

Functional contribution of the supraspinatus and infraspinatus muscle subregions during forward flexion training

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INTRODUCTION: Morphological studies have shown that the supraspinatus (SSP) and infraspinatus (ISP) muscles can be anatomically divided into six (anterior-superficial, anterior-middle, anterior-deep, posterior-superficial, posterior-middle, posterior-deep) and three (superior, middle, inferior) subregions, respectively, based on their attachment sites and muscle fiber orientation^{1,2}. Forward flexion is a common functional motion, presenting with high activity of the anterior deltoid muscle as the prime mover, and high activity of the SSP and ISP muscles as the joint stabilizers³. To our knowledge, while a single in-vivo study investigated the functional behavior of the individual muscle subregions during active forward flexion in submaximal and maximal load conditions⁴, no study investigated these behaviors in low load conditions necessary and critical for rehabilitative interventions after rotator cuff repair surgery. Therefore, the purpose of the current study was to implement ultrasound shear wave elastography (SWE) to determine the functional behavior of the anterior deltoid, and the SSP and ISP subregions during forward flexion training in low load conditions.

METHODS: Ten healthy male volunteers (mean age 21 ± 3 yrs.; height 172.9 ± 4.2 cm; weight 63.5 ± 7.8 kg) without restrictions to their dominant shoulder, were recruited to the study after IRB approval and signed informed consent. A Mach 30 ultrasound equipment (Supersonic Imagine) and a 10-2 MHz linear array probe (SL10-2) were used to quantify stiffness (kPa) during muscle contractions as a surrogate for muscle activity³. Muscle activity were obtained for the anterior deltoid, anterior-superficial and anterior-middle subregions of the SSP, and superior and middle subregions of the ISP muscles during forward flexion. Maximum forward flexion force/contraction (MVC) was measured by a hand-held dynamometer (MicroFET2TM, Hoggan Scientific). Subjects were asked to hold their dominant side arm at 10% MVC at various flexion angles: 0°, 30°, 60°, 90°, 120°. The ultrasound probe was placed over the deltoid, SSP, and ISP muscle subregions (Fig. 1) according to the previous studies³. After continuous SWE imaging, three images were taken from each position for analysis, and regions of interest (ROI) were placed to obtain quantitative properties outcomes. One-way repeated ANOVA analysis was implemented to investigate differences in measurements among forward flexion angle positions. Significance was set at $P < 0.05$.

RESULTS: Muscle activity of the anterior deltoid peaked at 90°, significantly higher than those at 0°, 30°, and 60° ($P < 0.05$) (Fig. 2). Activity of the anterior-superficial subregion of the SSP muscle was significantly higher at 30°, 60°, and 90° compared to that at 0°. In contrast, activity of the anterior-middle subregion was significantly higher at 30°, 60°, 90°, and 120° compared to that at 0°. Activity of the superior subregion of the ISP muscle was significantly higher at 60° and 90° compared to that at 0°. In contrast, activity of the middle subregion was significantly higher at 60°, 90°, and 120° compared to that observed at 0°.

DISCUSSION: The functional behavior of the SSP and ISP muscle subregions during forward flexion with weights showed differences between the superficial and deep subregions. Anatomically, it has been demonstrated that the anterior-superficial subregion of the SSP and superior subregion of the ISP muscles attach to superficial sites, while the anterior-middle subregion of the SSP and middle subregion of the ISP muscles attach to deep sites and joint capsule⁵. A previous study describing the activity of the anterior deltoid showed a mountain shape behavior with a peak in activity at 90° during forward flexion with isometric contraction against gravity³. The activity of the SSP and ISP muscle subregions were described by an initial peak in activity at the anterior-superficial subregion of the SSP muscle at the initial range of motion, with a subsequent transition to the middle and inferior subregions of the ISP muscle towards the mid-range of motion³. In the current study implementing weights at 10% MVC, the activity of the anterior deltoid displayed a similar behavior to previous outcomes. In contrast, the SSP and ISP muscle subregions showed different behaviors during forward flexion with weights. Specifically, the SSP muscle subregions presented activity from 30° with peaks at 60° and 90° (mid-range of motion), with the superior and middle subregions of the ISP muscle also showing high activity starting at 60° with peaks at 60° and 90°, respectively.

SIGNIFICANCE/CLINICAL RELEVANCE: The anterior-middle subregion of the SSP and middle subregion of the ISP muscles demonstrated high activity in a wide range of motion compared to the anterior-superficial subregion of the SSP and superior subregion of the ISP muscles. These findings suggest activation of the superficial subregions of the SSP and ISP muscles within a localized range during forward flexion with weights, while deep subregions, attached to the capsule, activate throughout the entire range of motion. Surgically, independent and concomitant repair techniques of deep and superficial layers of the tendons could be important to consider to restore functional capacity during forward flexion. In terms of rehabilitation interventions, forward flexion training with weights up to 60° could be effective for strengthening all SSP and ISP muscle subregions.

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REFERENCES: 1. Kim et al., 2007.; 2. Bacle et al., 2017.; 3. Hoshikawa et al., 2022.; 4. Alenabi et al., 2019; 5. Yuri et al., 2019.

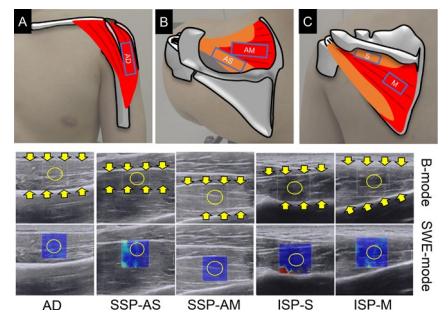


Figure 1. Probe orientation for the A) AD: anterior deltoid; B) SSP muscle subregions, AS: anterior-superficial, AM: anterior-middle; C) ISP muscle subregions, S: superior, M: middle.

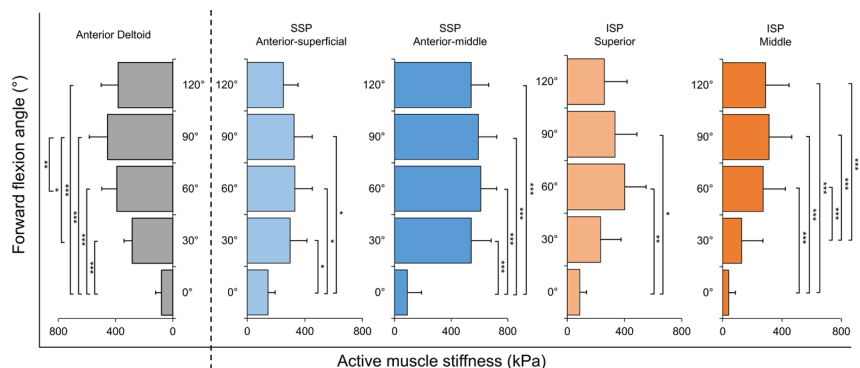


Figure 2. Active muscle stiffness outcomes for each muscle and muscle subregion during forward flexion. *: $p < 0.05$ **: $p < 0.01$ ***: $p < 0.001$