# MUSCULOSKELETAL ULTRASOUND

A brief overview of diagnostic and therapeutic applications in musculoskeletal medicine.

By Elmer G. Pinzon, MD, MPH and Randy E. Moore, DC, RDMS

The use of musculoskeletal ultrasound (US) has been in the realm of radiology and physiatric medicine specialists for over 50 years following the foundation of the American Institute for Ultrasound in Medicine (AIUM) in 1951.[1] The AIUM is a "multidisciplinary association dedicated to advancing the safe and effective use of ultrasound in medicine through professional and public education, research, development of guidelines, and accreditation."[2] With these principles in place to promote this mission, the AIUM, in collaboration with the American College of Radiology (ACR), developed the *AIUM Practice Guideline for the Performance of the Musculoskeletal Ultrasound Examination*, effective as of October 1, 2007. Practice guidelines of the AIUM are intended to provide the medical ultrasound community with guidelines for the performance and recording of high-quality ultrasound examinations.

Initially, diagnostic ultrasound applications were limited due to poor resolution and lack of real-time imaging capability.[3] During the subsequent years, physiatrists began to lead the medical community with the use of therapeutic ultrasound techniques.[4] In the 1980s, with the use of real-time ultrasonographic imaging and detailed anatomic imaging, diagnostic musculoskeletal ultrasound became capable of fully evaluating the musculoskeletal system. With equipment cost reductions and resolution improvements, this field has expanded to various clinical practices that diagnose and treat musculoskeletal disorders. Many practitioners have now incorporated diagnostic ultrasound to diagnose pathology in tendons, nerves, ligaments, joint disorders and, subsequently, for use in performing therapeutic procedures with ultrasound-guidance techniques.

## Fundamental Concepts in Musculoskeletal Ultrasound

Musculoskeletal ultrasound involves the use of high-frequency sound waves (3-17 MHz) to image soft tissues and bony structures in the body for the purposes of diagnosing pathology or guiding real-time interventional procedures. Using high-resolution scanning produces detailed anatomic images of tendons, nerves, ligaments, joint capsules, muscles and other structures in the body. Practitioners may now use ultrasound guidance to diagnose tendonosis, partial- or full-thickness tendon tears, nerve entrapments, muscle strains, ligament sprains and joint effusions—as well as guide real-time interventional procedures for treatment modalities.

Some basic terminology used in ultrasound lexicon:[5,6]

**Echotexture** refers to the coarseness or non-homogeneity of an object.

**Echogenicity** refers to the ability of tissue to reflect ultrasound waves back toward the transducer and produce an echo. The higher the echogenicity of tissues, the brighter they appear on ultrasound imaging.

**Hyperechoic** structures are seen as brighter on conventional US imaging relative to surrounding structures due to higher reflectivity of the US beam.

**Isoechoic** structures of interest are seen as bright as surrounding structures on conventional US imaging due to similar reflectivity to the US beam.

**Hypoechoic** structures are seen as darker relative to the surrounding structures on conventional US imaging due to the US beam being reflected to a lesser extent.

**Anechoic** structures that lack internal reflectors fail to reflect the US beam to the transducer and are seen as homogeneously black on imaging.

**Longitudinal** structure is imaged along the long axis.

**Transverse** structure is imaged perpendicular to the long axis.

**Shadowing** is the relative lack of echoes deep in an echogenic structure due to attenuation of the ultrasound beam (e.g., to large calcifications, bone, gas, metal).

**Posterior acoustical enhancement** is the brighter appearance of tissues deep in an area where there are few strong reflectors to attenuate the sound beam (e.g., simple fluid is anechoic since there are no internal reflectors to produce echoes). Thus, the sound beam that passes through the fluid is stronger than when at the same depth in soft tissue.

**Anisotropy** is the effect of the beam not being reflected back to the transducer when the probe is not perpendicular to the structure being evaluated (e.g., an angled beam on bone would create an anechoic artifact since the beam is reflected at the angle of incidence away from the transducer).

## Ultrasound Imaging Advantages

Musculoskeletal ultrasound provides several distinct advantages in relation to basic radiography (X-rays), computed tomography (CT) and magnetic resonance imaging (MRI)—especially in focused musculoskeletal and neurological examinations.[1,7] Ultrasound is a hands-on, dynamic, and interactive examination which allows the practitioner to use real-time high-resolution soft tissue imaging. It also facilitates dynamic examination of anatomic structures while interacting with the patient during the conduct of the imaging study. US imaging is minimally affected by metal artifacts (e.g., cochlear implants, hardware, or pacemakers) and can also be used in certain patients that are contraindicated for MRI imaging (e.g., claustrophobic or obese patients). US imaging facilitates the ability to guide minimally-invasive, interventional procedures (e.g., intraarticular injections and aspirations). It also enables rapid contralateral limb examination for comparison studies. The obvious advantages of US—such as portability, relatively low cost compared to other imaging, lack of radiation risk, and no known contraindications—are good reasons to consider using this modality.

## Ultrasound Disadvantages

Practitioners, however, must also recognize several notable disadvantages in musculoskeletal ultrasound.[1,7] Its most important limitations lie in its limited field of view and limited penetration thus potentially resulting in incomplete evaluation of bony and joint anatomy. Yet, ultrasound provides a very high quality picture of a relatively small area so that clinicians should use US to confirm or characterize pathological changes within a defined body region. From an equipment standpoint, musculoskeletal ultrasound study is also limited by the variable quality and variable expense of the US equipment. From the operator/examiner standpoint, musculoskeletal ultrasound study is limited by the examiner's skill level, a lack of educational infrastructure and, as yet, a lack of certification or accreditation process in this early phase of musculoskeletal imaging.

*"Ultrasound is a hands-on, dynamic, and interactive examination which allows the practitioner to use real-time high-resolution soft tissue imaging. It also facilitates dynamic examination of anatomic structures while interacting with the patient during the conduct of the imaging study."*

## Ultrasound Equipment

The ultrasound equipment consists of a transducer (probe) attached to the main body of the machine via a cord. Transducers/probes used for superficial imaging studies are available in a range of high-frequency (15-7 MHz), small-footprint, linear array transducers (i.e., "hockey stick") to high-frequency (17-5 MHz) linear array transducers.

The low- to medium-frequency (5-2 MHz) curvilinear array transducer's lower frequency facilitates examination of deeper tissues (e.g., hip/gluteal region).[1,5-7] To generate ultrasound waveforms, the machine generates an electric current to crystals inside the transducer which, in turn, vibrate. The vibrating crystals generate a sinusoidal sound wave, a form of mechanical energy. The transformation of electrical energy to mechanical energy—known as piezoelectricity—can be expressed in terms of frequency, wavelength, amplitude, and propagation speed. Through the use of ultrasound coupling gel, sound waves travel into the body until they encounter an acoustic interface which reflects the wave. The reflected sound wave is detected by the transducer using a "reverse piezoelectric effect" to transform the mechanical sound energy wave to electrical signals for processing. By alternately generating and recording the amplitudes and travel times of sound beams (also known as "pulsed ultrasound), the ultrasound machine can use sophisticated computer software to generate the black and white, two-dimensional image of the body part. An acoustic interface that reflects a large amount of sound energy will appear brighter on the monitor as compared to less reflective interfaces which appear darker. For example, a large amount of sound energy is reflected at the interface between bone and muscle, resulting in bone appearing bright (or white) on the monitor screen. Most importantly, it is important to understand that all ultrasound images are not based on the absolute material properties of a tissue but rather on the relative material properties of that tissue compared with adjacent regions being studied or viewed.

## Diagnostic Applications in Musculoskeletal Ultrasound

Ultrasound scanning generates a 2-dimensional view of a 3-dimensional structure. The ability to skillfully manipulate the transducer using specific movements

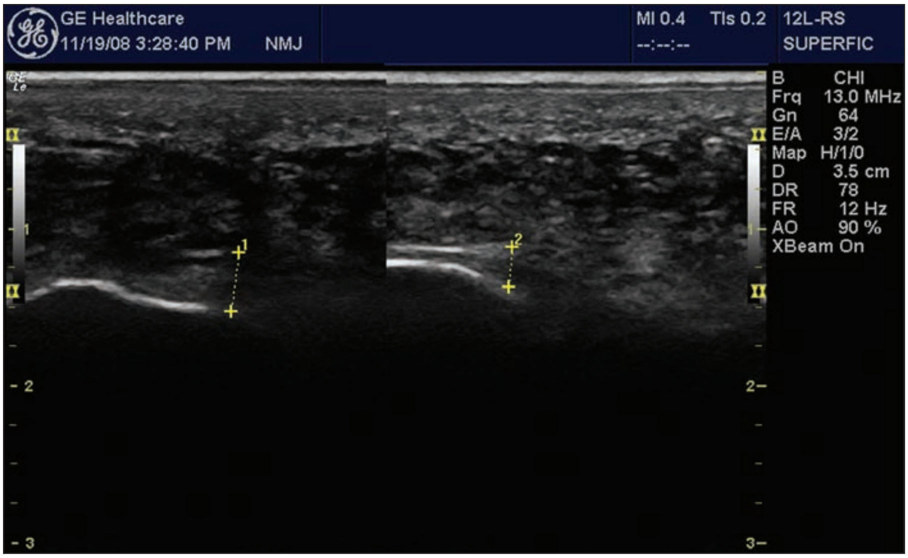


**FIGURE 1.** *Dr. Pinzon's plantar fascia foot comparison: affected and unaffected plantar fascia tendonitis.*

(sliding, tilting, rotating, and heel-toeing) ensures that the targeted structures are investigated fully. The transducer must be moved fully through the entire range of the structure to scan fully and avoid errors of omission. Anisotropy is a major pitfall of inexperienced practitioners; specifically when an otherwise normal, smooth structure appears "dark" on US imaging since the beam didn't encounter the structure perpendicular to the plane of the structure.[1,5-8] A beam that encounters the tendon perpendicular to the surface will be reflected backward and toward the transducer, while a beam encountering the surface at any angle is reflected obliquely and away from the transducer. The tendon appears bright (hyperechoic) in the former case, while the tendon appears artifactually dark (hypoechoic) in the latter case. During the musculoskeletal examination, the examiner should avoid anisotropy by continually manipulating the transducer to direct the generated beam perpendicular to the target structure. With experience, the physician will develop scanning skills for image optimization and transducer manipulations (sliding and rotating) will become automatic and effortless. In order to facilitate the learning process, ultrasound manufacturers have established presets for various musculoskeletal applications.

Scanning skills involve some key steps in the process of an adequate musculoskeletal ultrasound evaluation.[1,5-9] First, the examiner must select the appropriate transducer for the region being studied and is further determined by the depth of the target region (i.e., inverse relationship between frequency and penetration depth). Second, ultrasound gel is placed on the transducer and applied to the skin and adjustments of depth control on the console must be optimized. Third, the focal zone position (i.e., narrowest point of the beam representing the region of best lateral resolution) is adjusted so that the focal zone is located at the same length and position as the target structure. Fourth, after choosing the focal zone number and location, the practitioner must then adjust the overall gain to provide optimal visualization of the target region. Lastly, the practitioner must adjust the depth gain compensation (i.e., time gain compensation) to correct for the normal attenuation of sound waves that occurs as the waves propagate through body tissues. Attentuation results in reduction of the acoustic energy and increases as a function of depth and frequency. These scanning skills require dedication, training and many hours of practice to master in the clinic.

## Musculoskeletal Ultrasound Anatomy Basics

Basic normal musculoskeletal ultrasound anatomy should be reviewed in detail to provide in-depth knowledge of normal and abnormal musculoskeletal anatomy on the ultrasound examination. A basic and fundamental introduction is reviewed here.[10]

### Skeletal Muscle

On longitudinal views, the muscle septae appear as bright/echogenic structures, and are seen as thin, bright, linear bands (i.e., "feather" or "veins on a leaf"). On tranverse views, the muscle bundles appears as speckled echoes with short, curvilinear, bright lines dispersed throughout the darker/hypoechoic background (i.e., "starry night").

### Fascia

Fascia is a collagenous structure that usually surrounds the musculotendinous areas of the extremities. Fascia is encompassed by subcutaneous tissue. The fascia is often seen inserting onto bone and blending with the periosteum. Normal fascia appears as a fibrous, bright hyperechoic structure (see Figure 1).

### Subcutaneous Tissue

Subcutaneous tissue is isoechoic (equal brightness) to that of skeletal muscle. The difference between subcutaneous tissue and skeletal muscle visualized on ultrasound is that the septae do not lay in lines or layers. A thick, continuous hyperechoic band usually separates subcutaneous fat from muscle.

### Cortical Bone

Normal cortical bone appears as a well-defined, linear, smooth, continuous echogenic line with posterior acoustic shadowing (image beyond the interface appears black). The hyperechogenicity of bone is caused by the high reflectivity of the acoustic interface.

### Periosteum

Occasionally visualized as a thin, echogenic line running parallel with the cortical bone on ultrasound. Injuries to the bone—especially to the cortex, periosseous soft tissues, and periosteum—will produce a periosteal reaction which may be visualized.

### Tendons

A normal tendon on ultrasound examination is a bright/echogenic linear band that can vary in thickness according to its location. The internal echoes are described as having a fibrillar echotexture on longitudinal views. On ultrasound, the parallel series of collagen fibers are hyperechoic and separated by darker/hypoechoic surrounding connective tissue. Normally, the collagen fibers are continuous and intact. When interruptions in tendon fibers exist, they are visualized as anechoic/black areas within the tendon. As solid structures, they are noncompressible and do not normally exhibit blood flow.

**Ligaments**

On ultrasound examination, a normal ligament is a bright, echogenic, linear structure. However, for ligaments having a more, compact, fibrillar echotexture, the individual strands/fibers of the ligaments are more closely aligned. Ligaments are composed of dense connective tissue, similar to tendons, but with much more variability in the amounts of collagen, elastin, and fibrocartilage. This makes imaging a ligament more variable than a tendon. Ligaments can easily be distinguished from tendons by tracing the ligament to the bony structures to which it attaches with a characteristic "broom-end" appearance in transverse views.

**Peripheral Nerves**

High-frequency transducers allow the visualization of peripheral nerves that pass close to the skin surface. Peripheral nerves appear as parallel hyperechoic lines with hypoechoic separations between them. On longitudinal views, their appearance is similar to tendons, but less bright/echogenic. On transverse views, peripheral nerves, individual fibers, and fibrous matrix present with multiple, punctuate echogenicities (bright dots) within an ovoid, well-defined nerve sheath. Nerves are differentiated from tendons by their echotexture, relative lack of anisotropy, location and proximity to the vessels.

**Bursae**

In a normal joint, the bursa is a thin, black/anechoic line which is less than 2mm thick. The bursa fills with fluid when irritated or infected. Depending on the extent of effusion, the bursa will distend and enlarge, with inflammatory debris expressed as internal brightness echoes (see Figure 2).

**Vessels**

Veins and arteries appear as hypo- or anechoic tubular structures that can be compressed and exhibit blood flow on Doppler examination. Arteries will remain pulsatile during compression, whereas veins do not. Usually, localizing vessels may facilitate in localizing nerves which lie beside them.

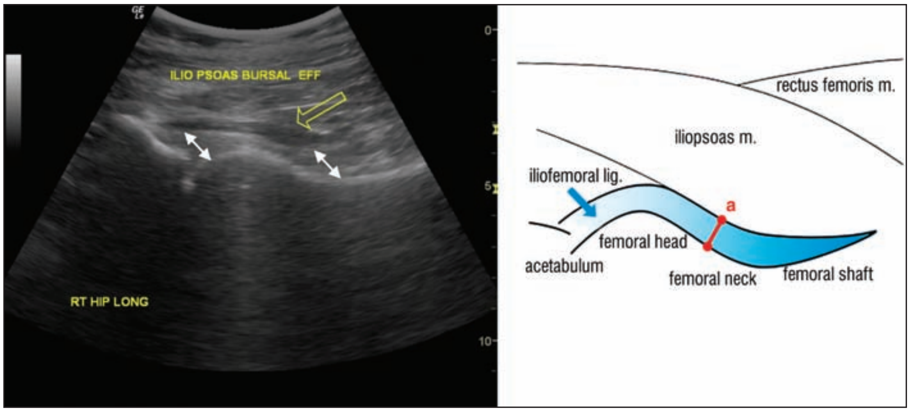


**FIGURE 2.** *Hip ilio psoas bursa. Longitudinal view of the hip. Cortical outline of femoral head and neck is as landmark to determine capsule contour. Anechoic/black fluid is seen in interface between capsule (between double-end arrows) and the ilio psoas muscle.*

Diagnostic ultrasound imaging is instrumental in detecting injuries in the above structures.[1,11]

**Tendon Injuries**

Tendonosis manifests as tendon enlargement, hypo-echogenicity and increase in interfibrillar distance—primarily due to intratendinous edema. Partial-thickness tears present as additional findings of focal regions of anechogenicity accompanied by loss of the normal fibrillar pattern but tendon continuity is maintained. High-grade, partial thickness tearing is imaged as tendon thinning due to tendon substance loss. Full-thickness tearing is seen as tendon gaps occurring in conjunction with tendonosis-related changes. Tenosynovitis may appear as either simple anechoic with easily displaceable fluid surrounding the tendon or complex fluid with mixed echogenicity. Complex fluid seen on imaging within the tendon sheath should be diagnostically aspirated if infection is suspected.

**Ligament Injuries**

Low-grade injuries are imaged as enlarged, hypoechoic ligaments with normal echotexture, while partial- and full-thickness tears reveal fibrous disruption. Stress testing may be able to differentiate between partial vs. complete tears and assess joint stability as in the case of tendon pathology.

**Nerve Injuries**

Similar to tendons and ligaments, affected nerves reveal regional swelling, diffuse hypo-echogenicity and loss of fascicular pattern. A "notch sign" is a reflection of entrapment sites which are localized by evaluating swelling proximal to the entrapment site and a focal narrowing at that site.

**Muscle Injuries**

Low-grade muscle strains exhibit subtle regions of hypoechogenicity accompanied by reduction in the normal pennate echotexture, making the affected area look "washed out." High-grade contusions and injuries reveal variability in frank fiber disruption and hetergenous fluid as seen in hematomas.

**Bone and Joint Disorders**

Periostitis or stress fracture is seen with irregularities in the smoth, superficial surface of bone. Ultrasound is very sensitive in the detection of joint effusions. Joint effusions are anechoic, compressible, and devoid of Doppler flow. Complex, heterogenous-appearing fluid may be indicative of infection for which aspiration is recommended. Synovitis appears as noncompressible, echogenic tissue within a joint and hyperemia on Doppler. Periarticular erosions, crystal-related deposits and gouty tophi may also be seen in the joint evaluation. Enlarged bursae contain simple anechoic fluid but, similar to joint effusions, may contain complex fluid. Periarticular and peritendinous ganglia may be present as multilobulated, anechoic noncompressible structures devoid of blood flow.

## Therapeutic Applications in Musculoskeletal Ultrasound

The use of ultrasonography in interventional musculoskeletal radiology is well

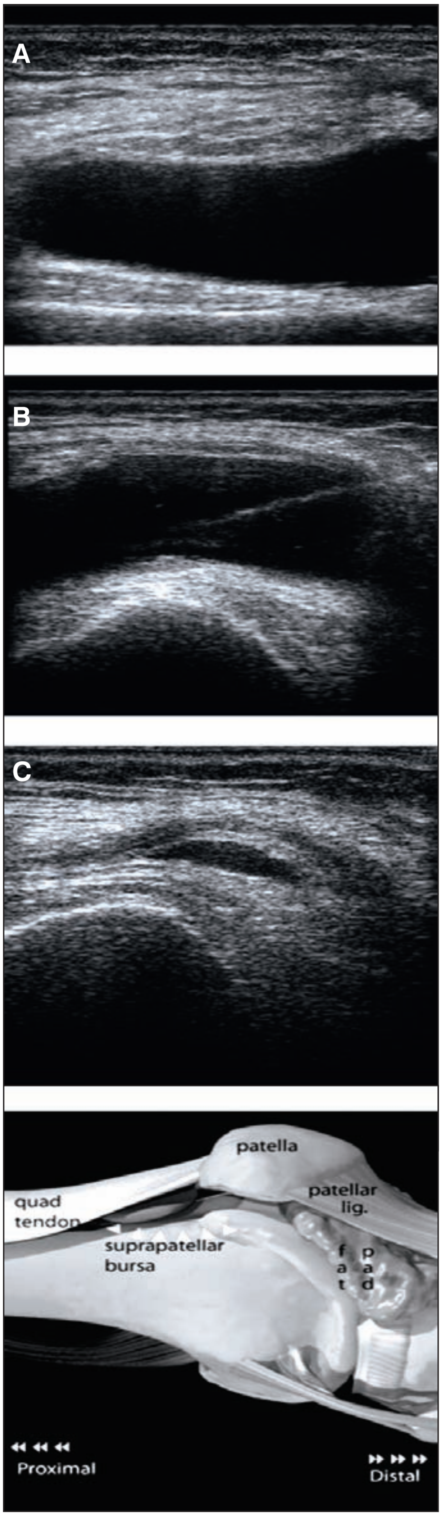


**FIGURE 3.** *Suprapatellar aspiration. A. longitudinal views of the suprapatellar pouch/bursa demonstrate a large anechoic fluid collection; B. needle insertion for aspiration; C. post aspiration view. Ultrasound image prior to aspiration allowed determination of no internal debris in the often recurring site of fluid accumulation.*

established and is used primarily to guide needle placement for injections, aspirations and biopsies.[12] The choice of ultrasound transducer is critical, with high-frequency (7-12 MHz) linear array transducers used most frequently. For deeper structures, such as hips and larger patients, lower frequency curvilinear probes may be required, although they may be prone to anisotropic artifact. Regardless of the probe selected, a complete sonographic examination (including Doppler exam) of the proposed area should be conducted to determine critical structures such as nerve and vessels. This allows the determination of needle trajectory and avoidance of areas of potential infection.

Most musculoskeletal US procedures are performed with a "free-hand technique" which allows direct, dynamic visualization of the needle tip. After planning the safest route of needle access, a line parallel to the long axis of the probe face can be drawn on the skin and the patient's skin and transducer is sterilized and draped. The needle is directed toward the intended target under vigilant observation with the long axis of the needle and in line with the long axis of the transducer face.

Strategies to discriminate the needle tip under US involve keeping the tranducer face as perpendicular to the needle as possible by heel-toe angling and probe rocking. By doing so, reverberation artifact posterior to the needle is seen and aids in highlighting the needle. Other approaches include sweeping the transducer from side to side while moving the needle in and out; injecting a small amount of local anesthetic to localize the needle tip; and rotating the probe ninety degrees to examine the needle in short axis and determine the needle's pathway.

Intra-articular interventional injections using US may be used for joint aspirations (e.g., detection of crystal arthropathy or septic arthritis; see Figure 3) or therapeutic intra-articular injections with corticosteroids or viscosupplementation (e.g., treatment of joint arthritis; see Figure 4). Diagnostic injections with use of short- and long-acting anesthetics can determine the patient's symptom improvements with long-acting agents. Most hip and shoulder joints may accept up to 10 mL but small joints of the hands and feet may only accept 1-2 mL.

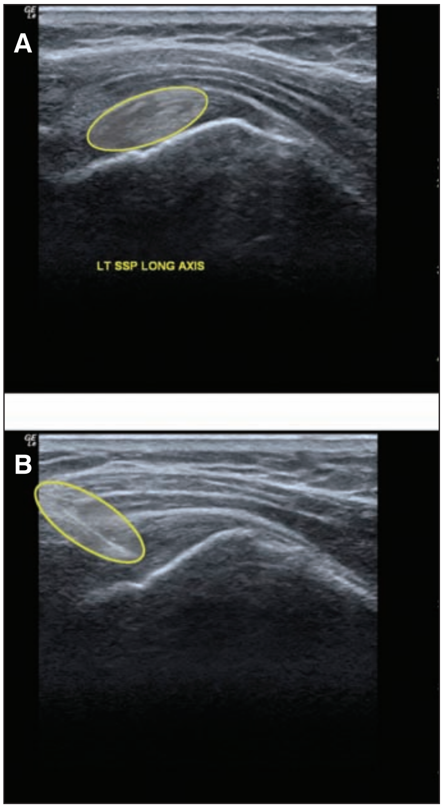


**FIGURE 4.** *Supraspinatus injection. A. longitudinal probe placement on the anterior/lateral shoulder reveals a nearly full thickness tear of the supraspinatus tendon. B. ultrasound guided injection.*

## Potential Ultrasound-Guided Routes of Access

Some of the most potential routes of access to the most commonly injected joints under ultrasound-guidance are presented here.[12]

### Shoulder Joint

The patient is best positioned in a seated or lateral decubitus position. The patient's hand is positioned resting on the opposite shoulder, and the key landmarks of the triangular-shaped posterior labrum, humeral head, and joint capsule are identified. The glenohumeral joint is best accessed from the posterior rather than anterior approach. The needle is introduced laterally in the axial plane and advanced medially, with the needle target between the posterior aspect of the humeral head and posterior labrum.

### Elbow Joint

The patient is best positioned in a seated or supine position with elbow flexed and arm across the chest. The probe is positioned along the posterior elbow and oriented sagitally with the triceps tendon longitudinally placed. The needle is introduced superiorly, passing beside the triceps tendon and through the posterior fat pad to enter the joint space. Key landmarks are the olecranon fossa of the humerus, posterior fat pad and the olecranon.

**Hip Joint**

The patient lies supine and the joint is accessed anteriorly. With joint effusions or larger patients, the most optimal approach is with the probe aligned along the long access of the femoral neck. The needle is introduced from the inferior approach, passing through the joint capsule to rest on the subcapital femur. In thinner patients, easier access with the US probe oriented axially is preferred. With femoral head and acetabular rim in view, the needle is introduced from an anterolateral approach.

**Knee Joint**

For distended knee joints with effusions, the suprapatellar bursa, the best access is usually with patient lying supine with knee flexed slightly. The probe is held parallel to the quadriceps tendon and slid medially or laterally until the quadriceps fibers disappear and the needle is directed into the bursa. For knee joints without effusions, the medial patellofemoral facet is the best target with the probe in the axial plane of the patella and medial femoral condyle visible. The probe is turned ninety degrees and oriented along the joint line and the needle is then introduced either inferiorly or superiorly into the joint.

**Ankle Joint**

With the patient lying in supine position, the anterior tibiotalar joint is examined in a sagittal plane. The examiner may perform plantarflexion or dorsiflexion maneuvers to identify the talus movements across the tibia. Avoidance of the dorsalis pedis artery and extensor tendons should be noted. The needle entry into the joint is in a sagittal plane using an inferior approach.

## Conclusions and Summary

The integration of diagnostic and interventional musculoskeletal ultrasound into clinical practice is a welcome alternative to procedures that might otherwise be performed under fluoroscopic or computed tomographic guidance in the fields of radiology, physiatry and anesthesia. When performing diagnostic musculoskeletal ultrasound examinations, the practitioner must follow the following vital steps to maximize the best outcomes[1,11,13]:

1) define a specific clinically-relevant question that may be answered by the ultrasound examination;
2) position the physician, patient, and machine for the best access;
3) maintain full control of the transducer probe using the “hands-on” approach;
4) completely evaluate the region of concern to avoid any unnecessary errors by viewing multiple images to reconstruct a 3-dimensional view;
5) evaluate the targeted structures in both longitudinal (long axis) and transverse (short axis) planes to increase diagnostic sensitivity and reduce artifactual anisotropy.

When using ultrasound guidance for interventional procedures, several principles should be maintained[1,12,13]:

1. determine the specific procedure or goal for diagnostic or therapeutic value;
2. review the entire regional anatomy adequately, including the use of Doppler US;
3. use sterile techniques as recommended;
4. choose the long-axis (“in-plane”) approach, so that the needle tip and shaft are linearly aligned with the long axis of the transducer and thus providing ultrasonographic visualization of the needle at its target;
5. maintain the needle tip position throughout the procedure; and
6. recognize the inherent limitation of the physician, technique, and equipment while using the “freehand technique.” ■

*Elmer “Al” Pinzon, MD, MPH, FABPMR, FABPM is a minimally-invasive interventional spine and musculoskeletal specialist. He is board certified in physical medicine and rehabilitation as well as fellowship trained in minimally-invasive spinal procedures, musculoskeletal and sports medicine, and electrodiagnostics. Dr. Pinzon is the president-owner of University Spine & Sports Specialists, PLLC in Knoxville, Tennesee. He also serves as Assistant Professor, Department of Surgery, Division of Surgical Rehabilitation at the University of Tennessee Medical Center in Knoxville. Email: epinzon@utmck.edu*

*Randy E. Moore, DC, RDMS is a chiropractic medicine and musculoskeletal ultrasound specialist in Sunman, Indiana. He operates MSK Masters which performs musculoskeletal sonography training, education and consulting. MSK Masters offers onsite and in-office instruction for individual practitioners, group practices, residency programs and sonography programs (www.MSKMasters.com). Dr. Moore has taught at the Cleveland Clinic Sports Health Center and has had the opportunity to teach team physicians for Cleveland Browns football, Cavaliers basketball and Indians baseball. He has also been an ultrasound team member with the U.S. Olympic Committee for the men’s and women’s Olympic swim teams.*

**References**

1. Smith J and Finnoff JT. Diagnostic and Interventional Musculoskeletal Ultrasound: Part 1. Fundamentals. *PM&R*. Jan 2009. Vol 1:64-75.

2. *AIUM Practice Guideline for the Performance of the Musculoskeletal Ultrasound Examination*. October 1, 2007. American Institute of Ultrasound in Medicine. Laurel, MD.

3. Valente C and Wagner S. History of the American Institute of Ultrasound in Medicine. *J Ultrasound Med.* 2005. 24:131-142.

4. Kremkau F. *Diagnostic Ultrasound: Principles and Instruments, 6th Ed*. WB Saunders. Philadelphia, Pennsylvania. 2002. p 428.

5. Lew HL, Chen CP, Wang TG, and Chew KT. Introduction to musculoskeletal diagnostic ultrasound: Part 1: examination of the upper limb. *Am J Phys Med Rehabil*. Apr 2007. 86(4):310-321.

6. Chew KT, Stevens KJ, Wang TG, Fredericson M, and Lew HL. Introduction to musculoskeletal diagnostic ultrasound: Part 2: examination of the lower limb. *Am J Phys Med Rehab*. Mar 2008. 87(3):238-248.

7. Khoury V, Cardinal E, and Bureau NJ. Musculoskeletal sonography: a dynamic tool for usual and unusual disorders. *Am J Roentgenol*. Jan 2007. 188(1):W63-73.

8. Filippucci E, Unlu A, Farina A, and Grassi W. Sonographic training in rheumatology: a self-teaching approach. *Ann Rheum Dis*. 2003. 62:565-567.

9. American Institute for Ultrasound in Medicine. AIUM technical bulletin. Transducer Manipulation. *J Ultrasound Med.* 1999. 18:169-175.

10. Moore RE. Musculoskeletal Ultrasound for the Extremities: Systematic Technique and Protocols. *Practical Guide to Sonography of the Extremities, 3rd ed*. 2007. MSKMasters. Pp 3-7.

11. Smith J and Finnoff JT. Diagnostic and Interventional Musculoskeletal Ultrasound: Part 2. Clinical Applications. *PM&R*. Feb 2009. Vol 1:162-177.

12. Louis LJ. Musculoskeletal Ultrasound Intervention: Principles and Advances. *Radiol Clin N Am*. 2008. 46:515-533.

13. Diagnostic Musculoskeletal US for Physiatrists: New Perspectives from Different Vantage Points. 69th AAPM&R Annual Assembly Preconference Course. San Diego Marriott. Nov 19, 2008.