Musculoskeletal Ultrasound: A Primer for Primary Care

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

When performing diagnostic musculoskeletal ultrasound examinations, the practitioner must adhere to the following vital steps to maximize the best outcomes:

• Define a specific clinically relevant question that may be answered by the ultrasound examination
• Position the physician, patient, and machine for the best access
• Maintain full control of the transducer probe using the “hands-on” approach
• Completely evaluate the region of concern to avoid any unnecessary errors by viewing multiple images to reconstruct a 3-dimensional view
• Evaluate the targeted structures in both longitudinal (long axis) and transverse (short axis) planes to increase diagnostic sensitivity and reduce artefactual anisotropy

When using ultrasound guidance for interventional procedures, several principles should be maintained:

• Determine the specific procedure or goal for diagnostic or therapeutic value
• Review the entire regional anatomy adequately using methods including Doppler ultrasound
• Use sterile techniques as recommended
• 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, provide ultrasonographic visualization of the needle at its target
• Maintain the needle tip position throughout the procedure
• Recognize the inherent limitation of the physician, technique, and equipment while using the “free-hand technique”

Musculoskeletal ultrasound (MSK US) has been around for more than 50 years, since the foundation of the American Institute for Ultrasound in Medicine (AIUM) in 1951. Initial efforts centered around diagnostic ultrasound applications, but they were limited due to poor resolution and lack of real-time imaging capability. In subsequent years, however, physiatrists began to lead the medical community with the use of therapeutic ultrasound techniques. In the 1980s, with the use of real-time ultrasonographic imaging and detailed anatomic imaging, diagnostic MSK US became capable of fully evaluating the musculoskeletal system. In 2012, the AIUM released a revised version of its Practice Guideline for the Performance of the Musculoskeletal Ultrasound Examination, which provided the medical ultrasound community with guidelines for the performance and recording of high-quality ultrasound examinations. Recently, with equipment cost reductions and resolution improvements, this field has expanded to various clinical practices that diagnose and treat musculoskeletal disorders. This article will discuss some concepts in MSK US that will be helpful for the practicing physician.

**Fundamental Concepts**

MSK US involves the use of high-frequency sound waves (3-17 MHz) to image soft tissues and bony structures in the body. 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 ten donnosis, 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. Table 1 contains basic terminology used in the ultrasound lexicon.

**US Imaging Advantages**

MSK US provides several distinct advantages in relation to basic radiography (x-rays), computed tomography, and magnetic resonance imaging (MRI)—especially in focused MSK and neurological examinations. Because MSK US is performed in real time, it allows the practitioner to see high-resolution soft tissue imaging while interacting with the patient during the conduct of the imaging study. US imaging is minimally affected by metal artifacts (eg, cochlear implants, hardware, or pacemakers) and also can be used in certain patients who have contraindications to MRI imaging (eg, claustrophobic or obese patients). US imaging facilitates the ability to guide minimally invasive,

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**Table 1. Basic Terminology Used in the Ultrasound Lexicon**

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>Echotexture</td>
<td>Refers to the coarseness or non-homogeneity of an object.</td>
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<tr>
<td>Echogenicity</td>
<td>Refers to the ability of tissue to reflect US waves back toward the transducer and produce an echo. The higher the echogenicity of tissues, the brighter they appear on US imaging.</td>
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<tr>
<td>Hyperechoic</td>
<td>Structures are seen as brighter on conventional US imaging relative to surrounding structures due to higher reflectivity of the US beam.</td>
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<tr>
<td>Isoechoic</td>
<td>Structures of interest are seen as bright as surrounding structures on conventional US imaging due to similar reflectivity to the US beam.</td>
</tr>
<tr>
<td>Hypoechoic</td>
<td>Structures are seen as darker relative to surrounding structures on conventional US imaging due to the US beam being reflected to a lesser extent.</td>
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<tr>
<td>Anechoic</td>
<td>Structures that lack internal reflectors fail to reflect the US beam to the transducer and are seen as homogeneously black on imaging.</td>
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<tr>
<td>Longitudinal</td>
<td>Structure is imaged along the long axis.</td>
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<tr>
<td>Transverse</td>
<td>Structure is imaged perpendicular to the long axis.</td>
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<tr>
<td>Shadowing</td>
<td>The relative lack of echoes deep in an echogenic structure due to attenuation of the US beam (eg, due to large calcifications, bone, gas, metal).</td>
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<tr>
<td>Posterior acoustical enhancement</td>
<td>The brighter appearance of tissues deep in an area where there are few strong reflectors to attenuate the sound beam (eg, 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.</td>
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<tr>
<td>Anisotropy</td>
<td>The effect of the beam not being reflected back to the transducer when the probe is not perpendicular to the structure being evaluated (eg, an angled beam on bone would create an anechoic artifact since the beam is reflected at the angle of incidence away from the transducer).</td>
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interventional procedures (eg, 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.

US Disadvantages
Practitioners, however, must also recognize several notable disadvantages of MSK US. The most important limitations lie in its limited field of view and penetration, which potentially can result in incomplete evaluation of bony and joint anatomy. From an equipment standpoint, MSK US is limited by the variable quality and variable expense of the equipment. From the operator/examiner standpoint, MSK US is limited by the examiner’s skill level and a lack of educational infrastructure. It is also in the early processes of certification and accreditation.

US Equipment
To generate US waveforms, the machine generates an electric current to crystals inside the transducer, which, in turn, vibrate. The vibrating crystals generate a sinusoidal sound wave. 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 US”), the US 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 US 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 of MSK US
US Anatomy
Basic, normal MSK anatomy should be reviewed in detail to provide in-depth knowledge of normal and abnormal MSK anatomy on the US examination. A basic and fundamental introduction of anatomy is reviewed in Table 2.8

US scanning generates a 2-dimensional view of a 3-dimensional structure. The ability to skillfully manipulate the transducer using specific movements (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 completely and avoid errors of omission. Anisotropy is a major pitfall of inexperienced practitioners; this occurs when an otherwise normal, smooth structure appears “dark” on US imaging because the beam didn’t encounter the structure perpendicular to the plane of the structure. 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 MSK examination, the examiner should avoid anisotropy by continually manipulating the transducer to direct the generated beam perpendicular to the target structure. With experience, the practitioner will develop scanning skills for image optimization, and transducer manipulations (sliding and rotating) will become automatic and effortless. To facilitate the learning process, US manufacturers have established presets for various MSK applications.

Scanning skills involve some key steps in the process of an adequate MSK US evaluation. First, the examiner must select the appropriate transducer for the region being studied, which is further determined by the depth of the target region (ie, inverse relationship between frequency and penetration depth). Second, US 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 (ie, 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 (ie, time gain compensation) to correct for the normal attenuation of sound waves that occurs as the waves propagate through body tissues.
<table>
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<tr>
<th>Structure</th>
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<tbody>
<tr>
<td>Skeletal Muscle</td>
<td>On longitudinal views, the muscle septae appear as bright/echogenic structures and are seen as thin, bright, linear bands (“feathers” or “veins on a leaf”). On transverse views, the muscle bundles appear as speckled echoes, with short, curvilinear, bright lines dispersed throughout the darker/hypoechoic background (“starry night”).</td>
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<tr>
<td>Fascia</td>
<td>Fascia is a collagenous structure that usually surrounds the musculotendinous areas of the extremities. Fascia is encompassed by subcutaneous tissue. The fascia often is seen inserting into bone and blending with the periosteum. Normal fascia appears as a fibrous, bright hyperechoic structure.</td>
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<tr>
<td>Subcutaneous Tissue</td>
<td>Subcutaneous tissue is isoechoic (equal brightness) to that of skeletal muscle. The difference between subcutaneous tissue and skeletal muscle visualized on US is that the septae do not lay in lines or layers. A thick, continuous hyperechoic band usually separates subcutaneous fat from muscle.</td>
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<tr>
<td>Cortical Bone</td>
<td>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.</td>
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<tr>
<td>Periosteum</td>
<td>Occasionally visualized as a thin, echogenic line running parallel with the cortical bone on US. Injuries to the bone—especially to the cortex, periosseous soft tissues, and periosteum—will produce a periosteal reaction that may be visualized.</td>
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<tr>
<td>Tendons</td>
<td>A normal tendon on US 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 US, 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.</td>
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<tr>
<td>Ligaments</td>
<td>On US 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.</td>
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<tr>
<td>Peripheral Nerves</td>
<td>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.</td>
</tr>
<tr>
<td>Bursae</td>
<td>In a normal joint, the bursa is a thin, black/anechoic line that is &lt;2 mm thick. The bursa fills with fluid when it is irritated or infected. Depending on the extent of effusion, the bursa will distend and enlarge, with inflammatory debris expressed as internal brightness echoes.</td>
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<tr>
<td>Vessels</td>
<td>Veins and arteries appear as hypo- or anechoic tubular structures that can be compressed and exhibit blood flow on Doppler examination. Arteries remain pulsatile during compression, whereas veins do not. Usually, localizing vessels may facilitate in localizing nerves, which lie beside them.</td>
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Attenuation 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.

US is very useful in diagnosing damages or injuries to structures. Table 3 reviews common injuries seen on US.1,11

**Therapeutic Applications In MSK US**

The use of ultrasonography in interventional MSK radiology is well established and is used primarily to guide needle placement for injections, aspirations, and biopsies.12 The choice of US transducer is critical, with high-frequency (7-12 MHz) linear array transducers being used most frequently. For deeper structures, such as hips, and larger patients, lower frequency curvilinear probes (4-9 MHz) 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 nerves and vessels. This allows the determination of needle trajectory and avoidance of areas of potential infection.

Most interventional 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. The patient’s skin and transducer then are 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 transducer 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 90° to examine the needle in short axis and determine the needle’s pathway.

Intra-articular interventional injections incorporating US may be used for joint aspirations (eg, detection of fluid accumulation) and gout flares.

**Figure 1.** Suprapatellar aspiration. Ultrasound image prior to aspiration allowed determination of no internal debris in the often-recurring site of fluid accumulation. A, longitudinal views of the suprapatellar pouch/bursa demonstrate a large anechoic fluid collection; B, needle insertion for aspiration; C, post aspiration view.

**Figure 2.** 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.
crystal arthropathy or septic arthritis; Figure 1) or therapeutic intra-articular injections with corticosteroids or viscosupplementation (eg, treatment of joint arthritis; Figure 2). Diagnostic injections using 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 to 2 mL.

Potential US-guided Routes of Access
Some of the most promising routes of access to the most commonly injected joints under US 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 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

<table>
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<th>Structural Injury</th>
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<td>Tendon Injuries</td>
<td>Tendonosis manifests as tendon enlargement, hypoechochogenicity, and an 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 either as 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.</td>
</tr>
<tr>
<td>Ligament Injuries</td>
<td>Low-grade injuries are imaged as enlarged, hypoechochogenic ligaments with normal echotexture, while partial- and full-thickness tears reveal fibrous disruption. Stress testing may be able to differentiate between partial versus complete tears and assess joint stability, as in the case of tendon pathology.</td>
</tr>
<tr>
<td>Nerve Injuries</td>
<td>Similar to tendons and ligaments, affected nerves reveal regional swelling, diffuse hypoechochogenicity, 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.</td>
</tr>
<tr>
<td>Muscle Injuries</td>
<td>Low-grade muscle strains exhibit subtle regions of hypoechochogenicity 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 heterogeneous fluid, as seen in hematomas.</td>
</tr>
<tr>
<td>Bone and Joint Disorders</td>
<td>Periostitis or stress fracture is seen with irregularities in the smooth, 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, heterogeneous-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 also may 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.</td>
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</table>
probe oriented axially is preferred. With the 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 the patient lying supine with the 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 90° 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. The dorsalis pedis artery and extensor tendons should be avoided. The needle entry into the joint is in a sagittal plane using an inferior approach.

Summary
The integration of diagnostic and interventional MSK US 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.

Authors’ Bios: Elmer G. Pinzon, MD, MPH, FABPMR, is the president, medical director, and owner of University Clinical Vignette: Plantar Fascia Tendonosis

Drawing from his own personal experience, the author presents a case of chronic right heel pain treated by ultrasound-guided therapy.

An endurance sports enthusiast, Dr. Pinzon developed chronic right heel pain over the plantar fascia/heel region that has lasted 9 months (Figure). He developed right plantar fascia tendonosis and was treated with various conservative treatments including: plantar fascia stretching, gelHEEL pads, custom-molded orthotics, physical therapy heel mobilization/myofascial release techniques, topical analgesics, and heel counter in athletic footwear. After some failed conservative treatment options, he chose to have a musculoskeletal ultrasound (MSK US)-trained specialist pursue sonographic-guided local corticosteroid injection using a posteromedial approach beneath and within the fascial substance, enabling infiltration of a corticosteroid/anesthetic solution. The solution of 20 mg of methylprednisolone and 0.5% marcaine was injected into the thickest part of the plantar fascia from its attachment to the calcaneous, without significant resistance noted. Subsequently cold/ice treatment was applied and avoidance of significant weight-bearing was ordered for 2 days after the procedure. Four weeks post-injection procedure and after continued stretching, topical analgesics, and orthotics, Dr. Pinzon noted >90% improvement including dramatic improvement in his chronic right heel pain. Dr. Pinzon now is able to participate in some of his endurance sporting endeavors.

Figure. Plantar fascia foot comparison: affected and unaffected plantar fascia tendinitis.
Spine & Sports Specialists, PLLC. He also is a clinical assistant professor in the Department of Surgery, Division of Surgical Rehabilitation at the University of Tennessee Graduate School of Medicine in Knoxville, Tennessee. Dr. Pinzon specializes in minimally invasive interventional spine and pain medicine, and musculoskeletal medicine.


References

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He is a contributing editor for the Journal of the American Podiatric Medical Association and serves on the Editorial Board of Podiatry Today. He is active in clinical research and teaching, and in 2009 he performed the first diabetic peripheral nerve decompression in Barcelona, Spain, on closed circuit television for 74 of Europe’s top surgeons, neurologists, and endocrinologists. He has published 29 articles in peer-reviewed medical journals, authored chapters in medical textbooks, and co-authored a textbook on the interpretation of neurosensory testing.

Dr. Barrett has no financial information to disclose.

References