis and measurement of rotator cuff tears. Iannotti and coworkers,[23] in their evaluation of office-based U/S by orthopedic surgeons measuring full-thickness rotator cuff tears, have yielded similar findings. However, several studies have reported less than satisfactory results in terms of accuracy.[24–26] Interstudy comparison is difficult because of a lack of standardization of technique, clinical experience of different operators, and changes in equipment over time.

Understanding the anatomy of the rotator cuff is essential for successful shoulder U/S examination, because the overlying bony structures create obstacles to ultrasound imaging. The rotator cuff consists of the supraspinatus, subscapularis, infraspinatus, and teres minor tendons. The relations of the rotator cuff are illustrated in Figure 4. The long head of the biceps runs in the interval between the supraspinatus and the subscapularis tendons from the superior glenoid tubercle. These muscles provide dynamic stability to the inherently unstable, extremely mobile glenohumeral joint. The subscapularis originates anteriorly from the scapula and inserts into the lesser tuberosity of the humerus. The supraspinatus originates posteriorly from the scapula above the scapular spine and inserts into the anterior aspect of the greater tuberosity. The infraspinatus originates posteriorly from the scapula below the scapular spine and inserts into the greater tuberosity of the humerus posteriorly to that of the supraspinatus. The teres minor arises posteriorly from the scapula and inserts posteriorly and inferiorly to that of the infraspinatus at the greater tuberosity. The three posterior muscle tendons have a common insertion into the greater tuberosity and are difficult to distinguish.

Standardized Technique in Examination of the Shoulder

The shoulder is an important, yet complicated, joint to examine. Proper positioning of the patient is important for successful U/S of the shoulder. Typically, the patient is seated upright on a revolving stool. The examination should be systematic, with predetermined structures scanned step by step. U/S of the shoulder begins with the long head of the biceps tendon, which is often used as a reference landmark. The biceps tendon is examined in the longitudinal and transverse planes with the patient's forearm or hand resting in a supinated position on the thigh. Moving from the biceps tendon medially is the subscapularis, which is best examined with the patient's arm in external rotation. The tendon is traced from the bicipital groove and lesser tuberosity. Imaging of the supraspinatus is obstructed by the overlying acromion. The maneuver for exposing the supraspinatus beneath the acromion anteriorly is to have the patient put a hand in his or her back pocket with the palm toward the gluteal muscles while keeping the elbow directed posteriorly. The tendon is examined in perpendicular planes, bearing in mind that the axis of the tendon is approximately 45° between the sagittal and coronal planes of the body. The poste-

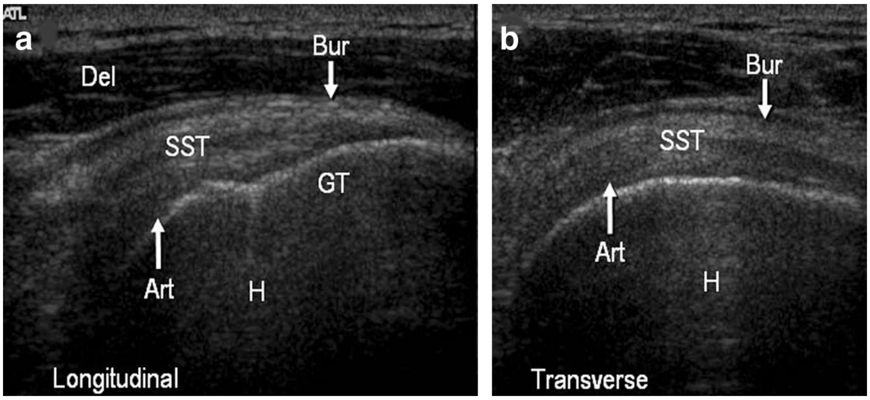

FIGURE 6 *Normal supraspinatus tendon (SST). Bur, bursal surface; Art, articular surface of the tendon; GT, greater tuberosity of the humerus (H).* a, *The longitudinal scan resembles a parrot's beak. The deltoid muscle (Del) has relatively lower echogenicity compared with the SST.* b, *The transverse scan shows parallel convexity.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

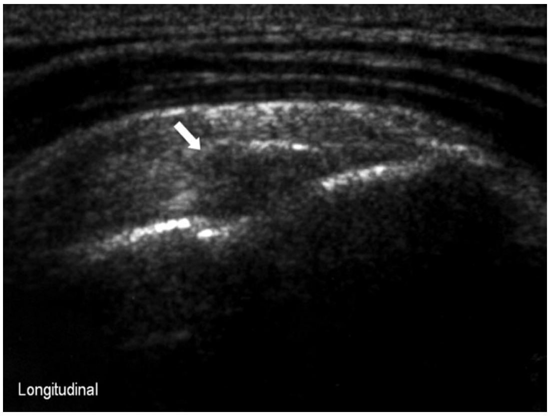

FIGURE 7 *Calcific tendinosis of the supraspinatus tendon. Echogenic foci with acoustic shadowing (*arrow*).*

rior glenohumeral joint, infraspinatus, and teres minor are examined by putting the patient's arm across the chest with his or her hand on the opposite shoulder. The posterior cuff is examined by tracing from the bony landmark of the spine of the scapular and moving the transducer inferiorly to the infraspinatus and then laterally to visualize the posterior glenohumeral joint.

Because the cuff tendons inserting into the greater tuberosity are relatively indistinct from each other, it is difficult to distinguish them. One way to tell them apart is by sequential measurements. The supraspinatus forms approximately 1.5–2 cm of width on the transverse plane, starting from the edge of the biceps tendon, and the infraspinatus forms the next 1.5 cm posteriorly. Figure 5 illustrates the sequence of ultrasound examination of the shoulder.

Supraspinatus Tendon Pathologies

The normal longitudinal ultrasound appearance of the supraspinatus resembles a parrot's beak. The transverse view of the supraspinatus shows the parallel convexity of the subacromial–subdeltoid bursa above and the humeral epiphysis below, as illustrated in Figure 6.

Supraspinatus Tendinosis

The term "tendinosis" (or "tendinopathy") has superseded the term "tendonitis" as studies have shown the absence of active inflammation in these conditions.[27] Tendinosis appears as focal or diffuse, poorly demarcated hypoechoic regions accompanied by swelling. Confusion often occurs here because partial tendon tears may appear hypoechoic. The presence of an internal fibrillar pattern and the lack of tendon atrophy differentiate tendinosis from partial tears. A markedly echogenic appearance with posterior acoustic shadowing arising from the tendon substance can occur in calcific tendinopathy, as shown in Figure 7.

Full-Thickness Supraspinatus Tear

Rotator cuff tears are characterized by the degree of tear (i.e., either partial or full thickness), the amount of tendon retraction in the longitudinal plane, and the width of the defect in the transverse plane. Full-thickness tears can present with nonvisualization of the rotator cuff, where there is total absence of the supraspinatus tendon on U/S.[28] This feature can be seen in massive rotator cuff tears, which are associated with a high-riding humeral head on radiographs. The fluid collection between the deltoid and humerus may be mistaken as the supraspinatus. In the absence of the supraspinatus tendon, compression with the ultrasound probe will obliterate this space, as illustrated in Figure 8. In addition to compressibility, the fluid should not be mistaken for cuff tissue, because there is no internal fibrillar echotexture of the fluid.

The edge of the tendon stump can be tapered off to fibrosed synovium.[29] This produces a contour

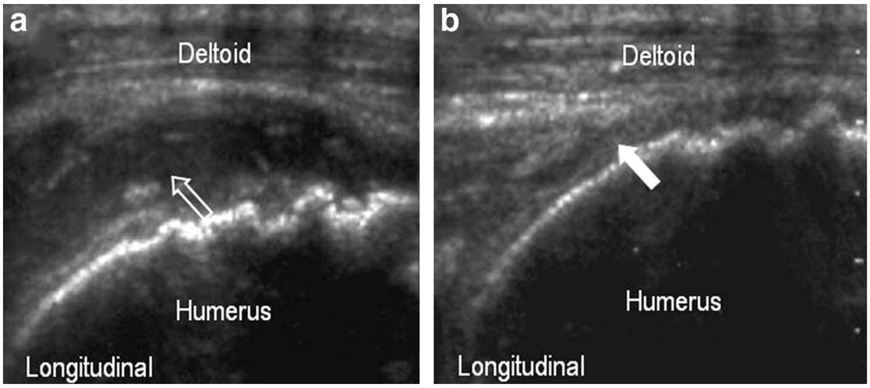

FIGURE 8 *Massive tear of the rotator cuff. Longitudinal ultrasound scan showing nonvisualization of the supraspinatus tendon.* a*, Effusion in the space (*open arrow*) between the deltoid muscle and humeral head.* b*, Compression with the ultrasound probe obliterates (*arrow*) this space in between.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

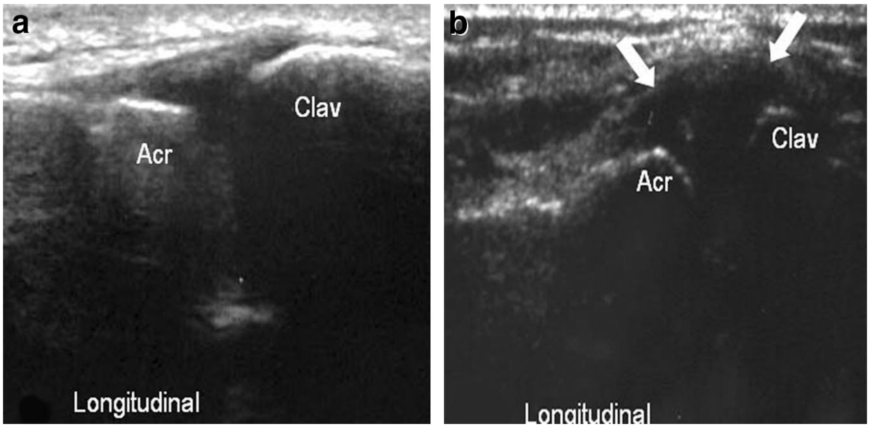

FIGURE 9 a, *Normal acromioclavicular joint.* b, *Acromioclavicular joint effusion demonstrating the geyser's sign, as shown by* arrows. *Acr, acromion; Clav, clavicle.*

alteration in that the normal outer convex border of the rotator cuff is flattened or becomes concave. The most common ultrasound feature of full-thickness tears of the supraspinatus is the hypoechoic defect, which appears as sharp demarcations from the bursal to the articular surface of the tendon.[30] Shoulder effusions and bursal fluid have been shown to correlate strongly with rotator cuff abnormalities.[31] It distributes within the glenohumeral joint, to the tendon sheath of the long head of biceps, to the subacromiodeltoid bursa through the tear and through the acromioclavicular joint to produce the geyser sign, as illustrated in Figure 9.[31] The loss of tendon causes the deltoid at the bursal surface to sink into the gap to produce the deltoid herniation sign, and accompanying exaggeration of articular hyaline cartilage produces a double-cortex appearance as well as cortical irregularities.[32] These features can be seen in Figure 10.

Partial-Thickness Supraspinatus Tear

A partial-thickness tear appears as a hypoechoic area within or at the bursal or articular aspect of the tendon, usually located at the critical area over the anatomic neck of the humerus.[19] Differentiating between partial tears and severe localized degeneration of the tendon can be difficult using U/S, which is less sensitive in such cases than it is for detecting full-thickness tears.[21] The intrasubstance tears are hypoechoic areas within the tendon substance with intact articular and bursal surfaces. Articular-surface tear can be seen as a hypoechoic defect that continues to the articular surface of the tendon. Cortical irregularity is a common finding at the articular extension of a tendon tear.[33] In bursal-surface tears, the hypoechoic defect is in continuity with the bursal surface of the tendon. Ultrasound appearance of both

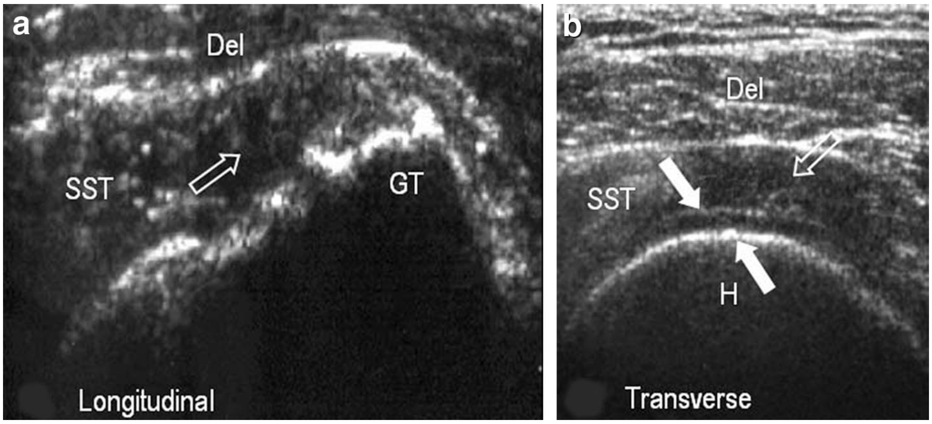

FIGURE 10 *Full-thickness tear of the supraspinatus tendon.* a, *Longitudinal sonogram depicting a focal hypoechoic defect (*open arrow*) with deltoid muscle (Del) herniation from above. Exaggeration of cartilage reflection is seen here in the absence of an overlying tendon. Cortical irregularities are seen at the greater tuberosity (GT).* b, *Transverse sonogram showing double-cortex sign (*arrows*), representing the articular hyaline cartilage above and the cortex of the humeral head below.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

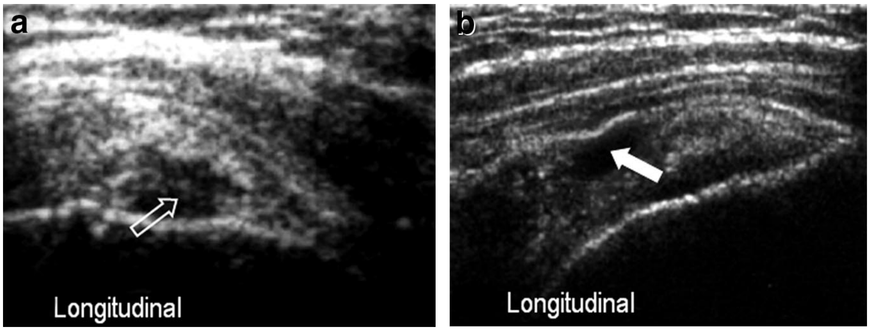

FIGURE 11 *Longitudinal sonogram of partial-thickness tear of the supraspinatus.* a*, Hypoechoic defect interrupting the articular surface of the tendon (*open arrow*).* b*, Hypoechoic defect interrupting the bursal surface of the tendon (*arrow*).*

articular- and bursal-surface partial tears of the supraspinatus are illustrated in Figure 11.

Although most partial tears occur in the critical zone of the supraspinatus tendon, some tears, commonly known as rim rent tears, involve a small, articular surface avulsion adjacent to the greater tuberosity.[34] This type of tear appears as a small, hypoechoic defect with a central hyperechoic line on the articular surface. The transverse view appears as a bull's eye lesion, with central punctuate echo surrounded by a hypoechoic halo of fluid or edematous tendon.

Biceps Tendinosis

The long head of the biceps tendon is kept in place within the groove by the transverse humeral ligament and coracohumeral ligaments. A full-thickness tear is represented by complete discontinuity of the fibrillar pattern of the tendon, whereas a partial-thickness or intrasubstance tear of the biceps tendon produces a hypoechoic defect. Surrounding tenosynovitis is commonly seen in bicipital tendinosis, as shown in Figure 12. The tendon can subluxate or dislocate out of the groove when the integrity of the transverse humeral ligament is breached in association with supraspinatus or subscapularis tendon tears. Biceps tendon subluxation out of the groove can be demonstrated by internal and external rotation of the shoulder; this usually occurs medially. An empty bicipital groove can be seen when the biceps tendon is completely dislocated or torn. Complete biceps tendon tears are differentiated from dislocations by tracing the muscle belly, which will also be absent but only visualized distally because of muscle retraction.

Tennis Elbow, Lateral Epicondylitis

Tennis elbow, or lateral epicondylitis, is the most common soft-tissue injury affecting the elbow joint. It is thought to arise from chronic repetitive injury. The lateral epicondyle is the origin of the common extensor tendons of the wrist and hand. Tendons of the extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, and extensor carpi ulnaris fuse to form the common extensor tendon origin.

In lateral epicondylitis, the tendon origin appears thickened and hypoechoic on ultrasound.[35] There may be hypoechoic linear clefts within the tendon, representing intrasubstance tears—a common occurrence in tendinopathy.[10] As seen in Figure 13, chronic epicondylitis is associated with tendon thickening, calcification, and cortical irregularity, or spur formation of the epicondyle.[10,36]

De Quervain Tenosynovitis

De Quervain tenosynovitis is an idiopathic condition involving the abductor pollicis longus and extensor pollicis brevis tendons in the first extensor compartment at the level of and proximal to the radial styloid.[37] Pain is usually brought about by thumb movements or, specifically, by the

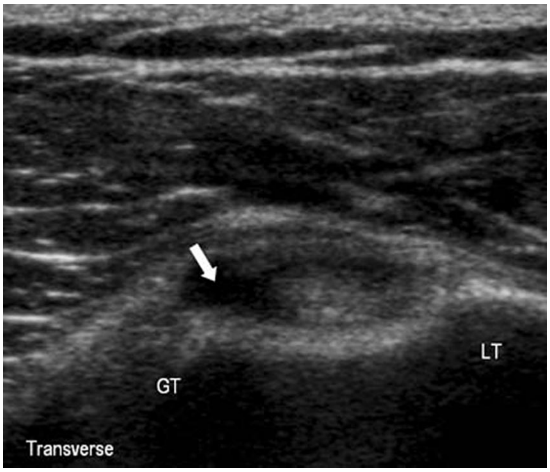

FIGURE 12 *Transverse sonogram of the bicipital tendon, depicting tendinosis with effusion within its sheath (*arrow*). GT, greater tuberosity of humerus; LT, lesser tuberosity of humerus.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

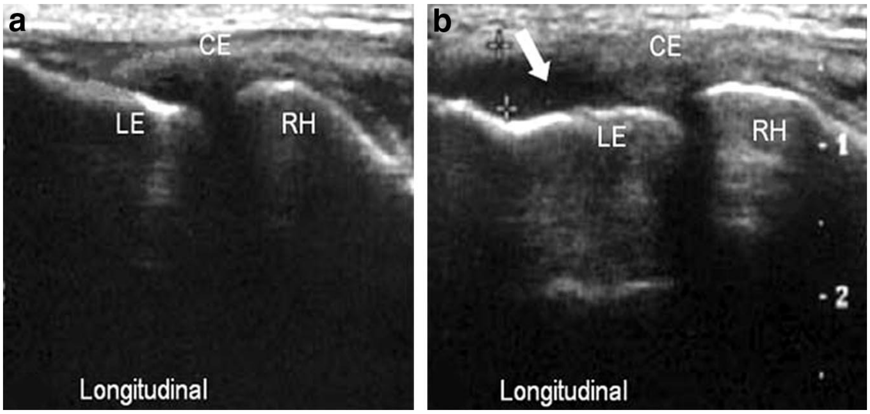

FIGURE 13 *Common extensor origin.* a, *Normal longitudinal scan of the common extensor tendon, with a parallel echogenic fibrillar pattern.* b, *Lateral epicondylitis. Abnormal focal swelling and hypoechogenicity (*arrow*) were seen at the tendon insertion site. LE, lateral epicondyle; RH, radial head; CE, common extensor tendon.*

Finkelstein test, in which the patient makes a fist with his or her fingers over the thumb, with the wrist adducted. The tendon sheath appears thickened with hypoechoic fluid on ultrasound, as shown in Figure 14. A hypoechoic or anechoic ring surrounds the hyperchoic tendon in peritendineal effusion of tenosynovitis, giving the appearance of a target sign.

NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE MUSCLE

U/S is an effective assessment tool for diagnosis of acute muscle injury, such as muscle contusions, strains, tears, and hematoma, as well as chronic lesions such as fibrous scars. U/S can be helpful for predicting the expected recovery period, and it is ideal for serial assessment to document muscle healing and recovery.[38] Muscle fibers are grouped into fascicles and are separated by septa of fibroadipose tissue. The whole muscle is enclosed in a fascial sheath. On ultrasound, muscle appears hypoechoic with hyperechoic septations, as illustrated in Figure 15.[38] The intramuscular septations appear as hyperechoic dots combined to form a reticular pattern on a hypoechoic background in the transverse view.[38] In the longitudinal view, the intermuscular septa appear markedly hyperechoic, and the intramuscular septa appear as parallel hyperechoic striae.[38] The characteristic feature of muscle is that its alignment varies with contraction of the muscle.

Muscle strains can be classified into grade 1, which is a strain injury with no macroscopic tissue disruption; grade 2, which is a partial-thickness tear with associated partial loss of muscle strength; and grade 3, which is a full-thickness tear with complete loss of muscle strength and which may be associated with a retraction of ruptured muscle ends.[39,40] Grade 1 muscle strains often appear normal, but the muscle may have an increased echogenic appearance because of perifascial fluid buildup.[41] Grade 2 muscle strains are represented by disruption of echogenic parallel striae of the muscle, with associated fluid collection.[41] In grade 3 muscle strains, complete disruption, with retraction of muscle fibers, surrounded by hypoechoic hema-

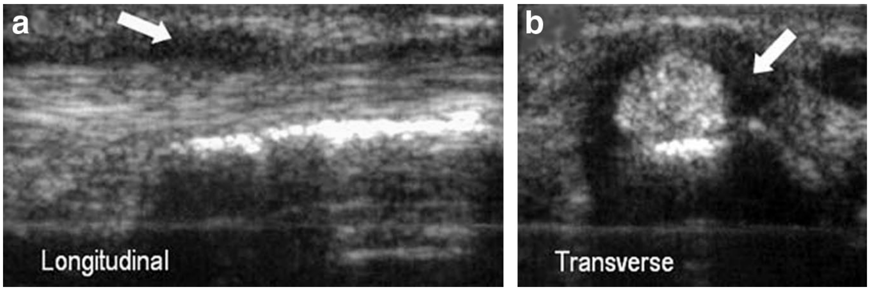

FIGURE 14 *De Quervain tenosynovitis.* a, *Longitudinal sonogram depicting hypoechoic fluid swelling within the tendon sheath (*arrow*) of the abductor pollicis longus and extensor pollicis brevis.* b, *Transverse sonogram showing a hypoechoic ring (*arrow*) around the tendon, producing the appearance of a target sign.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

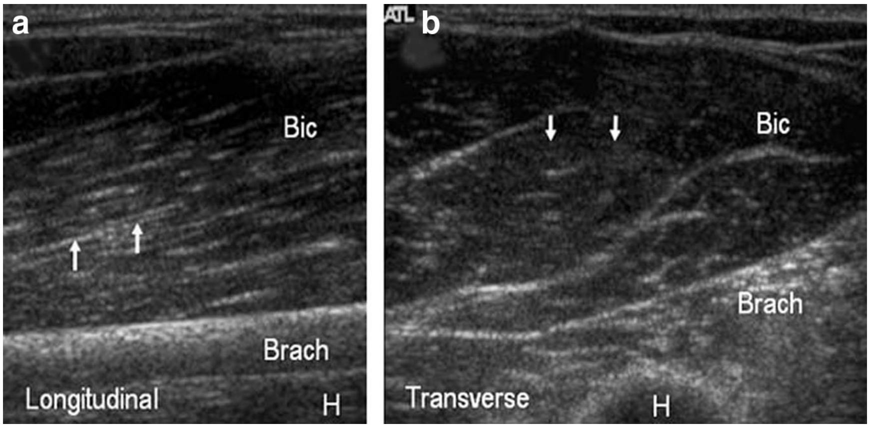

FIGURE 15 *Normal biceps brachii muscle.* a, *Longitudinal sonogram showing intramuscular septations (*arrows*) seen as hyperechoic lines separating hypoechoic muscle bundles.* b, *Transverse sonogram showing the intramuscular septations (*arrows*) that appear as hyperechoic dots on a hypoechoic background. Bic, biceps brachii muscle; Brach, brachialis muscle; H, humerus.*

toma, is the characteristic feature.[42] Other acute muscle injuries include blunt injuries to muscle (contusions), in which the ultrasound appearance depicts an ill-defined hyperechoic region in the muscle, with associated hypoechoic hematoma. In recurrent or chronic injuries, fibrous scar formation can occur, which appears on ultrasound as a hyperechoic lesion that is unchanged with muscle contraction.

NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE BURSA

Subacromial Bursa

The subacromial bursa lies between the deltoid and the rotator cuff and is not easily seen in normal conditions. The opposing sides of the bursa should be no more than 2 mm apart.[43] The bursa may swell in association with supraspinatus impingement or tears. Supraspinatus impingement can be demonstrated on ultrasound by pooling of fluid in the subacromial–subdeltoid bursa with active arm elevation.[44] Fluid inside the subacromial bursa usually collects in its caudal portion and can be found both in superficial and full-thickness tears of the rotator cuff. The bursa is best evaluated at the lateral aspect of the shoulder between the supraspinatus tendon and the deltoid muscle.[43] Effusions can distend along this deltoid shelf, which is the point of least resistance. It produces the teardrop sign, as seen in Figure 16.[45] Apart from chronic repetitive or inflammatory conditions, bursitis can result from trauma.

NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE NERVE

Peripheral nerves have a fascicular pattern in the longitudinal plane, as shown in Figure 17. It demonstrates a speckled appearance in the transverse plane as the neuronal fascicles appear hypoechoic with hyperechoic connective stroma.[46]

Carpal Tunnel Syndrome

The diagnosis of carpal tunnel syndrome is usually made on the basis of clinical features and is then confirmed by nerve conduction studies. Carpal tunnel syndrome can also be diagnosed with U/S by demonstrating an increase in the cross-sectional area of the median nerve at the level of the pisiform bone, as shown in Figure 18.[47] The advantages of U/S are that it is painless and allows visualization of other underlying causes, such as a mass lesion. The reported cross-sectional area for diagnosis of the condition varied mostly between 9 and 11 mm^2.[48–50] U/S seems to be a promising tool for the diagnosis of carpal tunnel syndrome. In one study comparing U/S diagnosis of carpal tunnel syn-

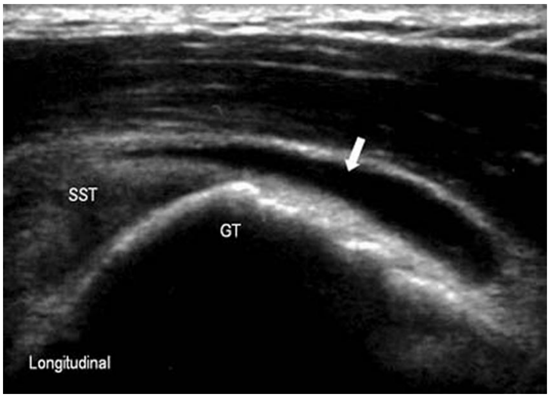

FIGURE 16 *Longitudinal sonogram depicting a distended subacromiodeltoid bursa, demonstrated by the teardrop sign (*arrow*). SST, supraspinatus; GT, greater tuberosity of the humerus.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

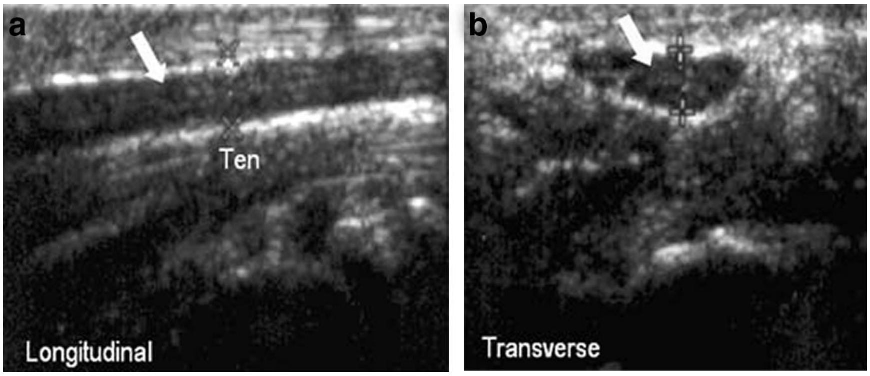

FIGURE 17 *Normal median nerve (arrow): longitudinal and transverse views. The nerve is relatively hypoechoic compared with the tendons (Ten).*

drome with nerve conduction studies, the sensitivity was found to be 70 *vs.* 98%, and specificity 63 *vs.* 19%, respectively.[50] Future research is needed to gain further insight into the possible additional value of this diagnostic modality.

OTHER APPLICATIONS OF U/S

In musculoskeletal medicine, treatment with injections into joints, bursae, or tendon sheaths are carried out for various pathologies. In addition to diagnosis of pathologies, ultrasound can be used to monitor needle position during the injection procedure. U/S has been shown to be an accurate, safe imaging modality for guiding musculoskeletal injections.[51] Actual techniques for ultrasound-guided procedures are not within the scope of this paper. But, to mention a few applications, ultrasound can be used for guiding glenohumeral joint injections,[52] subacromial injections,[53] aspiration of calcific tendonitis,[54] and elbow joint[52] and carpal tunnel injections.[55]

LIMITATIONS IN DIAGNOSTIC U/S

The limitations of U/S stem from operator dependence for this diagnostic procedure. This diagnostic tool lacks uniformity because of the dynamic nature of musculoskeletal examinations. The mobile nature of joints (in combination with random probe placements), gives rise to unlimited permutations in image variations. This is best illustrated by ultrasound examination of the rotator cuff in the shoulder, where clinical accuracy depends heavily on the scanning technique. To be able to correctly employ the diagnostic procedure and interpret findings, there is a long learning curve.

CONCLUSION

Musculoskeletal ultrasound has multiple advantages as a primary diagnostic modality. It is portable and highly accessible. An important feature of ultrasound is its ability for dynamic imaging. In addition to making side-to-side comparisons, it allows clinicians to correlate their patients' symptoms directly with anatomic visualization. The main disadvantages are operator dependence and the long learning curve. Nevertheless, with proper use as an adjunct diagnostic tool, it can become a valuable extension to one's physical examination.

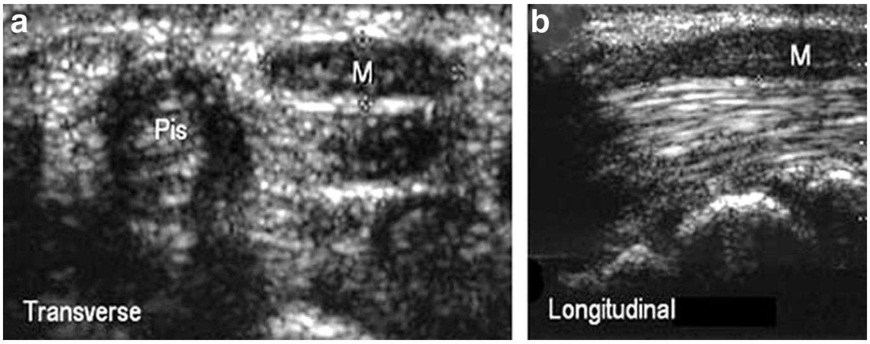

FIGURE 18 *Carpal tunnel syndrome.* a, *Transverse sonogram of the median nerve (M) at the level of the pisiform bone (Pis).* b, *Longitudinal sonogram displaying swelling of the median nerve (M) proximal to the retinaculum.*

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

ACKNOWLEDGMENTS

We acknowledge Dr. Kathryn Stevens from the Department of Radiology at Stanford University School of Medicine for her technical advice and assistance with the ultrasound images. We also thank Ms. Sylvia Guillory for her editorial assistance.

REFERENCES

1. Kremkau FW: *Diagnostic Ultrasound: Principles and Instruments*. Philadelphia, PA, W.B. Saunders, 1998
2. Van Holsbeeck M, Introcaso J: Sonography of tendons, in Bralow L (ed): *Musculoskeletal Ultrasound*, ed 2. St Louis, MO, Mosby, Inc., 2001, pp 77–129
3. Grassi W, Filippucci E, Farina A, Cervini C: Sonographic imaging of tendons. *Arthritis Rheum* 2000;43:969–76
4. Chhem RK, Kaplan PA, Dussault RG: Ultrasonography of the musculoskeletal system. *Radiol Clin North Am* 1994; 32:275–89
5. Jacobson JA, van Holsbeeck MT: Musculoskeletal ultrasonography. *Orthop Clin North Am* 1998;29:135–67
6. Martinoli C, Derchi LE, Pastorino C, Bertolotto M, Silvestri E: Analysis of echotexture of tendons with US. *Radiology* 1993;186:839–43
7. Crass JR, van d, V Harkavy LA: Tendon echogenicity: ex vivo study. *Radiology* 1988 ;167:499–501
8. Farin PU, Jaroma H, Harju A, Soimakallio S: Medial displacement of the biceps brachii tendon: evaluation with dynamic sonography during maximal external shoulder rotation. *Radiology* 1995;195:845–8
9. Fomage B, Rifkin M: Ultrasound examination of tendons. *Radiol Clin North Am* 1998;26 87–107
10. Connell D, Burke F, Coombes P, et al: Sonographic examination of lateral epicondylitis. *AJR Am J Roentgenol* 2001; 176:777–82
11. Kainberger FM, Engel A, Barton P, Huebsch P, Neuhold A, Salomonowitz E: Injury of the Achilles tendon: diagnosis with sonography. *AJR Am J Roentgenol* 1990;155:1031–6
12. Bianchi S, Zwass A, Abdelwahab IF, Banderali A: Diagnosis of tears of the quadriceps tendon of the knee: value of sonography. *AJR Am J Roentgenol* 1994;162:1137–40
13. Bianchi S, Zwass A, Abdelwahab IF, Zoccola C: Evaluation of tibialis anterior tendon rupture by ultrasonography. *J Clin Ultrasound* 1994;22:564–6
14. Matsen FA, Arntz CT, Lippitt SB: Rotator cuff: imaging techniques, in Rockwood CA, Matsen FA (eds): *The Shoulder*. Philadelphia, PA, W.B. Saunders Co., 2006, pp 789–93
15. Hedtmann A, Fett H: Ultrasonography of the shoulder in subacromial syndromes with disorders and injuries of the rotator cuff [in German]. *Orthopade* 1995;24:498–508
16. Middleton WD, Reinus WR, Totty WG, Melson CL, Murphy WA: Ultrasonographic evaluation of the rotator cuff and biceps tendon. *J Bone Joint Surg Am* 1986;68:440–50
17. Read JW, Perko M: Shoulder ultrasound: diagnostic accuracy for impingement syndrome, rotator cuff tear, and biceps tendon pathology. *J Shoulder Elbow Surg* 1998;7: 264–71
18. Roberts CS, Walker JA, Seligson D: Diagnostic capabilities of shoulder ultrasonography in the detection of complete and partial rotator cuff tears. *Am J Orthop* 2001;30:159–62
19. van Holsbeeck MT, Kolowich PA, Eyler WR, et al: US depiction of partial-thickness tear of the rotator cuff. *Radiology* 1995;197:443–6
20. van Moppes FI, Veldkamp O, Roorda J: Role of shoulder ultrasonography in the evaluation of the painful shoulder. *Eur J Radiol* 1995;19:142–6
21. Teefey SA, Hasan SA, Middleton WD, Patel M, Wright RW, Yamaguchi K: Ultrasonography of the rotator cuff. A comparison of ultrasonographic and arthroscopic findings in one hundred consecutive cases. *J Bone Joint Surg Am* 2000;82:498–504
22. Teefey SA, Rubin DA, Middleton WD, Hildebolt CF, Leibold RA, Yamaguchi K: Detection and quantification of rotator cuff tears. Comparison of ultrasonographic, magnetic resonance imaging, and arthroscopic findings in seventy-one consecutive cases. *J Bone Joint Surg Am* 2004;86:708–16
23. Iannotti JP, Ciccone J, Buss DD, et al: Accuracy of office-based ultrasonography of the shoulder for the diagnosis of rotator cuff tears. *J Bone Joint Surg Am* 2005;87:1305–11
24. Alasaarela E, Leppilahti J, Hakala M: Ultrasound and operative evaluation of arthritic shoulder joints. *Ann Rheum Dis* 1998;57:357–60
25. Brandt TD, Cardone BW, Grant TH, Post M, Weiss CA: Rotator cuff sonography: a reassessment. *Radiology* 1989; 173:323–7
26. Burk DL Jr, Karasick D, Kurtz AB, et al: Rotator cuff tears: prospective comparison of MR imaging with arthrography, sonography, and surgery. *AJR Am J Roentgenol* 1989;153: 87–92
27. Khan K, Cook J: The painful nonruptured tendon: clinical aspects. *Clin Sports Med* 2003;22:711–25
28. Teefey SA, Middleton WD, Bauer GS, Hildebolt CF, Yamaguchi K: Sonographic differences in the appearance of acute and chronic full-thickness rotator cuff tears. *J Ultrasound Med* 2000;19:377–8
29. Farin PU, Kaukanen E, Jaroma H, Vaatainen U, Miettinen H, Soimakallio S: Site and size of rotator-cuff tear. Findings at ultrasound, double-contrast arthrography, and computed tomography arthrography with surgical correlation. *Invest Radiol* 1996;31:387–94
30. Wiener SN, Seitz WH Jr: Sonography of the shoulder in patients with tears of the rotator cuff: accuracy and value for selecting surgical options. *AJR Am J Roentgenol* 1993; 160:103–7
31. Hollister MS, Mack LA, Patten RM, Winter TC III, Matsen FA III, Veith RR: Association of sonographically detected subacromial/subdeltoid bursal effusion and intraarticular fluid with rotator cuff tear. *AJR Am J Roentgenol* 1995;165: 605–8
32. Bouffard JA, Lee SM, Dhanju J: Ultrasonography of the shoulder. *Semin Ultrasound CT MR* 2000;21:164–91
33. Wohlwend JR, van HM, Craig J, et al: The association between irregular greater tuberosities and rotator cuff tears: a sonographic study. *AJR Am J Roentgenol* 1998;171: 229–33
34. Tuite MJ, Turnbull JR, Orwin JF: Anterior versus posterior, and rim-rent rotator cuff tears: prevalence and MR sensitivity. *Skeletal Radiol* 1998;27:237–43
35. Miller TT, Shapiro MA, Schultz E, Kalish PE: Comparison of sonography and MRI for diagnosing epicondylitis. *J Clin Ultrasound* 2002;30:193–202
36. Lin J, Jacobson JA, Fessell DP, Weadock WJ, Hayes CW: An illustrated tutorial of musculoskeletal sonography: part 2, upper extremity. *AJR Am J Roentgenol* 2000;175:1071–9
37. Wolfe ST: *Green's Operative Hand Surgery,* ed 4. Philadelphia, PA, Churchill Livingstone, 1999
38. Van Holsbeeck M, Introcaso J: Sonography of muscle, in Bralow L (ed): *Musculoskeletal Ultrasound,* ed 2. St Louis, MO, Mosby, Inc., 2001, pp 23–75
39. Palmer WE, Kuong SJ, Elmadbouh HM: MR imaging of myotendinous strain. *AJR Am J Roentgenol* 1999;173:703–9
40. Boutin RD, Fritz RC, Steinbach LS: Imaging of sports-related muscle injuries. *Radiol Clin North Am* 2002;40: 333–62
41. Lee JC, Healy J: Sonography of lower limb muscle injury. *AJR Am J Roentgenol* 2004;182:341–51
42. Takebayashi S, Takasawa H, Banzai Y, et al: Sonographic

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

findings in muscle strain injury: clinical and MR imaging correlation. *J Ultrasound Med* 1995;14:899–905

43. van HM, Strouse PJ: Sonography of the shoulder: evaluation of the subacromial-subdeltoid bursa. *AJR Am J Roentgenol* 1993;160:561–4
44. Farin PU, Jaroma H, Harju A, Soimakallio S: Shoulder impingement syndrome: sonographic evaluation. *Radiology* 1990;176:845–9
45. Riederer B, Chhem R, Cardinal E, Peetrons P: Shoulder: nonrotator cuff disorders, in Chhem R, Cardinal E (eds): *Guidelines and Gamuts in Musculoskeletal Ultrasound.* New York, NY, Wiley-Liss, 1999, pp 1–38
46. 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 ;197:291–6
47. Buchberger W, Judmaier W, Birbamer G, Lener M, Schmidauer C: Carpal tunnel syndrome: diagnosis with high-resolution sonography. *AJR Am J Roentgenol* 1992; 159:793–8
48. Duncan I, Sullivan P, Lomas F: Sonography in the diagnosis of carpal tunnel syndrome. *AJR Am J Roentgenol* 1999;173: 681–4
49. Lee D, van Holsbeeck MT, Janevski PK, Ganos DL, Ditmars DM, Darian VB: Diagnosis of carpal tunnel syndrome. Ultrasound versus electromyography. *Radiol Clin North Am* 1999;37:859–72
50. Swen WA, Jacobs JW, Bussemaker FE, de Waard JW, Bijlsma JW: Carpal tunnel sonography by the rheumatologist versus nerve conduction study by the neurologist. *J Rheumatol* 2001;28:62–9
51. Naredo E, Cabero F, Beneyto P, Cruz A, Mondejar B, Uson J: A randomized comparative study of short-term response to blind injection versus sonographic-guided injection of local corticosteroids in patients with painful shoulder. *J Rheumatol* 2004;31:308–14
52. Koski JM: Ultrasound-guided injections in rheumatology. *J Rheumatol* 2000;27:2131–8
53. Chen MJ, Lew HL, Hsu TC, et al: Ultrasound-guided shoulder injections in the treatment of subacromial bursitis. *Am J Phys Med Rehabil* 2006;85:31–5
54. Aina R, Cardinal E, Bureau NJ, Aubin B, Brassard P: Calcific shoulder tendinitis: treatment with modified US-guided fine-needle technique. *Radiology* 2001;221:455–62
55. Grassi W, Farina A, Filipucci E, Cervini C: Intralesional therapy in carpal tunnel syndrome: a sonographic-guided approach. *Clin Exp Rheumatol* 2002;20:73–6

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.