In-vivo evaluation of the Achilles free tendon toe-region stiffness

Dongyu Deng[1], Hiroto Shiotani[2], Yasuo Kawakami[2,3]
[1]Graduate School of Sport Sciences, Waseda University, Saitama, Japan
[2] Faculty of Sport Sciences, Waseda University, Saitama, Japan
[3] Human Performance Laboratory, Waseda University, Tokyo, Japan
Email: deng.dongyu@suou.waseda.jp

Summary

Under low tensile loads (passive plantar flexion to dorsiflexion), a significant Achilles tendon (AT) strain was observed but the degree was very small (1.2% on average). The mean estimated AT toe-region stiffness was 515 ± 119 N/mm with no significant sex difference.

Introduction

Previous ultrasound-based *in-vivo* studies have reported significant variability in AT strain under comparable relative force levels, with some exceeding the physiological strain limit of tendon tissues (~5%) suggested by *in-vitro* studies [1, 2]. This discrepancy may be due to 3D displacement and deformation of the AT, leading to misalignment with the ultrasound probe during measurements and resulting different landmarks were tracked. In this study, we obtained 3D centroid length using axial magnetic resonance imaging (MRI) [3] to track the identical anatomical landmarks in 3D. The purpose of this study was to measure AT 3D centroid length changes and stiffness under low tensile load through passive ankle joint dorsiflexion.

Methods

Eighteen participants, comprising 10 females (mean ± SD: 23.9 ± 4.1 yr, 1.64 ± 0.04 m, 57.1 ± 8.4 kg) and 8 males (25.1 ± 4.0 yr, 1.81 ± 0.03 m, 77.6 ± 5.4 kg) were included. Participants' ankle joints were secured using a custom foot fixture at three joint angles: plantar flexion (PF) 20°, neutral position, and dorsiflexion (DF) 20°, and axial MRI scans (slice thickness: 0.3 mm, field of view: 240 × 240 mm, matrix size: 480 × 480 pixels) of the AT were performed (Fig. 1).

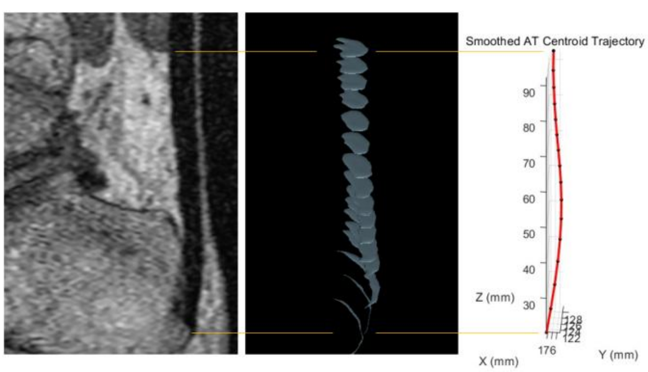

Figure 1: AT 3D reconstruction (neutral position) and the corresponding smoothed centroid path.

The centroid length of the AT from the soleus muscle belly end to calcaneal tuberosity tip was analyzed [3] using open-source software Slicer and custom MATLAB programs. At least 15 equidistant (projection along the longitudinal axis) slices were selected to plot the AT central trajectory. Passive joint torques under the three joint conditions were measured using a myometer. The AT force was estimated using the 3D AT moment arm length [4] and passive joint torque. The AT toe-region stiffness was calculated using the data at PF20° and DF20°, as no detectable centroid length change was observed from PF20° to the neutral position in several participants. The Mann-Whitney U test was used to examine sex differences, while one sample t-test was used to assess whether the AT centroid strain from PF20° to DF20° significantly differed from zero.

Results and Discussion

The AT centroid length at PF20° (resting) was 71.8 ± 16.0 mm and 72.7 ± 16.0 mm for DF20°. The AT centroid strain from PF20° to DF20° was 1.2 ± 0.3% (0.8-1.7%) which is significantly greater than zero ($p < 0.01$). The estimated AT force was 62.5 ± 24.6 N for PF20° and 494.8 ± 139.5 N for DF20°. The AT toe-region stiffness was 515 ± 119 (313 - 781) N/mm on average, with no significant sex difference (p = 0.594).

Our findings demonstrate that even in the toe region which is characterized by low tensile loads and the AT typically being more compliant than in its linear region, AT exhibits sizable amount of stiffness. Differences in stiffness values suggest individual variation in AT mechanical properties at the toe-region, with no sex specificity. The range of AT strain detected in our study closely aligns with the toe-region range observed in cadaveric studies. When compared to previous *in-vivo* results, it is reasonable that our estimated AT force range falls within its toe region. These results can validate our *in-vivo* 3D approach. Our approach to AT mechanical property under passive loading can provide a compromise between the sizable tensile load and accuracy. Future studies should consider applying this method to evaluate AT mechanical properties during active muscle contractions.

Conclusions

The AT demonstrates substantial resistance to stretching even under low tensile loads. The 3D method offers a more reliable measurement of AT length than 2D methods.

References

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