Upper Subscapularis Tendon Detachment Does Not Alter Mechanical Properties of Adjacent Tendons in a Rat Model

Mengcun Chen[1], Courtney Nuss[1], Jeremy D. Eekhoff[1], Louis J. Soslowsky[1], Andrew F. Kuntz[1,2]
[1]University of Pennsylvania, Philadelphia, PA, [2]Corporal Michael J. Crescenz VA Medical Center, Philadelphia, PA
mengcc@pennmedicine.upenn.edu

Disclosures: Mengcun Chen (N), Courtney Nuss (N), Jeremy Eekhoff (N), Louis J. Soslowsky (N), Andrew F. Kuntz (5 – Smith and Nephew)

INTRODUCTION: Rotator cuff tears are highly prevalent injuries that can lead to significant pain and shoulder joint dysfunction[1]. Following a tendon tear, secondary joint damage may arise from disruption of the rotator cuff force balance, which is maintained by the subscapularis anteriorly, the infraspinatus and teres minor posteriorly, and the supraspinatus[2]. Our previous investigations of supraspinatus and infraspinatus tendon injuries demonstrated that such disruptions represent a key mechanical mechanism leading to overload of the remaining intact tendons, ultimately resulting in tissue degeneration and joint functional impairment[2,3]. However, although the subscapularis serves as the primary anterior stabilizer of the force balance and its tears are increasingly recognized[4], the consequent effects on shoulder joint biomechanics and tissue integrity remain poorly understood. Therefore, the objective of the present study was to elucidate how force imbalance resulting from subscapularis tendon tears impact the integrity of adjacent intact tendons. We hypothesized that subscapularis tendon tears would compromise the mechanical properties of adjacent tendons through pathological overload resulting from the disruption of the rotator cuff force balance.

METHODS: *Animal model:* Forty adult male Sprague–Dawley rats (400–450 g) were used in this IACUC-approved study. Animals were assigned to one of four experimental groups (n = 10 per group): (1) sham, (2) biceps tenotomy only, (3) detachment of the subscapularis tendon upper border (i.e., the thick superior portion of the tendon) with biceps tenotomy, or (4) detachment of the full upper band of the subscapularis tendon with biceps tenotomy. Only males were included because of the greater prevalence of rotator cuff tears in men[1]. All surgical procedures were performed on the right shoulder. Animals were euthanized 8-weeks postoperatively and the rotator cuff tendons of the right shoulder were harvested for biomechanical evaluation. *Sample Preparation:* The supraspinatus, infraspinatus, and subscapularis tendons were harvested with the humerus. Non-tendon soft tissue was meticulously dissected away. The subscapularis tendon was then separated into its distinct upper and lower bands at the clear delineation point to facilitate individual biomechanical assessment. *Mechanics*: Tendon cross-sectional areas were measured using a laser-based device[5] and humeri were potted in polymethyl-methacrylate for testing. Each tendon was mounted in a custom fixture with a fixed gauge length of 6 mm from its insertion site. Biomechanical testing was performed on an Instron 5543 test frame (Instron, Norwood, MA). The testing protocol included three stages: (1) preconditioning (10 cycles between 0.5% and 1.5% strain at 0.5 Hz), (2) stress relaxation (6% strain held for 10 minutes), and (3) quasi-static ramp-to-failure (0.1% strain/s). Elastic properties (stiffness, modulus), viscoelastic properties (percent relaxation), and failure parameters (maximum force, maximum stress) were analyzed using a custom MATLAB script. *Statistics:* All datasets were screened for statistical outliers using the 2.2× interquartile range criterion. Group comparisons were performed using one-way ANOVA followed by Bonferroni post-hoc tests. Significance was set at $p<0.05$.

RESULTS: Mechanical testing demonstrated that tendon properties were not compromised 8 weeks after subscapularis tendon detachment (Figure 1). The only differences detected between surgical groups were a subtle increase in cross-sectional area of the lower subscapularis band with upper band detachment compared to biceps transection only ($p=0.046$) and a modest increase in percent relaxation in the infraspinatus tendon following biceps tenotomy compared with the sham control ($p=0.041$). However, no differences in stiffness and max force were observed among the four surgical groups for either the supraspinatus or infraspinatus tendons. Similarly, no differences were found across surgical groups in modulus or max stress (data not shown). These findings indicate that detachment of neither the upper border nor the full upper band of the subscapularis tendon compromised the mechanical integrity of the adjacent intact tendons. Moreover, even the upper band of the subscapularis exhibited comparable mechanical properties across all surgical groups, indicating unexpected healing after detachment.

DISCUSSION: Despite minor alterations in tendon size and viscoelasticity, the absence of significant mechanical changes in the adjacent supraspinatus and infraspinatus tendons aligns with the finding that even the surgically detached upper subscapularis tendon exhibited comparable mechanical properties to the sham controls eight weeks after injury. Surprisingly, during tendon dissection, both detachment of the upper border and detachment of the full upper band of the subscapularis tendons appeared to have nearly complete healing, with minimal scar tissue formation or fatty infiltration in either group. This response may be attributed to different use of the upper limbs between rats and humans which could affect the function and healing response of the subscapularis tendon despite the similar anatomy between species[6]. Similarly, our previous findings also demonstrated an absence of fatty infiltration following surgically induced rotator cuff tears in rats[7]. These findings suggest that the present rat model of partial or complete detachment of the upper subscapularis tendon may not fully recapitulate the clinical condition in humans, where torn subscapularis tendons typically retract medially and show limited healing[8]. Interestingly, the current results suggest that direct surgical detachment of the subscapularis tendon may not appreciably disrupt the shoulder force balance in the current rat model, which contrasts with our previous work where detachment of the supraspinatus and/or infraspinatus tendons in the same species led to evident joint imbalance and secondary degeneration of the surrounding intact tendons and glenoid cartilage[9,10]. Future studies should consider employing a different surgical approach, such as partial resection of the subscapularis tendon, to eliminate the potential for tendon healing and establish a more consistent and robust model of anterosuperior rotator cuff force imbalance.

SIGNIFICANCE: Direct surgical detachment of the upper subscapularis tendon did not result in notable joint imbalance or compromised mechanical integrity of the adjacent intact tendons in the present rat model, likely due to unexpected robust subscapularis tendon healing. An alternative subscapularis detachment with partial tendon resection may be warranted to establish a reliable and reproducible model of anterosuperior rotator cuff force imbalance.

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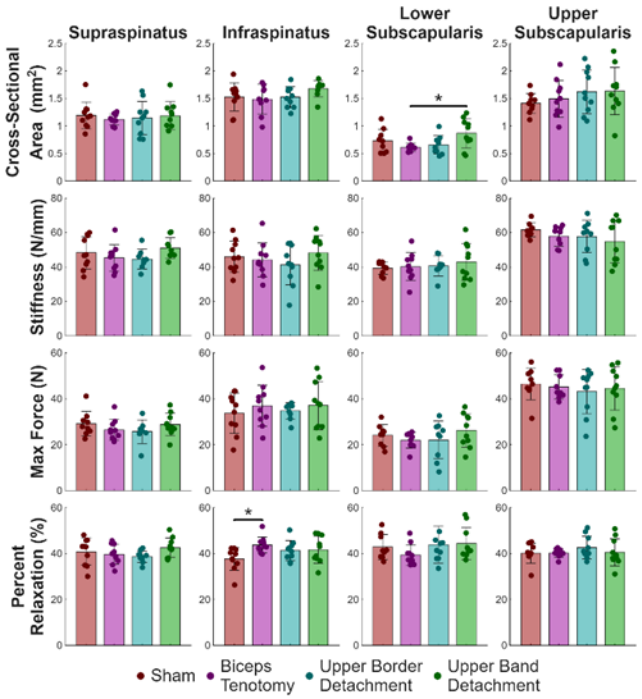

Figure 1. Mechanical properties remained largely unaltered across surgical groups, with only modest changes to the cross-sectional area of the lower subscapularis band and percent relaxation of the infraspinatus.