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Emerging Issues

# Emerging Technological Advances in Musculoskeletal Ultrasound

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## Introduction

Musculoskeletal (MSK) ultrasound (US) use has increased greatly in the past few decades [1,2]. There was a 71.7% increase in outpatient diagnostic MSK US studies from 2000 to 2009, with most of the increase due to use by nonradiologist physicians and podiatrists [3]. In the field of PM&R, residents, fellows, and practitioners are increasingly seeking US education [4].

Ultrasound technology continues to evolve. This piece describes several emerging US technologies that hold promise for enhancing the diagnostic and interventional capabilities of PM&R physicians. A growing body of evidence supports the use of US technologies such as elastography in the evaluation of tendon, muscle, and nerve disorders [5-7]. Ultrasound tissue characterization (UTC) can be used to characterize detailed tendon structures [8]. Other US techniques such as contrast-enhanced US (CEUS) and superb microvascular imaging (SMI) are emerging technologies in the assessment of joint and tissue inflammation and vascularity [9-11]. Three-dimensional (3D) and fusion US imaging can aid trained operators in better visualizing anatomic detail and guiding challenging procedures [12-14].

## Elastography

Elastography is a technique that complements grayscale and Doppler US. It allows the operator to examine a key mechanical property of tissues, which is relative stiffness or elasticity. Although several elastography techniques exist, the 2 primary types are sonoelastography and shear wave elastography [15]. Sonoelastography has established use in oncology in differentiating breast, thyroid, liver, prostate, and lymph node malignant versus benign lesions based on differences in tissue stiffness [16-20]. Elastography functionality can be purchased with newer US machines from companies including but not limited to GE, Philips, Toshiba, Mindray, Konica Minolta, and Esaote. An elastography-compatible probe and specialized software can also be purchased as an add-on to existing US machines, depending on the company. Some machines are capable of both sonoelastography and shear-wave elastography, whereas others are capable of only one type of elastography.

## Sonoelastography

Sonoelastography (also known as strain or compression elastography) relies on the operator's skilled, repetitive manual compression of the target tissue with the US transducer. It relies on the Young modulus to detect strain in the axial plane, which is defined as the change in length or tissue displacement compared to a tissue's original length [21]. Tissues that are stiffer deform less and have lower strain values when stress is applied. Less stiff (ie, softer) tissues deform and displace more and have higher strain values. Thus, sonoelastography can be used to evaluate relative tissue stiffness compared to a reference such as subcutaneous fat or a gel pad.

Stiffness is a mechanical property of tendons, muscles, and nerves that currently cannot be assessed clinically or noninvasively by any conventional imaging technology. Tendons are tissue responsive to mechanical load at a cellular and molecular level. Pathologic tendons appear less stiff on sonoelastography when compared to normal tendons [22,23]. Rehabilitation and tendon-loading programs such as eccentric and heavy slow resistance aim to improve tendinopathy symptoms by inducing changes in tendon mechanical properties [24-26]. Preliminary studies using sonoelastography to assess Achilles, patellar, and elbow common extensor tendinopathy have shown promise in diagnosing tendon disorders, enhancing the ability to predict tendon pain in athletes, and monitoring treatment outcomes [27-30]. Figure 1 illustrates Achilles tendinopathy in an elite soccer player on grayscale US, sonoelastography, and magnetic resonance imaging (MRI). Video 1 shows


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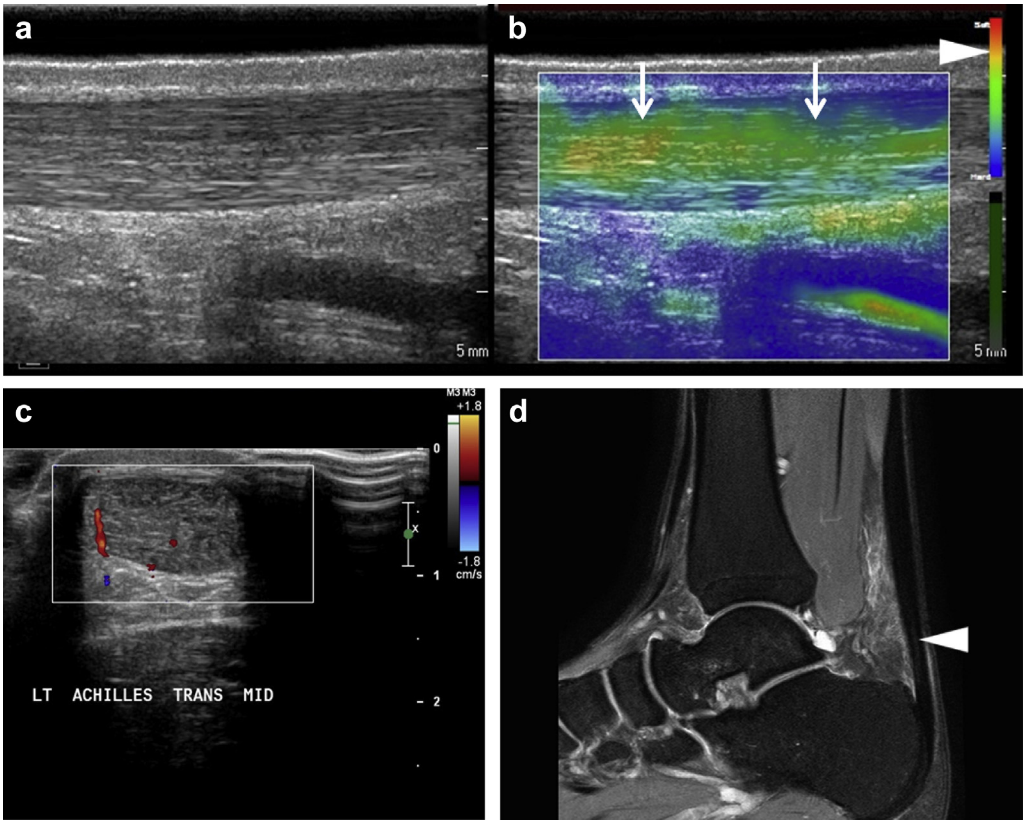


**Figure 1.** A 27-year-old elite soccer player presented with 5 months of left Achilles tendinopathy symptoms. Grayscale ultrasound (US) and sonoelastography images were acquired using a Philips iU22 US machine with an L17-5 transducer. (a) Longitudinal US image demonstrated subtle heterogeneous intratendinous echogenicities in the midportion and midsubstance of the Achilles tendon. (b) Sonoelastogram showed green to yellow color, suggestive of decreased intratendinous stiffness with softening of the midportion and midsubstance of the Achilles tendon suggesting chronic tendon injury (arrows). Sonoelastography color map bar is shown on the right upper corner of the image (arrowheads; red indicates soft, yellow-green indicates intermediate stiffness, and blue indicates hard tissue). (c) Achilles tendon neovascularization with several vessels entering the ventral surface of the Achilles. (d) Corresponding sagittal, proton-density—weighted MR image reveals increase signal intensity (arrowhead) in the midsubstance of the minimally thickened tendon, suggestive of Achilles tendinopathy.

real-time sonoelastography in an athlete with Achilles tendinopathy.

For Achilles tendinopathy, combining grayscale US and sonoelastography improved diagnostic sensitivity (0.96) and specificity (0.95) with improved clinical correlation ($P < .001$) compared to routine grayscale and color Doppler US (sensitivity 0.67, specificity 0.94) [22]. Another study found that Achilles tendon softening detected by sonoelastography at the start of the competitive season was predictive of subsequent development of Achilles tendon symptoms during the season in elite Australian Rules football players [30]. Sonoelastography has also been used to monitor Achilles tendon healing post rupture. Tan et al reported significantly decreased stiffness in areas of tendon fiber disruption that became progressively stiffer with healing at an average follow-up of 38.6 months [31]. This highlights the potential clinical utility of sonoelastography as a supplementary tool in monitoring tendon healing.

In addition to evaluating tendon disorders, sonoelastography has also been used to evaluate skeletal muscle disorders. Preliminary studies have described the utility of sonoelastography in objectively evaluating myopathies, spasticity, and myofascial trigger points and in guiding botulinum toxin injections for spasticity [15]. Although the Modified Ashworth Scale (MAS) and Modified Tardieu Scale are commonly used to grade muscle spasticity, both involve subjective rather than objective assessments. Sonoelastography has been used to evaluate gastrocnemius, biceps brachialis, and finger and wrist flexor muscle spasticity in stroke patients [32-34]. A case series of children with spastic cerebral palsy (CP) found that sonoelastography use could aid the operator in identifying differences between relaxed and contracted muscles. This information was then used to guide botulinum toxin injections [6]. Elastography has also been applied in the evaluation of inflammatory myopathies [35,36]. Botar-Jid et al evaluated patients with inflammatory muscle diseases including dermatomyositis and polymyositis and found concordance between the elastography colorgram and serum creatine kinase and lactic dehydrogenase markers [36]. However, other studies have suggested that