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Application and Research Progress of Real-Time Shear Wave Elastography in Quantitative Assessment of Musculoskeletal System

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ABSTRACT

Shear wave elastography (SWE) is a new ultrasonic elastography technique that can quantitatively obtain the elastic modulus of biological tissue without additional operator pressure. Because SWE technology has the advantages of quantitative measurement, good repeatability and real-time dynamic observation, it has been widely used in the evaluation of liver, thyroid, breast, gynecology, musculoskeletal system, urinary system and other diseases. Especially in recent years, SWE has been more widely used in the musculoskeletal system. This article introduces the progress in the research and application of elastography in the musculoskeletal system and reviews the progress in the clinical research and application of SWE in the evaluation of muscles and tendons, peripheral nerves, joints and ligaments, soft tissues and muscle masses.

KEYWORDS

Ultrasound examination; Elastic imaging technology; Shear wave elastic imaging; Quantify; Musculoskeletal ultrasound; Skeletal muscle

1. INTRODUCTION

Shear wave elastography (SWE) has been established as an excellent diagnostic method for liver fibrosis, breast cancer, and thyroid cancer. SWE also has new applications in the field of obstetrics and gynecology and has shown good repeatability in measuring the hardness of the cervix [1]. SWE can evaluate patients with unexplained infertility by measuring endometrial hardness [2]. At present, there have been many studies in the musculoskeletal field using SWE, which has recently been widely used in clinical practice [3].

2. APPLICATION OF SWE IN TENDONS AND MUSCLES

Studies have shown that the rigidity of skeletal muscle is greater when it is contracted than when it is relaxed. Wang and coauthors [4] reported that there was no significant difference in the mean mid-section rigidity of skeletal muscle between older and younger women in a relaxed state, but younger women had higher muscle rigidity when they contracted, especially at higher levels of contraction. Eby and collaborators [5] conducted the SWE study to quantify bicep stiffness in 133 healthy adults at 90° elbow flexion and full extension, which also showed that the modulus of elasticity increases with age, with women often having higher values than men.

Lacourpaille and collaborators [6] used SWE imaging to assess skeletal muscle hardness in six different relaxation and contraction states: tibialis anterior, lateralis femoris, biceps brachialis, triceps brachialis, abductor pinkie, and medial head of gastrocnemius muscle. The participants, 14 muscular dystrophy patients and 13 healthy controls, found that the hardness of all skeletal muscles in patients with muscular dystrophy was significantly higher than that in healthy controls, with little change in the abductor muscle of the little finger.

Carpenter and collaborators [7] conducted a SWE study in eight patients with biopsy-confirmed distal myopathy accompanied by marginal cavitation-associated myopathy (GNE) and five healthy volunteers to assess quantitative differences in shear wave velocity between these two groups of skeletal muscle. The mean velocity was significantly lower in patients with GNE-associated myopathy than in healthy controls, and muscle anisotropy was reduced in patients with GNE-associated myopathy. The study showed that by using SWE velocity measurements to assess temporal changes in muscle volume and weakness, a series of assessments of GNE-associated myopathy could be performed. Some researchers used multimodal ultrasound and SWE to jointly evaluate the changes in the anal levator complex of patients and made new discoveries in the study of early stress urinary incontinence after vaginal delivery [8].

3. THE APPLICATION OF SWE IN NERVES

Few studies have used SWE to assess peripheral nerves. In our experience, nerves in patients with neuropathy exhibit higher shear wave velocities than normal nerves, and abnormal median nerves in patients with carpal tunnel syndrome propagate faster than those in normal nerves.

In the SWE study by Kantarci and collaborators [9], in 37 consecutive patients diagnosed with carpal tunnel syndrome and 18 healthy volunteers, median nerve hardness (66.7 kPa) at the carpal tunnel entrance was significantly higher in patients with carpal tunnel syndrome than in normal subjects (32.0 kPa). The severe or very severe group (101.4 kPa) was also higher than the mild or moderately severe group (55.1 kPa). SWE showed that 40.4 kPa was the cutoff value, and the sensitivity, specificity, positive predictive value, negative predictive value and accuracy were 93.3%, 88.9%, 93.3%, 88.9% and 91.7%, respectively.

In an experimental study conducted by Palmeri and collaborators [10] on fresh cadavers and two normal volunteers, SWE improved the visualization of several peripheral nerves, including the sciatic nerve and the brachial plexus, with potential uses in regional anesthesia procedures.

Andrade and collaborators [11] used the Aixplorer scanner to assess the effect of 90° flexion and 180° ankle dorsiflexion extension on sciatic nerve shear wave velocity in 90 healthy subjects. In this study, the shear wave velocity of the sciatic nerve increased significantly at maximum knee extension and ankle dorsiflexion, but no change was observed at 90° knee flexion. The ankle joint dorsiflexion was repeated 5 times, and the shear wave velocity of the sciatic nerve gradually decreased. However, this difference did not reach statistical significance. The results of this study suggest that the elastic properties of the sciatic nerve can be evaluated noninvasively during passive movement.

4. SWE IS APPLIED IN JOINTS AND LIGAMENTS

Although ultrasound is widely used to evaluate rheumatic diseases, to our knowledge, there have been no studies on the efficacy of SWE in evaluating arthritis. There are also few SWE studies on ligaments. In our experience, normal ligaments in the relaxed state show moderate shear wave velocity, while the velocity increases in the contracted state. The speed within gouty stones in patients with gout depends on their consistency, with harder gouty stones showing a higher velocity than soft gouty stones and thickened synovium.

Mhanna and collaborators [12] studied the mechanical properties and in vivo adaptations of the transverse carpal ligaments in 10 female pianists and 10 female nonpianists, as progressive hardening of these ligaments may restrict the carpal tunnel and cause compression of the median nerve. The study showed that the transverse wrist ligaments were significantly stiffer in the piano players than in the nonpiano players, and the shear wave velocity was 10.2% higher in the piano group than in the control group (5.52 m/sec±0.46 vs. 5.01 m/sec±0.58, respectively). In both groups, the transverse carpal ligaments were stiffer on the radial side.

In a recent SWE study, Wu and collaborators [13] assessed the thickness and elasticity of the coracohumeral ligament (CHL) in 30 healthy subjects and 20 patients clinically diagnosed with neutral unilateral shoulder adhesion capsultis and maximum external rotation of the shoulder. This article reports an increase in the thickness and hardness of CHL in the symptomatic shoulder compared to the unaffected contralateral shoulder. The shear modulus of the affected shoulder joints is larger when the external rotation degree of the two shoulder joints is the same. The authors suggest that CHL stiffness in patients with shoulder capsular adhesion may be related to a limited range of motion during external rotation of the glenohumeral joint. Our previous studies have shown that water immersion ultrasound can avoid the pressure effect of the probe on the tissue [14]. At the same time, the use of the water immersion method can improve the accuracy and repeatability of SWE measurements, especially measurements of the median nerve [15].

5. APPLICATION OF SWE IN SOFT TISSUE AND MUSCLE MASS

SWE has shown promise in the characterization and treatment follow-up of breast lumps. The repeatability of SWE measurements for nodules at different depths of the breast is different, and the repeatability of measurements for deeper nodules is higher because they are less affected by probe pressure. At the same time, the sound guide pad can improve image quality [16]. Athanasiou and collaborators [17] studied routine ultrasound and SWE of 28 benign and 20 malignant breast lesions in 46 patients, all of which were detected by SWE. Since shear waves do not travel through fluids, the authors were able to clearly distinguish between complex cysts and solid lesions because the shear wave signal was lost. In a recent study of 33 breast cancer patients, Athanasiou and collaborators [18] reported a good correlation between three-dimensional (3D)SWE and dynamic contrast-enhanced MRI imaging in tumor volume measurement and a reduction in hardness and elasticity heterogeneity in 10 well-responding patients in a selected subgroup. SWE is also used in thyroid nodules, and most malignant lesions are harder than benign nodules [19]. There are currently two studies on the utility of SWE in evaluating musculoskeletal soft tissue masses. Among them, Pass and collaborators [20] conducted traditional ultrasound typing and SWE studies on 105 biopsy-confirmed musculoskeletal soft tissue tumors, 39 of which were malignant and 66 of which were benign. In this study, there was no significant quantitative or qualitative association between shear wave velocity and malignancy. Although there may be some evidence of an association between lower shear wave velocity and soft tissue malignancy, particularly on the transverse plane, this has not led to substantial improvements in the ability to detect malignancy in the conventional ultrasound model consensus classification [21]. Another similar SWE shear-wave elastography study of 50 soft tissue tumors (15 of which were malignant and 35 benign) at the same institution showed more encouraging results. In that study, the longitudinal shear velocity of malignant tumors was on average 30% slower than that of benign tumors, and the longitudinal and transverse shear velocity measurements were moderately correlated with each other [22]. However, based on the results of these two studies, it is too early to draw definitive conclusions about the utility of SWE in evaluating soft tissue tumors, and further prospective studies are needed. SWE has been shown to be a promising measurement tool for identifying changes in muscle mechanics during aging [23-25].

6. CONCLUSION

SWE is an exciting and rapidly evolving ultrasound technique that can quantify elastic tissue properties. It can be used to supplement conventional ultrasound in the initial characterization of various trauma and pathological conditions of the musculoskeletal system and during posttreatment and follow-up. This can be important in early disease when abnormalities in musculoskeletal soft tissue cannot be detected or characterized by traditional ultrasound methods. It may also be useful in staging chronic diseases, determining response to treatment, and monitoring age-related changes. New approaches to SWE, such as 3D-SWE, may add new information that traditional 2D SWE cannot provide. Finally, future SWE studies to characterize musculoskeletal soft tissue masses may reveal another application of this evolving technique, which offers great promise as an adjunct to traditional ultrasound.

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