《Invited Lecture Review》

Musculoskeletal Ultrasound in Sports Medicine^{*1}

**Amy X YIN, MD,^{*2} Melissa COLBERT, MD,^{*2}
Joel STEIN, MD,^{*3} Joanne P BORG-STEIN, MD^{*2}**

Introduction

Diagnostic musculoskeletal ultrasound is the use of sound waves to evaluate soft tissues and bony structures in the body. Ultrasound has been used extensively as a therapeutic modality for decades. However, its diagnostic application did not arise until the introduction of high-frequency transducers in the 1980s, which allowed for more detailed anatomic imaging necessary to evaluate the musculoskeletal system.¹⁾

Musculoskeletal ultrasound provides several advantages over other imaging techniques including plain radiography, computer tomography (CT), and magnetic resonance imaging (MRI). Ultrasound is able to provide a fast, portable, and relatively inexpensive way for high-resolution imaging of soft tissue. There is no radiation, minimal metal or hardware artifact interference, and no known contraindications. Images are produced in real-time, which allows for interactive and dynamic examinations of anatomic structures.²⁾ Precise localization of symptomatic structures by sonopalpation, localizing the maximally tender structures with the ultrasound probe, can allow for focused examination. Provocative testing can be performed under ultrasound visualization to evaluate pathologies such as dislocating tendons or nerves.^{3,4)} Ultrasound can also easily be used to guide procedures like aspirations or injections.⁴⁾

However, there are several disadvantages to muscu-

loskeletal ultrasound as well. The most significant limitations relate to the field of view and scope of penetration.¹⁾ Since only a limited area is visualized with ultrasound, pain that is poorly localized may be better evaluated with other imaging modalities like plain radiographs, CT, or MRI. Ultrasound also has lower resolution at greater body depth and incomplete penetration into bone. This makes it difficult to fully assess intra-articular regions, areas deep to the bone, deep body regions, and anatomy of obese patients.⁵⁾ The use of musculoskeletal ultrasound is further limited by the skill of the examiner and the great variety in technical specifications of ultrasound machines available.

Musculoskeletal ultrasound, when used appropriately, can be an important tool in the arsenal of the musculoskeletal and sports medicine clinician. This article provides an overview of the fundamentals of clinical musculoskeletal ultrasound imaging.

Basics

Clinicians should have a basic understanding of the equipment, educational resources, and common terminology in musculoskeletal ultrasound.

1. Equipment

Ultrasound equipment consists of a machine body, housing a central processing unit (CPU) or the "computer brain," and a transducer probe which is connect-

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^{*2} Department of Physical Medicine & Rehabilitation, Spaulding Rehabilitation Hospital, Harvard Medical School, 125 Nashua St, Boston, MA, 02114, USA

^{*3} Department of Rehabilitation Medicine, New York-Presbyterian Hospital, Weill Cornell Medical College, Columbia University Medical Center, Harkness Pavilion Room HP-1-165, 180 Fort Washington Ave, New York, NY 10032, USA
E-mail : ayin@partners.org

ed to the machine body by a cord. Essentially, the CPU sends electrical current into the transducer, where there is an array of crystals which become stimulated and vibrate. The vibration of these crystals generates sound waves. The sound waves travel into the body until they encounter an acoustic interface, or a point where there is a change in the density of tissues. Depending on the density of the tissue the sound waves hit, a portion of the wave is reflected back to the transducer and a portion passes through. The transducer receives the reflected signal and transmits it to the CPU, where an image is generated based on the depth and amplitude of the returning sound wave.⁵⁾ Thus, ultrasound images are not based on absolute density of a tissue but the relative density to adjacent regions.¹⁾ Note that ultrasonographic coupling gel is used to facilitate transmission of these sound waves between the transducer and the body.

Current ultrasound machines differ significantly in terms of performance, size, and cost. Costs can range from \$20,000 to more than \$100,000, depending on quality of the machine, the machine capabilities, and the number and types of transducer probes. The imaging frequency range is one key aspect in determining the ultrasound machine's capabilities. The frequency of sound wave an ultrasound machine can generate is determined by the electrical current the CPU produces and the type of crystal in the transducer. In general, ultrasounds that can generate higher frequency sound waves produce better spatial resolution and higher quality imaging. Ultrasound machines may also have special features such as high-sensitivity Doppler imaging, spatial compounding, frequency compounding, harmonic imaging, or extended fields of view (panoramic imaging), which may enhance the utility of the ultrasound machine.¹⁾

2. Education & Training

Clinicians who incorporate musculoskeletal ultrasound into their practice usually learn via peer mentoring, continuing education courses, and online educational opportunities and resources (See **Table**). There is currently no cohesive educational infrastructure or

certification/accreditation process to standardize the ultrasound practitioner.

3. Terminology

There are several key terms essential for understanding and describing musculoskeletal ultrasound. First, musculoskeletal ultrasound is typically conducted in orthogonal (perpendicular) planes. Both transverse and longitudinal views should be obtained. The transverse plane provides a short axis, cross-sectional view of the structure and surrounding tissues, while the longitudinal view provides imaging of structures in the long axis.⁶⁾

Second, echogenicity is the relative capability of different structures to reflect sound waves.⁶⁾ Echogenicity can be described as hypoechoic, hyperechoic, isoechoic, or anechoic. Hypoechoic tissue appears darker relative to other structures because fewer sound waves are reflected back to the transducer, either because of decreased density or increased depth. Hyperechoic tissues appear brighter relative to neighboring structures because their greater density causes more sound waves to be reflected back to the transducer. Isoechoic structures have equal echogenicity and appear similar to one another on imaging. Anechoic structures are devoid of echogenicity altogether and appear black.¹⁾ Echotexture is the internal pattern of echoes within a structure and can vary depending on the plane of view.⁷⁾

Third, anisotropy describes something that has different properties in different directions. In the setting of musculoskeletal ultrasound, anisotropy occurs when a structure appears differently depending on the angle the sound wave hits that structure.⁶⁾ A structure that demonstrates anisotropy may appear smooth and homogeneous when the transducer is perpendicular to the plane of the structure. However when the transducer and thus the sound waves are angled, that same structure may appear to have hypoechoic or heterogeneous region. One example is that tendon fibers are hyperechoic when the transducer is placed perpendicular to the tendon, but may appear hypoechoic if the ultrasound waves contact the fibers at an oblique angle. Tissues susceptible to anisotropy, from greatest to least

Table Online educational resources for musculoskeletal ultrasound

American Institute for Ultrasound in Medicine (AIUM) : www.aium.org
European League Against Rheumatism (EULAR) : www.eular.org
European Society of Skeletal Radiology (ESSR) : www.ESSR.org
University of Michigan Ultrasound : http://www.med.umich.edu/rad/muscskel/mskus/

susceptible include tendon, ligament, nerve, muscle.¹⁾

Anatomy

Since the main clinical use of musculoskeletal ultrasound is the examination of tissues for diagnosing pathology or targeting interventions to sites of abnormalities, clinicians should be familiar with the normal and abnormal ultrasonographic appearance of bodily structures.

1. Tendons

The ultrasonographic appearance of tendons is normally hyperechoic with a parallel fibrillar pattern during longitudinal scanning (See Fig. 1) and a “broom-end” appearance during transverse scanning.⁸⁾ As previously noted, tendons exhibit significant anisotropy. With sonopalpation, tendons should not appear to compress since they are solid structures. They should also normally not exhibit blood flow on Doppler evaluation. Bursas adjacent to tendons are not typically visible unless there is pathological change. The exceptions to this rule are the subacromial-subdeltoid, retrocalcaneal, and the deep infrapatellar bursae.⁷⁾

Common abnormal findings with ultrasound evaluation of tendons include tendinosis, tenosynovitis, or tendon tears. Tendinosis may appear as diffuse or regional

tendon enlargement, new areas of hypoechogenicity (See Fig. 1), and/or an increase in the interfibrillar distance due to intratendinous edema and an increase in interfibrillar ground substance.^{7,8)} The echotexture is usually relatively maintained.

Partial-thickness tendon tears will have the additional finding of focal regions of anechogenicity with loss of the normal fibrillar pattern. High-grade partial-thickness tears may appear as tendon thinning because of loss of tendon substance. Full-thickness tears will appear as a tendon gap. High-grade partial-thickness tears and non-retracted full-thickness tears may be differentiated using dynamic stress or provocative testing via passive stretching or muscle activation which can reveal the gapping of a full thickness tear. Comparison with the unaffected side may help also detect subtle changes.²⁾

Tenosynovitis may vary in appearance between a simple, anechoic fluid collection to a complex, mixed-echogenicity collection surrounding a tendon.⁸⁾ Synovial hypertrophy and intratendinous calcifications, which appear as linear or ovoid hyperechoic structures, may also be visible.⁷⁾

2. Ligaments

Ligaments demonstrate a similar appearance to tendons on ultrasound imaging, and may also appear fibril-

Fig. 1

LEFT : Longitudinal view of an Achilles tendon demonstrating the normal fibrillar pattern.

RIGHT : Longitudinal view of an Achilles tendon demonstrating tendinosis with an area of hypoechogenicity (arrow).

lar during longitudinal scanning and have a “broom-end” appearance on transverse scanning, but can be less compact than tendons with a more diverse pattern of collagen bundles⁷⁾ (See **Fig. 2**). Ligaments can be distinguished from tendons by tracing the ligament to the bony structures they attach to.

Ligamentous abnormalities manifest very similarly to tendons. Low-grade ligamentous injuries may appear as enlarged and/or hypoechoic ligaments with relatively normal echotexture. More severe injuries such as partial- or full-thickness ligament tears may demonstrate fiber disruption. Again, comparison with normal anatomy or dynamic testing may help provide more information. For example, stress testing may not only differentiate partial versus full-thickness tear but also assess joint stability.²⁾

3. Muscles

The ultrasonographic appearance of muscle fascicles is typically hypoechoic, with surrounding connective tissue (epimysium and perimysium) that is hyperechoic.⁹⁾ The hyperechoic perimysium also separates individual muscles via intermuscular septae. The contrast between hypoechoic muscle fibers and hyperechoic intramuscular septae, as viewed in the transverse plane, is frequently described as a ‘starry night’ appearance

(See **Fig. 3**). In the longitudinal plane, muscle may appear pinnate like a “feather” or “veins on a leaf,” with fascicles attaching obliquely at the musculotendinous junction.⁷⁾

The most common muscle abnormality seen on ultrasound is muscle strain or tear. Muscle strain is classified into three grades. Grade 1 muscle strain is defined as microscopic tissue disruption, which may have a normal appearance on ultrasound. A minimal increase in echogenicity of the muscle due to perifascicular fluid can be noted. Grade 2 muscle strain is defined as a partial thickness muscle tear with concomitant decrease in muscle strength. Ultrasound examination will reveal interruption of the parallel fibers in the echogenic perimysial striae. Grade 3 muscle strain denotes a full thickness tear and total loss of muscle function, seen on ultrasound as a rounded hyperechoic muscle end surrounded by hypoechoic hematoma. Muscle atrophy can also be demonstrated on ultrasound by decreased muscle size and increased echogenicity.¹⁰⁾

4. Nerves

Nerves demonstrate mixed echogenicity on ultrasound because the hypoechoic nerve fascicles are surrounded by hyperechoic interfascicular and external epineurium.¹¹⁾ Nerves appear fascicular on longitudinal scanning and exhibit a “honeycomb” appearance on transverse scanning (See **Fig. 4**). Nerves can be differentiated from tendons by their echotexture, relative lack of anisotropy, location, and proximity to vessels.⁷⁾

Abnormal nerve findings may include regional swelling or diffuse hypoechogenicity, signaling inflammation, and loss of normal fascicular patterns of peripheral nerves (See **Fig. 5**). Entrapment of peripheral nerves can be localized by evaluation of swelling proximal to entrapment sites and focal narrowing at the site of entrapment, which is also known as a “notch sign”.¹¹⁾

Bone & Joints

On ultrasonographic imaging, bones appear as a linear, smooth hyperechoic border.¹²⁾ Because most of the ultrasound beam is reflected, structures underlying the bone will appear almost completely black. This is known as posterior acoustic shadowing.⁷⁾

Joint abnormalities visualized on ultrasound imaging include effusions, synovitis, or bursitis.⁷⁾ Simple joint effusions appear as compressible hypoechoic fluid contained within the joint capsule (See **Fig. 5**). Synovitis is characterized by thick synovium with irregular echoge-

Fig. 2 Longitudinal view of the normal sacrotuberous ligament (LIG) between the sacrum (SACRUM) and ischial tuberosity (ISCH TUB) demonstrating the more diverse pattern of collagen bundles.

Fig. 3

LEFT : Transverse view of the left rectus abdominis muscle with a Grade 2 muscle strain and partial thickness tear (arrows) demonstrated by enlargement of the muscle, change in the muscle echogenicity, interruption of some muscle fibers, and hypoechoic hematoma.

RIGHT : Transverse view of the right rectus abdominis muscle with the normal "starry night" appearance.

Fig. 4 Transverse view of the median nerve (Median N) demonstrating normal "honeycomb" appearance.

nicity. Bursitis may be present if there is expanded synovial fluid of variable echogenicity within a hypoechoic sac containing visible margins (acute), or a similar sac that is thickened (chronic).

Bony abnormalities such as periostitis, superficial or small bone fractures, or stress fractures may be seen on ultrasound, and appear as irregularities or disruptions of the normally smooth bony surface.¹²⁾ However, in contrast to joint pathology, bony pathology is less reli-

Fig. 5 Ultrasound of a hip joint with an effusion (arrow) demonstrated by a hypoechoic collection in front of the hyperechoic bone border.

ably evaluated by ultrasound and alternate studies should be utilized.

Fig. 6 Transverse view of the greater saphenous vein (arrow) anterior to the medial malleolus demonstrating the normal tubular hypoechoic appearance of vessels.

6. Vessels

Arteries and veins appear as tubular hypoechoic or anechoic structures (See **Fig. 6**) that demonstrate blood flow on Doppler examination.⁷⁾ Arteries are differentiated from veins due to their pulsatile blood flow during compression by sonopalpation.

Clinical Applications & Conclusion

Musculoskeletal ultrasound is a powerful diagnostic aid in the evaluation of soft tissues and bony structures. Musculoskeletal complaints that are difficult to diagnosis in the office by history and physical examination alone can be assisted by the use of ultrasound. A full discussion of the spectrum of pathologies that can be evaluated by musculoskeletal ultrasound is beyond the scope of this paper, especially given its continuous rapid evolution.

Furthermore, ultrasound-guided procedures are increasingly performed. The benefits of conducting ultrasound-guided interventions include direct visualization of targeted areas as well as neurovascular structures that should be avoided, and precise needle localization and position for direct injection of medications. A few ultrasound-guided injections supported by randomized controlled trials include corticosteroid injections of the shoulder, injections into tendons of the hand, such as

for de Quervain's tenosynovitis and trigger finger, as well as botulinum toxin type A injections in various muscles and tendons sheaths. There are also prospective comparative studies suggesting the possible utility of ultrasound-guided prolotherapy and autologous substances injections.¹³⁾

In summary, ultrasound produces detailed anatomic images of tendons, ligaments, muscles, nerves, bones, joints, and other structures in the body. Diagnostic and interventional musculoskeletal ultrasound can be a key tool for physicians in the care of their patients in the field of sports medicine.

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