Musculoskeletal ultrasound involves the use of high-frequency sound waves to image soft tissues and bony structures in the body for the purposes of diagnosing pathology or guiding real-time interventional procedures. Recently, an increasing number of physicians have integrated musculoskeletal ultrasound into their practices to facilitate patient care. Technological advancements, improved portability, and reduced costs continue to drive the proliferation of ultrasound in clinical medicine. This increased interest creates a need for education pertaining to all aspects of musculoskeletal ultrasound. The primary purpose of this article is to review diagnostic ultrasound technology and its potential clinical applications in the evaluation and treatment of patients with neurological and musculoskeletal disorders. After reviewing this article, physicians should be able to (1) list the advantages and disadvantages of ultrasound compared to other available imaging modalities; (2) describe how ultrasound machines produce images using sound waves; (3) discuss the steps necessary to acquire and optimize an ultrasound image; (4) understand the difference ultrasound appearances of tendons, nerves, muscles, ligaments, blood vessels, and bones; and (5) identify multiple applications for diagnostic and interventional musculoskeletal ultrasound. Part 2 of this 2-part article will focus on the clinical applications of musculoskeletal ultrasound in clinical practice, including the ultrasonographic appearance of normal and abnormal tissues as well as specific diagnostic and interventional applications in major body regions.

NORMAL AND ABNORMAL TISSUES

The primary clinical utility of musculoskeletal ultrasound is to examine soft tissues in the body for the purpose of diagnosing pathological changes or performing interventional procedures. After obtaining the necessary equipment, knowledge, and skills to perform the examination, physicians must familiarize themselves with the normal and abnormal appearances of tissues. Seamless integration of musculoskeletal ultrasound into clinical practice requires skill, time, and patience.

Ultrasound can be used to readily identify and differentiate tendons, muscles, ligaments, nerves, and vessels at a resolution of <1 mm. These tissues generally are described by their echogenicity (isoechoic, hypoechoic, anechoic, hyperechoic), echotexture (internal echo pattern), degree of anisotropy (i.e., occurs when an otherwise-normal but smooth structure appears “dark” on ultrasonographic imaging as a result of the fact that the ultrasound beam did not encounter the structure perpendicular to the plane of that structure), compressibility, and the presence or absence of blood flow on Doppler examination. These features are summarized in Table 1 and Figure 1.

Tissue echogenicity is characterized as hyperechoic, hypoechoic, anechoic, or isoechoic. Hyperechoic structures are brighter (or whiter) than normal or in relation to surrounding structures, whereas hypoechoic structures are darker (or blacker) than normal or in relation to surrounding structures. Anechoic structures are devoid of echoes and appear black. Isoechoic structures are similar in brightness to surrounding structures. These terms can be used in an absolute sense (i.e., tendons are generally hyperechoic, or bright) or in a relative sense (a tendon affected by tendinopathy often appears darker than expected or relative to surrounding tendons and therefore is hypoechoic).

Echotexture refers to the internal pattern of echoes, which can vary depending on whether the structure is imaged transversely or longitudinally. Tendons exhibit a fibrillar
Table 1. Normal ultrasonographic characteristics of soft tissues

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Echogenicity</th>
<th>Echotexture Appearance</th>
<th>Susceptibility to Anisotropy</th>
<th>Compressibility</th>
<th>Doppler Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tendon</td>
<td>Hyperechoic</td>
<td>Broom end</td>
<td>+++</td>
<td>---</td>
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<tr>
<td>Ligament</td>
<td>Hyperechoic</td>
<td>Broom end</td>
<td>++</td>
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<tr>
<td>Nerve</td>
<td>Mixed</td>
<td>Honeycomb</td>
<td>+</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Muscle</td>
<td>Mixed</td>
<td>Starry night</td>
<td>+</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Vessel</td>
<td>Hypoechoic or anechoic</td>
<td>---</td>
<td>---</td>
<td>++a - +++v</td>
<td>+v - +++a</td>
</tr>
</tbody>
</table>

--- = absent; + = mildly present; ++ = moderately present; +++ = significantly present; a = arteries; v = veins.

pattern when imaged longitudinally and a “broom-end” pattern when imaged transversely [1-3]. These patterns result from the compact arrangement of hyperechoic collagen bundles within the tendon, separated by the hypoechoic intervening ground substance [1-3]. The synovial sheaths or paratenons of tendons frequently can be visualized with a high-frequency (>10 MHz) transducer and appear as a thin, hyperechoic tissue layer surrounding the tendon bulk.

**Tendons**

Because of the tightly packed arrangement of collagen bundles within a tendon, tendons demonstrate significant anisotropy. As solid structures, they are noncompressible and do not normally exhibit blood flow. Tendons can be examined dynamically through passive, active, or resisted joint motions, sonopalpation, or transducer compression [1-4]. Most bursa adjacent to tendons are not visualized unless distended; exceptions include the subacromial-subdeltoid, retrocalcaneal, and deep infrapatellar bursae.

**Nerves**

The fascicular longitudinal and honeycomb transverse echotexture patterns of nerves are caused by the hypoechoic nerve fascicles surrounding by hyperechoic connective tissue (external and interfascicular epineurium) [3,5,6]. Nerves are best examined transversely, during which long segments of nerves can be traced (eg, ulnar nerve from brachial plexus to the hand). Nerves are differentiated from tendons by their echotexture, relative lack of anisotropy, location, and proximity to vessels. Provocative testing during ultrasound evaluation of nerves may involve a sonographic Tinel’s sign to localize a regenerating nerve stump or neuroma, range of motion to induce nerve subluxation or dislocation, or muscle or joint motion to demonstrate dynamic stenosis within a musculotendinous or osseofibrous structure, respectively [4,5,7].

**Ligaments**

Ligaments appear similar to tendon but are less compact and contain a more diverse pattern of collagen bundles attributable to the relative multidirectional nature of their incurred stresses. Ligaments appear fibrillar during longitudinal scanning. Their echotexture is often not distinguishable during transverse scanning because of their thin size, but when transverse imaging is possible, they have a “broom-end” appearance. Ligaments can easily be distinguished from tendons by tracing the ligament to the bony structures to which it attaches. For example, the medial collateral ligament is easily differentiated from the pes anserine tendons by its anatomic course (adductor tubercle to proximal medial tibia), ligamentous echotexture (Table 1), and deep location relative to the overlying pes anserine tendons. Dynamic ligament testing can be performed under ultrasound to facilitate differentiation of a high-grade partial versus complete ligament tear or to document joint instability [4,8,9].

**Muscles**

Fascia and joint capsules have a similar ultrasound appearance to ligaments and are easily identified based upon location. The mixed hypo- and hyperechogenicity of muscle arises from the regular pattern of hypoechoic muscle fascicles within the hyperechoic peri- and epimysium [6,10]. Longitudinally, muscle demonstrates a “feather” or “veins on a leaf” pattern, whereas transversely they appear as a “starry night.” Dynamically, compression or muscle contraction can reveal partial thickness strain injuries [6,10].

**Vessels**

Veins and arteries appear as hypo- or anechoic tubular structures that are easily compressible and exhibit blood flow on Doppler examination. Because veins and arteries are the only tissues that should normally exhibit blood flow, they are easily distinguished from tendons, nerves, and ligaments. In addition, although both veins and arteries are generally easily compressible, arteries will remain pulsatile during compression, whereas veins will not. Identification of veins and arteries during diagnostic scanning will facilitate locating nerves as these 2 structures often course side by side in the body.
Bone

The ultrasound appearance of bone is distinctive, manifesting as a well-defined, linear, smooth, hyperechoic border (refer to Figure 3, Part 1 of this review) [11-13]. The hyper-echogenicity of bone is caused by the high reflectivity of the acoustic interface. In fact, virtually the entire sound beam is reflected and therefore ultrasound is unable to “see” beyond bone or other highly calcified structures, rendering the image beyond the interface nearly black. This phenomenon is referred to as posterior acoustic shadowing. Consequently, ultrasound can only provide information about the superficial portion of visualized bones. With respect to joints, high-frequency (>10 MHz) scanners typically can be used to identify the superficial portions of the constituent bones, a

Figure 1. (a) Transverse view of carpal tunnel, demonstrating mixed echogenicity honeycomb pattern of median nerve (N), in contrast to the hyperechoic, fibrillar appearance of the surrounding finger flexor tendons (T). (b) Longitudinal view of flexor carpi radialis traversing superficial to the scaphoid bone in the wrist. Note the hyperechoic, fibrillar echotexture, which is characteristic of all tendons. (c) Longitudinal view of dorsal wrist, producing a transverse view of the dorsal scapholunate ligament (circled), appearing as a tightly packed, hyperechoic, fibrillar structure. (d) Correlative transverse view of dorsal wrist, producing a longitudinal view of the dorsal scapholunate ligament (arrows). Typical of all ligaments, the ligament is better visualized longitudinally rather than transversely and can be located by placing the transducer across the adjacent bony landmarks (lunate and scaphoid). (e) Longitudinal view of median nerve in the forearm (arrows). Hypoechoic fascicles alternating with hyperechoic epineurium are shown. The fascicular pattern of nerves can be compared with the tightly packed fibrillar pattern of tendon (see b). (f) Transverse view of the calf musculature. Note the “starry night” appearance of the gastrocnemius and soleus muscles in cross-section (Figure 1 continues).
thin hyperechoic joint capsule, and a small amount of easily displaceable anechoic intra-articular fluid [12-15]. Normal synovium is not able to be visualized with ultrasound.

**Tendon Injuries**

Most tissues in the musculoskeletal system demonstrate a similar spectrum of pathological ultrasound changes throughout the body. Tendinosis manifests as tendon enlargement, hypoechogenicity, and an increase in the interfibrillar distance (Figure 2) [1-3]. These changes are the result of intratendinous edema and an increase in interfibrillar ground substance. These changes may be regional or diffuse, and it is important to note that the fibrillar tendon echotexture is maintained [2,3]. Partial-thickness tearing demonstrates the additional finding of focal regions of anechogenicity accompanied by loss of the normal fibrillar pattern, confirmed on both longitudinal and transverse images [2,3]. However, tendon continuity is maintained.

High-grade partial-thickness tearing may demonstrate tendon thinning rather than thickening as the result of a loss of tendon substance. Full-thickness tearing manifests as a tendon gap occurring in a background of tendinosis-related changes. Differentiation of nonretracted full-thickness tears from high-grade partial-thickness tears may be facilitated by muscle activation, passive stretch, or manual compression with the transducer, all of which may reveal the gapping of a full thickness tear [3,4].

Tenosynovitis may appear as simple, anechoic, easily displaceable fluid surrounding the tendon, or as complex fluid with mixed echogenicity. Synovial hypertrophy may also be present and is frequently associated with hyperemia on Doppler examination [2,3]. The ultrasonographic appearance of complex fluid within the tendon sheath is nonspecific, and diagnostic aspiration should be completed if infection is suspected. Intratendinous calcifications appear as linear or ovoid hyperechoic structures with variable amounts of posterior acoustic shadowing, depending on their density (Figure 3) [3,16]. Similar to bone, when calcifications are dense, ultrasonographic evaluation of structures deep to the calcification is problematic.

**Ligament Injuries**

The manifestations of ligament injury are similar to those described for tendons. Low-grade injuries manifest as enlarged, hypoechogenic ligaments with an otherwise-normal echotexture, whereas partial- and full-thickness tears dem-
onstrate fiber disruption. Comparison with unaffected ligaments in other areas facilitates detection of more subtle abnormalities. Stress testing may be used to differentiate partial versus complete tears and assess joint stability [4].

**Nerve Injuries**

Peripheral nerves also can be evaluated for signs of entrapment or inflammation. Similar to tendons and ligaments, affected nerves exhibit regional swelling and diffuse hypoechoogenicity, often accompanied by a loss in their normal fascicular pattern [3,5,6,17]. Entrapment sites may be localized by evaluating for swelling proximal to the entrapment site and a focal narrowing at that site, that is, a “notch sign” [3,5,6]. Dynamic testing can evaluate for subluxation or dislocation [18].

**Muscle Injuries**

Low-grade muscle strains exhibit subtle regions of hypoechoogenicity accompanied by obscuration of the normal pen- nate echotexture; the affected area looks “washed out” [6,10]. Higher grade injuries and contusions demonstrate variable degrees of frank fiber disruption and heterogenous fluid typical of a hematoma.

**Bone and Joint Disorders**

Irregularities in the otherwise superficial, smooth surface of bone may be indicative of periostitis or stress fracture [12]. Further evaluation of any suspicious bone disorder is necessary because of the inherent limitations of ultrasound. Ultrasound is very sensitive for detecting joint effusions throughout the body [19,20]. Simple effusions are anechoic, compressible, and devoid of Doppler flow. Complex, heterogeneous appearing fluid is a nonspecific finding and may be indicative of infection [20]. Aspiration is recommended as clinically indicated. Synovitis appears as noncompressible, echogenic tissue within a joint (or tendon sheath), possibly exhibiting hyperemia on Doppler examination. Periarticular erosions, crystal disease-related deposits, and gouty tophi can all be observed during joint evaluation; however, one should recognize that potentially clinically important findings may not be accessible to ultrasound examination deep within a joint [12]. Enlarged bursae typically contain simple anechoic fluid, but complex fluid may be present, similar to joint effusions. Periarticular and peritendinous ganglia appear as multilobulated, anechoic, noncompressible structures devoid of blood flow [21,22].

**CLINICAL APPLICATIONS**

During the past 10 years, the clinical applications of diagnostic and interventional musculoskeletal ultrasound have expanded rapidly. Technological advancements and an increasing diversity of users have established ultrasound as a clinical
problem-solving tool in musculoskeletal medicine. The prerequisites for successful scanning as well as basic scanning principles have been reviewed in Part 1 of this 2-part article [11]. When approaching a regional musculoskeletal disorder, the physician is reminded to follow a standard examination protocol to answer a predefined clinical question, evaluating target structures both transversely and longitudinally.

**Shoulder**

The high prevalence of rotator cuff disorders coupled with ultrasound’s ability to evaluate tendons with high resolution have established ultrasound as a front-line diagnostic tool in many patients presenting with shoulder pain [23,24]. The earliest consistent application of musculoskeletal ultrasound was the evaluation of rotator cuff and associated soft tissue pathologies [25,26]. Since that time, clinical applications in the shoulder have increased dramatically.

The shoulder region can typically be examined with high-frequency (>10 MHz) linear array transducers, although in larger patients mid-range frequency (6-10 MHz) transducers may be required [23,24,27,28]. Specific guidelines for ultrasonographic evaluation of the shoulder have been established (see Table 3, Part 1 of this 2-part article [11]). Examiners should be aware that the curved geometry of the rotator cuff tendons creates anisotropy during most examinations, particularly at the musculotendinous junction [23,28,29]. Transducer repositioning, as previously described, should be used to differentiate anisotropy from true pathology [23,28,29].

Ultrasound can be used to detect and characterize tendon disorders affecting the biceps and rotator cuff, including biceps tenosynovitis, tendinosis, and partial- or full-thickness tearing [23,24,30-33]. In addition, sonography is better tolerated and preferred by patients compared with a magnetic resonance imaging (MRI) scan [34].

Physicians must recognize that fluid around the biceps tendon may represent tenosynovitis or an extension of a glenohumeral joint effusion, because the bicipital sheath directly communicates with the joint [23,28,31]. In fact, loose bodies arising from the glenohumeral joint may be identified within the biceps sheath. Bicipital tenosynovitis is suggested by the presence of concomitant bicipital tendinopathy or tearing, echogenic synovial hypertrophy, pain during sonopalpation, and hyperemia on Doppler examination [23,31]. A dynamic evaluation can reveal bicipital instability during external rotation [32].

In experienced hands, ultrasound can identify the presence and extent of partial-thickness and full-thickness rotator cuff tears with accuracy similar to MRI (see Figure 6b, Part 1 of this 2-part article) [11,24,27,30,33,35-39].

In addition, ultrasound can be used to identify fluid in the subacromial-subdeltoid bursa, bursal hypertrophy, and impingement of hypertrophied rotator cuff tendons or bursal tissue against the lateral acromion during arm elevation (ultrasonographic impingement sign) [33,40,41]. Consequently, when clinically relevant information is desired regarding the status of the rotator cuff or biceps tendon, ultrasound may be considered as an initial diagnostic test after obtaining appropriate radiographs [24,27,33,35,38,39].

For example, with respect to a patient presenting with an appropriate history, shoulder pain, stiffness, passive motion loss, and a normal radiograph, an unremarkable ultrasound would support the diagnosis of adhesive capsulitis, facilitating implementation of appropriate treatment [42,43]. Ultrasound enables follow-up of partial-thickness or small full-thickness rotator cuff tears for signs of structural progression. Ultrasound-guided injections into the bicipital tendon sheath and subacromial-subdeltoid bursa may be performed for diagnostic or therapeutic purposes [44-48]. In a subset of patients presenting with symptomatic calcific rotator cuff tendinopathy, the use of ultrasound can delineate the presence and extent of the calcification, excluded concomitant rotator cuff tears (atypical in this group), and facilitate treatment via ultrasound-guided percutaneous lavage and aspiration (Figure 4) [16,49-53]. Examiners are reminded that ultrasound cannot completely investigate the glenohumeral labrum or intra-articular regions of the glenohumeral, acromioclavicular, or sternoclavicular joints [24-28]. Consequently, physicians must rely on alternative diagnostic imaging such as radiographs, computed tomography (CT), or MRI to definitively confirm the presence or absence of pathologies affecting these areas.

Ultrasound can be used to detect loose bodies in the posterior glenohumeral joint recess and fragmentation of bony margins consistent with erosive arthritis and synovitis. When necessary, ultrasound can facilitate accurate diagnostic aspiration or therapeutic injection into these joints [44,45]. Ultrasound also may be used to identify relevant periarticular pathologies, such as spinoglenoid notch cysts associated with posterior labral tears, or acromioclavicular joint cysts associated with massive rotator cuff tears [23,54]. Ultrasound

![Figure 4](image.png)

**Figure 4.** Longitudinal view of supraspinatus tendon. A 22-gauge needle (arrows) has been guided into a symptomatic, hyperechoic, intratendinous calcification. With the use of a lavage technique, the hydroxyapatite crystals are aspirated, resulting in an eggshell appearance. Left screen = lateral, right screen = medial, top screen = superficial, bottom screen = deep (Philips iU22, Philips Medical Systems, Bothell, WA).
guidance can facilitate cyst aspiration for temporary symptom control as clinically indicated [54].

Ultrasound provides significant advantages over MRI and CT scans to evaluate the postoperative shoulder [55]. Diagnostic evaluation is most commonly performed to exclude rotator cuff tear after rotator cuff repair or total shoulder arthroplasty [55]. Examination of the postoperative shoulder is one of the most challenging diagnostic musculoskeletal examinations and should only be performed by experienced practitioners [54].

**Elbow**

The superficially located structures about the elbow are amenable to ultrasound examination with high-frequency (>10 MHz) transducers. With respect to the lateral elbow, ultrasound provides excellent imaging of the common extensor tendon. Although not typically required for initial diagnosis, ultrasound can assist in management of refractory cases lateral epicondylitis (also called tennis elbow) by characterizing the extent of tendon tearing and identifying the presence of comitant radial collateral ligament injury (Figure 5) [56,57]. As clinically indicated, the radial nerve may be traced as it passes through the supinator to identify focal swelling and stenosis suggestive of radial tunnel syndrome [7]. Nerve examination may be supplemented by visualization during pronation-supination. The radiocapitellar articulation may be examined for osteoarthritic changes or a plica, and effusion or loose bodies may be seen in the annular recess adjacent to the radial neck [19,20]. A comprehensive articular assessment would require radiographs, CT, or MRI.

Ultrasound guidance may be used to aspirate effusions, diagnostically block the radial nerve at the supinator, or guide corticosteroid injection into the common extensor tendon region [20,58,59]. Because of the inconsistent and often marginal long-term results of corticosteroid injections to treat common extensor tendinopathy/lateral epicondylitis, in recently described procedures, researchers have attempted to more directly stimulate a healing response [58,59]. Ultrasound-guided percutaneous tenotomy, platelet-rich plasma injection, sclerosing therapy, and autologous blood injections have all produced promising short-term improvements in refractory cases, although prospective randomized studies and longer-term follow-up are currently lacking [60-64].

Ultrasound has similar applications on the medial elbow, particularly with respect to the management of flexor-pronator tendinopathy or medial epicondylitis (also called Golfer’s elbow) [65,66]. In addition, ultrasound can readily trace the ulnar nerve from the mid-humerus to mid-arm, providing anatomic localization of ulnar nerve compression about the elbow [67,68]. Thus, ultrasound can supplement electrodagnostic testing by demonstrating the location of structural nerve changes, as well as potentially identifying underlying causes such as loose bodies, synovitis, osteophytes, tumors, subluxation or dislocation, or a snapping triceps tendon [3,18,67,68].

Identification of ulnar nerve subluxation may influence the approach to therapeutic injection in this region, as well as the distance measurements used to calculate nerve conduction velocity across the elbow [69]. The medial collateral ligament (also known as ulnar collateral ligament) can be evaluated to reveal partial or complete tears [9,70]. Valgus stress testing during ultrasound visualization can reveal asymmetric increases in ulnohumeral joint laxity as an indicator of instability, thus assisting in diagnosis and triage [9,71]. Finally, the median nerve can be identified in the mid-arm and traced distally as it traverses through the pronator teres, identifying potential entrapment sites in patients presenting with proximal median neuropathies [3].

For most physicians, applications in the anterior elbow are limited. Imaging the distal bicep tendon is technically challenging, and MRI remains the test of choice in most cases. Loose bodies may be identified in the anterior recesses, but CT scan is much more sensitive when the primary indication for diagnostic testing is a search for loose bodies throughout the elbow [20]. In comparison, the triceps tendon is easily examined using ultrasound, revealing tendinopathy, partial tearing and, in rare cases, full-thickness tearing. Elbow effusions are best visualized posteriorly when the elbow is flexed, within the olecranon fossa [19,20]. Loose bodies may also be detected in this location (Figure 6). Ultrasound can be used for diagnostic elbow joint aspiration and injection via a posterior approach when clinically indicated [20].

**Wrist-Hand**

Ultrasound can provide exquisitely detailed images of tendons, nerves, vessels, joint capsules, retinacula/pulleys, and some ligaments in the wrist-hand [72-74]. The superficial location of these structures allows interrogation with high-frequency linear transducers (12-17 MHz), providing resolu-
tion of less than a millimeter. If available, small footprint linear array transducers allow greater maneuverability and may be particularly useful during ultrasound-guided procedures. Clinically, ultrasound is a powerful tool to differentiate among multiple potential pain generators in patients presenting with regional wrist-hand complaints and can facilitate therapeutic aspiration or injection.

On the dorsal wrist, the tendons within all 6 wrist extensor compartments may be traced from their musculotendinous junctions to their distal insertions [72]. Ultrasound can be used to identify the presence of tendinopathy, partial-thickness tearing, or full-thickness tearing, thus assisting in triage and management [75]. Associated tenosynovitis or intrasynovial pannus can be accurately identified, particularly with the use of power Doppler [75,76]. Dynamic examination may reveal symptomatic snapping of tendons as they cross other tendons, joint, bony prominences/osteophytes, or synovial pannus [4].

Provocative supination-pronation testing during ultrasonographic visualization can objectively document extensor carpi ulnaris subluxation in patients presenting with dorsoulnar wrist pain and snapping [4,77]. All dorsal wrist tendon sheaths are accessible to ultrasound-guided aspiration/injection. Within the first dorsal extensor compartment, ultrasound can readily identify fibrous or fibroosseous septae between the abductor pollicis longus and extensor pollicis brevis tendons, the presence of which have been implicated in suboptimal injection responses to injections in cases of DeQuervain’s tenosynovitis [72,78-80]. In these cases, ultrasound guidance can ensure injectate distribution into both subcompartments.

The dorsal radiocarpal and distal radioulnar joint recesses can be assessed for effusion or synovitis [72]. Ultrasound-guided aspiration/injection can proceed as clinically indicated. In most patients the dorsal scapholunate ligament may be identified as a fibrillar, hyperechoic structure spanning the dorsal osseous margins of the scaphoid and lunate (Figure 1d) [72]. The ligament is located by scanning in an anatomic transverse plane just distal to Lister’s tubercle on the dorsal radius. This is a common location for periarticular ganglion cysts, which are readily identified by ultrasound as well-defined, noncompressible, anechoic structures devoid of internal blood flow [21]. Ultrasound-guided aspiration, with or without corticosteroid injection, may provide short-or intermediate term relief (Figure 7) [22]. The superficial radial nerve can be imaged as it emerges from beneath the brachioradialis tendon and courses distally and dorsally over the first extensor compartment tendons, facilitating identification of local neuropathy or post-traumatic neuroma.

Similar to the dorsal wrist, all volar wrist tendons may be traced proximal to distal, allowing the physician to identify the presence and extent of tendinopathy and associated tenosynovitis [72,75]. The volar radiocarpal joint recesses may be investigated for effusion and synovitis [72]. The volar-radial wrist is the second most common location for periarticular ganglia, usually arising from the scaphotrapeziotrapezoidal articulation [21]. These ganglia typically are located between the flexor carpi radialis ulnarily and the radial artery radially. Ultrasound guidance may be used to aspirate/inject any of these areas as clinically indicated, although the operator should exercise appropriate caution because of the proximity of neurovascular structures [21,22].

The role of ultrasound in the evaluation of carpal tunnel syndrome continues to evolve [80,81]. When abnormal, the median nerve will appear enlarged and hypoechoic, and will demonstrate some obscuration of its internal fascicular structure when imaged transversely (Figure 8) [82]. The severity of ultrasonographically documented anatomic changes correlates closely with electrophysiologic abnormalities [81].

Figure 6. Longitudinal view of the posterior elbow, demonstrating a calcified loose body in the olecranon fossa (arrows) in a patient with elbow pain, stiffness, and normal radiographs. Left screen = proximal, right screen = distal, top screen = superficial, bottom screen = deep (Philips IU22, Philips Medical Systems, Bothell, WA).

Figure 7. Transverse view of dorsal wrist in an athlete presenting with a symptomatic, complex, dorsal wrist ganglion associated with the scapholunate ligament. Using ultrasound guidance, a 19-gauge needle (arrows) is safely advanced between tendons into the cyst for therapeutic aspiration and injection. Left screen = radial, right screen = ulnar, top screen = superficial, bottom screen = deep (Philips IU22, Philips Medical Systems, Bothell, WA).
The most useful indicator of median neuropathy at the carpal tunnel is an increased in the cross-sectional area at the carpal tunnel entrance, delineated by the pisiform ulnarly and the scaphoid tubercle radially. A cross-sectional area of >15 mm² is clearly abnormal, whereas 10-15 mm² is equivocal and <10 mm² is normal. The carpal tunnel ultrasound examination may provide useful information when electrodagnostic studies are equivocal, or secondary causes of carpal tunnel syndrome are suspected (e.g., ganglia, flexor tendon tenosynovitis). Anatomic variants such as a bifid median nerve and and/or persistent median artery are readily identified. Ultrasound guidance can be used to safely direct carpal tunnel injections as well as facilitate percutaneous treatment of underlying pathologies, such as periarthicular ganglion cysts or synovial pannus. In patients presenting with symptoms referable to Guyon’s canal, ultrasound examination may reveal ulnar nerve structural changes indicative of neuropathy, as well as secondary causes of ulnar nerve compression such as pisotriquetral ganglia, ulnar artery aneurysms, or anomalous muscles.

Within the hand, ultrasound can image the flexor and extensor tendons in their entirety, identifying tendinopathy, partial-thickness tearing, or full-thickness tearing. Passive or active motion may facilitate differentiation of high-grade partial-thickness tears from full-thickness tears. The collateral ligaments may be imaged at the metacarpophalangeal and interphalangeal joints and appear as moderately thick, hyperechoic, fibrillar structures. Low-grade sprains appear as enlarged, diffusely hypoechoic ligaments, whereas partial or complete fiber disruptions indicate higher grade injuries. Radial or ulnar stress testing during ultrasound examination will differentiate high-grade partial-from full-thickness sprains, as well as provide a functional assessment of joint stability. Ultrasound can image the ulnar collateral ligament of the thumb, and identify the presence or absence of a Stener lesion with acceptable accuracy.

Very high-frequency linear transducers (>12 MHz) can readily identify the A1, A2, and A4 pulleys in most patients. Disruption of the A2 pulley (Climber’s finger) is manifested as pulley discontinuity and can be confirmed ultrasonographically when active finger flexion results in volar subluxation of the flexor tendon as demonstrated ultrasonographically. Patients with stenosing tenosynovitis (trigger finger) usually demonstrate thickening of the A1 pulley and dyskinetic tendon movement during active or passive finger flexion-extension. Most cases are clinically obvious and do not require confirmatory imaging. However, when nonguided injections fail to alleviate symptoms, ultrasound guidance will ensure injectate placement and may reveal additional underlying pathologies of clinical importance.

The ability of ultrasound to image the collateral ligaments, flexor and extensor tendons, and volar plate allow ultrasound to provide potentially useful diagnostic information in the setting of finger dislocations. Ultrasound can be used to clearly identify the involved structures, facilitate stability assessment, and identify radiographically occult fractures. In patients presenting with atraumatic finger joint complaints, ultrasound can be used to detect occult effusion and synovitis with better sensitivity than clinical examination, potentially revealing an underlying inflammatory arthropathy. Early detection is relevant because of the emerging emphasis on early aggressive treatment with disease modifying agents. The role of ultrasound guidance to aspirate/inject finger joints has been well established in the literature.

Although ultrasound is a powerful clinical tool when appropriately applied in the wrist-hand region, it is not without limitations. Currently, ultrasound cannot adequately evaluate the triangular fibrocartilage complex or intercarpal joints and ligaments with sufficient diagnostic accuracy for clinical use. In addition, like other body regions, a variety of tumors, most commonly giant cell tumors, may manifest in the wrist-hand regions. Although ultrasound can assist in localizing, characterizing, and biopsying soft tissue tumors, it is frequently not the optimal imaging modality for soft tissue mass evaluation. Physicians performing ultrasound should be aware of these limitations to avoid misdiagnosis.

**Hip Region**

Ultrasound examination of the hip region is relatively challenging because of the deep location of the target structures, complex anatomy, and extensive investigation area. Large footprint medium-high frequency (7-10 MHz) linear transducers or low-medium frequency (2-6 MHz) curvilinear transducers are required, providing increased imaging depth at the expense of resolution.

The hip joint can be readily examined for effusion or synovitis, and techniques for ultrasound-guided hip aspira-
and tears but is not likely as sensitive as MRI scan. However, ultrasound may guide diagnostic/therapeutic injections into hip bursae or gluteal peritendinous regions. The diagnostic role of ultrasound with respect to the lateral femoral cutaneous nerve remains undefined, most high-resolution scanners can readily identify the nerve at the level of the pelvic brim, anterior superior iliac spine, facilitating diagnostic or therapeutic ultrasound-guided blockade in patients presenting with burning anterolateral thigh pain consistent with meralgia paresthetica [99]. The greater trochanteric (ie, subgluteus maximus) bursa is not visualized during ultrasonography unless abnormal. When clinically indicated, ultrasound can precisely guide diagnostic/therapeutic injections into hip bursae or gluteal peritendinous regions. The diagnostic role of ultrasound in the posterior hip region is limited. Ultrasound may help to identify moderate-to-severe hamstring tendinopathy and tears but is not likely as sensitive as MRI scan. However, ultrasound guidance may be used to accurately guide ischial bursa aspiration/injection or proximal hamstring peritendinous injections [101]. Ultrasound-guided techniques for piriformis sheath and sacroiliac joint injections have been described and may be useful alternatives to fluoroscopically guided procedures, particularly when radiation is contraindicated (eg, pregnancy) [102,103].

Although the diagnostic role of ultrasound continues to evolve with respect to the hip, physicians should exercise caution when considering using ultrasound as a primary imaging modality for regional hip pain. The technical limitations of ultrasound favor CT or MRI for diagnostic purposes in most cases. Ultrasound may be considered when specific information is desired about superficial structures (eg, adductor tendons, iliopsoas tendons, lateral femoral cutaneous nerve), with the understanding that the small field of view provided by the ultrasound exam limits the ability to exclude significant findings beyond the examined region. On the contrary, once pathology is identified, ultrasound may be effectively used to guide needles to virtually any target location within the hip region.

Knee Region

Diagnostic examination of the knee can typically be performed with high-frequency (>10 MHz) linear transducers because of the superficial location of most target structures. The primary indications for ultrasound in the anterior knee are to evaluate the extensor mechanism and to identify and aspirate knee effusions. The echogenic, fibrillar trilaminar structure of the distal quadriceps tendon is readily revealed with the use of high-frequency transducers, facilitating assessment of tears in native or postarthroplasty knees [104,105]. Although patellar tendinopathy is typically a straightforward clinical diagnosis, structural changes are more likely to be observed on ultrasound than MRI in symptomatic patients [106]. Tendon neovascularization as detected by power Doppler examination appears to correlate with clinical symptoms, although the relationship is not absolute (Figure 10) [106,107].

Initial experience with ultrasound-guided sclerosis of neovessels and dry needling coupled with autologous blood injections has produced favorable results [108,109]. Further prospective investigation of these promising therapeutic interventions is warranted. Ultrasound examination may assist in triage and rehabilitation progression by differentiating tendinosis from high-grade partial thickness tearing, as well as determining the presence of associated superficial or deep infrapatellar bursopathy. Identification of these latter conditions as pain generators with the use of sonopalpation may lead to therapeutic ultrasound-guided injection. Knee effusions are best detected in the suprapatellar pouch by using sagittal views and appear as anechoic fluid collections [15,110,111]. Doppler examination may reveal hyperemia consistent with synovitis. When clinically indicated, ultrasound guidance may be used to aspirate effusions and inject therapeutic agents [110,111].

Figure 9. Ultrasound-guided intra-articular hip injection. Needle (arrows) has penetrated the anterior hip capsule at the femoral head (FH)-neck junction, entering the anterior joint recess. From this position, the hip joint can be injected. Note the curved image geometry created by the 5-2 MHz curvilinear array transducer used for the procedure. A = acetabulum, left screen = distal, right screen = proximal, top screen = superficial, bottom screen = deep (Philips IU22, Philips Medical Systems, Bothell, WA).
Patients presenting with lateral knee pain or swelling may be evaluated for the presence of distal iliotibial band syndrome, lateral perimeniscal ganglion cysts, biceps femoris tendinopathy, or common fibular (peroneal) nerve disorders [110,112-114]. The complex anatomy of this region limits the diagnostic utility of ultrasound, but when clinically indicated, ultrasound can be used to guide therapeutic cyst aspiration and injection, peritendinous injection, or distal iliotibial band injection [112].

In the posterior knee, ultrasound is most commonly used to diagnose and treat popliteal cysts (Baker cysts; see Figure 4, Part 1 of this 2-part article) [11,115]. The use of ultrasound can readily detect Baker cysts, can identify cyst leakage or rupture, and can guide therapeutic aspiration and injection [115]. Ultrasonographically, Baker cysts appear as anechoic or hypoechoic fluid collections located between the medial gastrocnemius and semimembranosus tendons that clearly communicate with the posterior tibiopatellar joint [15,115]. If the appearance is atypical or a communicative stalk cannot be identified with certainty, clinicians should search for other conditions that may produce posterior knee pain, including popliteal artery aneurysm, semimembranosus tendinopathy, or tumors. An MRI scan should be obtained as necessary.

Although ultrasound may clearly identify the medial collateral ligament, ultrasonographic examination does not typically provide additional clinically useful information. Ultrasound may be used to document pes anserine bursitis and guide therapeutic injection of the saphenous nerve in patients presenting with medial knee pain syndromes. Ultrasound is not predictably useful for excluding the presence of intra-articular knee disorders such as cruciate ligament disruption, (osteo-)chondral injury, or meniscal tear [110,116].

Ankle-Foot

Virtually all tendons and nerves about the ankle and foot region are amenable to diagnostic ultrasound examination. High-frequency (>10 MHz) linear array and small footprint linear array transducers are typically used.

In patients presenting with posterior ankle pain, ultrasound can be used to identify Achilles tendinopathy and differentiate between tendinosis and partial-thickness tearing (Figures 2 and 11) [117]. Doppler examination may reveal tendon neovascularization, which is typically present in more severe and symptomatic cases [118]. Associated paratenonitis, retrocalcaneal bursitis, and retro-Achilles (superficial Achilles) bursitis may be identified as primary or contributing conditions [117,119]. Ultrasound-guided bursa and paratenon injections may assist in diagnosis and management of these latter conditions, although caution must be exercised with respect to the use of corticosteroids in the vicinity of the Achilles or other ankle-foot tendons [119-122].

Figure 10. (a) Longitudinal view of the proximal patellar tendon in an athlete with chronic, refractory proximal patellar tendinopathy. Note marked tendon thickening, diffuse hypoechoogenicity, extensive neovascularization on Doppler examination. (b) Extended field of view (ie, panoramic) imaging of the same patient, providing a more global view of the tendon. This image allows a better appreciation of the extent of tendon thickening relative to normal (denoted by arrows). Left screen = proximal, top screen = superficial, bottom screen = deep (Philips IU22, Philips Medical Systems, Bothell, WA).

Figure 11. Longitudinal view of Achilles tendon in former runner with chronic heel pain. The tendon exhibits structural changes of chronic tendinopathy, including moderate thickening, diffuse hypoechoogenicity, and neovascularization on Doppler examination. In addition, there is an irregular anechoic region on the undersurface of the tendon, adjacent to the calcaneus, consistent with partial thickness tearing. Left screen = cranial, right screen = distal, top screen = superficial, bottom screen = deep (Philips IU22, Philips Medical Systems, Bothell, WA).
Recent uncontrolled case series have reported symptomatic improvement in patients with chronic Achilles tendinopathy treated with ultrasound-guided sclerosis of neovessels or intratendinous injection of dextrose (prolotherapy) [123,124]. Further research is warranted in this regard. Ultrasound can be used to readily identify Achilles tendon rupture and assist in triage. In selected patients, tendon apposition during ankle plantar flexion has been associated with a favorable outcome after nonoperative management [125].

Deep posterior ankle pain may be caused by flexor hallucis longus tendinopathy or tenosynovitis, posterior ankle joint effusion/synovitis or loose bodies, or os trigonum syndrome, all of which may be evaluated ultrasonographically on more sophisticated machines [117]. Therapeutic tendon sheath injection or diagnostic/therapeutic os trigonum injection can be completed ultrasonographically as clinically indicated [122].

In the posteromedial ankle, ultrasound can be used to readily depict the structures within the tarsal tunnel and adjacent region [126]. Ultrasound can detect and characterize posterior tibial tendon disorders as accurately as MRI for clinical decision making [117,127]. Although uncommonly performed, ultrasound guidance can be used to inject the posterior tibial tendon sheath for diagnostic or therapeutic purposes [119,122]. The tibial nerve, medial and lateral plantar branches, and medial calcaneal branch can all be investigated using high-frequency transducers, facilitating identification of compression, inflammation, or neuroma. Ultrasound-guided nerve block can be performed as indicated. Periartricular ganglion cysts arising from the medial tibiotalar or subtalar joints may produce ankle pain or true tarsal tunnel syndrome [126]. They appear as anechoic, multiloculated structures and can be therapeutically aspirated using ultrasound guidance, although improvement is often temporary [117,122]. It is important to recognize that ultrasound cannot adequately evaluate the joint structures from which such a cyst may arise, and MRI would be recommended in such cases.

The peroneal tendons account for the majority of pain syndromes in the posterolateral ankle. The use of ultrasound accurately identifies and characterizes peroneal tendon disorders and is the test of choice for demonstrating tendon subluxation or dislocation (Figure 12) [117,128,129]. More recently, symptomatic peroneal tendon snapping within the retrofibular groove has been identified as a source of posterolateral ankle pain as demonstrated by ultrasound [117,128,129]. Therapeutic and diagnostic peroneus longus or brevis tendon sheath injections may be performed as clinically indicated [122]. Although uncommon, sural nerve disorders can manifest as posterolateral ankle pain. The nerve can be easily identified just anterior to the Achilles tendon and adjacent to the lesser saphenous vein. From this point, it can be traced distally in a transverse view to the level of its bifurcation at the base of the fifth metatarsal in most cases.

Tendon disorders are uncommon in the anterior ankle, although ultrasound can readily confirm a clinically suspected anterior tibialis tendon rupture [117]. Ankle joint effusions are best visualized anteriorly in an anatomical sagittal plane with the ankle in slight plantarflexion [117]. Effusions are usually simple but may be complex and contain a variable amount of synovitis or loose bodies [117]. Ultrasound-guided aspiration and injection can be performed; one should take care to avoid the dorsalis pedis artery and deep fibular (peroneal) nerve [20,122]. In the appropriate clinical setting, hyperechoic debris in the anterolateral gutter would support a clinical diagnosis of anterolateral impingement syndrome [130]. Ultrasound-guided injection may be helpful to accurately place the injectate into the meniscal tissue. Examination of the anterior talofibular, calcaneofibular, and posterior talofibular ligaments can be performed but is generally of no clinical utility because the ultrasonographic findings do not alter management [131].

Within the foot, ultrasound is most commonly used to confirm a clinical diagnosis of plantar fasciitis and characterize the structural severity [119,132]. Similar to lateral epicondylitis in the elbow, soft-tissue imaging is not indicated in most cases. In refractory or atypical cases, thickening (>4-5 mm), hypochoogenicity, and heterogeneity of the plantar fascia would support a clinical diagnosis of plantar fasciitis [132-134]. The absence of structural findings warrants a search for other causes.

Ultrasound-guided plantar fascia injections have been reported to provide greater therapeutic efficacy compared with nonguided injections in a single investigation, although firm conclusions in this regard await further study [119,133-135]. Ultrasound can evaluate all the midfoot joints via a dorsal approach, identifying arthritis, synovitis, and periar-
ticular ganglia [136]. Dorsal osteophytic lipping resulting in neuritis or tendinopathy can be depicted with static ultrasound and confirmed with dynamic testing. Diagnostic or therapeutic ultrasound-guided joint aspirations and injections may be performed for these conditions as clinically indicated [122,136].

Investigation of the plantar aspect of the midfoot remains challenging because of the complex anatomy and similar echogenicity of multiple layers of crossing tendons. The primary indication for ultrasound in this region is to confirm a clinically suspected plantar fibroma, appearing as a local, hypoechoic fusiform swelling located within the plantar fascia along its medial border [137]. A mass lesion presenting with any other appearance warrants further evaluation with CT or MRI. Within the forefoot, ultrasound can detect effusions and/or synovitis in the metatarsoophalangeal and interphalangeal joints, plantar plate disruptions, and Morton neuromas in addition to intermetatarsal bursitis, facilitating identification of potential pain generators in patients presenting with forefoot pain or metatarsalgia [138,139].

Morton neuroma appears as a well defined, noncompressible, hypoechoic mass lesion within the plantar aspect of the intermetatarsal space at the level of the metatarsal heads, as visualized from a plantar approach [138,139]. Continuity with the interdigital nerve confirms the diagnosis but is inconsistently visualized even when sophisticated machines are used [18]. Morton neuroma is often accompanied by intermetatarsal bursitis, appearing as an anechoic, compressible fluid collection dorsal to the Morton neuroma as visualized from a plantar approach [138,139]. Therapeutic joint aspiration and injection, as well as Morton neuroma and intermetatarsal bursa injection, can be performed with the use of ultrasound guidance [122,140].

Despite the broad range of clinical applications in the ankle and foot, ultrasound cannot adequately evaluate the intra-articular structures of the hindfoot or midfoot joints, and has limited capability to image many deeply located structures in the plantar midfoot region. Radiographs are recommended to supplement any ultrasound examination and, when clinically indicated, advanced diagnostic imaging should be pursued in the form of MRI, CT, or bone scan.

THE FUTURE OF MUSCULOSKELETAL ULTRASOUND IN PHYSIATRY

The integration of diagnostic and interventional musculoskeletal ultrasound into clinical practice represents a significant development in the field of physiatry. Having successfully prescribed therapeutic ultrasound for more than 50 years, physiatrists now have the opportunity to use musculoskeletal ultrasound as a clinical decision-making tool for the benefit of their patients. With this opportunity comes the challenge of creating the future of musculoskeletal ultrasound in physiatry. To meet this challenge, physiatrists must (1) develop an infrastructure to provide musculoskeletal ultrasound education, (2) implement practice guidelines to ensure the appropriate application of ultrasound technology, (3) establish a method of documenting competency among physiatrists who choose to integrate musculoskeletal ultrasound in their practices, and (4) continue to explore and document cost-effective clinical applications of musculoskeletal ultrasound in physiatric practice. These actions are necessary to establish physiatrists as credible users of musculoskeletal ultrasound as viewed by our patients, our colleagues in other medical specialties, and third-party payers. To our advantage, we have walked down this path before, as our field successfully managed the evolution of electrodiagnostic and spinal injection techniques during the 20th century. The 21st century now presents a similar challenge with the proliferation of diagnostic and interventional musculoskeletal ultrasound.

Physiatrists share a long and rich history with ultrasound technology and are uniquely positioned to be leaders in the field of musculoskeletal ultrasound. The information presented in this 2-part article is relevant to all physiatrists as we witness the rapid infiltration of diagnostic and interventional ultrasound into musculoskeletal medicine. More importantly, the authors hope that this review will inspire interested and motivated physiatrists to integrate musculoskeletal ultrasound into their practices and participate in the activities that will solidify the position of this powerful technology in the future.

REFERENCES


