Regionally Distinct Strain Responses of the Supraspinatus Tendon to Glenohumeral Elevation and Loading

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INTRODUCTION: Rotator cuff (RC) tears are a major reason for pain, dysfunction, & loss of quality of life, and account for millions of physician visits annually.[1] The most commonly affected component of the RC is the supraspinatus tendon (SST), yet despite its clinical relevance, its response to varying joint angles and loading conditions *in vivo* remains unknown. Current understanding of RC mechanics is largely predicated upon *ex vivo* uniaxial testing despite recent literature suggesting regionally distinct and positionally dependent SST behavior.[2] The purpose of this study was to determine the role of glenohumeral joint (GHJ) position and SST loading on sub-failure regional surface strain *in situ*.

METHODS: Ten fresh-frozen cadaveric shoulders (mean age: 62 years, 8M) with no history of glenohumeral joint (GHJ) pathology were obtained from the University of Minnesota's anatomy bequest program. Specimens were dissected to expose the rotator cuff—the lateral acromion and coracoacromial ligament were removed in order to visualize the supraspinatus. Each RC muscle was retained 1-2 cm proximal to the musculotendinous junction. Krakow stitches were placed into the SST, subscapularis, and infraspinatus/teres minor for muscle loading. The scapula was mounted into a custom testing device, that allowed for manual manipulation of the humerus via an intramedullary nail. Static loads were applied to the muscles of the RC along their lines of action to seat the humeral head within the glenoid. Four GHJ testing conditions were evaluated along a physiologic arc of elevation in the scapular plane: (1) neutral, (2) 45° elevation, (3) 60° elevation, and (4) full elevation. Motion capture cameras (Nexus, MX 40, Vicon Motion Systems Ltd., Oxford, UK) were used to provide real-time kinematic feedback for positioning. Initial position was recorded, and the humerus was bore-sighted with the humeral epicondyles perpendicular to the plane of the glenoid. The humerus was moved to each test position and held static to assess baseline strain (position condition). Subsequently, the SST was loaded to 100 N over 5 seconds (load condition).[3] The SST was speckled and visualized using Nikon D7500 cameras. Digital Image Correlation (DIC) was used to calculate 1st principal Lagrangian Strain (%) and strain orientation (°). The surface of the SST was discretized into anterior (A) and posterior (P) regions using 3-matic software (Materialise, Leuven, Belgium). Repeated measures ANOVAs and preplanned comparisons were performed to evaluate the effects across the experimental conditions. Missing outcomes were imputed with predictive mean matching.[4] Post-hoc pairwise comparisons were performed using the Tukey method to control for multiplicity. For each combination of position and region, strain and orientation were compared by load vs. no load with paired t-tests also adjusted using the Tukey method.

RESULTS: At 45° of elevation without load, the A-SST region exhibited significantly greater strain as compared to the P-SST region ($p = 0.01$, $d = 0.74$). At full elevation with load, A-SST region strain was significantly greater as compared to the P-SST region ($p = 0.019$, $d = 0.53$). Within the A-SST region, strain magnitude was greater with the application of load compared to the unloaded condition ($p = 0.04$) at full elevation. No significant differences in strain were observed within the P-SST region between loading conditions ($p > 0.05$). There were no significant differences in strain across elevation angles within the A- or P-SST regions in the unloaded condition ($p > 0.05$). With load, there was a significant effect of position on P-SST strain magnitude ($p = 0.05$, $\eta^2 = 0.17$); however, post hoc comparisons did not reach statistical significance ($p > 0.05$) (**Fig. 1**). There were no significant differences in strain orientation between the A- and P-SST regions at 45°, 60°, or full elevation with or without load ($p > 0.05$). At full elevation, P-SST region strain orientation was significantly more aligned with the tendon's long axis with load compared to the unloaded condition ($p = 0.05$). Strain orientation in the P-SST region at 45 elevation was more aligned with the tendon's long axis than at full elevation ($p = 0.04$, $d = 0.8$) (**Fig. 2**).

DISCUSSION: The SST demonstrated regionally distinct mechanical behavior between anterior (A) and posterior (P) regions. At 45° elevation without load, strain magnitude was significantly greater in the A region, supporting the presence of regional inhomogeneity under unloaded conditions. This persisted at full elevation with load, suggesting that elevation angle and muscle loading amplifies the differential strain distribution across the tendon. Our results align with previous findings that the morphologically distinct "anterior cable" of the SST acts as a primary load-bearing structure under varying joint angles and loading conditions.[5-7] Our study also revealed differential strain orientation responses between tendon regions under load. These findings are consistent with fiber-level mechanics reported by Lake et al. who demonstrated that collagen fiber reorganization contributes to the non-linear mechanical behavior of the SST.[2] Taken together, this differential response implies that the A and P tendon regions serve distinct mechanical roles that may influence how load is distributed and transferred during shoulder motion, and where pathology localizes.

SIGNIFICANCE/CLINICAL RELEVANCE: This study provides evidence of regionally distinct mechanical behavior in the SST. Tear propagation models, surgical repair strategies, and rehabilitation protocols should account for regional differences in load response and injury susceptibility.

References: [1] Oh LS, *CORR*, 2007; [2] Lake SP, *JOR*, 2009; [3] Takani KC, *Theor Iss Ergo Sci*, 2017; [4] van Buuren S, *J Stat Softw*, 2011; [5] Itoi E, *JOR*, 1995; [6] Hoshikawa K, *J Mech Behav Biomed Mater*, 2025; [7] Bey M, *JOR*, 2002

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Figures/Tables:

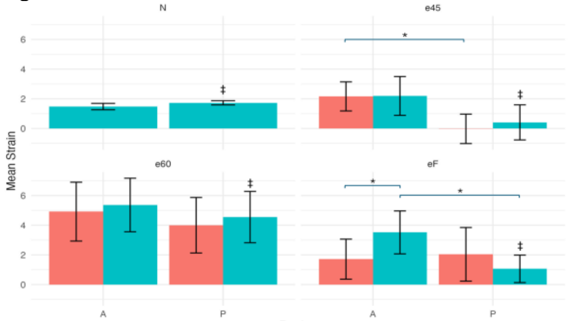

Figure 1. Strain by position, region, and load condition

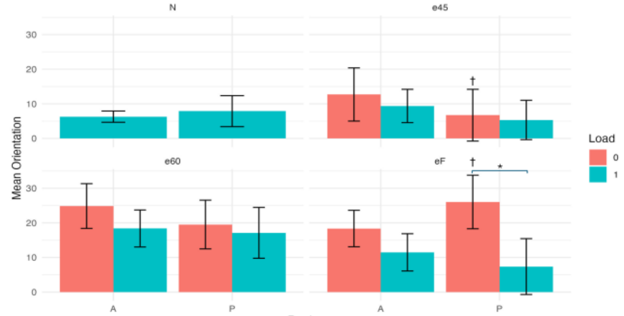

Figure 2. Strain orientation by position, region, and load condition