Assessment of Superficial and Deep Muscle Activity in the Upper Extremity Using Ultrasound Shear Wave Elastography

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INTRODUCTION: Quantitative assessment of muscle activity can inform clinical rehabilitation of upper extremity disorders [1]. To achieve comprehensive measurement of upper extremity muscle activity using the common method of electromyography (EMG), use of strictly surface electrodes is insufficient. Instead, intramuscular electrodes are required for deep muscles or small superficial muscles where cross-talk is problematic [2]. These electrodes can cause pain during motion, which may affect muscle activation patterns [3]. A linear relationship has been shown between muscle shear wave velocity, an indirect measure of tissue elasticity found using ultrasound shear wave elastography, and muscle activity measured using surface EMG, in various upper extremity muscles [3, 4]. This relationship may provide the basis for noninvasive assessment of muscle activity using an imaging system that is familiar to clinicians. However, to our knowledge, the relationship has not been validated in deep muscles using intramuscular EMG for comparison. This is necessary to demonstrate that elastography can be applied to assess a wide range of muscles. The objective of this study was to measure the association between shear wave velocity and activation within the brachioradialis (superficial) and brachialis (deep) muscles. Further, we compared this relationship between surface and intramuscular EMG electrodes in the brachioradialis.

METHODS: Four healthy individuals [3 female, age: 22.5 ± 1.66 years] (mean ± SD) provided written informed consent for this IRB-approved study. EMG and ultrasound shear wave velocity were simultaneously recorded in one deep (brachialis) and one superficial (brachioradialis) muscle of the dominant arm during isometric elbow flexion. Fine wire intramuscular and surface EMG electrodes (Delsys Inc.) were placed following guidelines [5,6]. EMG data were sampled at 2000 Hz. For shear wave velocity measurements, a 5-18 MHz linear array ultrasound transducer (SuperSonic Imagine Aixplorer Mach 30, standard optimization, elbow musculoskeletal mode) was placed over the muscle belly so that the recorded image was in the longitudinal plane and the rectangular region of interest (ROI) was centered in the targeted muscle. ROI placement defined the area in which pixel-wise measurements occurred, resulting in a color map of shear wave velocity values. Following trials at rest and maximum voluntary contractions (MVCs), three 5-second contractions were recorded in randomized order at intensities of 15-75% MVC in 15% increments. Visual feedback of the normalized EMG signal was provided. Data processing involved averaging EMG and shear wave velocity data across each trial for each participant. Briefly, the EMG data was rectified and normalized to MVC. Then, the middle 3-seconds of each isometric contraction was extracted and the root mean squared (RMS) values were calculated. From each contraction, shear wave velocity was calculated using a custom-written MATLAB algorithm that averaged the pixel values from three color maps, only including pixels with a manufacturer quality rating above 0.7 [7]. To assess the relationship between EMG and shear wave elastography, linear regressions were calculated separately for each individual and EMG electrode type, similar to Bouillard et al. [4]. Regression values were then averaged across subjects.

RESULTS SECTION: Muscle activity and shear wave velocity showed a linear relationship for all combinations of muscles and EMG electrode types (brachioradialis/surface, brachioradialis/intramuscular, and brachialis/intramuscular), with a visible trend in the shear wave velocity color maps indicating increasing warmth with increased contraction intensity (Fig. 1). The average slope between normalized EMG RMS and shear wave velocity was similar across muscles and EMG electrode types (Fig. 2). For the brachioradialis surface electrode, the mean slope across subjects of the normalized EMG RMS and shear wave velocity relationship was 10.61 ± 0.91 m/s / %MVC (r^2 = 0.73 ± 0.09). For the brachioradialis intramuscular electrode, the mean slope was 10.93 ± 1.23 m/s / %MVC (r^2 = 0.64 ± 0.07), and for the brachialis intramuscular electrode, it was 10.61 ± 0.16 m/s / %MVC (r^2 = 0.63 ± 0.08). In contrast, EMG measured at the surface in a superficial muscle (brachioradialis) demonstrated a correlation that was 7% higher on average than intramuscular EMG in both superficial (brachioradialis) and deep (brachialis) muscles (r = 0.85 ± 0.07, r = 0.80 ± 0.05, and r = 0.79 ± 0.05, respectively).

DISCUSSION: To our knowledge, this is the first study to quantify the relationship between ultrasound shear wave velocity and muscle activity for both superficial and deep elbow muscles using intramuscular EMG. These data are critical for evaluating the utility of shear wave elastography as a substitute for invasive EMG methods to assess the activity of deep and small superficial muscles. While surface EMG over the brachioradialis demonstrated a higher correlation than intramuscular EMG in the brachioradialis and brachialis, a strong linear relationship ($r > 0.7$) was seen for all muscles and EMG electrode types. Immediate future work will capture a larger sample size to further support this claim. Constraints exist in shear wave elastography that may limit its use during non-isometric tasks including challenges of achieving image clarity during dynamic tasks and lack of temporal accuracy due to a low color map updating frequency (1.2 Hz). However, benefits exist that outweigh these limitations. In addition to being noninvasive, shear wave elastography provides a full color map that correlates with muscle activity over a broad chosen area, an advantage over the localized, point-specific assessment of traditional EMG methods. Future work will expand these analyses to determine the utility of measuring activation in broad upper extremity muscles, such as the deltoid.

SIGNIFICANCE/CLINICAL RELEVANCE: This study demonstrates that the muscle activity of both superficial and deep muscles can be evaluated in a noninvasive manner using ultrasound shear wave elastography. This technology could assist in the future clinical rehabilitation of upper extremity disorders.

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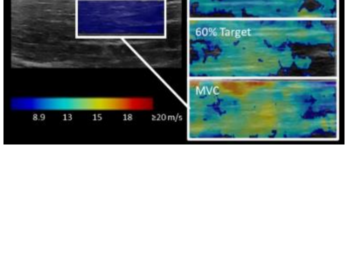

Figure 1. An ultrasound image in the longitudinal plane of the brachialis and overlaid shear wave velocity color maps from a variety of contraction intensities for a representative subject. Increasing warmth (fewer blue pixels) indicates greater shear wave velocity.

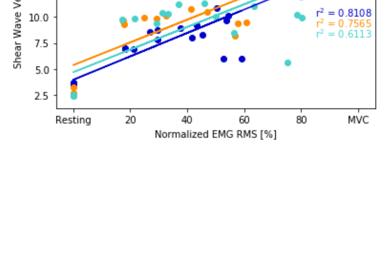

Figure 2. The normalized EMG RMS / shear wave velocity relationship for the brachioradialis surface electrode (blue), brachioradialis intramuscular electrode (orange), and brachialis intramuscular electrode (teal) for a representative subject.