Supraspinatus Tendons Have Different Mechanical Properties Across Sex

Kelsey Robinson, MD
Adam Pardes, BS
Benjamin Freedman, PhD
Louis Soslowsky, PhD

McKay Orthopaedic Laboratory
University of Pennsylvania
Philadelphia, PA

Introduction

Degenerative rotator cuff tears are common[1] with known risk factors such as age, hypercholesterolemia, family history, and smoking[2-5]. Although there is a disproportionate incidence of Achilles ruptures in males[6] and ACL tears in females[7], sex is not a clear risk factor for degenerative rotator cuff tears. Previous work has demonstrated that male rat Achilles tendons have decreased modulus compared to females[8], which may provide a biomechanical explanation for some of the disproportionate clinical incidence of acute ruptures in males. However, whether the differences in mechanical properties in the Achilles tendon exist in the rotator cuff is unknown. Therefore, the objective of this study was to determine the mechanical properties of the uninjured male, female, and ovariectomized (OVX) supraspinatus tendon in a rat model and compare them to known sex differences in the Achilles tendon[8]. We hypothesized that, like the Achilles, female and OVX supraspinatus tendons would exhibit decreased cross-sectional area but, in contrast to the Achilles, there would be no differences in material properties compared to male supraspinatus tendons.

Methods

Shoulders were harvested from 36 aged-matched adult male (n = 12), female (n = 12), and OVX (6 weeks after OVX; n = 12) Sprague-Dawley rats (IACUC approved). The supraspinatus tendon was fine dissected and Verhoeff's stain lines were placed at the bony insertion site and 8 mm proximally. Tendon cross-sectional area was measured with a custom laser device[9]. Humeri were secured in PMMA, and cyanoacrylate was used to secure the tendon between two pieces of sandpaper leaving an 8mm gage length. A custom fixture was used to secure the potted samples in an Instron ElectroPuls E3000 affixed with a 250 N load cell. Tendons were submerged in a 1x PBS bath maintained at 37°C and underwent preconditioning, stress relaxation, low strain dynamic frequency sweep (0.1-10 Hz), and fatigue testing at 2 Hz (~7-40% maximum stress) until failure. Quasi-static, dynamic, and fatigue mechanical properties were computed and one way ANOVAs with post-hoc Bonferroni corrections (a = 0.05/3) were used to compare groups.

Results

The cross-sectional area of female supraspinatus tendons was significantly smaller than male (30%) tendons and OVX (15%) tendons (not shown). Percent relaxation was not different across groups (not shown). There were no differences in toe or linear moduli (Figure 1A) or transition strain across sex; however, toe and linear stiffness (Fig. 1B) and insertion stiffness were greater in male supraspinatus tendons (120%, 140%, and 190%, respectively) than in females. The dynamic modulus of male supraspinatus tendons was lower (80%) compared to female tendons at all frequencies (Figure 1A) and male tendons had higher (180%) hysteresis (Figure 1C) compared to females, but there were no differences in tan(δ) between groups (not shown). Fatigue testing showed that the secant modulus of male supraspinatus tendons was lower (80%) compared to females (Figure 1A) and secant stiffness was higher (115%) compared to females (Figure 1B). Previous sex differences research in the Achilles tendon demonstrated that male Achilles tendons have lower elastic, dynamic, and secant moduli compared to female tendons[8].

Discussion

We measured the uninjured mechanical properties of supraspinatus tendons of male, female, and ovariectomized rats. While male and female tendons were found to have similar quasi-static material properties, male tendons had lower dynamic and secant moduli compared to females at all frequencies tested. Their higher hysteresis throughout loading suggests that they may be less able to resist deformation under stress than female tendons. Male tendons also had higher stiffness under both quasi-static and fatigue loading conditions, which is expected, in part, given their larger cross-sectional area. Interestingly, some of these findings are different in the supraspinatus tendon based on previous work that quantified sex differences in the Achilles tendon[8]. Although similar differences in dynamic and fatigue mechanical properties were found in both supraspinatus and Achilles tendons, they differed under quasi-static loading conditions. Unlike male Achilles tendons, which had lower modulus compared to females[8], male supraspinatus tendons did not exhibit sex

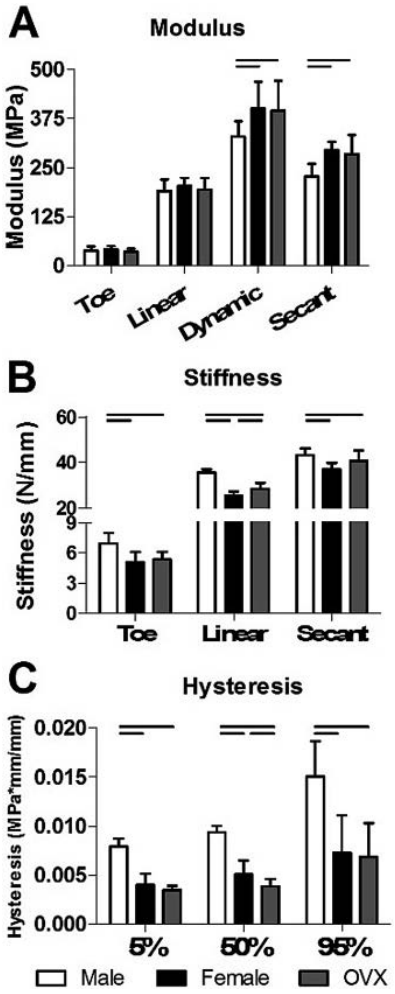

Figure 1. Mechanical testing results. Moduli **(A)** and stiffness **(B)** were calculated during quasi-static, dynamic, and fatigue loading of supraspinatus tendons. Hysteresis **(C)** was measured at 5%, 50%, and 95% fatigue life. Males have lower modulus during dynamic and fatigue loading, higher stiffness, and higher hysteresis than females.

differences in toe and linear modulus, but did have higher stiffness (Figure 2). Although male supraspinatus tendons demonstrated lower mechanical properties with fatigue loading and clinical tears of the supraspinatus tendon are usually degenerative, there is not a disproportionate rate of clinical supraspinatus tendon tears across sex as there is with the Achilles tendon. This may be because the supraspinatus is not subjected to the same loads as the Achilles in vivo. Nevertheless, it is interesting to note that males have increased rates of acute full thickness supraspinatus tears in humans[10] despite the fact that their quasi-static material properties do not differ across sex in the rat model. This clinical finding could be explained by differences in supraspinatus muscle composition across sex, which may lead to altered loading of the tendon and an increased rate of acute tears. Future work will investigate sex differences in histologic features of the supraspinatus tendon and muscle.

Conclusion

This work begins to define the differences in mechanical properties of the supraspinatus tendon across sex and

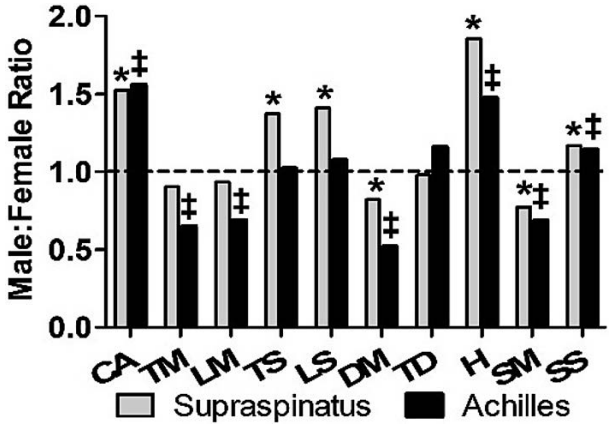

Figure 2. Tendon-specific sex differences in mechanical properties. Ratio of male to female means were taken for each parameter. Data that were significantly different between male and female supraspinatus or Achilles tendons are indicated by * and ‡, respectively. There were significant differences in dynamic and fatigue mechanical properties in both supraspinatus and Achilles tendons. Male supraspinatus tendons had higher stiffness while male Achilles tendons had lower elastic moduli compared to female tendons. No direct comparisons were made between supraspinatus and Achilles tendon property male:female ratio. Dotted line represents a ratio of 1.0. CA: cross-sectional area, TM: toe modulus, LM: linear modulus, TS: toe stiffness, LS: linear stiffness, DM: dynamic modulus (1 Hz), TD: tan(δ), H: hysteresis, SM: secant modulus, SS: secant stiffness.

indicates that sex differences can be tendon-specific which may have implications in the way clinical injuries are managed.

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