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Reliability of ultrasound shear-wave elastography in assessing low back musculature elasticity in asymptomatic individuals

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ABSTRACT

Patients with low back pain commonly exhibit impaired morphology and function of spinal musculature that may be quantifiable using shear-wave elastography (SWE). The purpose of this study was to assess the intra-rater and test-retest reliability of SWE elasticity measures of the lumbar erector spinae and multifidus muscles during rest and differing levels of contraction in asymptomatic individuals. This single-group repeated-measures design involved a baseline measurement session and a follow-up session 3 days later. The lumbar multifidus was imaged at rest and during three levels of contraction (minimal, moderate, and maximum). The lumbar erector spinae (illiocostalis and longissimus muscles) were imaged at rest only. Overall reliability estimates were fair to excellent with ICCs ranging from 0.44 to 0.92. Reliability was higher in the lumbar multifidus muscles than the erector spinae muscles, slightly higher during contraction than during rest, and substantially improved by using the mean of 3 measurements. By reliably quantifying impaired spinal musculature, SWE may facilitate an improved understanding of the etiology and treatment of low back pain and other muscle pain-related conditions such as trigger points and fibromyalgia.

1. Introduction

Despite recent advances in technology and spinal imaging, low back pain (LBP) remains a leading cause of both healthcare costs and physical disability (Manchikanti et al., 2014). Ninety percent of people with LBP experience pain with unknown origin or pathology, also referred to as “nonspecific LBP” (Haldeman et al., 2012). In an attempt to better understand nonspecific LBP, much research has focused on identifying impaired morphology and function of spinal musculature, particularly of the lumbar multifidus (Freeman et al., 2010; Kalichman et al., 2017). Morphology of the spinal musculature has been quantified using magnetic resonance imaging (MRI) (Goubert et al., 2017), computed tomography (CT) (Danneels et al., 2000), and B-mode ultrasound (Wallwork et al., 2009). While many of these studies have shown differences such as atrophy (Goubert et al., 2017) and fatty infiltrate (Teichtahl et al., 2015) in patients with LBP compared to healthy individuals, other studies have questioned the clinical relevance of such findings (Niemeläinen et al., 2011; Suri et al., 2015).

Function of the spinal musculature has been similarly quantified using electromyography (EMG) and B-mode ultrasound. Such studies have reported both delayed and attenuated contraction of the lumbar multifidus in patients with LBP (Hungerford et al., 2003; Wallwork et al., 2009), even after remission of symptoms (Macdonald et al., 2011). While both EMG and B-mode ultrasound can be used to indirectly measure muscle contraction, both techniques have substantial limitations. EMG can provide valuable information about the neural control of movement, however it does not directly measure muscle force, which in addition to neuromotor activation, is dependent upon biomechanical muscle factors such as cross sectional area and force-velocity relationships (Hug et al., 2015a). Additionally, EMG of the lumbar multidifus and other deeper spinal muscles is an invasive procedure that requires an electrode be placed within the muscle to ensure a reliable signal (Stokes et al., 2003). Using B-mode ultrasound to quantify muscle contraction relies on comparing thickness or cross-sectional area measures during a contraction to muscle measures during rest. This means that the ability of B-mode ultrasound to quantify

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muscle contraction is likely context-dependent and affected by the type of muscle contraction, the muscle being imaged, the excursion of the muscle, and pressure from surrounding musculature (Koppenhaver et al., 2009b).

Shear-wave elastography (SWE) is an emerging ultrasound technology that visually depicts and quantifies elasticity, or stiffness, of soft tissue. Newer techniques, such as supersonic shear imaging, are relatively operator independent, reproducible, and allow for quantification of both superficial and deep tissues. To date SWE has primarily been used to quantify soft tissue lesions such as breast (Li et al., 2013), liver, and thyroid tumors (Ferraioli et al., 2014) where abnormally stiff tissue may indicate malignant lesions. Since the initial demonstration of the visualization of reasonable changes in muscle stiffness via SWE in 2010 (Shinohara et al., 2010) musculoskeletal application of SWE, especially of muscle tissue, is rapidly increasing. Recently SWE has been advocated to be the best method of estimating individual muscle force (Hug et al., 2015b) and used to quantify local alternations of muscle impairments (e.g. myofascial trigger points) (Maher et al., 2013). Initial assessments of the reliability and validity of SWE muscle measurements suggest good potential, but such studies generally have been performed on assumingly less anisotropic muscles in more superficial regions (e.g. gastrocnemius, biceps brachii, rectus femoris, deltoid) (Eby et al., 2013; Hatta et al., 2016; Saeki et al., 2017; Taş et al., 2017). A recent study using SWE to assess the reliability of the abdominal muscles found moderate to high reliability (intraclass correlation coefficient, ICC = 0.45–0.97) that tended to be lowest in the deeper abdominal muscles (i.e. transversus abdominis) (MacDonald et al., 2016).

The single study to date that assessed lumbar spinal muscles with SWE found excellent reliability of the lumbar multifidus measurement (ICC = 0.95–0.99), however, this study included a very small sample (n = 10) and measured only resting muscle conditions (Moreau et al., 2016). Considering the functional importance of the lumbar multifidus muscle in patients with LBP, and the potential of SWE to uniquely estimate both individual muscle force and quantify local muscle impairments, more research on the reliability of SWE assessment in low back musculature is warranted across multiple muscles and contraction states in larger samples. Moreover, it is important to first determine the reliability of SWE in asymptomatic subjects before extrapolating data to symptomatic people with LBP. Therefore, the purpose of the current study was to assess the intra-rater and test-retest reliability of SWE elasticity measures of the lumbar erector spinae and multifidus muscles during rest and differing levels of contraction in asymptomatic individuals.

2. Methods

2.1. Participants

A total of 36 healthy volunteers were recruited from the Joint Base San Antonio area (San Antonio, TX, USA). All participants were Department of Defense beneficiaries (active duty military and civilian dependents) and were between the ages 18–65 years. Participants were excluded if they had current LBP, prior back surgery, or a history of serious spinal pathology, including fracture, cancer, or infection. Participants were also excluded if they were unable to lie on their stomachs and lift the required weight above their heads. The study was approved by the Institutional Review Board of Brooke Army Medical Center and all participants provided informed consent in accordance with the WORLD Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects.

2.2. Examiners

Physical therapy students performed all informed consent, screening, and imaging procedures. The examiners received 53 h of training on lumbar spine assessment and 12 h of didactic training on musculoskeletal ultrasound. Additionally, the examiners received 17 h of instruction and training on the specific ultrasound and SWE procedures used in the study. The same examiner imaged each participant on day 1 and at follow up. A secondary examiner assisted the primary examiner with verification of transducer placement and for saving images.

2.3. Procedures

This single-group repeated-measures design involved a baseline measurement session and a follow-up session 3 days later. After providing informed consent, participants were screened for inclusion/exclusion criteria. The screening included a short demographics and medical history questionnaire and a brief physical exam involving standing lumbar flexion and extension range of motion, a quadrant test, and posterior-to-anterior pressure on each vertebra.

2.3.1. Shear wave elastography imaging

All imaging was performed using an Aixplorer Multiwave (Supersonic Imagine, Bothell, WA) and a SL 10-2 linear transducer. The Aixplorer Multiwave generates two types of waves for each image: a compression wave that creates a high-quality B-mode image and a shear wave that propagates within the tissue. Together these two waves allow for the calculation of tissue shear modulus and render a quantitative, color-coded map of tissue elasticity. For assessment of the lumbar musculature, the Aixplorer Multiwave was set to the penetration setting for SWE imaging. The preset elasticity range for the visual map of tissue Young's modulus was 0–100 kPa (kPa), which corresponds to a shear wave velocity range of 0–5.8 m/s.

Two lumbar spinal muscle groups were imaged on the right side L4/L5 of each participant. The lumbar erector spinae (illiocostalis and longissimus muscles) were imaged at rest only. Due to its clinical importance in patients with LBP (Freeman et al., 2010), the lumbar multifidus was imaged at rest and during three levels of contraction (minimal, moderate, and maximum). Before any images were obtained, participants were instructed in each level of contraction while receiving tactile cueing to the targeted muscle. For consistency and to maximize rest between contractile conditions, the order of imaging for each participant was as follows: erector spinae at rest, lumbar multifidus at rest, lumbar multifidus during minimal, moderate, and then maximal contractions. Since SWE takes several seconds for adequate image acquisition, each contraction was held for five to 10 s followed by at least 30 s of rest between each contraction. This imaging sequence was completed three times during each session.

2.3.2. Erector spinae muscles

Participants were positioned prone on a plinth with elbows flexed to 90°, and shoulders abducted to 120° and externally rotated to 90°. Pillows were placed under the subject's pelvis and legs to increase comfort, reduce lumbar lordosis, and maximize transducer contact. Manual therapy belts were secured at the participant's ankles and left shoulder to minimize movement of the lumbar spine and to provide resistance at the shoulder during later contractions (Fig. 1). The L4 spinous process was identified through palpation and marked as a reference point. The right iliac crest and right erector spinae muscle bulk were also palpated and marked as reference points (Fig. 2a). For the lumbar erector spinae muscles, the transducer was placed on the bulk of the muscle belly immediately above the iliac crest, as identified and marked through palpation. The transducer was oriented in the sagittal plane so that it was roughly parallel to the muscle fibers so that the left side of the image was cephalad and the right side was caudal (Fig. 2b). Once appropriately positioned, the transducer was tilted to optimize image clarity, especially of the deeper muscle region.

2.3.3. Lumbar multifidus muscles

Participants remained in the same position for imaging of the