Age-Related Changes Influence the In Vivo Biomechanical Properties of the Rat Gastrocnemius-Achilles Muscle-Tendon Unit

INTRODUCTION:
Achilles tendon (AT) ruptures are common in patients between 30 and 50 years of age, with an approximate incidence of 7/100,000 (1). Traumatic AT tears commonly occur during sports in middle-aged males that participate in sports intermittently (2). Normal aging leads to structural changes to the structure of tendons (increased total collagen content and collagen fiber diameter), which may influence AT biomechanics with functional implications for older individuals (3). The purpose of this study was to characterize how normal aging influences the passive biomechanical properties of the Gastrocnemius-Achilles muscle-tendon unit.

METHODS:
After Animal Care and Use Committee approval, rats from the National Institute of Aging (NIA) Aged Rodent Colonies were used to study age-related changes in Gastrocnemius-Achilles biomechanical properties. A total of 6 young (8 months old; 18 human years) and 6 middle-aged (24 months old; 52 human years) F344xBN hybrid rats underwent in vivo biomechanical testing of the muscle-tendon unit. The gastrocnemius (GC) was exposed and the calcaneus transected with the AT insertion intact. Animal were placed on a linear translating stage and the AT attached to a force transducer similar to an earlier report (4).

Non-destructive load-relaxation was performed in vivo and consisted of stretching the muscle-tendon unit from 0 to 8 mm of displacement in 2 mm increments; between each testing interval the GC was allowed to rest for 180s at 0mm resting length. Passive tension was recorded continuously during displacement. Following passive biomechanical measurements, muscle weights, volume displacement, and cross-sectional area of the GC were measured. Young's modulus (stiffness) was calculated by linear regression analysis of the slope of the linear portion of the load-displacement curve and muscle cross-sectional area. Statistical analysis was performed using a Two-way Repeated Measures ANOVA with Bonferroni post-hoc test with alpha 0.05.

Fung’s quasilinear viscoelastic (QLV) model was used to obtain two elastic parameters (A and B) and three viscous parameters (C, τ1, τ2) for time and history dependent in-vivo load-relaxation behavior of muscle-tendon units in this animal model (5). A two-tailed student T-test was used to compare all constants with alpha 0.05.

RESULTS:
Linear regression analysis revealed significantly increased GC-AT muscle-tendon unit stiffness of 25% at peak tensions in old rats (3.3 ± 0.2 N/mm) compared to young rats (2.5 ± 0.2 N/mm; p<0.05). Muscle weight (2.7g in young, 2.9g in middle-aged rats) and muscle volume (2.6g in young, 2.5g in middle-aged rats) were similar.

TABLE: Linear Regression Analysis of Percentage of Displacement (dL/L0) vs. Passive Tension Standardized by CSA

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Slope (Modulus)</th>
<th>R²</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td>Peak tension</td>
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<tr>
<td>8-month old</td>
<td>270.558 ± 20.294</td>
<td>0.971 ± 0.014</td>
<td>0.090</td>
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<tr>
<td>24-month old</td>
<td>402.277 ± 31.072</td>
<td>0.993 ± 0.003</td>
<td>0.043*</td>
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<tr>
<td>Equilibrium Tension</td>
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<td></td>
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<tr>
<td>8-month old</td>
<td>192.366 ± 16.133</td>
<td>0.972 ± 0.011</td>
<td>0.212</td>
</tr>
<tr>
<td>24-month old</td>
<td>285.258 ± 27.731</td>
<td>0.992 ± 0.003</td>
<td>0.049*</td>
</tr>
</tbody>
</table>

*p<0.05 was statistically significant; CSA, cross-sectional area; R², coefficient of determination

Fung’s QLV revealed similar time-dependent viscous muscle-tendon unit properties as determined by comparison of QLV model parameters (‘C,’ ‘τ1,’ and ‘τ2’) and a trend toward an increase in the instantaneous elastic response ‘A’ in the old group (2.9 ± 8.4 MPa) compared to the young group (5.7 ± 9.2 MPa; p=0.065). The product of AB was found to be significantly greater in old rats (1.4 ± 0.2) compared to young rats (0.7± 0.2; p<0.05).

FIGURE: Peak tensions (A) and equilibrium tensions (B) scaled to muscle cross-sectional area were significantly greater in old animals compared to young animals (*p<0.05) for the linear portion of the load displacement curve.

DISCUSSION:
Aging significantly influences the passive elastic biomechanical properties of the muscle-tendon unit, while viscous properties are maintained. Clinically, repeated supra-physiologic loading of the muscle-tendon unit during strenuous exercise beyond the tendons’ extensibility induces tendon microtrauma. Repeated microtrauma may lead to further biomechanical and vascular impairment with decreased healing potential of the muscle-tendon unit (6). This study demonstrates that the extensibility of older GC-AT muscle-tendon units was reduced, leading to supra-maximal peak tension at lower loading forces compared to young muscle-tendon units. This increase in stiffness of the muscle-tendon unit may explain the predisposition of middle-aged individuals to Achilles tendon tears, specifically in sports that involve repetitive loading at high tension (jumping, running).

The product of AB of the Fung’s QLV is proportional to the initial slope of the elastic response (5) and was significantly greater (50%) in older rats, implicating that a sudden increase in load leads to increased strain on the muscle-tendon unit. Normal aging decreases the elastic properties of the muscle-tendon unit. The decrease in muscle-tendon unit elasticity may contribute to the high incidence among middle-aged patients who participate in recreational sports only on occasion. Specifically, sports with sudden movements and high loads on the GC-AT unit may increase the risk of rupture.

The effect of normal aging on the passive biomechanical properties may explain the high prevalence among middle-aged occasional athletes and further study is needed to increase muscle-tendon unit elasticity in this age group to prevent injury.

SIGNIFICANCE:
The passive biomechanical changes in the musculoskeletal system during normal aging contribute to the risk of Achilles tendon injury.

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REFERENCES: