

# Shoulder position influences the strain distribution in the rotator cuff tendons

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**INTRODUCTION:** The rotator cuff (RC), composed of the supraspinatus (SSP), infraspinatus (ISP), and subscapularis (SSC) muscles and tendons, insert to superior and middle facets of the greater and lesser tubercles, respectively. These RC muscles are comprised of anatomical subregions based on the muscle fiber direction and tendon attachment<sup>1</sup>. Previous studies have suggested different roles of these subregions during shoulder motions<sup>2,3</sup>. A previous study determined the strain distribution in the superficial surfaces of the rotator cuff tendons with loading of the SSP and ISP muscles and their individual subregions<sup>4</sup>. However, the tension distribution in the tendons originating from different abduction angles is still unknown. The purpose of this study was to determine the tension, i.e.: strain, distribution in intact RC cadaveric shoulders from various anatomical subregions of the RC muscles and different abduction angles.

**METHODS:** Eight fresh-frozen cadaveric intact shoulders (35-69 yrs.; mean 61 yrs.) were used in this study after IRB approval. All soft tissues were removed except for the SSP, ISP and SSC muscles and tendons, and joint capsule. Scapula and humerus were cut to allow specimens to be mounted in a custom-built fixture. Anatomical subregions of the SSP (anterior and posterior), ISP (superior and middle/inferior), and SSC (superior, middle, and inferior) muscles were defined based on previous studies<sup>1</sup>. Specimens were mounted on the fixture set to 25° and 45° glenohumeral abduction. Whole muscles and individual subregions from each muscle were pulled using an MTS 858 Mini-Bionix II (Eden Prairie, MN) system. Loading regimes were based on previous studies<sup>4</sup> and were as follows: **SSP:** 60N for the anterior region; 20N for the posterior region; 80N for the whole muscle. **ISP:** 20N for the superior region; 60N for the middle/inferior region; 80N for the whole muscle. **SSC:** 20N for the superior region; 60N for the middle region; 20N for the inferior region; 80N for the whole muscle. 3D-Digital Image Correlation (DIC) (GOM ARAMIS<sup>TM</sup>, Germany) was implemented to measure strains (Major strains measured in the direction of maximum strain) of the superficial surface of the tendons. **Fig. 1** shows an example of a mounted humerus with strain outcomes in all 3 tendons (SSP (A), ISP (B), and SSC (C)). Regions of interests (ROI) were set as shown in **Fig. 1**, and average strains were measured in these ROIs. **Strain ratio** for each abduction angle and each tendon attachment is reported for each testing condition. For example, the strain ratio in the anterior region of the SSP tendon at 25° (**Fig. 2A**) is calculated as: Major strain of anterior region/(Major strain of anterior + posterior regions) (similar approach for all other conditions). Wilcoxon tests were used to compare the strains between the 25° and 45° glenohumeral abduction in each muscle and with each individual loading regime.

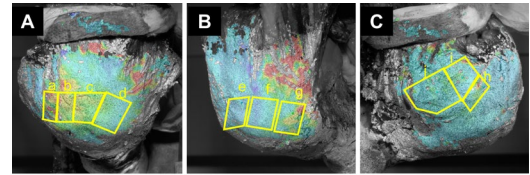
**RESULTS:** Strain ratios in the anterior region of the SSP when the whole muscle was loaded at 25° abduction were significantly higher than those at 45° ( $P < 0.05$ , **Fig. 2A**), while an opposite trend was found in the posterior region ( $P < 0.05$ ). Similar trends were found with loading of the anterior muscle region ( $P < 0.05$ ). Strain ratios in the superior facet when the whole SSP muscle was loaded at 25° abduction were significantly higher than those at 45° ( $P < 0.05$ , **Fig. 2B**), while an opposite trend was found in the middle facet ( $P < 0.05$ ). Higher strain ratios were observed in the superior half of the ISP tendon when the whole ISP muscle was loaded at 25° compared to those measured at 45° ( $P < 0.05$ , **Fig. 2C**), while an opposite trend was found in the inferior half of the ISP tendon ( $P < 0.05$ ). Strain ratios in the superior facet when the superior region of the ISP muscle was loaded at 25° were significantly higher than those at 45° ( $P < 0.05$ , **Fig. 2D**), while an opposite trend was found in the middle facet ( $P < 0.05$ ). Higher strain ratios were found at 25° than those at 45° in the biceps groove when the superior region was loaded ( $P < 0.05$ , **Fig. 2E**), while an opposite trend was found in the inferior region of the lesser tubercle ( $P < 0.05$ ). Similar trends were found with loading the inferior region of the SSC muscle ( $P < 0.05$ ).

**DISCUSSION:** There was a heterogeneous distribution of strain, i.e.: tension, within the tendons with the selected abduction angles and based on whole-muscle vs. subregion-specific loading. Higher strain ratios were observed in the anterior region of the SSP, in the superior facet and superior half of the ISP, and in the superior attachment of the SSC tendons at 25° vs. 45°. Conversely, the posterior region of the SSP, the inferior half of the ISP, and the inferior attachment of the SSC tendons showed higher strain ratios at 45°.

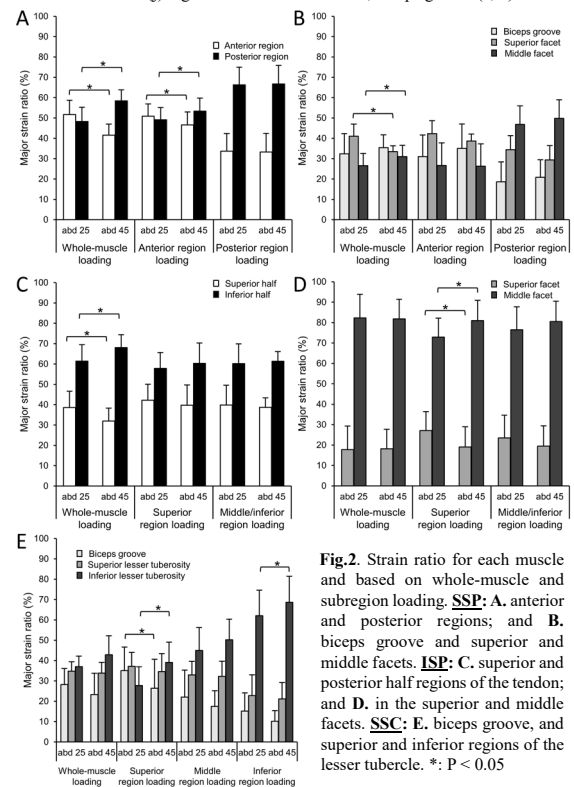
**SIGNIFICANCE/CLINICAL RELEVANCE:** Tension distributions generating from RC muscles and their individual subregions, thus function contribution, changed from the superior to the inferior tendon attachments with increasing shoulder abduction positions. These results support the importance in recreating the natural structure of the rotator cuff tendons during surgical repairs of rotator cuff tears.

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**REFERENCES:** 1. Ward et al., 2006. 2. Hoshikawa et al., 2021 3. Hoshikawa et al., 2021. 4. Yuri et al., 2023.



**Fig.1** Left shoulder specimen [SSP (A), ISP (B) and SSC (C)] mounted on a custom-made fixture at 25° glenohumeral abduction. Anterior (b) and posterior (c) regions of the SSP tendon; superior facet (b+c); superior half of middle facet (d); posterior half of superior facet (e); superior (f) and inferior (g) half of the ISP tendon; middle facet (f+g); superior (i) and inferior (j) regions of the lesser tubercle; biceps groove (a, h).



**Fig.2.** Strain ratio for each muscle and based on whole-muscle and subregion loading. **SSP:** A. anterior and posterior regions; and B. biceps groove and superior and middle facets. **ISP:** C. superior and posterior half regions of the tendon; and D. in the superior and middle facets. **SSC:** E. biceps groove, and superior and inferior regions of the lesser tubercle. \*:  $P < 0.05$