Ultrasonography as a Diagnostic, Therapeutic, and Research Tool in Orthopaedic Surgery

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Review Article

Ultrasonography as a Diagnostic, Therapeutic, and Research Tool in Orthopaedic Surgery

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Abstract

Ultrasonography is an imaging modality that facilitates the diagnosis of pathology and injection therapy without exposing the patient to radiation. In addition, ultrasonography has become popular because of its portability, low cost, and production of real-time tomographic images that provide a cross-sectional view of anatomic structures. Despite its benefits and widespread adoption in general medicine and other specialties, however, ultrasonography is not as well adapted as a diagnostic and research tool in orthopaedic surgery. An understanding of the basic principles of ultrasonography and the evidence supporting its use can aid the orthopaedic surgeon in applying this modality appropriately in clinical practice.

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Ultrasonography was first described in the musculoskeletal literature in 1958 as a tool for measuring articular tissue.[1] Currently, musculoskeletal ultrasonography is increasingly used in outpatient clinics for both diagnostic imaging and visualization for therapeutic injections, with a dramatic growth of 717% in private office procedures in the first decade of the 21st century.[2] Use of ultrasonography has expanded largely because of an increase in nonradiology operators. The growing popularity of this modality is also the result of its portability, lack of radiation exposure, low cost, and ability to produce real-time tomographic images that provide a cross-sectional view of anatomic structures as well as dynamic evaluation of pathology.[3]

Despite its benefits over other imaging modalities, ultrasonography remains underutilized in orthopaedic surgery compared with MRI, CT, and plain radiography. An understanding of the basic principles behind the technology and the evidence supporting its use for diagnosing musculoskeletal injuries and pathology, guiding therapeutic injections, and evaluating postoperative healing can benefit both orthopaedic surgeons and their patients.

Basic Science of Ultrasonography

Ultrasonography involves transmission of longitudinal sinusoidal sound waves from a transducer to the body. These waves are described in terms of wavelength (mm), frequency (Hz), and amplitude.[4] Ultrasonography images are created by the interactions of high-frequency sound waves with soft tissue. Depending on different tissue properties, these sound waves are reflected back to the probe transducer at varied intensities, creating contrasts.

The transducer contains piezoelectric crystals that vibrate when an electric current passes through them, thus generating an ultrasound beam. This phenomenon is known as

Figure 1

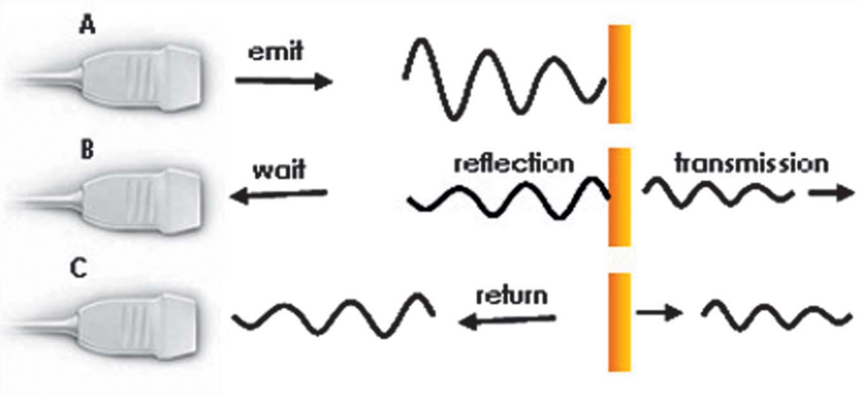


Image showing the waves emitted by the ultrasonography transducer. These waves are either transmitted through the tissue or reflected back to the receiver as echoes. **A,** Amplitude mode. **B,** Brightness mode. **C,** Motion mode. (Adapted with permission from Chan V: Generation of an ultrasound image. Ultrasound for Regional Anesthesia, 2008. http://www.usra.ca/regional-anesthesia/introduction/basic.php#ultrasoundimage. Accessed January 11, 2018.)

Table 1

Echogenicity Based on Tissue Type[a]

Tissue Type	Echogenicity
Bone	Hyperechoic
Tendon	Hyperechoic
Ligament	Hyperechoic
Nerve	Hyperechoic/Hypoechoic
Muscle	Hyperechoic lines/hypoechoic background
Fat	Hypoechoic
Vascular structure (ie, arteries, veins)	Anechoic
Cyst	Anechoic

[a] A hyperechoic image is bright (ie, white), a hypoechoic image is darker (ie, gray), and an anechoic image is completely dark (ie, black).

the piezoelectric effect.[5] As these waves pass through different body tissues, most of them continue on to penetrate deeper tissue, whereas some waves are reflected back to the transducer and become echoes (Figure 1). The combinations of echo signals reflected back to the transducer are again transformed to electrical signals that ultimately produce the image visualized on-screen. As noted previously, the amount of echoes returned to the transducer varies depending on the tissue through which the ultrasound wave passes. Air-containing organs (eg, the lung) return the least amount of echoes, whereas dense organs (eg, bone) return the most, a property called acoustic impedance.[3] Tissue interfaces with high differences in impedance or parallel alignment to the footprint of the probe will reflect signals more strongly.

Image resolution is based on the inverse relationship between wavelength (mm) and frequency (Hz). Ultrasound waves with high frequency and short wavelengths produce images with high axial resolution but cannot penetrate deeper tissue. Conversely, low-frequency waves (with long wavelengths) provide lower-resolution images but penetrate to deeper structures.[6]

The reduction in signal intensity as waves travel is known as attenuation.[7] Attenuation occurs because of the reflection and scattering of waves but primarily as a result of absorption (ie, the conversion of mechanical energy to heat as waves travel). Accordingly, waves with higher frequencies and longer paths have greater attenuation and are not as effective in penetrating to deeper tissues as are waves with low frequencies and short paths.

Image brightness on the ultrasonography display is determined by the amplitude of the echo wave detected by the transducer, called tissue echogenicity.[4] A strong reflection produces a bright, white image, which is termed hyperechoic[8-14] (Table 1). Tissues that reflect sound waves poorly or allow sound waves to travel easily produce a darker gray image, which is termed hypoechoic. Tissues that do not reflect any sound waves are completely black or anechoic on ultrasonography images.

Ultrasonography as a Diagnostic Tool in Orthopaedic Surgery

MRI is the current imaging standard for the diagnosis of tendon and ligamentous injuries and evaluation of postoperative healing. Despite its advantages, MRI can be expensive, time-consuming, and extremely susceptible to motion and metal artifact. This limits its application in the emergency setting or in patients with claustrophobia or metallic implants. In comparison, ultrasonography

Table 2

Use of Musculoskeletal Ultrasonography as a Diagnostic Tool

Study	Condition Examined	Study Information	Conclusion
Lee et al[8]	MCL injury	US review of 16 cases of clinically diagnosed MCL injury compared with 20 healthy control subjects	US correctly diagnosed MCL injury in 94% of the clinically positive cases by the thickening and heterogeneous signal of the injured ligament relative to that of control subjects.
Bianchi et al[9]	Quadriceps tendon injury	US evaluation of 29 quadriceps tendon injuries compared with 59 healthy control subjects	US is highly sensitive and specific for diagnosing partial- and full-thickness tears; the high-grade and full-thickness tears were confirmed at surgery.
Hartgerink et al[10]	Achilles tendon injury	US review of 26 patients with Achilles tendon injury who underwent subsequent surgery	US differentiated full- from partial-thickness tears or tendinosis with 92% accuracy.
Vlychou et al[11]	Partial-thickness RCTs	Prospective study of 56 patients with symptomatic impingement syndrome with unsuccessful nonsurgical treatment. All patients underwent US and MRI before surgical intervention.	US was as effective as MRI in detecting partial-thickness RCTs. US had a sensitivity of 95.6% and specificity of 70% for partial-thickness tears, compared with a sensitivity of 98% and specificity of 64% for MRI.
Prickett et al[12]	Full- and partial-thickness RCTs	A total of 44 cases of full- and partial-thickness RCTs; all patients underwent US and MRI before surgical intervention	US is a useful method for diagnosing RCTs in patients who have previously had a shoulder arthroscopy, with a sensitivity of 91% and specificity of 86% when compared with diagnostic arthroscopy
Cheng et al[13]	Chronic lateral ligament injury of the ankle	120 cases of clinically suspected ankle injuries evaluated by US, with results compared with surgical findings	The sensitivity, specificity, and accuracy of US were 98.9%, 96.2%, and 84.2%, respectively, for diagnosing anterior talofibular ligament injury and 93.8%, 90.9%, and 83.3%, respectively, for calcaneofibular ligament injury.
Chang et al[14]	Full-thickness RCTs	Retrospective review of 422 cases of arthroscopically confirmed RCTs with both US and MRI. US performance by an experienced technician was compared with US performance by an experienced radiologist.	US was highly operator dependent; sensitivity, negative predictive value, and accuracy with US were most similar to those of MRI when studies were performed by an experienced radiologist rather than by a US technician.

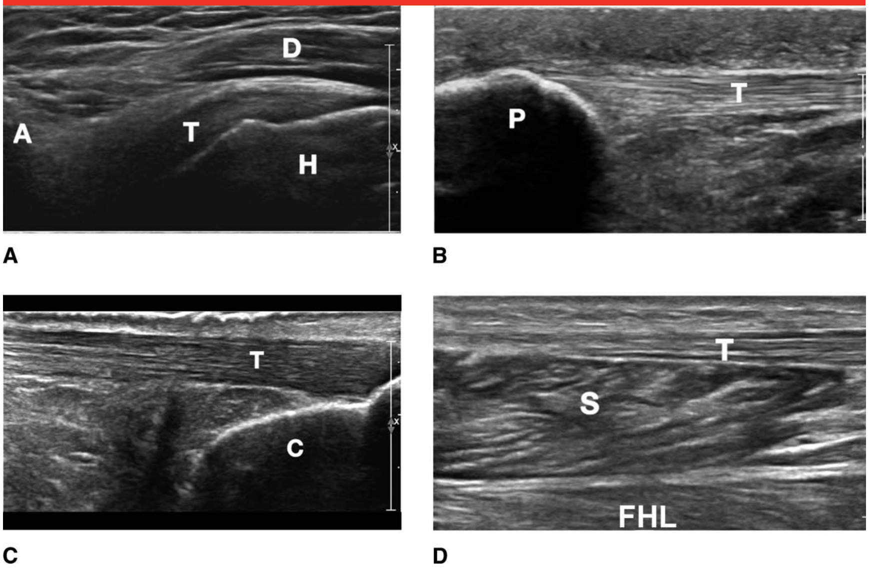
MCL = medial collateral ligament, RCT = rotator cuff tear, US = ultrasonography

images have excellent soft-tissue contrast and high spatial resolution and are obtained in real time, making ultrasonography an effective alternative for diagnosing musculoskeletal pathology. Studies have demonstrated high sensitivities and specificities that are comparable to those of MRI regardless of location (Table 2).

Tendon, Ligament, and Soft Tissue Evaluation

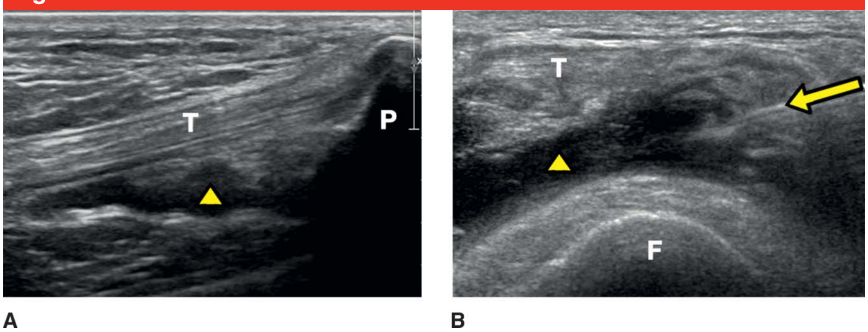
Ultrasonography is a powerful tool in orthopaedics because many musculoskeletal structures, such as tendons and ligaments, are imaged with high spatial resolution and contrast. Although ultrasound wave penetration can be a challenge with deeper musculoskeletal structures, many tendons and ligaments are relatively superficial and are readily imaged. In

Figure 2



Sonograms of tendons. **A,** Normal supraspinatus tendon (T) in the coronal plane. A = acromion, D = deltoid muscle, H = humerus. **B,** Normal patellar tendon (T) in the sagittal plane. P = patella. **C,** Normal Achilles tendon (T) in the sagittal plane. C = calcaneus. **D,** Normal muscle tissue of the lower leg and heel in the sagittal plane. FHL = flexor hallucis longus muscle, S = soleus muscle, T = Achilles tendon

Figure 3



Sonograms of effusions. **A,** Sagittal view of a small reactive joint effusion showing anechoic simple fluid within the suprapatellar recess of the knee (arrowhead). P = patella, T = quadriceps tendon. **B,** Transverse view of septic joint effusion showing highly complex joint effusion with echogenic debris (arrowhead). The aspiration needle is also visible (arrow). F = femur, T = quadriceps tendon

addition, real-time imaging of tendons and ligaments with ultrasonography facilitates dynamic assessment of the structures.

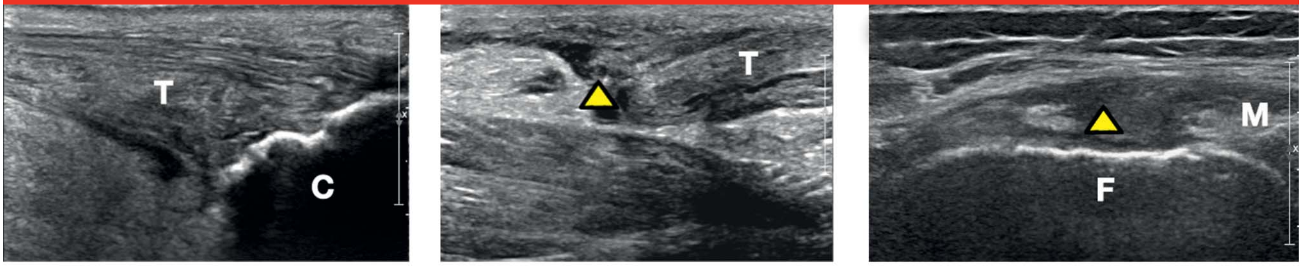
Musculoskeletal ultrasonography is best performed with a high-frequency linear-array transducer (ie, 9 to 20 MHz). Depending on the structures imaged, different probe frequencies within this range can be used. Probes with a higher frequency penetrate less deeply but image more superficial structures with higher resolution. Probes with a lower frequency penetrate deeper but with less resolution. Curved-array transducers with lower frequencies also can be used on structures that are particularly deep or in cases in which a larger field of view is needed for guided therapeutic injection.

The normal tendon appears as a bright or hyperechoic structure, with a fibrillar appearance that is most prominent while the fibers are parallel to the probe footprint (Figure 2, A through C). A normal ligament appears similar to a tendon but is slightly more compact. Normal striated muscle has a hypoechoic appearance, but the striated fibroadipose septa that surround the muscle bundles are hyperechoic (Figure 2, D). A joint effusion, fluid-filled bursa, or cyst is either completely anechoic or hypoechoic depending on its fluid composition and complexity (Figure 3). Solid structures, such as bone or calcium, completely reflect the sound waves, creating an echogenic line that shadows the structures deep to it.

Degenerated tendons and ligaments take on a relatively thickened and hypoechoic appearance because of the deterioration of the collagen fibers (Figure 4, A). Frank tears of a tendon or ligament are characterized by the actual visual disruption of the torn fibers, with larger tears demonstrating free-fluid anechoic signals between the torn and retracted fibers (Figure 4, B and C).

Anisotropy is an important artifact inherent in tendons and ligaments. When the probe is held at an angle that is as little as 5° off the long axis of the tendon or ligament fibers, the hyperechoic fibrillar tendon can appear artificially hypoechoic (Figure 5). This is a concern particularly with tendons that have a curved contour, such as the rotator cuff. In some circumstances, anisotropy can help distinguish tendons and ligaments from other structures. However, the normal anisotropy of a tendon can also potentially be confused

Figure 4



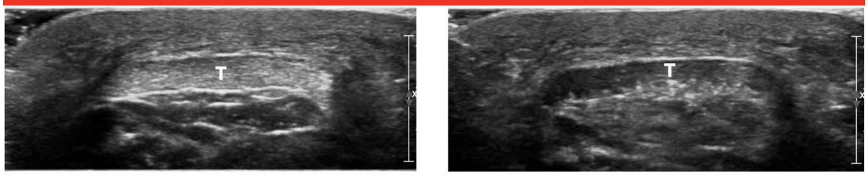
A B C

Sagittal view sonograms of tendons and ligaments. **A,** Severe tendinosis/degeneration of the distal Achilles tendon. C = calcaneus, T = tendon with loss of the normal fibrillar appearance. **B,** Complete rupture of the midsubstance Achilles tendon (T) with fluid and hemorrhage within the tear gap (arrowhead). **C,** Avulsion of the medial collateral ligament (M) from the femoral attachment with fluid and hemorrhage within the tear gap (arrowhead). F = medial femoral condyle

with a pathologically hypoechoic, degenerated tendon.

For evaluating curved structures, the focus should be on segments in the field of view in which the long axis of the tendon is parallel to the probe footprint. Thus, technical skill and anatomic knowledge by the operator is essential for a thorough and accurate evaluation. For this reason, MRI should still be considered at institutions where staff members are inexperienced in orthopaedic ultrasonography or in complex cases in which additional pathology of the cartilage, labrum, joint capsule, muscle, and bone may affect treatment.

Figure 5



A B

Sonograms in the axial plane showing anisotropy of a normal patellar tendon in cross section. Tendon fibers (T) are echogenic when perpendicular to the transducer (**A**) but are artificially hypoechoic when the probe is angled (**B**).

Shoulder Pathology

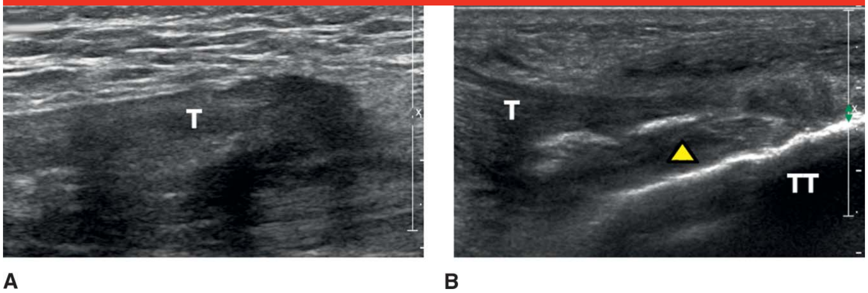
In the diagnosis of partial- and full-thickness RCTs, ultrasonography performed by a trained technician and interpreted by an experienced radiologist is accurate compared with MRI and diagnostic arthroscopy.[15,16] Iannotti et al[17] reported that the sensitivity of office-based ultrasonography in detecting tears in the anterior-to-posterior direction was 86%, compared with 93% for MRI; for tears in the medial to lateral direction, sensitivity was 83%, compared with 88% for MRI. Overall, ultrasonography was better able to detect full-thickness tears than partial-thickness tears: 88.1% (ie, 37 of 42 shoulders) versus 70.3% (ie, 26 of 37 shoulders), respectively. Errors in diagnosis during ultrasonography most often were related to the inability to distinguish between partial- and full-thickness tears that measured approximately 1 cm.[17]

To examine the accuracy of ultrasonography in detecting partial- and complete-thickness RCTs, Smith et al[15] systematically reviewed 62 studies involving 6,007 patients (6,066 shoulders). Ultrasonography demonstrated good sensitivity and good specificity for the assessment of partial-thickness tears (sensitivity, 0.84; specificity, 0.89) and full-thickness tears (sensitivity, 0.96; specificity, 0.93). However, Ok et al[18] found that ultrasonography conducted in the office setting by inexperienced or beginner orthopaedic surgeons had substantially lower sensitivity and specificity in the detection of partial-thickness RCTs compared with full-thickness RCTs. Another study demonstrated that ultrasonography was not reliable for detecting intra-articular partial biceps tendon tears (ie, 0 of 23 partial-thickness tears) compared with full-thickness biceps ruptures.[19] In dynamic evaluation of the biceps tendon for subluxation or dislocation, ultrasonography had 96% sensitivity and 100% specificity.

Knee Pathology

Ultrasonography can provide clinically useful information on a wide range of pathologic conditions affecting the knee joint. Both color and power Doppler techniques can be used to measure neovascularization in the lining of the joints, tendons,

Figure 6



Sonograms in the sagittal plane showing knee pathology. **A,** Rupture of the quadriceps tendon insertion. T = quadriceps tendon. **B,** Bony avulsion of the patellar tendon (T) with tear gap (arrowhead). TT = tibial tuberosity

and soft-tissue masses. Tendinopathy is less commonly seen in the quadriceps and patellar region. Both overuse and trauma can cause tendon degeneration. Local tenderness with associated thickening and decreased echogenicity along with disruption of the fibrillar pattern within the tendon can be found on diagnostic ultrasonography. Rupture of the patella and quadriceps tendon can occur at the musculotendinous junction or attachment site. In both partial- and full-thickness tears, there is a region of hypoechoic defect representing hematoma with tendon retraction (Figure 6).

Detection of medial and lateral collateral ligament injuries with ultrasonography is accurate, and depending on the etiology, both hypoechoic inhomogeneous structure and thickening of the injured ligament can be seen as a result of edema and hemorrhage. In a study comparing ultrasonography with arthroscopy in the diagnosis of acute rupture of the anterior cruciate ligament (ACL), ultrasonography had a sensitivity of 88% and a specificity of 98%.[20]

Fuchs and Chylarecki[21] found that using two indirect ultrasonography findings in combination (echo-poor space at the femoral insertion of the ACL and protrusion of the posterior fibrous capsule) increased the predictive value to 98% for the detection of acute ACL ruptures. In diagnosing meniscus tears, Shetty et al[22] found that ultrasonography had a sensitivity of 86.4% and a specificity of 69.2%, compared with a sensitivity of 86.4% and a specificity of 100% with MRI. Similarly, Akatsu et al[23] found a sensitivity of 88% and a specificity of 85% for ultrasonography in diagnosing meniscus tears. In patients with acute knee injuries, ultrasonography was two times more likely than MRI to correctly determine whether meniscal pathology was present when arthroscopy was used as the benchmark.[24]

Cyst and Bursal Pathology

In the upper and lower extremities, ultrasonography can readily identify fluid-filled structures, such as ganglion cysts or distended bursae. These cysts and bursae will appear anechoic or hypoechoic with a well-circumscribed sonographic appearance, features that lend themselves well to the diagnosis of relevant pathologic conditions.[4] For example, one recent evaluation of 158 consecutive patients found that ultrasonography had a sensitivity of 86.67% and a specificity of 100% for diagnosing knee bursitis.[25] Dynamic features such as ultrasound compression (ie, application of direct pressure of the ultrasonography probe on the structure being evaluated) can help differentiate types of cysts, including ganglion and synovial cysts.[25,26] In addition to characterizing cysts and bursae, ultrasonography can help localize these structures for aspirations and injections for both diagnostic and therapeutic purposes.[26,27]

Infection

The utility of ultrasonography in diagnosing a variety of musculoskeletal infections in both native tissue and orthopaedic implants/prostheses is well described.[28] This usefulness is attributed to the ability of the modality to identify fluid collections and differentiate between intra- and extra-articular processes, as well as its use during diagnostic arthrocentesis.[29] On a sonogram, septic joint fluid often has a complex appearance that is more echogenic than that of simple fluid. Fine or macroscopic intra-articular debris can often be seen, as well as joint capsule hyperemia on color Doppler scans. Such an appearance is nonspecific, however, and other inflammatory arthropathies can appear similar. Thus, ultrasonography is not sufficiently accurate to safely diagnose septic arthropathy by appearance alone. Combined with clinical, laboratory, and other imaging data, however, ultrasonography does provide important information for the ultimate diagnosis of orthopaedic infection.[30]

Fracture Diagnosis and Healing

Ultrasonography has been a useful tool for the diagnosis of acute fractures, primarily in the upper extremities, in both adult and pediatric patients, with a sensitivity as high as 98% for diagnosis of elbow fractures in children when performed by emergency department physicians.[31] This is particularly impressive considering that interpretation of radiographs (the benchmark for diagnosis of fractures in these studies) by emergency physicians for the presence of pediatric elbow fractures had a reported accuracy as low as 53%.[32] Ultrasonography is also accurate in the diagnosis of diaphyseal fractures, with a sensitivity of 100%, and long bone fractures, with a sensitivity of 95%.[33]

In some cases, ultrasonography may identify fractures not apparent on radiographs, such as occult hip or scaphoid fractures.[34,35] Ultrasonography also may facilitate the diagnosis of more chronic fractures, such as lower extremity stress fractures; however, the reported diagnostic performance has varied, with sensitivity ranging from 43% to 99% and specificity ranging from 13% to 79%.[36] In the diagnosis of these fractures, ultrasonography not only can improve the efficiency of patient evaluation in emergency departments and potentially reduce patients' exposure to radiation, but it also may have implications for resource-poor settings in which routine radiographic evaluation is not feasible.

Ultrasonography has also been useful in monitoring fracture healing status by determining the presence of callus formation and observing such formations. One prospective evaluation of skeletally mature patients who had undergone intramedullary nailing for an acute tibial shaft fracture determined that monitoring of healing with ultrasonography had a positive predictive value of 97% for routine fracture healing.[37] Of note, most ultrasonography examinations indicated that fracture healing occurred 6 weeks postoperatively, whereas fracture healing was not observed on radiographs until an average of 19 weeks after injury. This finding may suggest that ultrasonography can help identify delayed unions and nonunions earlier than radiographs can.[37] This notion was supported by a subsequent prospective study of tibial shaft fractures treated by intramedullary nailing.[38] Similar results have been found with monitoring of long bone fractures in the pediatric population.[39]

Pediatrics

The use of musculoskeletal ultrasonography in the pediatric population was described by Vanderhave et al.[40] Ultrasonography is a useful diagnostic tool for pediatric conditions of the lower extremity (eg, developmental dysplasia of the hip), spine (eg, unossified vertebral arches), and upper extremity (eg, neonatal brachial plexus palsy), and it can be a useful in minimally invasive treatments, such as injection of botulinum toxin for patients with cerebral palsy.

Ultrasonography as a Therapeutic Aid in Injections

Ultrasonography is a powerful tool for guiding injections of therapeutic medication and contrast material with precision and accuracy, minimizing local trauma and discomfort. The accuracy of ultrasonography-guided injections is similar to that of fluoroscopy-guided injections but without any ionizing radiation. A systematic literature review also confirmed the superior accuracy of ultrasonography in landmark-guided injections.[41]

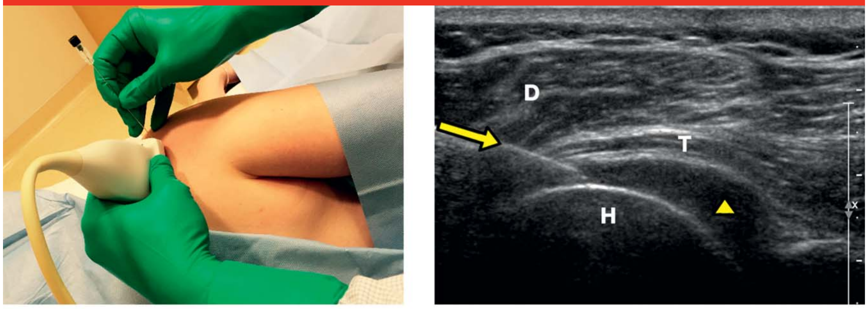
Accuracy is important because of the potential risks with therapeutic cortisone injection. For example, intratendinous injection of corticosteroid is associated with tendon rupture, and unintended extracapsular injection is associated with local tissue atrophy and necrosis. Ultrasonography can provide the accuracy needed to perform these procedures safely and efficaciously.[41]

A 22- to 25-g needle can be used for most ultrasound-guided injections. The needle is best visualized when it approaches the target parallel to the probe footprint. In our experience, most musculoskeletal interventions can be performed with a linear-array transducer, although needle visualization can be limited by target depth, body habitus, and operator experience. Curved-array transducers are used primarily for deeper structures, such as the hip, but they can also be used when other limitations are present. Ultimately, the user should choose the probe with which he or she is most comfortable for needle visualization. To minimize chondral toxicity, 1% lidocaine, 1% ropivacaine, or 0.25% bupivacaine is preferred for local anesthesia.[42,43] A comprehensive technical review of all therapeutic injections is beyond the scope of this article, but the techniques for some frequently injected joints warrant further discussion.

Glenohumeral shoulder injections can be performed with the patient in the lateral decubitus position, with the targeted shoulder on the nondependent side. The transducer is held in the axial plane, parallel to the infraspinatus tendon, exposing the posterior joint capsule. The needle is inserted along the posterolateral shoulder with the needle tip angled toward the posterior margin of the humeral head, deep to the tendon and joint capsule (Figure 7). As the therapeutic medication is injected, the material can be seen spreading within the intra-articular space in real time.

Injections of the subacromial/subdeltoid bursa can be performed with the patient supine. The probe can be held in the oblique coronal plane to visualize the deltoid muscle, acromion, and supraspinatus tendon. The bursa is visible as a thin hypoechoic line between the rotator cuff tendon and the deltoid muscle. With a lateral or anterolateral approach, the needle is inserted into the region of the bursa (Figure 8). In the absence of pathologic bursal fluid, the needle tip location can be

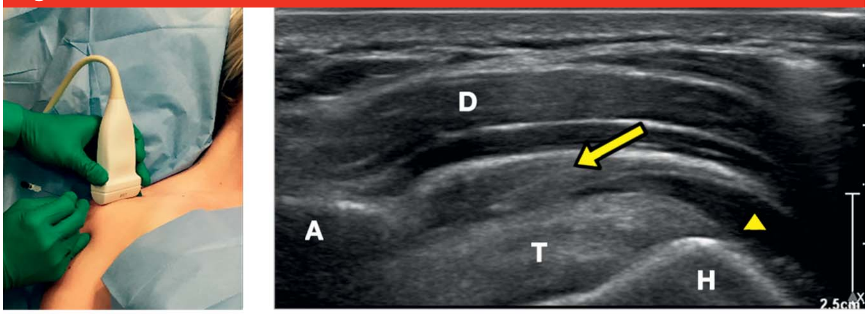
Figure 7



A B

A, Clinical photograph showing glenohumeral joint injection with the patient in the lateral decubitus position. **B,** Sonogram in the axial plane showing the needle (arrow) and injected intra-articular fluid (arrowhead). D = deltoid, H = humeral head, T = infraspinatus tendon

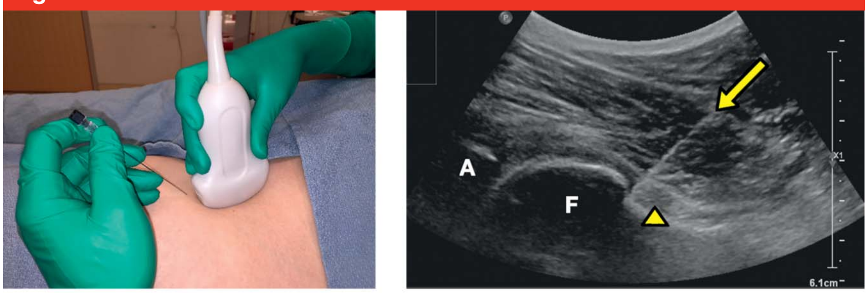
Figure 8



A B

A, Clinical photograph showing subacromial/subdeltoid bursal injection in the oblique coronal plane. **B,** Sonogram in the sagittal plane showing the needle (arrow) and injected fluid within the bursa (arrowhead). A = acromion, D = deltoid, H = humerus, T = supraspinatus tendon

Figure 9



A B

A, Clinical photograph showing hip injection. **B,** Sonogram in the sagittal plane showing the needle (arrow) and injected intra-articular fluid (arrowhead). A = acetabulum, F = femoral head

confirmed with a test injection of local anesthetic or saline, which distends the targeted bursa.

Hip injections can be performed with the patient in the supine position. The probe is held in the oblique axial plane, parallel to the femoral neck. The needle is angled along the plane of the femoral neck, with the targeted region just deep to the joint capsule at the femoral head-neck junction (Figure 9). Because the hip is generally a deep structure, a curved-array transducer may be used, particularly in patients with a large body habitus.

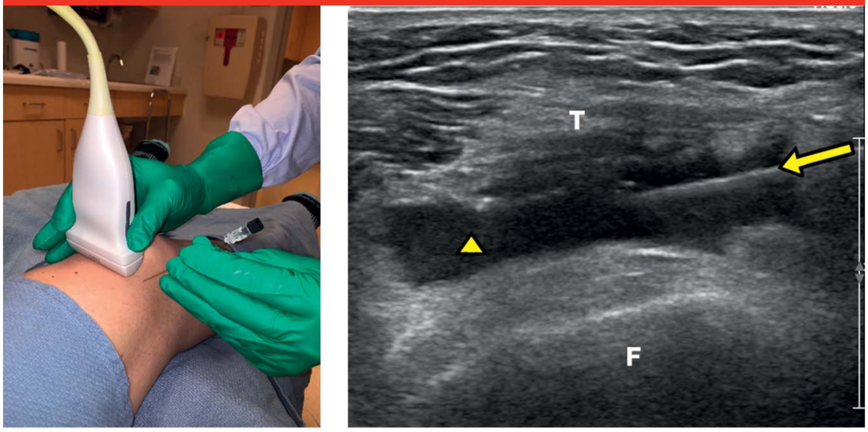
Knee joint injections are performed with the patient in the supine position and the knee in slight flexion. The most common targeted area is the suprapatellar recess. This recess can be seen with the probe in the midline sagittal plane to identify the quadriceps tendon and patella. Visualization of the recess is facilitated by the presence of a joint effusion. The probe can then be rotated into the axial plane and the needle inserted transversely into the recess using either a medial or a lateral approach (Figure 10). In the absence of joint fluid, as with bursal injections the needle tip location can be confirmed with the test injection of local anesthetic or saline.

Ultrasonography as a Research Tool in Orthopaedic Surgery

Ultrasonography has been useful for investigating the natural history of orthopaedic injuries or disease processes, such as progression of rotator cuff disease.[44,45] In addition, ultrasonography has been used to evaluate healing after orthopaedic surgery, particularly for assessing the integrity of tendon repairs.[46] For such evaluations, ultrasonography is not only minimally invasive but also results in minimal patient morbidity; in addition, ultrasonography is less time-consuming and less expensive than other imaging modalities, such as MRI.

Ultrasound elastography was recently developed for analyzing soft-tissue elasticity or deformability. With

Figure 10



A B

A, Clinical photograph showing knee injection. **B,** Sonogram in the axial plane showing the needle (arrow) and injected intra-articular fluid (arrowhead). F = femur, T = quadriceps tendon

application of a low-frequency strain or compression, the actual soft-tissue stiffness is assessed with qualitative visual or quantitative measurements. Because a disease process can alter the biomechanical properties of soft tissue, this technology offers a novel approach to evaluating tendon degeneration. Recent studies have demonstrated through elastography that normal asymptomatic tendons tend to be stiffer than tendons in symptomatic tendinopathy.[47,48] Such information on tendon degeneration has potential clinical applications and may yield prognostic information as well as serve as a marker for treatment response.

Ultrasonography is continually being investigated for novel diagnostic and therapeutic applications. For example, with the failures of metal-on-metal total hip arthroplasties secondary to adverse local tissue reactions, emerging evidence supports the use of ultrasonography to diagnose pseudotumors.[49,50]

Summary

Ultrasonography is useful for diagnostic, therapeutic, and research purposes in orthopaedic surgery. During orthopaedic diagnosis, the modality is radiation-free and has a lower cost and increased mobility compared with other imaging modalities with comparable performance. The accurate guidance it affords during injections of medication and contrast material minimizes trauma, and its versatility in monitoring repairs and disease processes reduces patient morbidity and facilitates research. For the practicing orthopaedic surgeon, investment in ultrasonography training or collaboration with colleagues in the musculoskeletal radiology field can be valuable, especially given the accessibility to patients and benefits in patient care.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 4, 8-11, 13, 14, 16-25, 32, 33, 35, 37-39, 44-46, and 50 are level II studies. References 2, 12, 31, and 49 are level III studies. Reference 34 is level V expert opinion.

References printed in **bold type** are those published within the past 5 years.

1. Dussik KT, Fritch DJ, Kyriazidou M, Sear RS: Measurements of articular tissues with ultrasound. *Am J Phys Med* 1958;37(3):160-165.

2. Sharpe RE, Nazarian LN, Parker L, Rao VM, Levin DC: Dramatically increased musculoskeletal ultrasound utilization from 2000 to 2009, especially by podiatrists in private offices. *J Am Coll Radiol* 2012;9(2):141-146.

3. Chan VP, Perlas A: Basic principles of ultrasound imaging, in Narouze SN, ed: *Atlas of Ultrasound-Guided Procedures in Interventional Pain Management*. New York, NY, Springer, 2011, pp 13-20.

4. Eisler T, Svensson O, Engström CF, et al: Ultrasound for diagnosis of infection in revision total hip arthroplasty. *J Arthroplasty* 2001;16(8):1010-1017.

5. Colquhoun KA, Alam A, Wilson D: Basic science: Ultrasound. *Curr Orthop* 2005;19(1):27-33.

6. Chan VWS, Abbas S: *Ultrasound Imaging for Regional Anesthesia: A Practical Guide*, ed 2. Toronto, ON, Toronto Printing Company, 2009.

7. Kossoff G: Basic physics and imaging characteristics of ultrasound. *World J Surg* 2000;24(2):134-142.

8. Lee JI, Song IS, Jung YB, et al: Medial collateral ligament injuries of the knee: Ultrasonographic findings. *J Ultrasound Med* 1996;15(9):621-625.

9. 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(5):1137-1140.

10. Hartgerink P, Fessell DP, Jacobson JA, van Holsbeeck MT: Full- versus partial-thickness Achilles tendon tears: Sonographic accuracy and characterization in 26 cases with surgical correlation. *Radiology* 2001;220(2):406-412.

11. Vlychou M, Dailiana Z, Fotiadou A, Papanagiotou M, Fezoulidis IV, Malizos K: Symptomatic partial rotator cuff tears: Diagnostic performance of ultrasound and magnetic resonance imaging with surgical correlation. *Acta Radiol* 2009;50(1):101-105.

12. Prickett WD, Teefey SA, Galatz LM, Calfee RP, Middleton WD, Yamaguchi K: Accuracy of ultrasound imaging of the rotator cuff in shoulders that are painful postoperatively. *J Bone Joint Surg Am* 2003;85(6):1084-1089.

13. **Cheng Y, Cai Y, Wang Y: Value of ultrasonography for detecting chronic injury of the lateral ligaments of the ankle joint**

compared with ultrasonography findings. ***Br J Radiol*** **2014;83(1033):20130406.**

14. Chang CY, Wang SF, Chiou HJ, Ma HL, Sun YC, Wu HD: Comparison of shoulder ultrasound and MR imaging in diagnosing full-thickness rotator cuff tears. *Clin Imaging* 2002;26(1):50-54.

15. Smith TO, Back T, Toms AP, Hing CB: Diagnostic accuracy of ultrasound for rotator cuff tears in adults: A systematic review and meta-analysis. *Clin Radiol* 2011;66(11):1036-1048.

16. Bryant L, Shnier R, Bryant C, Murrell GA: A comparison of clinical estimation, ultrasonography, magnetic resonance imaging, and arthroscopy in determining the size of rotator cuff tears. *J Shoulder Elbow Surg* 2002;11(3):219-224.

17. 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(6):1305-1311.

18. Ok JH, Kim YS, Kim JM, Yoo TW: Learning curve of office-based ultrasonography for rotator cuff tendons tears. *Knee Surg Sports Traumatol Arthrosc* 2013;21(7):1593-1597.

19. Armstrong A, Teefey SA, Wu T, et al: The efficacy of ultrasound in the diagnosis of long head of the biceps tendon pathology. *J Shoulder Elbow Surg* 2006;15(1):7-11.

20. Skovgaard Larsen LP, Rasmussen OS: Diagnosis of acute rupture of the anterior cruciate ligament of the knee by sonography. *Eur J Ultrasound* 2000;12(2):163-167.

21. Fuchs S, Chylarecki C: Sonographic evaluation of ACL rupture signs compared to arthroscopic findings in acutely injured knees. *Ultrasound Med Biol* 2002;28(2):149-154.

22. Shetty AA, Tindall AJ, James KD, Relwani J, Fernando KW: Accuracy of hand-held ultrasound scanning in detecting meniscal tears. *J Bone Joint Surg Br* 2008;90(8):1045-1048.

23. **Akatsu Y, Yamaguchi S, Mukoyama S, et al: Accuracy of high-resolution ultrasound in the detection of meniscal tears and determination of the visible area of menisci.** ***J Bone Joint Surg Am*** **2015;97(10):799-806.**

24. **Cook JL, Cook CR, Stannard JP, et al: MRI versus ultrasonography to assess meniscal abnormalities in acute knees.** ***J Knee Surg*** **2014;27(4):319-324.**

25. **Draghi F, Corti R, Urciuoli L, Alessandrino F, Rotondo A: Knee bursitis: A sonographic evaluation.** ***J Ultrasound*** **2015;18(3):251-257.**

26. **Giard MC, Pineda C: Ganglion cyst versus synovial cyst? Ultrasound characteristics through a review of the literature.** ***Rheumatol Int*** **2015;35(4):597-605.**

27. **Chiavaras MM, Jacobson JA, Yablon CM, Brigido MK, Girish G: Pitfalls in wrist and hand ultrasound.** ***AJR Am J Roentgenol*** **2014;203(3):531-540.**

28. Nazarian LN: The top 10 reasons musculoskeletal sonography is an important complementary or alternative technique to MRI. *AJR Am J Roentgenol* 2008;190(6):1621-1626.

29. **Laine JC, Denning JR, Riccio AI, Jo C, Joglar JM, Wimberly RL: The use of ultrasound in the management of septic arthritis of the hip.** ***J Pediatr Orthop B*** **2015;24(2):95-98.**

30. Fessell DP, Jacobson JA, Craig J, et al: Using sonography to reveal and aspirate joint effusions. *AJR Am J Roentgenol* 2000;174(5):1353-1362.

31. Zamzam MM: The role of ultrasound in differentiating septic arthritis from transient synovitis of the hip in children. *J Pediatr Orthop B* 2006;15(6):418-422.

32. Shrader MW, Campbell MD, Jacofsky DJ: Accuracy of emergency room physicians' interpretation of elbow fractures in children. *Orthopedics* 2008;31(12):orthosupersite.com/view.asp?rID=34697.

33. Barata I, Spencer R, Suppiah A, Raio C, Ward MF, Sama A: Emergency ultrasound in the detection of pediatric long-bone fractures. *Pediatr Emerg Care* 2012;28(11):1154-1157.

34. **Medero Colon R, Chilstrom ML: Diagnosis of an occult hip fracture by point-of-care ultrasound.** ***J Emerg Med*** **2015;49(6):916-919.**

35. Senall JA, Failla JM, Bouffard JA, van Holsbeeck M: Ultrasound for the early diagnosis of clinically suspected scaphoid fracture. *J Hand Surg Am* 2004;29(3):400-405.

36. **Wright AA, Hegedus EJ, Lenchik L, Kuhn KJ, Santiago L, Smoliga JM: Diagnostic accuracy of various imaging modalities for suspected lower extremity stress fractures: A systematic review with evidence-based recommendations for clinical practice.** ***Am J Sports Med*** **2016;44(1):255-263.**

37. Moed BR, Subramanian S, van Holsbeeck M, et al: Ultrasound for the early diagnosis of tibial fracture healing after static interlocked nailing without reaming: Clinical results. *J Orthop Trauma* 1998;12(3):206-213.

38. **Chachan S, Tudu B, Sahu B: Ultrasound monitoring of fracture healing: Is this the end of radiography in fracture follow-ups?** ***J Orthop Trauma*** **2015;29(3):e133-e138.**

39. **Wawrzyk M, Sokal J, Andrzejewska E, Przewratil P: The role of ultrasound imaging of callus formation in the treatment of long bone fractures in children.** ***Pol J Radiol*** **2015;80:473-478.**

40. **Vanderhave KL, Brighton B, Casey V, Montijo H, Scannell B: Applications of musculoskeletal ultrasonography in pediatric patients.** ***J Am Acad Orthop Surg*** **2014;22(11):691-698.**

41. **Amber KT, Landy DC, Amber I, Knopf D, Guerra J: Comparing the accuracy of ultrasound versus fluoroscopy in glenohumeral injections: A systematic review and meta-analysis.** ***J Clin Ultrasound*** **2014;42(7):411-416.**

42. Dragoo JL, Korotkova T, Kanwar R, Wood B: The effect of local anesthetics administered via pain pump on chondrocyte viability. *Am J Sports Med* 2008;36(8):1484-1488.

43. MacMahon PJ, Eustace SJ, Kavanagh EC: Injectable corticosteroid and local anesthetic preparations: A review for radiologists. *Radiology* 2009;252(3):647-661.

44. Yamaguchi K, Tetro AM, Blam O, Evanoff BA, Teefey SA, Middleton WD: Natural history of asymptomatic rotator cuff tears: A longitudinal analysis of asymptomatic tears detected sonographically. *J Shoulder Elbow Surg* 2001;10(3):199-203.

45. Moosmayer S, Tariq R, Stiris M, Smith HJ: The natural history of asymptomatic rotator cuff tears: A three-year follow-up of fifty cases. *J Bone Joint Surg Am* 2013;95(14):1249-1255.

46. **Badalihan A, Aihemaiti A, Shawutali N, et al: Outcome of a one-stage tensile stress surgical technique and early postoperative rehabilitation in the treatment of neglected Achilles tendon rupture.** ***J Foot Ankle Surg*** **2015;54(2):153-159.**

47. Drakonaki EE, Allen GM, Wilson DJ: Ultrasound elastography for musculoskeletal applications. *Br J Radiol* 2012;85(1019):1435-1445.

48. **Klauser AS, Miyamoto H, Bellmann-Weiler R, Feuchtner GM, Wick MC, Jaschke WR: Sonoelastography: Musculoskeletal applications.** ***Radiology*** **2014;272(3):622-633.**

49. **Muraoka K, Naito M, Nakamura Y, Hagio T, Takano K: Usefulness of ultrasonography for detection of pseudotumors after metal-on-metal total hip arthroplasty.** ***J Arthroplasty*** **2015;30(5):879-884.**

50. **Garbuz DS, Hargreaves BA, Duncan CP, Masri BA, Wilson DR, Forster BB: The John Charnley Award: Diagnostic accuracy of MRI versus ultrasound for detecting pseudotumors in asymptomatic metal-on-metal THA.** ***Clin Orthop Relat Res*** **2014;472(2):417-423.**