Current Ultrasound Application in the Foot and Ankle

Nahum Michael Beard, MD[a,b,*],
Robert Patrick Gousse, MD[b,1]

KEYWORDS

• Musculoskeletal ultrasound • Image-guided injection • Ultrasound of the foot/ankle
• Plantar fascia • Tendinosis • Tendonitis • Hydrodissection

KEY POINTS

- Ultrasound has been used in the foot and ankle for nearly 2 decades and is being used with increasing frequency and indication.
- Utilization in diagnosis demonstrates unique advantages that are complementary to other imaging modalities.
- High-resolution ultrasound is the modality of choice for needle placement, including joint injection.
- Increasing collaboration between foot and ankle surgery and skilled ultrasonographers is leading to innovation in minimally invasive treatment of common diagnoses.

INTRODUCTION

Ultrasound of the lower extremity was one of the first utilizations of Ultrasound in Musculoskeletal Medicine and continues to grow in practice and publication with diagnostic and interventional applications.[1–3] Before the 1990s, it was primarily used for the evaluation of mass and soft tissue lesions. There were early uses in joint imaging, especially with regard to characterization of the Baker cyst and in characterizing tendon abnormality.[2,3] In the last 15 years, more and more applications are being documented in the literature, further supporting the diagnostic and interventional use of ultrasound. Lower-extremity applications have been popular, likely because of the inherent strengths of ultrasound as they relate to the foot and ankle. Sufficient clarity and detail necessary for diagnosis or interventions under ultrasound are best when the structures are superficial, are discreet, and have clear landmarks; all accurate descriptors of foot and ankle anatomy. Musculoskeletal ultrasound's cost-effectiveness and absence of radiation is welcomed by providers and patients alike.[4] To date, the published literature abounds with applications of musculoskeletal ultrasound in foot and ankle diagnostics from mass lesions to nerve entrapment syndromes. Interventional applications continue to develop as well, ranging from accurate needle placement to emerging therapies for common diagnoses while also offering the foot and ankle surgeon alternative methods of performing traditional surgeries.

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[a] Department of Family Medicine, University of Tennessee Health Science Center, Saint Francis Family Medicine, 1301 Primacy Parkway, Memphis, TN 38119, USA; [b] Department of Orthopaedic Surgery and Biomedical Engineering, 1211 Union Avenue Suite 520, Memphis, TN 38104
[1] Present address: 1630 East Herndon Avenue, Fresno, CA 93720.
* Corresponding author. Campbell Clinic Orthopedics, 7545 Airways Boulevard, Southaven, MS 38671-5806.
E-mail address: nbeard@campbellclinic.com

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PLANTAR FASCIOSIS

Plantar fasciosis is a commonly encountered condition that often requires imaging for proper diagnosis.[5] Ultrasound provides an accurate and cost-effective modality to evaluating the bands of the plantar fascia and its attachments on the calcaneus. Biomechanics of the lower extremity create tensile forces that result in disruption of the fascia, producing heel pain.[4,6] The cause of plantar fascial pain is not fully understood; however, inflammation is noted on histologic evaluation of acute disease, whereas degeneration is noted in chronic plantar fasciosis.[4] The condition is noted to affect 10% to 20% of injured athletes and 10% of the general population, with 5% to 10% going onto surgical intervention.[6,7] Sonography can be effectively used to diagnose plantar fasciosis and assess response to interventions based on a 2016 systematic review of clinical trials.[7]

On ultrasound, the plantar fascia displays the classic compact fibrillar pattern (**Fig. 1**). This pattern is seen when the fascicles of a ligament or tendon are visualized in the long axis and directly perpendicular to the sound beam of a high-frequency ultrasound probe. The image typically demonstrates a dense grouping of transverse hyperechoic lines with minimal spacing and close parallel arrangement.[5] When evaluating patients, multiple characteristics have been described to identify diseased tissue. Thickness greater than 4 mm, increased Doppler signal, calcific disease, and loss of both echogenicity and fibrillar pattern were correlated with painful heels.[5,8] Not only is ultrasound a preferred tool for diagnosis of plantar fasciosis, but also it has been shown to be effective at monitoring a patient's response to treatment[8,9] Moustafa and colleagues[8] compared patients with painful plantar fasciosis against asymptomatic heels and monitored their response to dexamethasone injections. Each patient had a repeat ultrasound evaluation at their 3-week follow-up appointment to assess their plantar fascia. They noted a decrease in plantar fascia thickness and an associated reduction in symptoms, giving an objective finding to the patient's improvement during treatment. Multiple studies have found a correlation between plantar fascia thickness and pain. These changes have been described following various treatment modalities, such as nonsteroidal anti-inflammatory drug therapy, Botox type A injections, shockwave therapy, and laser therapy.[10] The use of ultrasound allows for instant and dynamic visualization of other structures in the foot that can cause heel pain. Ultrasound-guided Tinel of Baxter nerve can aid in accurate diagnosing and treatment plans. Baxter neuropathy along with medial calcaneal neuropathy can occur with or without plantar fasciopathy. Other differential diagnoses that can be visualized via ultrasound include plantar fibromatosis, foreign bodies, calcaneal stress fractures, rheumatoid nodules, plantar vein thrombosis, and rupture (**Fig. 2**).[4]

Measurement of the plantar fascia is an important aspect of diagnosis. In one study, men had an average thickness of 2.4 mm on the right foot and 2.5 mm on the left foot. Women had thinner fascia, with 1.8 mm bilaterally. The same study found that thickness increased with age, height, body mass index, and weight.[11] Decreases in thickness are associated with decreased pain and can be used to evaluate different treatment modalities.[10] It is

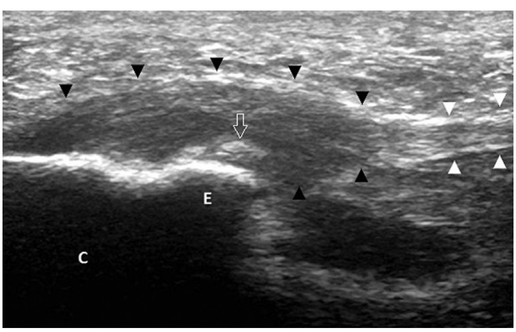

Fig. 1. Severe plantar fasciosis. Plantar long-axis view of the medial band. Normal thickness and compact fibrillar pattern is seen just distal to the origin (*white arrowheads*). The origin at the calcaneus (C) is grossly thickened with hypoechoic loss of layered architecture (*black arrowheads*) and calcific change (*white arrow*) at the enthesophyte (E).

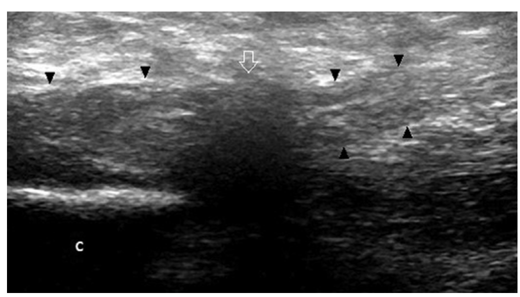

Fig. 2. Subacute high-grade partial tear of the plantar fascia. Long-axis view of the plantar fascia demonstrates complete loss of echotexture with a spheroid hypoechoic lesion (*arrow*). The surrounding fascia is edematous and thickened (*arrowheads*). C, calcaneus.

important to note that clinical context must be used in patients because one study found that every asymptomatic heel in runners had one abnormality.[9] Generally, plantar fascia thickness greater than 4 mm is considered to be abnormal but may be asymptomatic.[4,8,11]

PERIPHERAL NERVE DISORDERS

Use of ultrasound for peripheral nerve disorders is well established in the upper and lower extremities.[4,12–15] High-resolution sonography evaluation of classic abnormalities has considerable advantages over MRI with increased sensitivity (93 vs 67%) and equivalent specificity (67%) as demonstrated in a retrospective analysis of 53 patients with diverse peripheral neurologic diagnoses.[15] The common disorders of entrapment, vasculitis, trauma, neuroma, and tumor differentiation are relatively easily diagnosed by ultrasound in the context of history and physical examination.[12,15] The interactive and real-time nature of diagnostic ultrasound also offers unique advantages in the clinical decision-making process.

Peripheral nerve entrapment and mechanical neuritides are commonly treated by the foot and ankle orthopedist. These disorders can masquerade as other common causes of foot and ankle pain. Medial calcaneal, Baxters (first branch lateral plantar nerve), sural, and lateral calcaneal neuritis are in the differential of plantar fasciosis and heel pain. Saphenous neuritis can masquerade as causes of medial ankle pain, including stress fractures, osteoarthrosis, chronic deltoid sprains, and posterior tibialis dysfunction. Sural neuritis is in the differential with peroneal tendinopathy.

Ultrasound in the diagnosis of mechanical neuritides is divided into 3 distinct categories: direct imaging findings, indirect, and interactive. Direct imaging findings of nerve injury were first described in the upper extremity because of high utilization in cubital, radial, and especially the ubiquitous carpal tunnel syndrome.[12] The same principles are applied and supported by the literature in the lower extremities.[13,16] Direct imaging of the entrapped nerve is best applied at areas of nerve transition, such as exiting or transitioning between fascial planes, at muscle borders, and osseous fibrous tunnels.[12] The classic finding is hypoechoic enlargement proximal to the area of entrapment with a return to normal size or flattening or disappearance of the nerve.[12] Acute, nonphysiologic angle changes in the path of the nerve or “kinking” are also suggestive of entrapment (**Fig. 3**). As

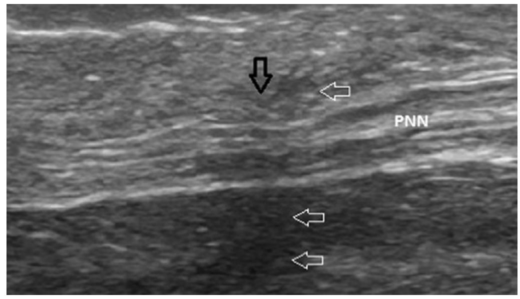

Fig. 3. Postoperative nerve entrapment at the tarsal tunnel. Long-axis view of the medial and lateral plantar nerves (PNN) with clear “kinking” of the nerves (*black arrow*) because of hypoechoic scar tissue (*white arrows*).

nerve entrapment worsens, findings will progress from subtle loss of internal echotexture to global hypoechogenicity and finally frank enlargement.[12] Cross-sectional area of a nerve has proven the most reproducible of standardized evaluations to date.[16] Ultrasound of the tibial nerve at the tarsal tunnel is very specific.[16] It revealed pathologic nerve enlargement in 100% of cases where previous electromyography and nerve conduction velocity (EMG-NCV) showed objective injury. A primary structural or compressive cause was identified in 60% of patients in the same series.[16] Recent studies of the carpal tunnel have demonstrated high specificity of Doppler signal within the nerve to clinical and EMG-NCV findings and should be looked for as suggestive in any nerve of analogous size to the median, where Doppler signal is potentially obtainable until further studies arise.

Direct visualization of nerve-specific abnormalities other than the mechanical neuritides is important to mention. Neuroma, nerve sheath tumors including schwannoma, neurilemmoma, and neurofibroma are easily visualized in the foot and ankle.[12,13,15,17] Morton neuroma is visualized as a round or oblong hypoechoic mass on average around 6 mm, with half being well-demarcated and the other half with poor demarcations.[13,18] They may appear biconcave in shape, having the appearance of a “ginkgo leaf.”[18] The unique appearance on ultrasound can help distinguish Morton neuroma from other interdigital soft tissue masses such as epidermoid tumors or ganglion cyst.[18] Lesions measuring greater than 20 mm in size are likely not a Morton neuroma.[18] Dynamic visualization of the plantar surface with a sonographic Mulder click can help clarify the diagnosis[13,18] (**Fig. 4**). Nerve trauma is seen as acute enlargement

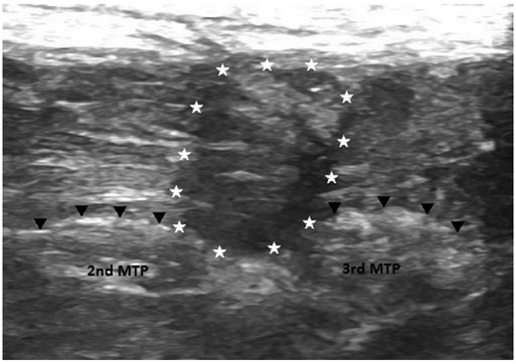

Fig. 4. Short-axis plantar view of the second webspace. A large Morton neuroma (*stars*) is seen extruded between the bright plantar capsules (*arrowheads*) of the second and third MTP joints.

with loss of internal echotexture plus or minus intraneural hematoma or frank interruption.[13] Ultrasound has a distinct advantage in the small cutaneous neuromata. The miniscule size of a distal or near terminal branch neuroma, in the range of millimeters, can be visualized under high-frequency ultrasound. Confirmation of symptoms through interventional means can facilitate a more definite diagnosis, that can allow for expedient intervention with injection or radiofrequency.[12,19]

Indirect findings include the presence or absence of other abnormality that may impinge or irritate the nerve. Nowhere in the foot and ankle is this more useful than in the tarsal tunnel, where the juxtaposition of the tibial nerve to joint, tendon, and vasculature is so intimate and the causes so diverse. Ultrasound gives excellent visualization of the tarsal tunnel contents and is comparable to MRI, and for small or subtle lesions may have an advantage over MRI.[20,21] Common ultrasound positive causes of tarsal tunnel syndrome include ganglia, talocalcaneal coalitions, varicosities, tenosynovitis, and posttraumatic/postoperative scar tissue (see **Fig. 3**).[12,20–23] Another important indirect finding that is helpful especially in the context of real-time ultrasound scanning is the evaluation of terminal innervation musculature. Denervation changes of decreased mass and change in echotexture including terminal fatty infiltration are readily appreciable.[12]

Interactive information is unique to ultrasound as an imaging modality because of real-time visualization of tissues while applying elements of physical examination or invasive interventions. Ultrasound-guided palpation to localize symptoms to visualized tissues and abnormality is helpful across all diagnostic utilization. Needle and fluid flow interactions during injection or needle-based procedures can reveal the presence of adhesions or tethering subtle scar tissue either from direct response to the physical contact or through relative change in echotexture from the injection of fluids. Often tissue that is indistinct becomes readily visualized with fluid acting as "contrast" between it and surrounding tissues. Unique to the nerve is the ultrasonographic "Tinel." This sign is produced by mechanical stimulation of the nerve (eg, tapping) with the ultrasound probe or manually under direct ultrasound visualization. It is usually present at the area or areas of abnormality and correlates with direct nerve changes such as enlargement.[12]

Selective low-volume anesthetic injection of a specific nerve under ultrasound guidance may be beneficial diagnostically as well, especially in distinguishing causes of pain. A prime example would be a block of Baxter nerve at the level of the abductor hallucis to distinguish this common neurogenic pain in the heel from plantar fasciosis or other causes. Fluid flow during a diagnostic or therapeutic injection along or surrounding a nerve or its fascial plane may become interrupted at the site of subtle entrapment or manifest a "pop" phenomenon as flow pressure builds and then releases as fascial tethers are cleared. The combination of these interventional findings especially in the context of direct or indirect evidence of abnormality can work with the rest of a clinical examination and appropriate nerve testing to help establish abnormality and a rationale for a treatment plan.

TENDINOPATHY

The tendons of the foot and ankle are well visualized under high-frequency ultrasound techniques because of the superficial nature and dynamic access to various positions of the foot and ankle. The main limitation continues to be user dependence with likely differences between minimally trained and highly experienced providers,[24] which is yet uncharacterized in the literature. Despite challenges of user dependence, series have shown good correlation between surgical findings and ultrasound as well as MRI and ultrasound.[24–26] Tendons are visualized routinely in the short and long axis with attention to tendon morphology, size, and relationship with associated structures, especially nerves, bursae, fat pad, and bone. Doppler imaging of associated neovasculature has a role in quantifying tendinopathy that is not clearly elucidated.[25] Finally, dynamic imaging can be very helpful and is a quality unique to ultrasound especially as regards tendon disruption or subluxation. The classic ultrasound description of tendon and ligament in the long axis is the compact fibrillar pattern, which is a linear appearance of tendon fascicles that can be interrupted or lost in the form of hypoechogenic changes, discontinuity, calcification, or disorganized appearance. The short axis often in combination with dynamic images is best at revealing split tearing and other longitudinal abnormalities (Figs. 5 and 6).

The role of ultrasound has been best described in the Achilles tendon (Figs. 7 and 8) with the highest-quality accompanying studies. It is very good, 96% accuracy, at diagnosing complete Achilles ruptures and 75% accuracy in diagnosing partial ruptures compared with surgical correlation. The authors of this retrospective chart review admit these results may underrepresent the accuracy of ultrasound, however, because the examinations were performed by general radiologists with limited exposure to musculoskeletal ultrasound.[24] In less severe abnormality as in the tendinosis/tendonopathy spectrum, the accuracy is much more variable but is reported as comparable to MRI in clinical disease with sensitivity/specificity 80/49 and 95/50, respectively.[24,25] Ultrasound utilization in prognosis is still relatively poor for mild clinical disease but excellent in Achilles rupture and can be used for treatment planning.[27,28] Westin and colleagues[28] compared operative versus nonoperative treatments of Achilles rupture and reported a high rerupture rate with 10 mm or more diastasis in the nonsurgical group measured by ultrasound at injury. There were no observed reruptures in nonoperative cases with less than 10-mm diastasis. Significantly better patient-reported outcomes using the Achilles Tendon Total Rupture Score and heel-rise height at 12 months were shown with diastasis less than 5 mm.[28] Preoperative ultrasound of the Achilles allows for accurate site marking of the rupture as well as the proximal and distal stumps and may facilitate minimally invasive repair techniques. Agreement on a standardized ankle joint angle between ultrasonographer and surgeon is advisable. Reported has been 30° of equinus, but there is no current standard.

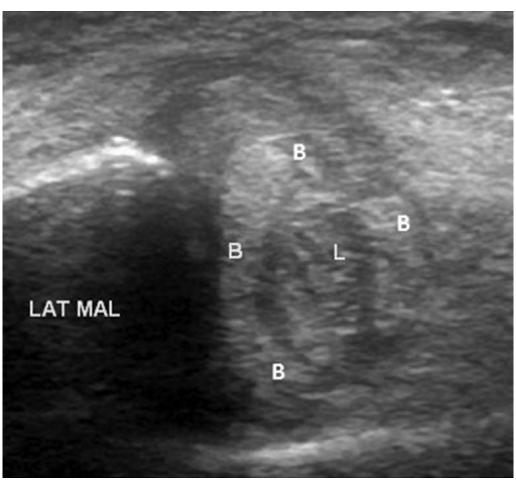

Fig. 5. Peroneal "banana peeling." Advanced degeneration of the peroneus brevis with longitudinal bundles (B) wrapping circumferentially around the oblong normal longus (L) at the level of the lateral malleolus (Lat Mal).

The other tendons of the foot and ankle are easily visualized on dynamic high-frequency ultrasound. Although head-to-head comparisons with MRI have not been done, ultrasound with its dynamic or interactive imaging is extremely effective in the imaging of the peroneals and is a good early test of abnormality, including peroneal dislocation, intrasheath subluxation, split tearing, tenosynovitis, os peroneum fracture, and acute strain (see Figs. 5 and 6). All of these have distinct ultrasonographic appearances and are arguably reliable to guide treatment. Recourse to MRI or computed tomography is necessary only in cases of associated significant bony disease or for purposes of preoperative planning.[26,29–31] The abnormality of the anterior and posterior tibialis tendons is also well documented with appropriate MRI correlation with equivalent usage for these disorders.[21,32–34] Cartilaginous accessory navicular, which may be difficult to visualize on MR, is fairly easily visualized on ultrasound. Ultrasound of the other foot extrinsics and intrinsics can be quite helpful, especially at the ankle and dorsum of the foot. On the plantar surface, ultrasound can lose resolution because of the depth of penetration and sonographic densities of the plantar tissues, making MRI the preferred imaging technique with notable exception at the plantar fascia. Ultrasound continues to have excellent indications for image-guided intervention throughout.[21]

LIGAMENTOUS EXAMINATION

Diagnostic evaluation of the ligamentous structures about the foot and ankle is well described and is part of standardized training programs in

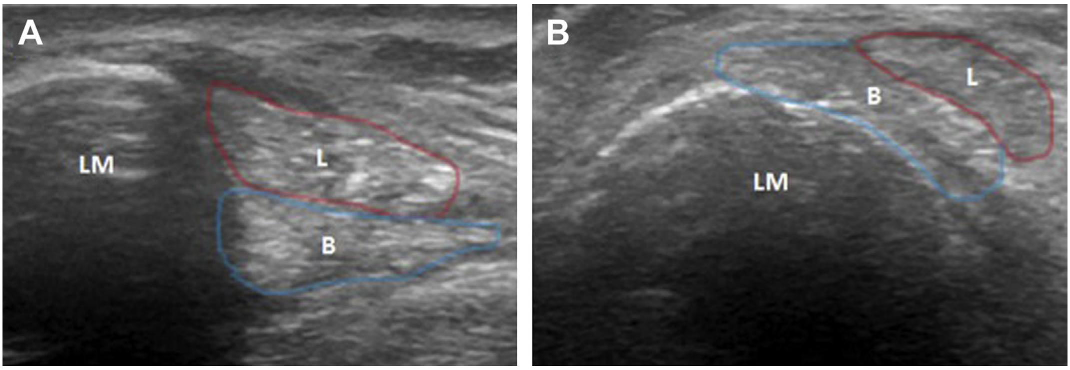

Fig. 6. Peroneal intrasheath subluxation. (*A*) Peroneus longus (L) and brevis (B) (highlighted for contrast) resting in a shallow fibular groove of the lateral malleolus (LM) with the ankle in neutral position. (*B*) Ankle in active dorsiflexion eversion. The peroneus brevis subluxes under the longus with palpable snap and pain in dynamic imaging.

musculoskeletal ultrasound. Evidence of acute sprain is characterized by disruption of the compact fibrillar pattern of the ligament edema or adjacent hematoma.[21] Chronic sprain can show loss of robust compact fibrillar pattern, and when severe, complete disorganization of the ligamentous tissue and nonvisualization.[21] Dynamic examination for ankle instability has been described but should have appropriate clinical relevance.[35] Small avulsion fractures associated with ankle and lateral column sprains are quite common, and ultrasound can be used to identify these early (Fig. 9). Early diagnosis is especially helpful in the case of intra-articular fractures, which can result in painful nonunion or persistent synovitis and may require more aggressive initial immobilization. In the pediatric population, such small avulsion invisible on plain films can be a marker of ankle instability.[21,36]

INJECTION

Perhaps the most common utilization in the foot and ankle is for simple injection guidance. Ultrasound-guided injections in the foot and ankle specifically have been shown to be accurate in both large and small joint and tendon sheaths (Fig. 10).[37,38] It also allows sufficient visualization so as to avoid intervening structures. Ultrasound is distinctly more accurate than landmark guidance for small joints and may have advantages in larger (tibiotalar, subtalar) joints if the anatomy is significantly deranged.[38,39] Increased short-term benefit of directed injections of corticosteroid in other major joints (shoulder, knee) has been demonstrated but is not yet proven for the foot and ankle.[40] Perhaps the best benefit of real-time sonographic intervention is the concept of

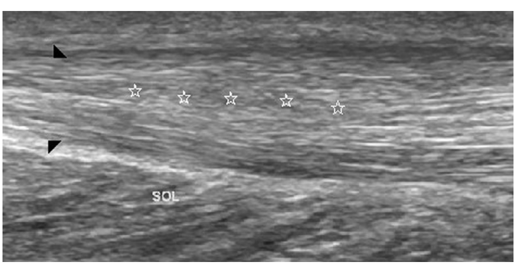

Fig. 7. Midsubstance Achilles tendinosis. Long-axis visualization reveals normal compact fibrillar pattern and thickness on the proximal end (*arrowheads*) giving way to fusiform thickening of the tendon and mild "ground glass" echotexture that appears centrally (*stars*). The distal soleus is visualized deep to the symptomatic area (SOL).

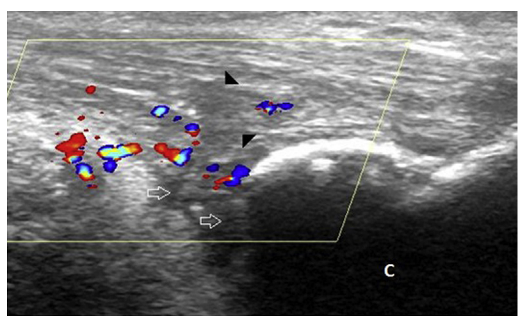

Fig. 8. Severe insertional Achilles tendinosis. A long-axis view of the Achilles insertion at the calcaneus (C) with loss of compact fibrillar pattern, peritendinous and intratendinous Doppler signal, hypoechoic regions (*arrowheads*), and irregular gross thickening of the retrocalcaneal bursa at its junction with Kager fat pad (*arrows*).

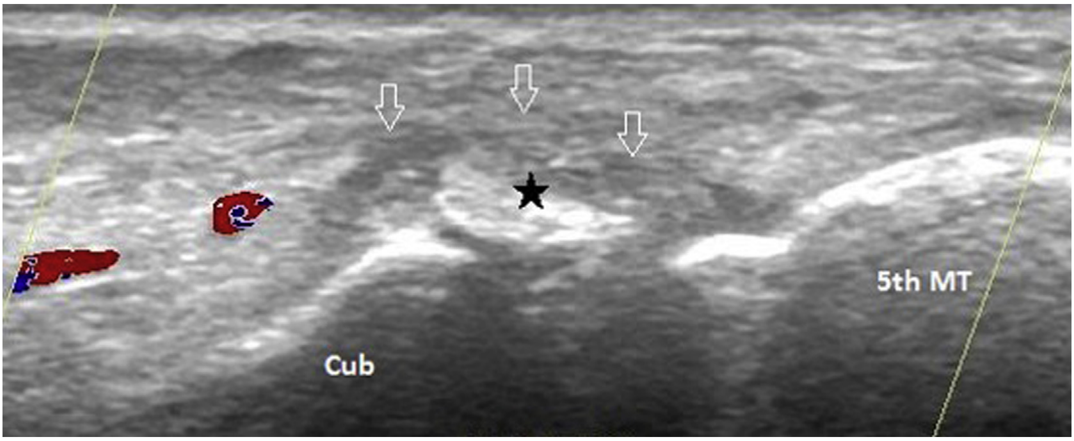

Fig. 9. Occult cuboid avulsion in an 18-year-old collegiate volleyball player after inversion injury with persistent lateral foot pain despite protected weight-bearing. Long-axis view of the lateral tarsometatarsal joint is visualized and corresponds to maximal tenderness. An intra-articular avulsion from the cuboid is seen (*star*). The joint capsule is thickened and distended (*arrows*) with Doppler signal approaching the area, consistent with secondary synovitis. Cub, cuboid; 5th MT, fifth metatarsal.

selective blockade. Selective local anesthetic application in painful joints or tendon sheaths/bursae allowing for examination or trial of ambulation while under anesthesia is well established and may correlate to surgical outcome.[41,42] Selective block is more specific than radiology findings of degeneration for determining source of pain and can result in improved success in joint arthrodesis for painful joints of the foot and ankle.[29,41,42] Selective block may not be as relevant in isolated tibiotalar joint arthrodesis for posttraumatic arthrosis in the context of long-term outcomes.[43] Advantages of ultrasound over traditional fluoroscopy for this indication include expedience in office application, allowing increased sonographer, patient, and foot and ankle surgeon dialogue.

GANGLION ASPIRATION

Ganglion cysts are filled with mucin and can produce pain due to compression of surrounding structures.[44] Because of this, they appear to contain hypoechoic homogenous fluid on examination.[45] Ultrasound aspiration and injection of ganglion cysts have become a popular treatment due to the minimally invasive execution and constitute one of the first utilizations of ultrasound guidance. Ultrasound allows for visualization of the structure's depth, dimensions, and

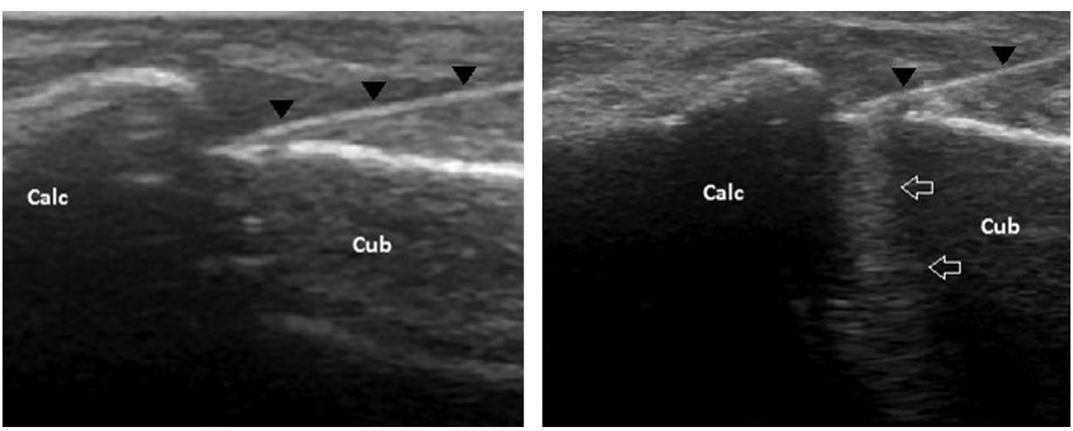

Fig. 10. Small joint corticosteroid injection. The calcaneous (Calc)/cuboid (Cub) joint is visualized in the long axis. A 25-gauge needle (*arrowheads*) is placed bevel down into the joint, and the steroid particulate is seen to flow into the joint with motion artifact (*arrows*).

proximity to nerves and vessels.[44] Thus, safe visualization of the needle entering the substance and dynamic emptying of the cyst can be noted in real time.[45] Ju and colleagues[44] found that 77% of their patients who underwent ultrasound-guided aspiration for a symptomatic lower-extremity ganglion cyst reported resolution of symptoms at 1-year follow-up. Percutaneous aspiration has less morbidity than open excision and allows physicians to conduct an ultrasonographic evaluation of a painful lesion.

SOFT TISSUE INJECTION

Needle localization for soft tissue injection independent of a joint or ganglion is well established and was first described nearly 2 decades ago.[46] As such, multiple substances have been introduced into the structures of the lower extremity with varying success,[47,48] including corticosteroid,[49] dextrose,[50] biologics like platelet-rich plasma and stem cells,[51] and even electricity.[52] Botulinum toxin has shown success for plantar fasciosis and for chronic exertional compartment syndrome.[53,54] Needle placement, without injection, used instead for fenestration under ultrasound has recently been described as a treatment of chronic compartment syndrome in a case report.[55] Independent of specific substances, ultrasound allows unparalleled real-time control for needle placement in routine or experimental models.

MORTON NEUROMA

Special attention deserves to be paid to ultrasound-guided injection of Morton neuroma. Ultrasound allows not just appropriate diagnosis but also ease of access for preferred nonsurgical treatments. A systematic review comparing the 2 methods found that ultrasound-guided injections provided better short-term and long-term relief.[56] According to a review done by Morgan and colleagues,[56] guided injections reduced pain by 66% in comparison to the 50% reduction noted in nonguided procedures. Ultimately, ultrasound provides accurate medication delivery, improved outcomes, and reduction in the amount of repeat injections given to patient and decreases the need for surgical intervention.[56]

The benefit of ultrasound lies in its cost-effectiveness and its application to multiple treatment modalities. Chuter and colleagues[57] described a series using ultrasound-guided radiofrequency ablation of Morton neuroma and found that it reduced symptoms and reduced the need for surgical excision by 85%, allowing for an in-office, percutaneous alternative to surgical treatment of these lesions.

EMERGING THERAPIES

The ability to accurately identify structures and disease as well as accurately place needles has begun to spawn innovations in treatment based around the concept of real-time interactions with the underlying abnormality. The movement from sporadic islands of clinical practice to an emergence in the literature has been slow but with increasing frequency. Treatments range from needle-based interventions and augmentation of traditional surgery with preoperative or intraoperative imaging to the development of new technologies to allow novel minimally invasive techniques.

HYDRODISSECTION

Sonographic hydrodissection is defined by the use of a fluid medium, usually local anesthetic or saline, to dissect between structures or fascial planes as directed by injection under continuous ultrasound visualization. To date, published studies and case reports are few but with increasing number in recent years. Most attention has been directed at the upper extremity with the technique used as an alternate effective means of treating carpal tunnel syndrome.[58,59] The basic technique includes identifying the region of nerve entrapment or compression and successful decompression using hydrodissection technique either in the long axis of the nerve or in the short axis, where circumferential dissection can be accomplished. The technique uses tissue treatment without direct needle impingement or trauma to the nerve and with minimal trauma to the tissues, even using needles as small as 25 gauge. Successful treatment of sural nerve entrapment has been documented in the foot and ankle.[60]

Ultrasound visualization combined with hydrodissection has been used in the case of foreign body removal, intraoperatively allowing the surgeon to insulate the foreign body from the surrounding structures with a bubble of fluid to allow surgical access.[61] When combined with accurate sonographic surgical guidance, this can minimize surrounding tissue injury during removal.[61–64] Hydrodissection can be applied in other soft tissue disorders, including tendinopathy (**Figs. 11** and **12**). Literature is limited to Achilles midsubstance disease. Symptomatic treatment of midsubstance Achilles tendinosis

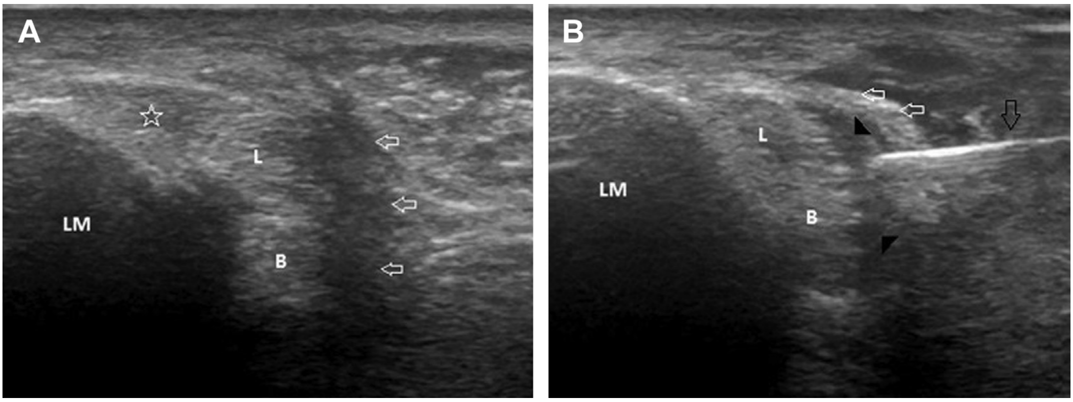

Fig. 11. (*A*, *B*) Hydrodissection of peroneals. A 40-year-old man after remote peroneal synovectomy with pain over the peroneals and loss of subtalar motion on his right side. Immediately after the procedure, pain decreased and range of motion markedly improved. (*A*) Peroneus longus (L) and brevis (B) at the lateral malleolus (LM). The superficial retinaculum is visualized (*star*) as is a mass of typical-appearing postoperative scar (*white arrows*) adhering to the peroneals and preventing physiologic motion. (*B*) Dilute local anesthetic is introduced under gentle pressure (*arrowheads*) by a 25-gauge needle (*black arrow*) dissecting the peroneals away from the scar, which now appear bright when contrasted with the fluid.

with hydrodissection-based stripping of the anterior paratenon away from Kager fat pad with high-volume fluid injection has been found to be effective in 2 trials to date.[65,66] This concept of treating the paratenon-fat pad junction in midsubstance disease has been recently combined with traditional percutaneous tendon stripping into an ultrasound-guided mini-open stripping/tenolysis by Alfredson[67] with good results in his series as well.

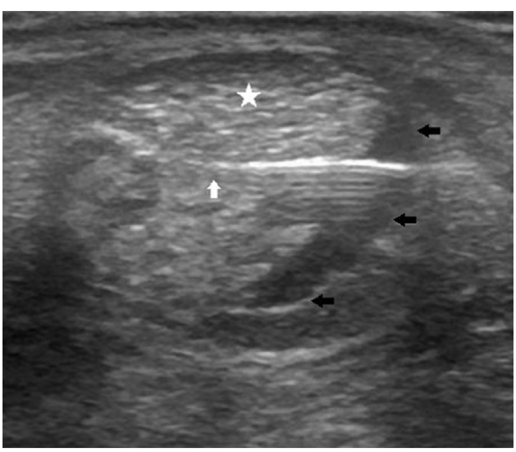

Fig. 12. Achilles hydrodissection. A short-axis view of the area of maximal tenderness of the midsubstance of the Achilles (*star*). A 25-gauge needle injects local anesthetic with partial dissection of Kager fat pad (*black arrows*) away from the lateral tendon. The needle tip (*white arrow*) is advanced directly under the tendon to facilitate further dissection.

ULTRASONOGRAPHIC AUGMENTATION OF SURGERY

Ultrasound has the potential to augment many aspects of traditional foot and ankle surgery. Perhaps most helpful is the ability to use ultrasound preoperatively or intraoperatively to identify soft tissue and bony structures over and above traditional palpation or landmark-guided techniques. Assistance in endoscopy is documented not just in helping with port placement but also with offering another means of visualization. Published cases and series include arthroscopy of the hallux and several techniques at the plantar fascia.[68–70] Ultrasound guidance in

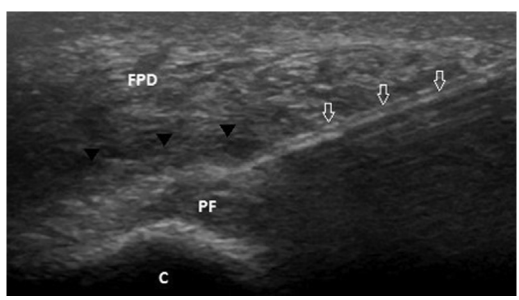

Fig. 13. Ultrasonographic fasciotomy. Long-axis view of the plantar fascia (PF) is partially obscured by a hypersonic surgical probe (*arrows*). It is debriding the proximal portion of the origin. Iatrogenic fluid is seen in the subcalcaneal bursa (*arrowheads*) separating the origin from the plantar fat pad (FPD). C, calcaneus.

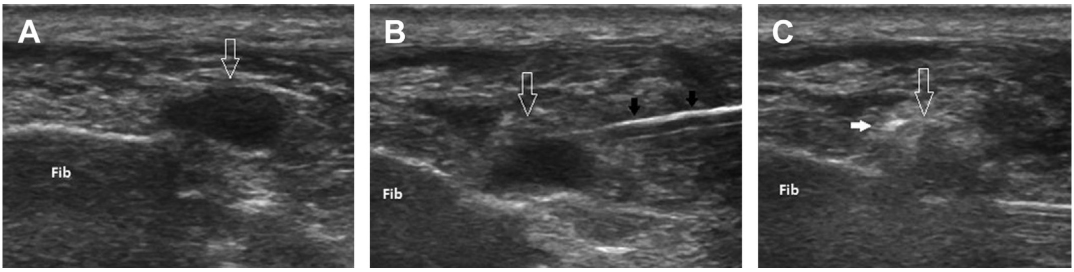

Fig. 14. (*A–C*) Percutaneous ablation of stump neuroma. A 75-year-old after right below knee amputation with a 5-mm fibular nerve stump neuroma. Surgical progression from left to right. The neuroma (*large white arrow*) is localized in the short axis adjacent to the fibular neck (Fib) in each image. (*A*) Large hypoechoic neuroma before instrumentation (*arrows*). (*B*) Canalization by an 18-gauge needle (*black arrows*) to the neuroma to allow radiofrequency ablation with 3-mm small joint arthroscopy RF probe. (*C*) After ablation. The hypoechoic structure is replaced with edema and vapor (*filled white arrow*).

open/mini-open Achilles surgery has been mentioned above with regard to the Achilles tenolysis and to foreign body removal. The arthroscope or open visualization has been abandoned by an increasing number of clinicians in favor of direct ultrasound visualization of the surgical instrumentation wielded percutaneously. New technologies include the adaptation of ultrasonic phacoemulsification technology to perform tenotomy or fasciotomy, but evidence of benefit is only at the case report level in the foot and ankle (Fig. 13).[71,72]

Percutaneous radiofrequency lesioning of the plantar fascia is demonstrating consistent results with mounting evidence and has been described using both needle-based and bipolar surgical devices.[52,73–77] Ultrasound has been introduced to facilitate needle/probe placement especially in the context of obesity.[52] The desire to minimize surgical trauma while maintaining transcutaneous visualization by ultrasound has led to the adaptation of traditional instrumentation in nontraditional techniques. A hook knife has been adapted in a new ultrasound-directed technique of performing a Strayer procedure.[78] A meniscotome has been used successfully to perform lower-limb decompression fasciotomies.[79] Basic technique for adapting small joint arthroscopy tools like shavers and bone burs is described and has recently been successfully used to perform a novel percutaneous osteotomy in a case of calcaneal enthesophyte fracture nonunion.[80,81] Augmentation of traditional surgery techniques and tools, although promising, is not yet well established and requires a team of highly skilled interventional ultrasonographers and orthopedic surgeons to effectively apply (Figs. 13–15).

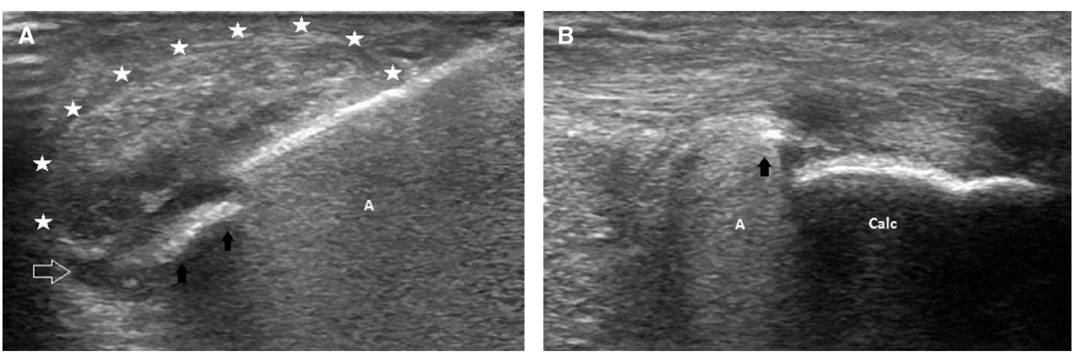

Fig. 15. (*A*, *B*) Retrocalcaneal bursectomy in insertional Achilles disease. (*A*) Short-axis view of the Achilles (*stars*). A 3.5-mm arthroscopic shaver is introduced via a lateral portal to debride the undersurface of the Achilles. The active shaver tip (*black arrows*) is advanced to the medial, proximal-most aspect of the hypoechoic bursa (*white arrow*) on the undersurface of the tendon. (*B*) Long-axis view. The active shaver tip (*black arrow*) is seen beneath the Achilles proximal to the calcaneus (Calc). In both images, portions of Kager fat pad are obscured by an active vibration artifact (*A*) as the shaver is activated.

SUMMARY

From its earliest applications, the development of musculoskeletal ultrasound has included indications in the foot and ankle. Inherent in the foot and ankle are attributes that make ultrasound ideal, especially the relatively superficial anatomy. As a diagnostic modality, it is relatively inexpensive, complementary with MRI, and allows for interactive diagnostics in subtle or complicated cases. User dependence and the need for highly trained sonographers continue to be major drawbacks. Foot and ankle ultrasound has been established as an effective and preferred modality for needle placement, but has in recent years moved beyond simple injections, inspiring innovation in technique and technology in treating the challenging diagnoses of the foot and ankle. Ultrasound will continue to adapt to service the foot and ankle surgeon even as foot and ankle surgery continues to guide and direct its safe and effective innovation. Perhaps this is ultrasound's greatest strength in that it can by its interactive nature draw the ultrasonographer, the surgeon, and the patient into a dialogue that facilitates care.

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