Relative Contribution of Material and Morphological Properties to Altered Achilles Tendon Stiffness in Aging

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Introduction

Both material properties (e.g., Young’s Modulus (E)) and morphological properties (e.g., cross sectional area (CSA) and slack length (l\text{slack})) affect tendon stiffness (k\text{t}). While previous studies have observed reduced Achilles tendon (AT) k\text{t} in older adults versus young adults1,2, the mechanisms for this reduced stiffness are unclear. Some findings suggest decreased E and increased local CSA1. Others suggest that increased collagen crosslinking in aging decreases E but increased mechanical stiffness3. Differences in methodological approaches across laboratories make it difficult to come to consensus about age-related changes in tendon structure-function. The objective of this study was to take comprehensive, functionally relevant measures of AT material and morphological properties to assess the relative contributions leading to decreased k\text{t} in older adults. We hypothesized that changes in morphology (i.e., lower CSA, longer l\text{slack}) would counteract increased E and explain age-related decreases in AT k\text{t}.

Methods

In this preliminary study, we recruited three young adults (YA: 25.3 +/- 3.2 yrs) and one older adult (OA: 77 yrs). Tendon stiffness (k\text{t}) was measured during isometric contractions of the right leg with the knee fully extended and the ankle fixed at 0°, 15° and 30° plantarflexion. Subjects were instrumented with an ultrasound probe over the medial gastrocnemius (MG) - AT junction, electromyography electrodes over the skin superficial to the tibialis anterior (TA), lateral gastrocnemius (LG), and soleus (SOL) muscles, and 3D motion capture markers on the medial knee, medial malleolus, and head of the 1st metatarsal. Measurements of k\text{t} were taken as the slope of the AT force-displacement relationship at a matched absolute force across age groups. AT l\text{slack} was measured from the most proximal point of the AT-calcaneus junction to the MG-AT junction at 0 degree angle. CSA was measured along the length of the AT, in 10% AT length increments by taking manual measurements from ultrasound images in ImageJ. E for the AT was calculated using the relationship k\text{t}=E*CSA/l\text{slack} using the CSA form the most distal measurement location.

Results and Discussion

As expected, the older adult had reduced AT k\text{t} versus the younger adults (Table 1). These preliminary results suggest that in both age groups, CSA increased as you move proximally up the AT. However, differences in older adult vs. younger adults CSA varied depending on the AT location. The older adult had larger CSA near the AT-MG junction but smaller CSA distally. In partial support of our hypothesis, our results suggest that age-related decreases in k\text{t} may be driven by changes in morphology rather than material properties of the AT. Though our participant sample size is limited, we found that large increases in l\text{slack} overshadowed smaller changes in CSA and E to yield a more compliant older AT.

Table 2: Achilles tendon (AT) material and morphological properties across age.

<table>
<thead>
<tr>
<th></th>
<th>k\text{t} [kN/m]</th>
<th>E [GPa]</th>
<th>CSA [mm²]</th>
<th>l\text{slack} [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger Adults</td>
<td>136.3 ± 25.2</td>
<td>35.0 ± 8.7</td>
<td>71.9 ± 6.5</td>
<td>18.3 ± 1.7</td>
</tr>
<tr>
<td>Older Adult</td>
<td>115.9</td>
<td>32.3</td>
<td>83.2</td>
<td>23.2</td>
</tr>
</tbody>
</table>

Figure 1: Cross-sectional area (CSA) along the free length of the Achilles tendon (AT). Error bars indicate SD.

Significance

Here, we lay the groundwork to address the key factors that impact AT structure-function across the lifespan. Understanding how changes in morphological and material properties of tendon trade-off in aging is important because therapeutic approaches to alter tendon mechanics, (e.g., drugs, exercise, exoskeletons) often target specific tendon properties.

Acknowledgments

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References