Topics in Magnetic Resonance Imaging
14(1): 103–112

Musculoskeletal Ultrasound: An Alternative Imaging Modality for Sports-Related Injuries

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Summary: Advanced technology and increasing clinical experience have established sonography as a reliable imaging modality for sports-related injuries. Tears of muscles and tendons, tendinosis, and tenosynovitis are promptly diagnosed using ultrasound. Dynamic assessment of joints can be performed, allowing diagnoses of conditions that may remain undetected when evaluated with conventional magnetic resonance imaging. Sonography provides expeditious image guidance for procedures such as drainage of fluid collections and cysts. This article reviews the applications of sonography to sports-related injuries in which its diagnostic performance may be comparable to magnetic resonance imaging. **Key Words:** Ultrasonography—Musculoskeletal—Muscle injuries—Tendon injuries—Athletic injuries.

INTRODUCTION

Magnetic resonance imaging (MRI) is the standard of care for evaluation of the musculoskeletal system at most centers in the United States. It is widely accepted for evaluating sports-related injuries owing to its high sensitivity in detecting soft tissue, ligament, cartilage, and bone marrow abnormalities. Current technology allows high-resolution imaging in shortened time. Standardized pulse sequences minimize variability due to operator dependence and can be acquired at various sites with minimal medical supervision.

Few imaging centers in the United States have developed expertise in musculoskeletal sonography, which is an established practice in Europe, Canada, Australia, Asia, and South America. Although the relative low expense of ultrasound systems makes sonography an attractive option for soft-tissue imaging, it is technically demanding and requires considerable examiner experience. Physician availability during examination is required because of the technical complexity and the importance of analyzing dynamic studies. Rather than relying on static images provided by technologists, radiologists traditionally perform musculoskeletal sonography themselves. Referring physicians (especially orthopedic surgeons) may feel uneasy with ultrasound images because anatomic landmarks are not clearly identified due to the limited field of view.

Recent advances in equipment have dramatically improved the image quality of ultrasound systems. High-frequency (9–13 MHz) linear transducers markedly enhance image resolution and are standard in most commercially available systems. Current technology allows in-plane resolutions of 200–450 μm and section thicknesses of 0.5–1.0 mm, which exceed that obtainable with routine MRI (1). Additional hardware and software packages allow extended field-of-view reconstructions of areas up to 60 cm long. This provides more anatomic landmarks and understandable images to referring physicians and facilitates measurements of large structures.

The interaction with the patient during a sonographic examination helps determine possible pathology and allows for a focused investigation. Serial ultrasound can be useful in following healing processes, and it provides essential feedback to both the athlete and clinician (2). Real-time ultrasound offers the best dynamic study currently available and allows for prompt image-guided procedures such as aspiration of fluid collections. Bilateral examinations can be performed expeditiously. There is no risk to patients with pacemakers and cochlear implants, and artifacts due to ferromagnetic implants do not occur. Use of

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Doppler further allows depiction of tissue inflammation and vascularity.

Although MRI is the most sensitive method for evaluation of soft-tissue injuries, sonography has proved to be effective for several indications. This article focuses on the most accepted indications of musculoskeletal sonography applicable to sports-related injuries.

TENDON ABNORMALITIES

Tendons represent the anatomic structure most commonly evaluated with musculoskeletal ultrasound. Normal tendons demonstrate a hyperechoic fibrillar echo texture; this appearance is due to a highly organized collagenous makeup (Fig. 1) (3). This makes tendons strongly anisotropic to sonographic examination, and adequate imaging is obtained only when the ultrasound beam is perpendicular to its collagen fibers.

Tears

Partial tears are characterized by hypoechoic or anechoic focal defects involving either the surface or substance of the tendon (Fig. 2). Longitudinal tears are best visualized in the transverse plane and appear as anechoic clefts (3,4). Continuous fibers are seen adjacent to a partial tear, and retraction is not a significant feature (3). However, partial tears are difficult to differentiate from tendinosis, because both pathologies may coexist and there may be overlap in their imaging features (4). Complete tears demonstrate disruption of all fibers and retraction of the torn edges, which may be seen within a hypoechoic or anechoic hematoma (Fig. 3) (3).

Nonretracted complete ruptures of rotator cuff tendons (i.e., perforations) show a full-thickness hypoechoic or anechoic area extending from the articular to bursal surface (Fig. 4). In case of a retracted massive rotator cuff tear, there is nonvisualization of the tendon with the deltoid muscle approximated to the greater tuberosity and humeral articular surface (5). The reported sensitivities for detection of rotator cuff tendon tears range from 33% to 100% due to variability in operator experience, equipment, and gold standards in several studies (4). More recent reports have demonstrated that sonography of the rotator cuff tendons can produce results at least equal to MRI if the technique is performed by an experienced individual. van Holsbeeck et al. (6) demonstrated that sonography can diagnose partial-thickness rotator cuff tears with 93% sensitivity and 94% specificity. In a study of 100 shoulders, Teefey et al. (7) obtained 100% sensitivity, 85% specificity, and 96% accuracy in detecting full-thickness rotator cuff tears. These results are comparable to those obtained with MRI (100% sensitivity and 95% specificity in the diagnosis of full-thickness tears) (8).

A few studies also demonstrate promising results in the evaluation of tears of ankle tendons. Waitches et al. (9) demonstrated 100% sensitivity and 93% accuracy in detecting tears of the posterior tibial, peroneal, and flexor digitorum longus tendons, with surgery as gold standard. Longitudinal splits of the peroneal tendons are demonstrable with sonography (10). In a study of 26 cases of tears of the Achilles tendon compared with surgical find-

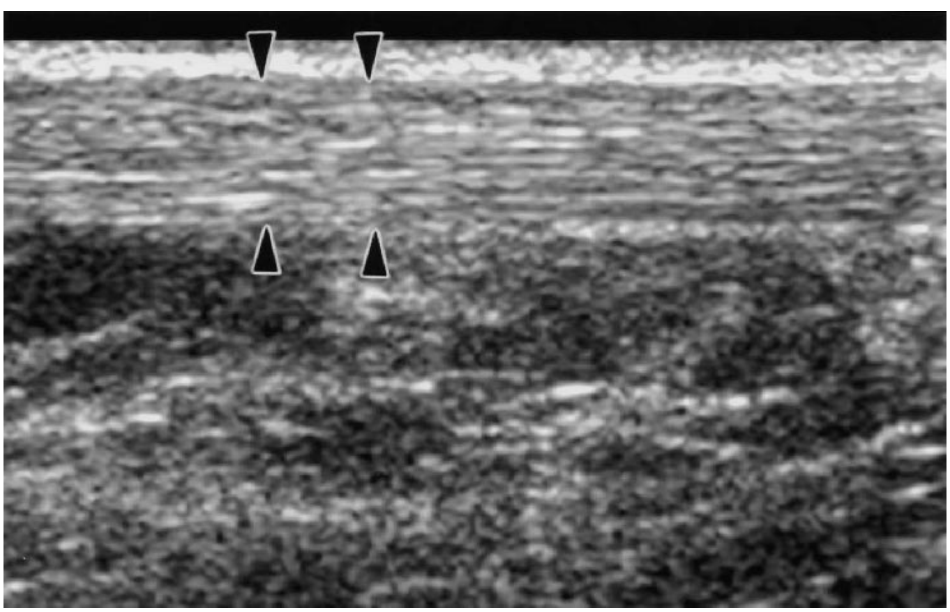
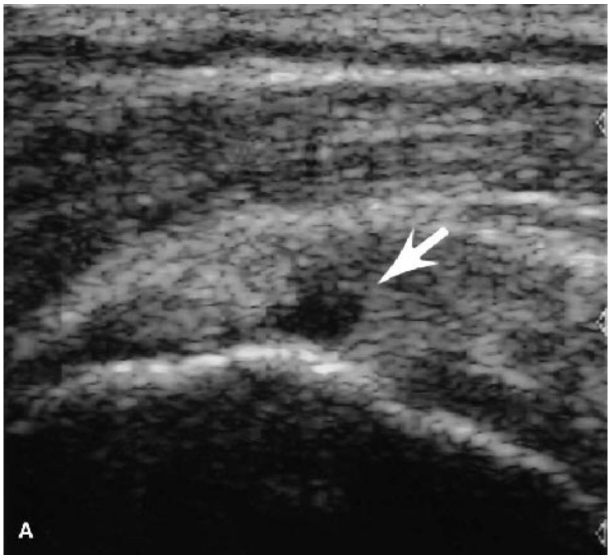


FIG. 1. Longitudinal scan of a normal tendon (between arrowheads) using a 12-MHz linear transducer. The typical hyperechoic fibrillar appearance is obtained when the ultrasound beam is perpendicular to the collagen fibers.



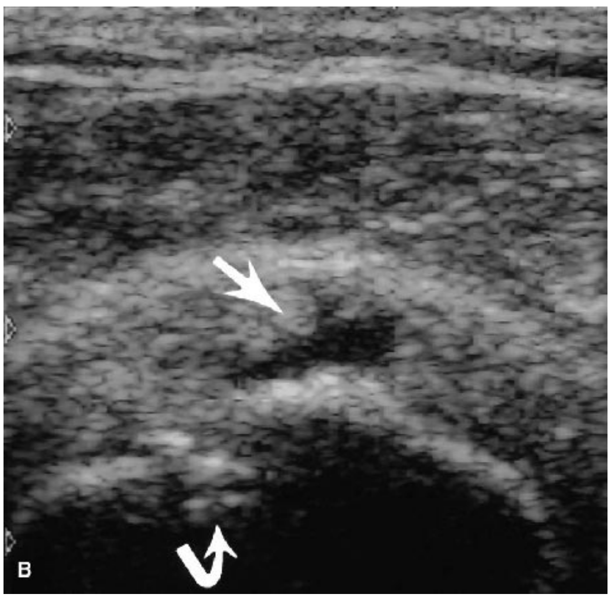


FIG. 2. Undersurface partial tear of the supraspinatus tendon. Longitudinal **(A)** and axial **(B)** scans demonstrate an anechoic gap (arrow) corresponding to discontinuity of tendon fibers. Visualization of this abnormality in two orthogonal planes increases diagnostic confidence. Cortical irregularity is a common finding adjacent to tears and is identified (curved arrow).

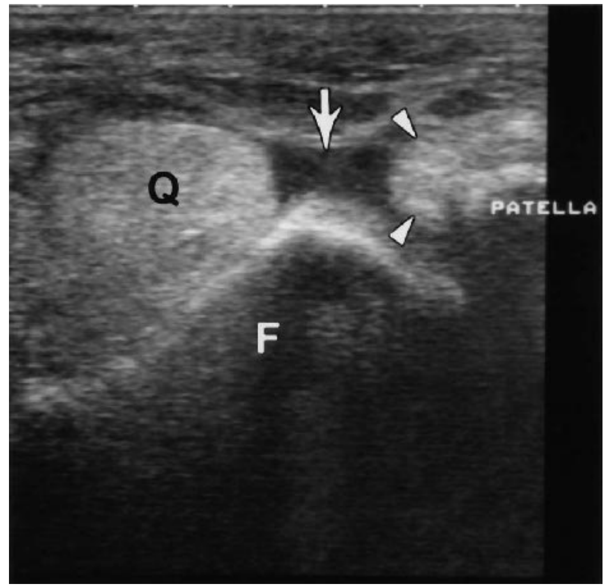


FIG. 3. Complete tear of the quadriceps tendon. Longitudinal scan of the suprapatellar region. A full-thickness defect filled with anechoic hematoma (arrow) is noted adjacent to the superior pole of the patella, in which residual tendon fibers are identified (arrowheads). The quadriceps tendon (Q) is retracted and hyperechoic due to hemorrhagic changes. F = femur.

ings, sonography differentiated full- from partial-thickness tears or tendinosis with 92% accuracy (11). Undetectable tendon at the site of injury, tendon retraction, and posterior acoustic shadowing demonstrated statistically significant correlation with full-thickness tears (11).

Tendinosis and tenosynovitis

Tendinosis usually presents as swelling and a diffusely heterogeneous hypoechoic appearance. These findings may be subtle or equivocal in mild cases, in which comparison with the asymptomatic side is invaluable. Calcifications and focal hypoechoic areas (representing fibromyxoid degeneration or partial tears) may be seen (3). Patellar tendinosis (also called jumper's knee) appears as hypoechoic enlargement of the proximal patellar tendon (Fig. 5) (12). Increased flow on color Doppler imaging may be detected (13). Similar findings may be identified in tendons of the rotator cuff (Fig. 6), elbow (14), and ankle (15). Premkumar et al. (16) compared the diagnostic accuracy of sonography with MRI in a series of 44 posterior tibialis tendons. The authors reported 80% sensitivity and 90% specificity for diagnosing tendinopathy, and 90% sensitivity and 80% specificity for diagnosing peritendinosis (16). In addition, Astrom et al. (15) demonstrated that ultrasound and MR provide similar information in the evaluation of chronic Achilles tendinopathy.

Tenosynovitis is characterized by hypoechoic or anechoic fluid distending the tendon sheath (Fig. 7), with inflammatory changes of the corresponding tendon (thickening and/or hypoechoic echo texture). Synovial proliferation of the tendon sheath can be detected, thus confirming concurrent synovitis. Doppler may be helpful to further evaluate for increased vascularity secondary to the inflammatory process.

Dynamic evaluation of tendon and nerve dislocation

Subluxation and dislocation of tendons, nerves, and muscles may occur in specific extremity positions or

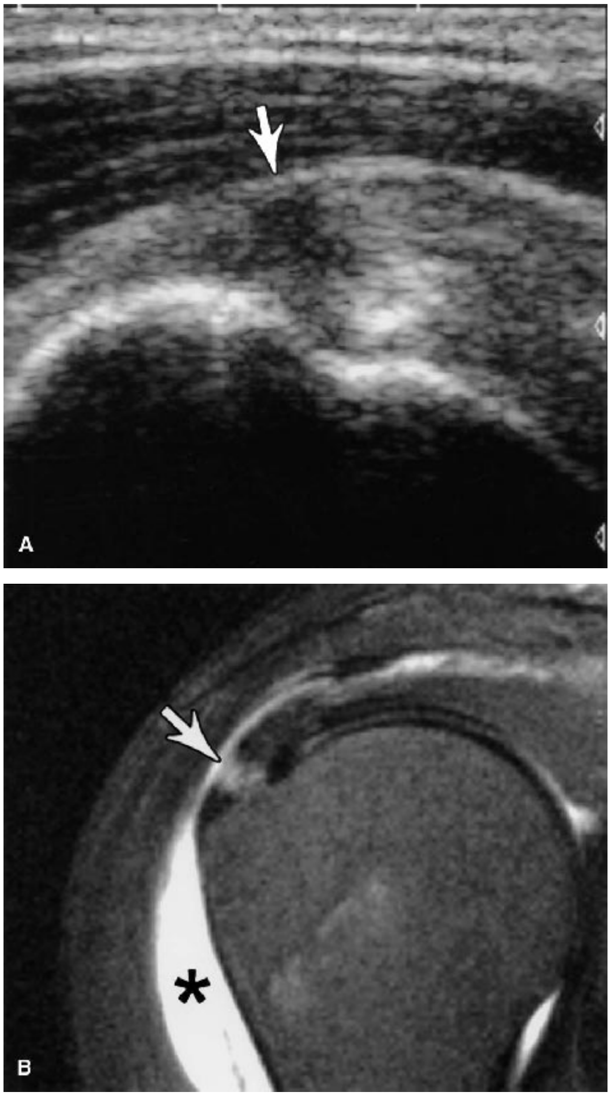


FIG. 4. Nonretracted full-thickness tear of the supraspinatus tendon. **A:** Longitudinal scan of the supraspinatus tendon demonstrates an abnormal hypoechoic gap corresponding to a full-thickness tear (arrow). **B:** Coronal oblique fat-suppressed T2-weighted MR image of the same patient also demonstrates the tear. A large quantity of fluid is present in the subdeltoid bursa (asterisk).

movements. Due to the static nature of MRI examinations, these abnormalities may reduce to normal anatomic location and remain undetected. Identification of tendon subluxation is important not only to explain symptoms, but also because it is a condition that predisposes to tears (17).

With active manipulation of joints during sonography, dislocation of tendons and nerves may be appreciated in real time. External rotation of the shoulder can elicit medial dislocation of the long head of the biceps tendon from the bicipital groove (Fig. 8) in patients with transverse humeral ligament and/or subscapularis tendon tears. In the elbow, ulnar nerve and triceps tendon dislocation can be detected with active flexion and extension of the joint (18). In the clinical setting of snapping hip syndrome, dynamic sonography has proven useful in the assessment of abnormal translation of the iliopsoas tendon and iliotibial band in relation to hip osseous structures (19). Ankle eversion and dorsiflexion demonstrate peroneal tendon subluxation as lateral translocation from the retromalleolar groove of the fibula (10).

MUSCLE INJURIES

Muscle fibers are arranged in parallel hypoechoic bundles surrounded by echogenic fibroadipose septa in a pennate configuration (Fig. 9). The importance of sonography in muscle injury is threefold (20): (1) to determine the extent of injury, as scar tissue formation is proportional to the degree of muscle involvement; (2) to determine the stage of healing—limited athletic activity is safe when the lesion has filled with hyperechoic tissue, and almost normal muscle architecture with peripheral organization is seen; and (3) assessment of the magnitude of scar formation—fibrotic scars are seen as hyperechoic zones within the muscle (Fig. 10) and often occur when the lesion was large or when sporting activities were resumed too early (21).

Sonography is capable of detecting a wide spectrum of muscle lesions caused by excessive fiber elongation. Minimal elongation injuries (grade 1) have no demonstrable fiber discontinuity (21); however, diffuse hyperechoic echo texture and swelling of the muscle may occur (Fig. 11) (22). Partial (grade 2) and complete (grade 3) tears show hypoechoic or anechoic fluid-filled gaps (Fig. 12) (21). Differentiation between elongations with and without tears is critical, because the former require at least 4 weeks of inactivity whereas the latter recover within a period of 1–2 weeks (21). As a general rule, muscle injuries should be assessed by ultrasound between 2 and 48 hours after the traumatic event, which is when the hematoma best outlines a potential tear (21).

Sonography is a reliable method to diagnose and stage tears involving the myotendinous junction of the medial gastrocnemius and plantaris muscles ("tennis leg") (Fig. 13) (23,24). This type of injury occurs most frequently during amateur sports practice due to powerful contraction of the gastrocnemius muscle with concomitant extension of the knee. This leads to excessive tensile force and disruption of the myotendinous junction characterized by detachment of the medial gastrocnemius muscle fibers from the distal aponeurosis (24). Rarely, the plantaris muscle may be involved (23). Clinical symptoms may overlap with those caused by ruptured Baker's cyst and deep ve-

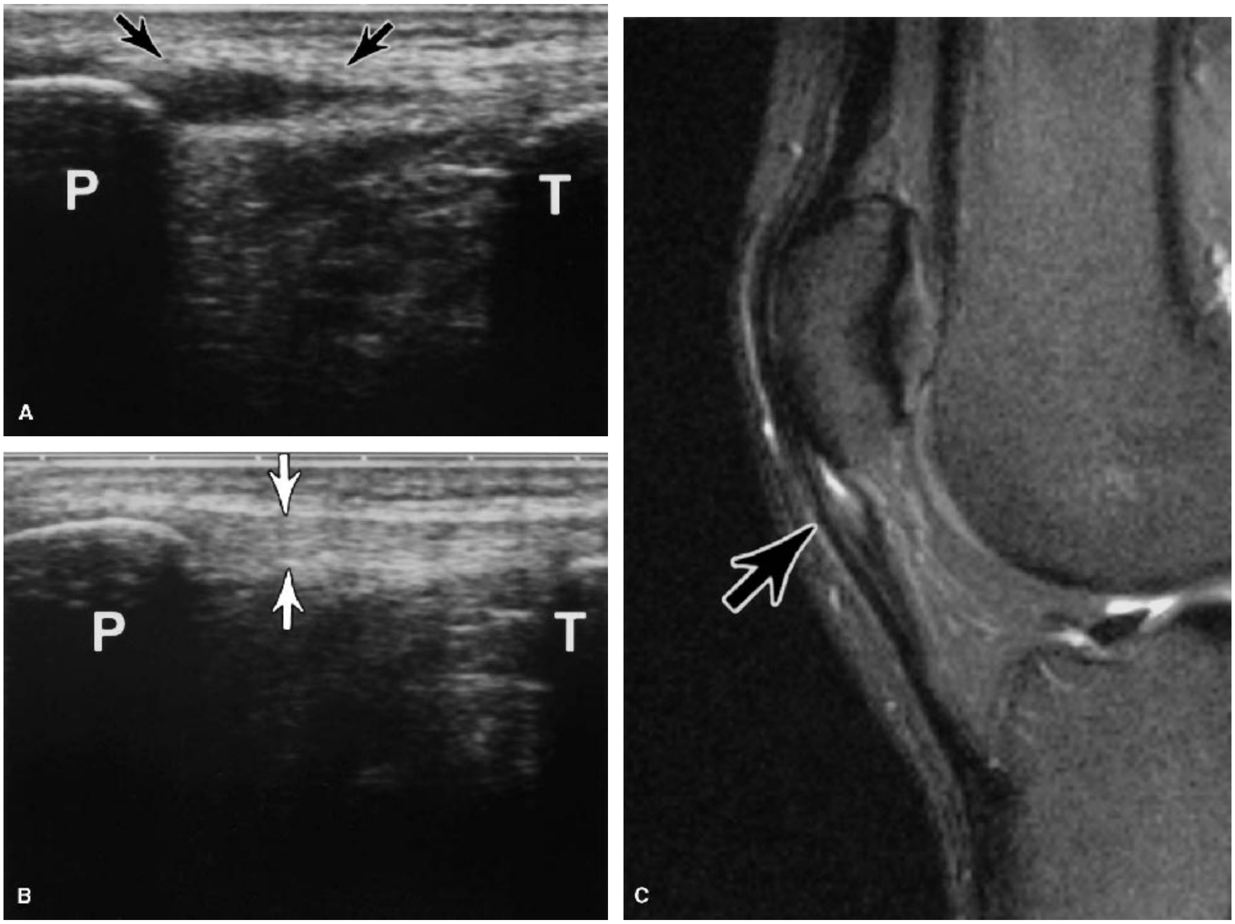


FIG. 5. Jumper's knee in a 29-year-old man. **A:** Longitudinal sonogram of the left knee (symptomatic) demonstrates a focal hypoechoic thickening (black arrows) adjacent to the inferior pole of the patella. **B:** Longitudinal sonogram of the contralateral knee (asymptomatic) shows a normal patellar tendon (between arrows) and demonstrates the advantage of prompt bilateral comparison. **C:** Sagittal fat-suppressed T2-weighted MR image of the left knee also demonstrates the abnormality (arrow) and high signal intensity suggestive of a partial tear.

nous thrombosis, which can be promptly differentiated with sonographic examination (23,24).

FLUID COLLECTIONS

Periarticular cysts are easily detected by ultrasound as well-defined anechoic structures with posterior acoustic enhancement. Sonography has been used effectively to diagnose and aspirate paralabral cysts of the glenoid (25). In the knee, meniscal and popliteal cysts can be promptly diagnosed (26). Ganglion cysts of the wrist can be differentiated from a fluid-filled dorsal radiocarpal recess using dynamic imaging. A joint recess typically collapses to some degree with wrist motion and transducer pressure, whereas a ganglion cyst tends to remain distended (26).

Subcutaneous, intramuscular, and intermuscular fluid collections are most commonly associated with posttraumatic hematomas. Most subcutaneous fluid collections are anechoic and easily compressible, with internal mobile septations. Intramuscular and intermuscular hematomas exhibit variable sonographic characteristics related to time elapsed since the traumatic event. In the first hours after trauma, the hematoma can still be diffuse, not collected, and appears as either hyperechogenicity of the muscle or abnormal distance between the muscle bundles with poor definition of the fibroadipose septa (21,24). After 2 hours, hematomas usually are hypoechoic or anechoic and may outline the torn margins of the affected muscle (21). If the aponeurosis is torn, the hematoma can spread outside of the muscle boundaries and not be seen.

Organization occurs in the ensuing 3–4 weeks, and progressive filling with fibrinous septations may occur. Occasionally, these fluid collections may remain hypoechoic or anechoic and have slow resorption (Fig. 14). This may require evacuation that can be easily performed with ultrasound-guided needle aspiration. Due to its lower cost

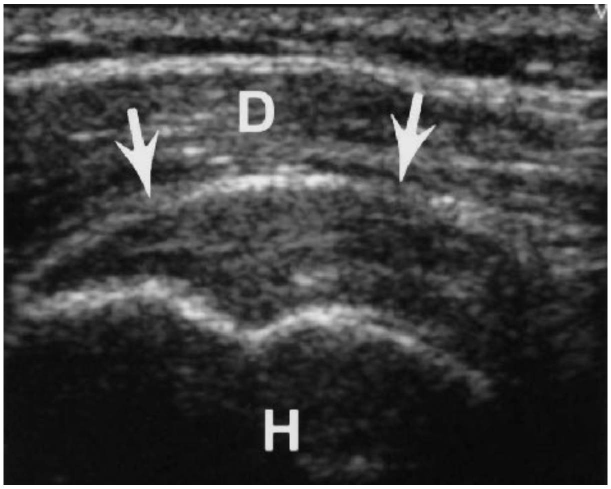


FIG. 6. Tendinosis of the supraspinatus tendon. Longitudinal scan shows diffuse swelling and hypoechogenicity (arrows) with no demonstrable tear or volume loss. D = deltoid; H = humeral head.

and availability, sonography is an effective method to follow soft-tissue hematomas.

Joint and bursal effusions are identified as anechoic fluid outlined by the synovial membrane. Synovitis can be detected by demonstrating villous projections along the inner lining of the synovium, which may demonstrate increased flow on Doppler examination.

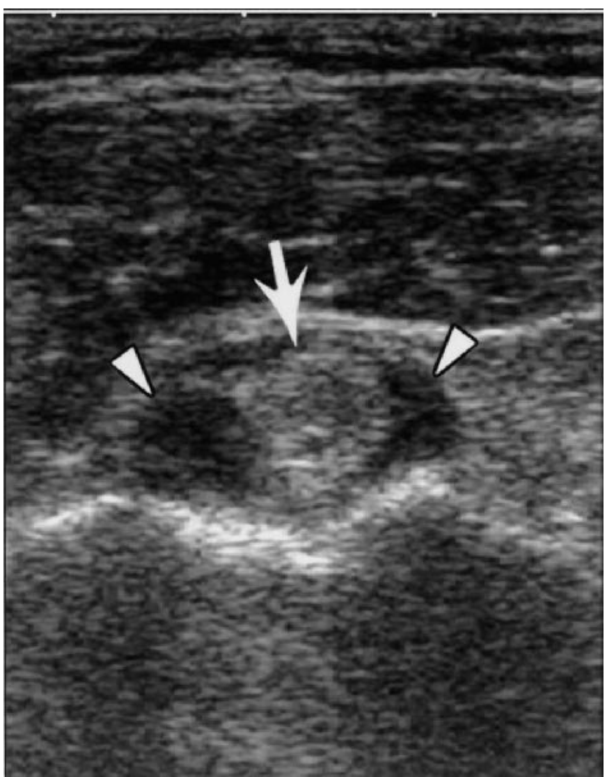


FIG. 7. Tenosynovitis of the long head of the biceps brachii. Axial scan at the level of the bicipital groove shows thickening and hypoechogenicity of the tendon (arrow), with surrounding fluid in the synovial sheath (arrowheads).

FIG. 8. Dislocation of the long head of the biceps brachii tendon in a 39-year-old woman. This patient sustained a subscapularis tendon tear after a fall. Axial scan at the level of the bicipital groove (G) obtained with external rotation of the shoulder shows medial displacement of the biceps tendon (curved arrow) and increased quantity of fluid in its sheath (arrow).

OTHER INDICATIONS

Sonography has experimentally been used in the evaluation of ligaments and cartilage, despite limitations in field

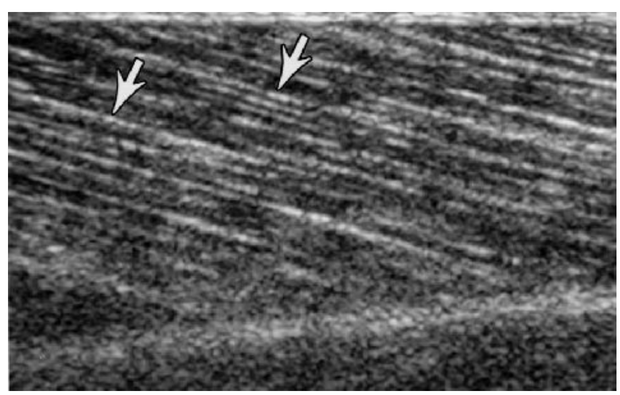


FIG. 9. Longitudinal scan of normal muscle using a 12-MHz linear transducer. Fibroadipose septa appear as linear hyperechoic areas (arrows) surrounding hypoechoic muscle bundles.

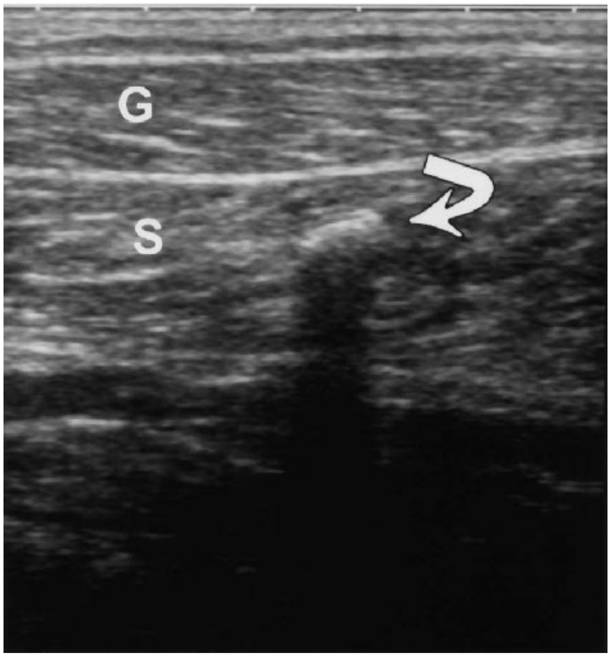


FIG. 10. Fibrotic scar in the soleus muscle 15 years after direct trauma sustained while the patient was training in martial arts. The hyperechoic scar (curved arrow) causes acoustic shadowing, which could be related to internal calcification or highly collagenous composition.

FIG. 12. Subacute tear of the hamstring muscles. Focal discontinuity of the fibroadipose septa is seen (arrow) with discrete internal fibrinous bridging, indicating early stages of healing.

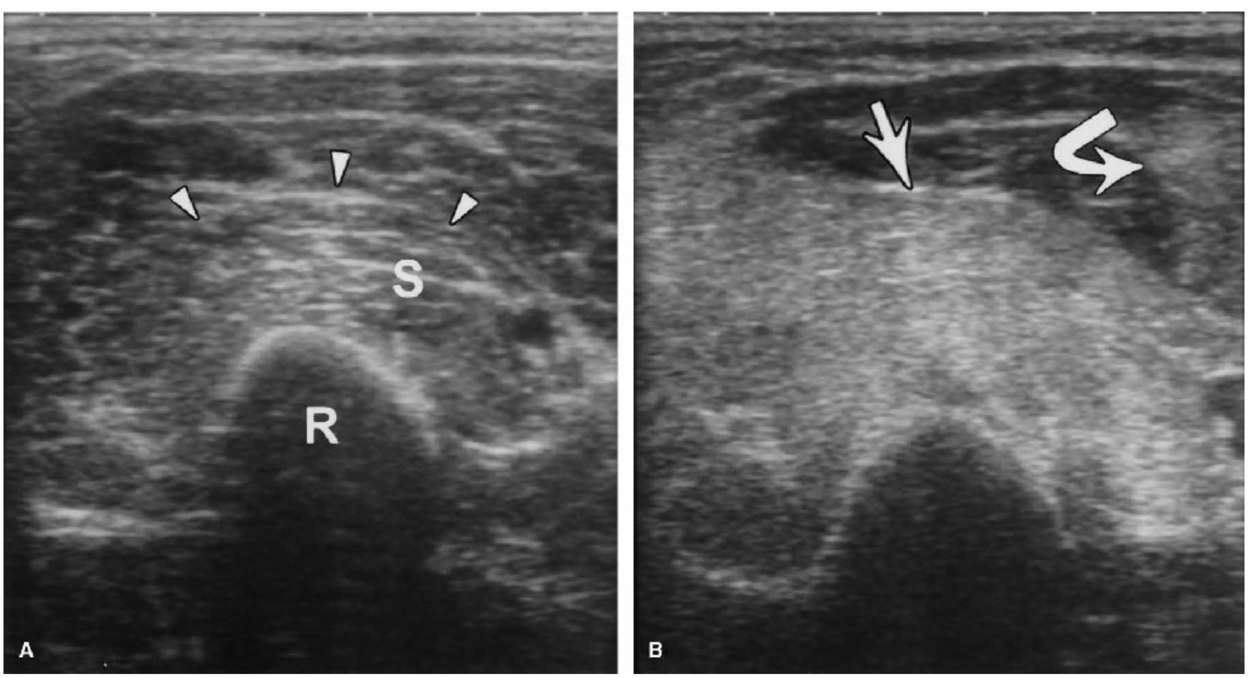


FIG. 11. Strain of the proximal forearm muscles in a 27-year-old man sustained after vigorous tennis practice without adequate physical conditioning. **A:** Normal muscles of the right proximal forearm. The supinator muscle (S) is outlined by arrowheads. R = radius. **B:** Marked diffuse swelling and hyperechogenicity of the left supinator muscle (arrow). Focal changes are noted in the left brachioradialis muscle (curved arrow).

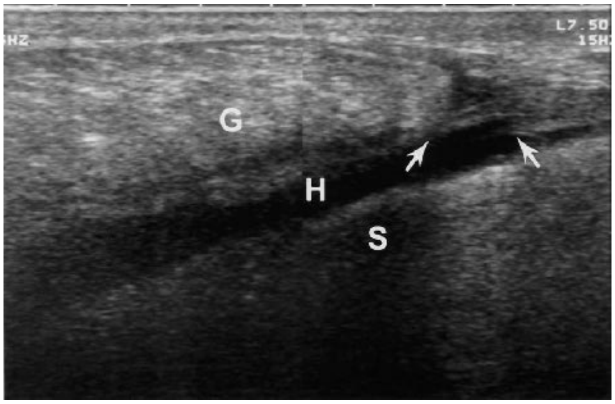


FIG. 13. "Tennis leg" injury in a 45-year-old man. Composite longitudinal scan of the medial gastrocnemius (G) shows partial disruption (arrows) at the myotendinous junction. An anechoic hematoma (H) is seen dissecting between the gastrocnemius and soleus (S) muscles.

of view and acoustic access. Future developments in these applications will be particularly helpful in patients with contraindications for MRI or invasive procedures with injection of contrast material.

The scapholunate, ulnar collateral (thumb and elbow), PCL, and anterior talofibular ligaments have been depicted by ultrasound with encouraging results (21,27–30). Injuries of the pulley system of the fingers have been effectively evaluated using dynamic ultrasound, with reported sensitivity of 98% and specificity of 100% (31). The anterior and posterior glenoid labra were studied with sonography, and the sensitivity in the diagnosis of tears has ranged from 67% to 95% (18,32). Cartilage defects and thickness have been assessed successfully with in situ and in vivo studies (33). Nevertheless, MRI presents unparalleled ability to demonstrate the entire articular surface of synovial joints and remains the method of choice for cartilage evaluation.

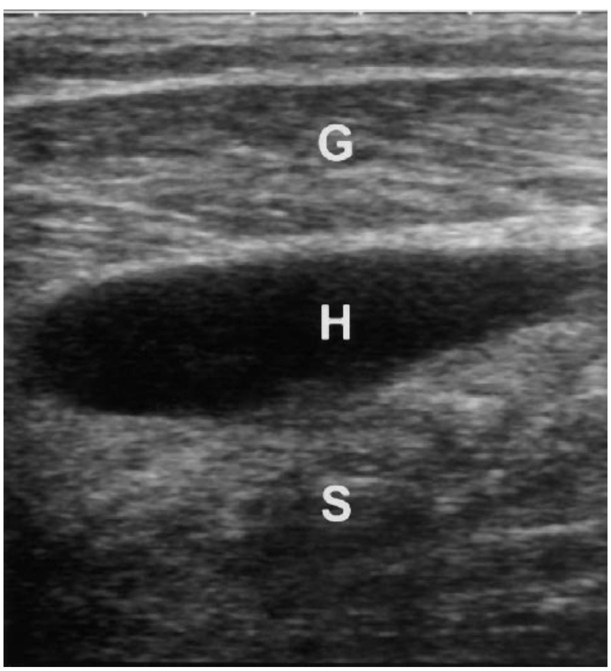


FIG. 14. Chronic intermuscular hematoma in a 30-year-old man. A hematoma (H) is seen between the medial gastrocnemius (G) and soleus (S) muscles, most likely related to a 'tennis leg' injury that occurred a few months earlier.

SUMMARY

Sonography is a reliable, accessible, and relatively inexpensive diagnostic modality for musculoskeletal imaging. With adequate equipment, training, and expertise, excellent results comparable to MRI can be obtained. Dynamic evaluation of joints with sonography allows diagnosis of conditions that may remain undetected with routine MRI. Additionally, musculoskeletal ultrasound provides direct correlation with patient symptoms and the option of prompt image-guided procedures. Continued research and experience have consistently established sonography as a reliable option for imaging specific sports-related injuries.

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