Investigation of the Validity of Modeling the Achilles Tendon as Having One Fixed Insertion Site

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Introduction

Muscle moment arm may be thought of as a quantitative indicator of a muscle's capacity to produce rotation about a joint for a given force. Duda et al. [1] have suggested that it is important to investigate the sensitivity of moment arms that are computed using musculoskeletal models to tendon attachment site choice. The Achilles tendon is typically modeled as having a single point insertion on the posterior aspect of the calcaneus. Although this insertion site is relatively small, its location relative to the subtalar joint axis may require a more sophisticated attachment representation in models, especially when subtalar joint function is considered. The purposes of this study were (1) to determine the sensitivity of Achilles tendon moment arm about the subtalar joint axis to variation in the location of its insertion site and (2) to investigate the suitability of using a single attachment site when modeling the Achilles tendon.

Statement of Clinical Significance

The triceps surae are large muscles capable of producing substantial moments at the ankle. Accurate prediction of these moments requires realistic representation of the Achilles tendon insertion and is essential for reliable model predictions of movement and the effects of orthopaedic surgeries at the ankle.

Methodology

A sensitivity analysis of the Achilles tendon moment arm about the subtalar joint axis to its insertion site placement was performed using a graphical computer model. The location of the insertion site was varied by ± 6mm in the A-P, S-I, and M-L directions. The origin of the muscle-tendon complex was taken to be that of the soleus to avoid the possibility that knee flexion angle would affect Achilles tendon moment arms. The subtalar joint axis used in the model was approximately that specified by Isman and Inman [2]. SIMM modeling software (MusculoGraphics, Inc.; Santa Rosa, CA) was used to construct the model and to calculate muscle moment arms.

The effective Achilles tendon insertion site (the point at which the resultant tendon force could be assumed to act) was measured in three cadaver specimens. The specimens were placed in neutral, maximally-everted, and maximally-inverted positions and a tension of 7N was applied to the Achilles tendon along a physiological line of action. Measurements made using a six-degree-of-freedom load cell (ATI ; Garner, NC) were used to compute the line of action of the resultant tendon force. The calcaneal surface on which the Achilles tendon inserted was located by fitting a plane to points sampled using a digitizing probe (Immersion Corp.; San Jose, CA). The effective attachment site was found by locating the intersection of the line of action and the calcaneal surface.

Results

The sensitivity analysis showed that the model-predicted moment arm of the Achilles tendon about the subtalar joint axis was substantially affected by displacement of the insertion site in the M-L direction. (Fig. 1) In each of the three cadaver specimens, the M-L location of the effective insertion site varied in a roughly linear fashion with subtalar joint angle. (Fig. 2) In all specimens, the effective insertion site shifted medially when the foot was everted and laterally when the foot was inverted.

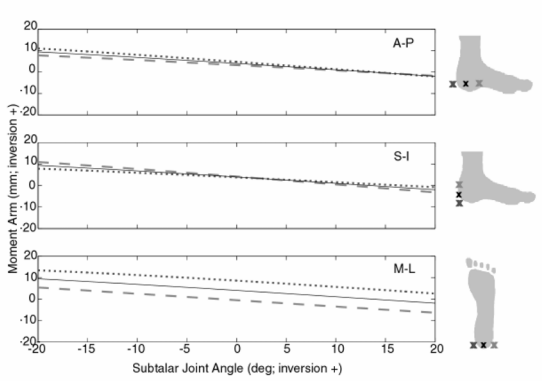

Figure 1: Sensitivity of the Achilles tendon moment arm about the STJ axis to the location of the tendon insertion in the A-P, S-I, and M-L directions

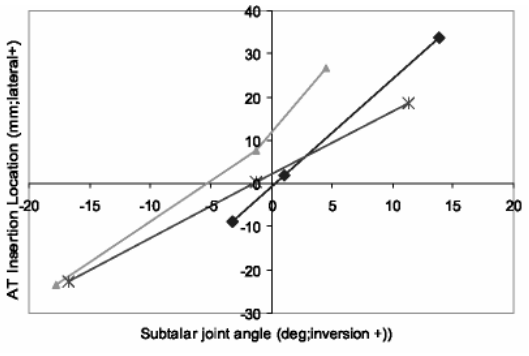

Figure 2: Medial-lateral location of the effective Achilles tendon insertion plotted versus STJ angle for three cadaver specimens.

Discussion

The results of this study demonstrate the need for more sophisticated representations of the Achilles tendon in investigations of its function about the subtalar joint. A single-segment tendon with an insertion that is fixed relative to the calcaneus may not permit accurate predictions of moment arm about the subtalar joint. It appears that the Achilles tendon may act as a self-balancing yoke, pulling on the lateral side of the calcaneus when the foot is inverted to produce an eversion moment about the subtalar joint axis, and having the opposite effect when the foot is everted. (Fig. 3) This conclusion is supported by the Achilles tendon moment arms about the subtalar joint axis reported by Klein et al. [3]. The method used in the present study for locating an effective attachment site from force data may be useful in the development of future musculoskeletal models.

Figure 3: Depiction of the effective insertion site of the Achilles tendon moving medially with eversion and laterally with inversion

References

[1] Duda, G.N. et al., J Biomech, **29**(9):1185-90, 1996. [2] Isman, R.E. and Inman, V.T., Bul Prosthet Res, pp. 97-129, 1969. [3] Klein, P. et al. J Biomech, **29**(1):21-30, 1996.

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