Shear Wave Elastography of the Supraspinatus Muscle and Tendon: Repeatability and Preliminary Findings

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INTRODUCTION: Chronic tendinopathies (e.g., rotator cuff tears) are common, painful, and debilitating. Clinical interventions such as physical therapy or surgery are often indicated, but the extent to which these interventions affect the tendon’s mechanical function or properties is difficult to assess, particularly under in-vivo conditions. Shear wave elastography (SWE) is an ultrasound-based imaging modality that shows promise for assessing muscle and tendon properties, but the repeatability of this technique and potential sources of error have not been rigorously examined. The objectives of this study were to assess: 1) the extent to which positioning error and human user error influence measurement accuracy, 2) intra-user, inter-user, and day-to-day repeatability, and 3) the extent to which active and passive conditions affect shear wave speed (SWS) repeatability for the rotator cuff’s supraspinatus muscle and tendon.

METHODS: To evaluate accuracy and repeatability over a range of SWS values, three custom ultrasound phantoms were constructed using pyphilus husk, gelatin, and water [1]. Pyphilus husk concentration was 5% by volume in each phantom, and SWS was manipulated by varying the concentration of gelatin (5%, 10%, and 15% by volume). SWE images of each phantom were acquired with a commercial ultrasound system (Siemens ACUSON S3000, 9L4 probe) under three testing conditions. The reference (i.e., “gold standard”) condition was with the probe rigidly clamped and five trials acquired sequentially without altering the setup. To assess positioning error, five SWE images were acquired with the probe rigidly clamped during each trial, but removed and reattached to the clamp between trials. To assess user error, five SWE images were acquired for each of two users (TB, JD) who manually operated the probe. The ultrasound software calculated the SWS at each pixel in a 3 cm x 2.5 cm region and the entire region was selected as the region of interest (ROI).

Following IRB approval, SWE images of the supraspinatus muscle and tendon were acquired from the dominant shoulder of 10 subjects (age: 44.7±18.8, range: 18-70). SWE images of the supraspinatus muscle and tendon were acquired under passive and active conditions. For passive testing conditions, subjects were seated with their elbow resting against a 30° abduction pillow and forearm pronated and resting on their thigh. For active testing conditions, subjects lifted their forearm off their thigh and abducted their shoulder, removing contact with the abduction pillow. Five images were acquired by one user (TB) for each subject. Five subjects were also imaged by a second user (JD). These five subjects were then imaged by both users approximately 24 hours later. No activity restrictions were placed on these subjects between testing sessions. A semi-automated thresholding algorithm was applied to the B-mode image to identify and select the ROI corresponding to the muscle tissue/condition of interest (muscle or tendon). Mean SWS was calculated as the average of the five trials.

Positioning error and user error were assessed from the phantom images by calculating bias and precision with respect to the mean SWS from the reference condition [2]. RMS error was also calculated as a complete measure of accuracy. Inter-user repeatability was assessed from the phantom images using the intra-class correlation coefficient (ICC). Similarly, inter-user, intra-user, and inter-day ICC values were computed using the SWE images acquired from human subjects. A paired t-test assessed differences in mean SWS between passive and active conditions. Significance was set as p<0.05.

RESULTS: Compared to the reference condition, imaging of the phantoms indicated that positioning errors and human usage errors have a minor impact on this technique. Specifically, positioning errors resulted in RMS values of 0.04 to 0.08 m/s, while user errors resulted in RMS values of 0.03 to 0.11 m/s. In addition, inter-user repeatability for the phantom testing was good to very good, with ICC values ranging from 0.68 to 0.85.

In-vivo SWE imaging of the supraspinatus muscle and tendon had high repeatability, with intra-and inter-user ICC values of greater than 0.87 and 0.73, respectively (Fig. 1). Day-to-day repeatability was tissue/condition dependent, with ICC values greater than 0.33 for passive muscle, 0.48 for passive tendon, 0.65 for active muscle, and 0.94 for active tendon (Fig. 1). Mean SWS of active muscle (3.74±0.64 m/s) was greater than passive muscle (2.23±0.29 m/s; p<0.001), and mean SWS of active tendon (5.97±1.72 m/s) was greater than passive tendon (2.80±0.59 m/s; p<0.001; Fig. 2).

DISCUSSION: The approach described here has high intra-user and inter-user repeatability, and high day-to-day repeatability for measuring supraspinatus SWS under a low level of muscle activation. Errors due to repositioning and user operation are small, with normalized RMS values (i.e., RMS/mean) of 2.6% for positioning error and 4.1% for user error when compared to the reference condition. The 4.1% error is a cumulative effect of positioning error and user operation error, and can be interpreted as the upper bounds of error. Compared to the mean SWS for active tendon (Fig. 2), this error is less than 2%.

The results are generally in good agreement with previous research [3-6]. However, in contrast to the work by Yoshitake and colleagues, the muscle and tendon images acquired under passive conditions in the current study showed only fair to moderate inter-day repeatability (Fig. 1). The day-to-day repeatability under active conditions was appreciably higher than passive conditions for both the supraspinatus muscle and tendon. It is important to note that the study participants’ activity levels between testing sessions was neither controlled nor documented. Consequently, variability in the subjects’ daily activities may have negatively affected day-to-day repeatability when acquiring images under passive conditions. Interestingly, it appears that a small level of muscle activity largely reduces this day-to-day variability. This finding suggests that acquiring SWE images under a low level of muscle activation maximizes repeatability, which is especially important when conducting a longitudinal study with multiple imaging sessions.

SIGNIFICANCE: This preliminary study is significant because it reports the repeatability of measures of shear wave speed, as well as the expected magnitude of common sources of error. This study is an important step toward establishing the clinical utility of SWE.