# Advances and utility of diagnostic ultrasound in musculoskeletal medicine

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**Abstract** Musculoskeletal ultrasound (US) can serve as an excellent imaging modality for the musculoskeletal clinician. Although MRI is more commonly ordered in the United States for musculoskeletal problems, both of these imaging modalities have advantages and disadvantages and can be viewed as complementary rather than adversarial. For diagnostic US, relative recent advances in technology have improved ultrasound's ability to diagnose a myriad of musculoskeletal problems with enhanced resolution. The structures most commonly imaged with diagnostic musculoskeletal US, include tendon, muscle, nerve, joint, and some osseous pathology. This brief review article will discuss the role of US in imaging various common musculoskeletal disorders and will highlight, where appropriate, how recent technological advances have improved this imaging modality in musculoskeletal medicine. Additionally, clinicians practicing musculoskeletal medicine should be aware of the ability as well as limitations of this unique imaging modality and become familiar with conditions where US may be more advantageous than MRI.

**Keywords** Ultrasound · Musculoskeletal · Sports injuries

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## Advantages and disadvantages of diagnostic US

There are several advantages and disadvantages to diagnostic musculoskeletal ultrasound as compared to other imaging modalities. First, diagnostic US is estimated to be less expensive than MRI [1]. Additionally, US is more patient friendly as claustrophobia, which may occur with MRI scanners, is not encountered with US imaging. When compared to MRI, patients with shoulder pain prefer diagnostic US [2]. MRI scans do have the advantage of examining a large area but may detect several "abnormalities" that may be clinically unrelated to the patient's complaints. Diagnostic US also can examine large areas with extended field of view (FOV) imaging, however the clinician can interact with the patient who can then direct the examination toward the symptomatic area [3] (Fig. 1). In this way, the clinician can focus the examination to the most relevant area.

US also has the advantage of being a dynamic study. For example, the affected part can be imaged in real time, observing for pathologic movement in tendon, bursa, muscles, or joints. Unfortunately, MRI does not offer this luxury, as there would be movement artifact distorting image quality. With diagnostic US, the patient simultaneously provides feedback and vital information to the examiner during the dynamic examination that may reveal tendon subluxation, joint subluxation, or ligamentous incompetence. Since the diagnostic US exam is real time, the patient and even the referring physician can receive results immediately and then can outline a treatment strategy within the same visit.

Unlike MRI, the traditional form of musculoskeletal imaging, clinicians are often unfamiliar with the images produced by US. Despite this, many specialties such as rheumatology, orthopedics, physiatry, and family practice

Fig. 1 Extended field of view (FOV) imaging allows the clinician to capture large areas of tissue that may be clinically involved. Here a longitudinal view of the entire medial gastrocnemius is viewed. Notice the pinnate appearance of the muscle fibers inserting on the brighter linear tendon. Ultrasound is an excellent modality for diagnosing injuries to muscle and tendon tissue

are integrating this imaging modality into their daily practices. The portability of US machines makes this feasible. Portable machines allow clinicians to examine patients in their offices, in the training room, and even on the field. Outside of a mobile scanner, this is not feasible with MRI.

Ultrasound offers advantages over fluoroscopy and CT scanning when utilized for interventional procedures. Although fluoroscopy or CT scan can be helpful in localization of the structure to be targeted, both require ionizing radiation. Fluoroscopy does not visualize soft tissues, relying on bony landmarks and often necessitates contrast in order to prevent inadvertent intravascular placement and to confirm placement. Some patients may be allergic to contrast and therefore need prophylactic medication to prevent a reaction. US does not utilize ionizing radiation and contrast is not needed. Therefore, various soft tissues and joints can be directly entered, aspirated, or drained. For example, when the piriformis muscle is injected with fluoroscopic techniques, it requires the use of pelvic bony landmarks to achieve correct placement [4], but without direct visualization it is not certain that the piriformis has been entered. However, recently Smith has described a novel technique whereby the piriformis can be entered utilizing direct ultrasound visualization [5]. This technique theoretically makes the rate of a false negative response much less. For more common injections, ultrasound guidance can also be advantageous. It has been estimated that attempted intra-articular knee injections may miss the joint in up to 29% of the cases [6]. With ultrasound guidance, the suprapatellar bursa, which communicates with the knee joint, cannot only be examined for an effusion and synovial proliferation, but can be entered under direct visualization.

Blind subacromial bursal injections as well are known to have an inaccuracy rate of 24–31% depending on the approach [7]. With ultrasound guidance however, this bursa appears as a visible thin hypoechoic (dark) line overlying the rotator cuff tendons and can be easily injected from a lateral approach (Fig. 2). In this way, ultrasound offers a more accurate and potentially more therapeutic interventional strategy to the musculoskeletal clinician than compared to blind subacromial injection [8].

One limitation that diagnostic ultrasound has is its dependence on body habitus. Ultrasound wave penetrance into tissue is inversely proportional to the wave frequency. For instance, a 12 MHz linear array transducer can visualize very superficial structures with high resolution, but imaging of a hip joint or rotator cuff in an obese or extremely muscular individual can be extremely limited. Although recent advances have improved high frequency linear array transducers, a lower frequency curvilinear transducer (3–5 MHz) may be needed to provide adequate penetration for deeper structures. With greater depth of penetrance, though, resolution can be sacrificed, making musculoskeletal US limited as a modality in obese or muscular patients. However, recent advances in tissue harmonics have improved visualization and resolution of deeper structures even in these challenging cases [3, 9].

Additional technical factors that affect US include artifacts that can mimic real pathology. Ultrasound involves the reliance of placing the transducer and hence the beam at a 90° angle to the structure being imaged [10]. Any deviance from this will result in the reflection of the beam away from the transducer, causing a reduction in the echogenicity (brightness) of the tissue being examined. This artifact is referred to as anisotropy and can be eliminated



Fig. 2 Longitudinal view of the supraspinatus tendon with faint hypoechoic linear subacromial bursa (arrow) and overlying deltoid muscle

by maintaining the beam perpendicular to the involved tissue (Fig. 3a and b). Good technique also involves maintaining adequate skin contact, confirming the presence of pathology in orthogonal planes, and using the appropriate transducer size for the specific situation.

## Tendon pathology

The evaluation of tendon pathology is probably the most common clinical indication to obtain a diagnostic musculoskeletal ultrasound. On US, normal tendon, which is composed of fascicles of collagen fibers running in parallel, appear as fibrillar hyperechoic (brighter) bands. In normal conditions, there will also be a flat hypoechoic structure surrounding the tendon, representing a synovial sheath containing a small amount of fluid [11]. An exception to this is the Achilles tendon, which has a closely adherent paratenon and is often normally imperceptible. In cases of
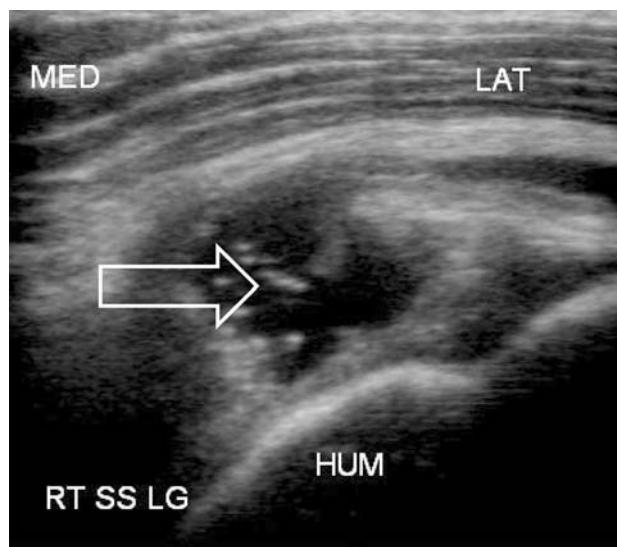
tenosynovitis, there will be an increase in synovial sheath fluid indicative of underlying inflammation. Exceptions do exist. A significant amount of fluid surrounding the bicep may indicate primary bicipital tendonitis. However, fluid around the biceps tendon may be a secondary sign of a complete rotator cuff tear as fluid communicates with the glenohumeral joint through the subacromial bursa [12].

Probably the most frequently studied musculoskeletal structure with US is the rotator cuff tendon. Many articles have been written defining criteria for partial and full thickness tears, the sensitivity, and specificity of diagnostic US, as well as the potential pitfalls associated with this modality [12–14]. Reports vary with the sensitivity as high as 100% for full thickness tears, but similar to MRI, US has a much lower sensitivity for partial thickness tears [14]. Several signs that indicate a full thickness rotator cuff tear include nonvisualization of the cuff, discontinuity of the cuff, cartilage interface sign, and interposition of the subacromial bursa (Fig. 4) or deltoid into the vacant tendon [12, 13, 15]. Criteria for determining partial cuff tears or tendonosis, like that of MRI, are somewhat controversial. These signs may include a thickened relatively heterogenous appearing tendon, cortical irregularity, as well as a defect in the cuff tendon that does not communicate fully through from the bursa to the articular side [15–17].

The Achilles tendon is another excellent structure well-defined with diagnostic US. The normal tendon thickness seen in cross-section (axial or transverse view) is approximately 5–6 mm [18, 19] (Fig. 5). Most pathology, including tears and tendonopathy occurs approximately 2–6 cm from the Achilles insertion [20]. US is helpful at



Fig. 3 (a) Transverse view of the proximal long head of the biceps in the bicipital groove. (b) Same image as in (a). Now the transducer is not 90 degrees to the tendon, causing it to appear hypoechoic (darker). This may mimic a tear of the tendon and is referred to as anisotropy



Fig. 4 Full thickness supraspinatus rotator cuff tear (arrow). Notice the dark fluid with some increased echogenicity within the tear. This is actually the subacromial bursa which has filled in the defect created by the cuff tear. (Photo Courtesy of Jay Smith, MD)

**Fig. 5** Transverse view of the Achilles tendon at the level of the posterior malleolus

confirming a complete versus partial tendon tear. However, a potential pitfall exists when the nearby medial plantaris tendon can be mistaken as partially intact Achilles tendon when in fact a complete tear is present [21].

Danielson et al. has recognized that tendonopathy may be due to abnormal penetrating neovascularization carrying nociceptive fibers [22]. Power or Color Doppler enables the examiner to identify these abnormal penetrating vessels in cases of Achilles tendonopathy [23, 24]. An eccentric calf-strengthening program is recommended to decrease this neovascularization [25]. This program theoretically decreases these infiltrating vessels via repetitive constriction. If this strengthening program does not resolve the patients' complaints, Alfredson has reported that injecting a sclerosing chemical into these aberrant vessels under US guidance results in normalization of the Achilles tendon and significant reduction of clinical symptoms [23].

Another advantage of ultrasonographic examination of tendons includes the ability to perform dynamic imaging. Small tendon tears on initial examination may go undetected. With sonopalpation or motion, further tendon separation may become apparent [26]. Owing to hematoma formation and associated debris, a complete Achilles tendon tear may be poorly demarcated. Yet with ankle dorsiflexion, a discontinuity will be more easily demonstrated [26]. Real time dynamic subluxation of tendons cannot be visualized with current MRI technology. With US however, biceps, peroneal, or posterior tibial subluxation or dislocation can be visualized with dynamic maneuvers. For the biceps, this may involve elbow flexion combined with forearm supination and glenohumeral external rotation. In the ankle, peroneal tendon subluxation over the lateral malleolus can be demonstrated with combined active ankle dorsiflexion and eversion [27].

## Ligament

Diagnostic musculoskeletal ultrasound has also been utilized to image various ligamentous injuries. A common elbow injury seen in overhead athletes, namely baseball pitchers, is a tear of the ulnar collateral ligament (UCL). This ligament (Fig. 6) normally resists the tremendous valgus forces that occur at the elbow during an overhead throw. Overtime, especially in pitchers, the anterior band of the UCL becomes lax and may rupture due to the tremendous valgus forces applied to the elbow during the throwing motion [28, 29]. Musculoskeletal ultrasound is an excellent imaging modality to clearly define the extent of an injury. Applying a valgus force during the examination, which simulates the force during the throw, has been shown to be an added benefit of this imaging modality in diagnosing UCL laxity [30].

Another common athletic ligamentous injury involving the ankle joint is a tear of the anterior talofibular ligament and if more severe, the calcaneal fibular ligament. Although ultrasound cannot detect underlying bone edema, it can aid in grading the severity of the tear, which may be helpful for prognosis and return to play. Like the elbow, applying additional stress may also aid in determining severity of ankle ligamentous injury [31].

Although it cannot detect intra-articular knee pathology such as meniscal or cruciate tears adequately, ultrasound can easily visualize the medial, lateral, and patellar ligaments quite readily. Particularly when combined with dynamic stress testing, US has been proven to be a sensitive test for detecting medial collateral ligament (MCL) tears [32]. The normal MCL is composed of a hyperechoic superficial and deep band separated by a hypoechoic layer representing loose areolar tissue [33]. In partial MCL injury or sprain,
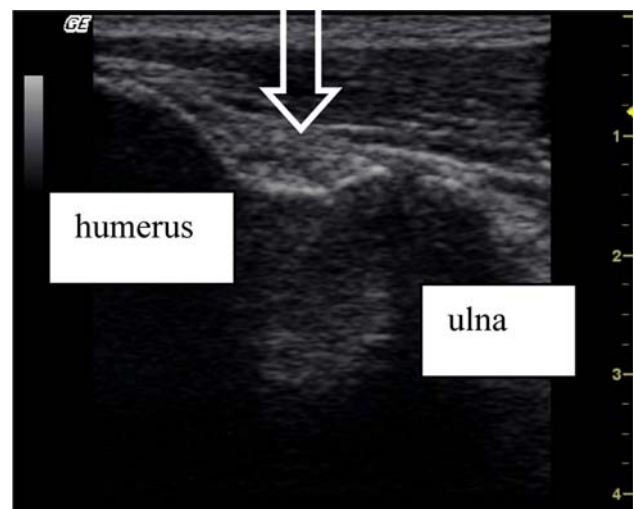


**Fig. 6** A normal appearing ulnar collateral ligament of the elbow (arrow)

thickening of the ligament will occur and the superficial and more commonly, the deep band will appear with decreased echogenicity. Complete rupture of the ligament will appear as an interruption of the hyperechoic bands within the ligament and there can be an associated fluid collection [33].

## Joints

Though plain radiographs and MRI are useful at assessing intra-articular and periarticular pathology, US can add a complementary role for these imaging modalities. For example, US is undeniably the best imaging modality for detecting small joint effusions, which are indicative of underlying joint pathology. In fact, effusions as small as one ml can be identified with diagnostic US [34] (Fig. 7). With these small effusions it may be difficult to blindly aspirate the joint. In these cases, US helps not only to locate the presence of an effusion but also serves as a guide for aspiration [35].

US can also aid in detecting the cause of the underlying effusion. Although MRI is superior at visualizing intra-articular pathology, Color or Power Doppler can detect concomitant increased blood flow detected in the synovium of inflammatory or infectious arthritis. The synovium in infectious or inflammatory arthritis is thickened, hypertrophic, and edematous, appearing as a hypoechoic band between muscle or fat [35, 36]. Most infectious effusions also have some component of echogenicity but may also give the appearance of a compressible hypoechoic mass [35]. Evaluation of large synovial joints is most easily performed at the suprapatellar recess of the knee, anterior synovial
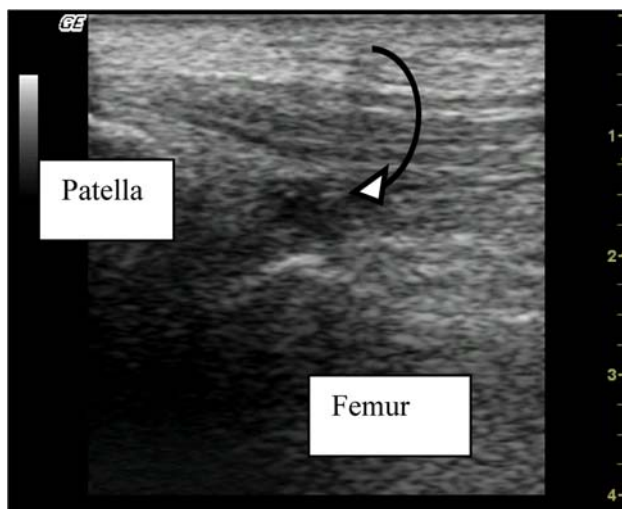


**Fig. 7** Normal appearing longitudinal view of the hypoechoic (dark) suprapatellar bursa (arrow) underlying the quadriceps tendon. The patella is the hyperechoic white structure to the left and the femur is the hyperechoic structure towards the bottom of the image. An effusion would be visible in this location

recess of the hip, and posterior synovial recess of the shoulder [35]. Measuring the thickness of the synovium in inflammatory arthritis has been shown to be a reliable means of following the effectiveness of therapy [37, 38].

Articular hyaline cartilage appears as a thin, hypoechoic line juxtaposed to the subchondral cortical bone. Early ultrasonographic findings compatible with cartilage pathology, in particular inflammatory and osteoarthritis, include edema. With edema there will be an increased thickness of the articular cartilage with inhomogenity and an ill-defined cartilage margin. Comparison with the opposite side may be helpful to obtain a baseline, however arthritic conditions are often symmetric. Chondral and osteochondral defects, which can occur through trauma, infarction, or osteonecrosis, can also be detected as loose bodies. If calcified, these loose bodies will appear with acoustic shadowing on musculoskeletal US [35].

Fibrocartilage, such as that found in the knee menisci, is composed of densely packed collagen fibers with interposed chondrocytes. This infrastructure is responsible for the homogenous hyperechoic appearance seen on US. Though US cannot penetrate into the joint proper to directly visualize cartilaginous injuries, there are secondary signs that may indicate underlying cartilage injury. Meniscal cysts in particular are most commonly located on the lateral joint line and often communicate with horizontal meniscal tears. They are frequently seen as hypoechoic, and occasional anechoic (without echogenicity) structures adjacent to the meniscus and often require surgical intervention for treatment [35].

Labral tears of the hip or shoulder can be identified using diagnostic musculoskeletal US, particularly if the defect extends to the peripheral joint margin where the cartilage can be examined [39]. Though MR arthrography remains the gold standard, it is an invasive and expensive procedure. With US, a non-invasive and relatively inexpensive test, there are a number of findings that indicate the presence of underlying labral pathology. Paralabral cysts of the hip or suprascapular ganglia are associated with concomitant labral pathology of the hip and knee joints, respectively. Van Holsbeeck has reported that US is particularly useful if used immediately after a dislocation. The intra-articular hemorrhage serves as a natural contrast medium and improves direct imaging of a labral tear [35]. However, until further research is performed utilizing US, MRI arthrography would still be considered the gold standard for imaging labral injuries.

## Muscle

It has been estimated that 30% of sports injuries affect muscles. The portability, ease of use, and superior spatial

resolution make ultrasonography an excellent imaging modality for detecting and classifying these injuries. Additionally, ultrasound can also identify non-traumatic or primary muscle pathology such as myositis [24, 40]. Occasionally patients are unable to completely localize the area involved especially when it involves a large muscle group such as the biceps femoris. However, extended FOV technology has made capturing large areas of muscle tissue feasible. US has an advantage over MRI when imaging obliquely running muscles. With MRI, the clinician has to follow obliquely running muscles like the sartorius on various cuts and sequences. However, the musculoskeletal ultrasonographer can follow this muscle from its origin to its insertion during one scan. Also if a muscle and its tendon is torn and retracted, MRI may not identify the location of the entire tendon. For example, in a complete quadriceps tear, standard knee MRI protocol may not include the distal torn portion. However, US offers the ability to track the torn portion proximally and is helpful in measuring the degree of retraction [11].

Muscle tears can result from either direct or indirect trauma [40]. In direct muscle injury, often there is significant contact, compression, and resultant destruction of muscle fibers. On US, these injuries are characterized by an irregular cavity with shaggy borders. Often this cavity may contain a hematoma that may limit complete evaluation but after 2–3 days the hematoma becomes anechoic, allowing true estimation of the injury. A complication of this direct trauma can be myositis ossificans (Fig. 8). With indirect muscle trauma there is
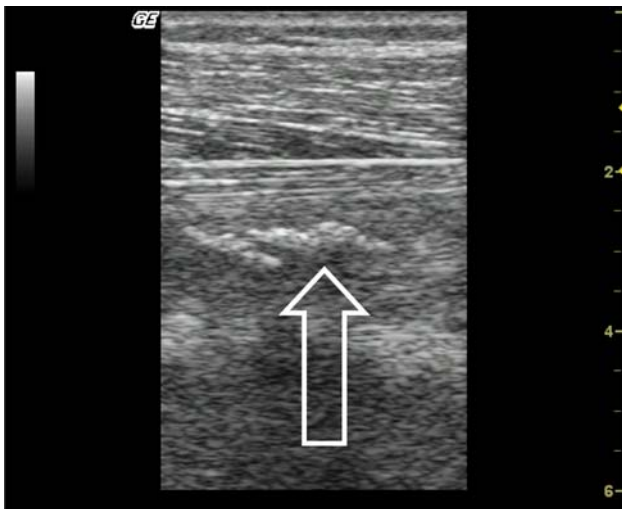


**Fig. 8** Longitudinal view of myositis ossificans (arrow) located deep within the vastus intermedius of a 40-year-old male basketball player. Note the irregular hyperechogenic (bright) structure representing the myositis ossificans. Four weeks prior to this, another basketball player's knee struck this athlete in the thigh that resulted in persistent pain with end range knee flexion

often an eccentric injury, which results in a tearing of muscle fibers at the myotendinous junction. These injuries can result in elongation, partial tear, or complete rupture. The more severe the injury, the more obvious the defect observed on US. Tears require good imaging technique with orthogonal views in the longitudinal and axial planes to properly identify the defect. These defects can appear as discontinuities of the muscle from the fibrillar tendon anchor. There may also be a hypoechoic gap identified with gentle transducer pressure is compressible, reproducing the patient's pain. This technique is often referred to as sonopalpation and is another advantage associated with US. As these muscular injuries heal, granulation tissue and regeneration occurs, appearing hyperechoic [40]. The degree of residual fibrous scarring may also help to predict the risk of recurrent injury [41].

## Nerve

There has been recent interest in imaging of the peripheral nervous system with US. One of the most common studied peripheral nerve entrapments is Carpal Tunnel Syndrome (CTS). In this condition, typically the proximal portion of the nerve becomes swollen while the portion coursing through the tunnel is compressed [42]. In one study, cross-sectional area of greater than $10.5 \text{ mm}^2$ was compatible with electrophysiological abnormalities seen on nerve conduction studies [43]. Additional abnormal US findings seen in CTS include a decrease in median nerve echogenicity and loss of the normal fascicular pattern. With more severe cases, there may also be an increase in blood flow within the nerve on Color Doppler [42]. Though US can be useful to help guide a therapeutic steroid injection near a neural structure for pain relief, a randomized study comparing it to blind injections has not been performed. However, by directly visualizing peripheral nerves, inadvertent injury can be avoided during injections. This complication has been described when performing blind carpal tunnel injections [44].

Morton's neuroma is an abnormal fibrous condition of the digital nerve most commonly located between the 3rd and 4th and second and third web spaces of the feet and may produce pain and paresthesias of the respective toes. When a neuroma is present, US examination of the plantar surface between the metatarsal heads will reveal an ill-defined, poorly reflective ovoid or fusiform mass measuring 5–7 mm in diameter [19, 45]. US can be additionally helpful in this painful condition since it can help guide a local steroid injection for pain relief [46].

## Bursae

Bursae are sac-like structures that facilitate movement of musculotendonous structures and are optimally visualized with diagnostic US [10]. Inflammation of these structures, commonly due to increased friction or trauma, can become a source of pain and dysfunction. The more common clinical conditions associated with these structures include subacromial, greater trochanteric, pes anserine, and olecranon bursitis. Normally, these structures on US appear as a thin hypoechoic line no more than 1–2 mm in height with hyperechoic boundaries reflective of a fluid tissue interface (Fig. 2) [47]. When enlarged, these bursae may be mistaken for soft tissue tumors yet they are fluid filled and therefore often compressible. Comparison with the opposite and hopefully asymptomatic side will provide a "normal" control for that patient. In chronic bursitis, the synovial walls of the bursa may become thickened with proliferative tissue and may have associated calcifications and internal hyperechoic debris [47]. The differentiation between infectious, metabolic, or inflammatory bursitis in these cases may be difficult, but US guided aspiration for fluid analysis helps decipher this clinical conundrum.

## Summary

Diagnostic US can serve as an excellent imaging modality for most musculoskeletal problems. Recent improvements in technology allow one to image various structures including tendon, muscle, joints, and even nerve with excellent resolution. Portability allows examination not only in the office but also in the training room and playing field. Low cost, real time imaging, and its ability to be used as a guide for interventional procedures make this imaging modality ideal for most musculoskeletal clinicians.

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