Amplification of Achilles Tendon Displacement by a Pivot-like Restriction Amplifies Final Displacement of Calcaneous and Rotation of Ankle with Possible Impact on Measured Strain.

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Introduction: A previous paper suggested that the curvature of the Achilles tendon, even under load, indicated that a retinaculum-like mechanism must exist to restrict posterior migration of the Achilles tendon as the ankle rotates [1]. It was further suggested that such a mechanism would modify the mechanics around the ankle such that the S/I displacement of the calcaneus would exceed the displacement of the tendon above the ankle, possibly introducing an error in measures of Achilles tendon strain. We have tested this prediction by comparing the displacement of the aponeuroses above the ankle and the movement of the calcaneus and predictions of the extent of influence of these mechanisms at the ankle based upon MRI-derived anatomical measures.

Materials and Methods: Gated Spin Tag fast gradient echo sequences were used for imaging on a 1.5T GE MR scanner with TE/TR/FA of 4.3ms/11ms/20o, 30cm FOV (256*160 matrix) with 0.6 phase FOV, 8 views/segment, 56 images/contraction cycle. The foot movement was regulated in terms of amplitude and speed, at a cycle rate of 30° s^{-1}, by a computer-controlled hydraulic piston-cylinder device, described in Ref. [2]. The force exerted by the subject and the target force desired were projected on to the magnet face for feedback purpose and also stored digitally. Each phase encoding level was triggered at two preset values of foot position, one at maximum plantarflexion and second at maximum dorsiflexion. A total of ~70 contractions at 40% Maximum Voluntary contractions (MVC) were required for the entire image. Five subjects were scanned in the lower half of the lower leg (with IRB approval). Analysis of the tag line displacements was performed with a LabView-based in-house algorithm. The intersection points of each tag line with the posterior aponeurosis of the soleus was measured as the ankle was oscillated over a range of ~ 30° to follow the displacement of the aponeurosis. Several points on the calcaneus were digitized in multiple frames as the ankle rotated. These were used to calculate the ankle center of rotation by a least squares solution to a series of simultaneous equations defining a set of concentric circles.

Results and Discussions: The calculated lever arm length from the ankle center of rotation to the calcaneo-tendinous junction was 53.1 +/- 3.8 (SD, range 50.4 –58.6) mm. The actual moment arm was always less than this value due to the anatomical relationship between the ankle and the Achilles tendon. Restriction of the outward movement of the Achilles tendon always resulted in an acute angle between the direction of tendon pull and the line between the ankle center of rotation and the calcaneo-tendinous junction. The moment arm is modified by the sine of this angle and is correctly measured by the minimum distance between a line through the Achilles tendon and the ankle center of rotation [3]. ***Displacement of tendon and calcaneus****:* An unstrained posterior aponeurosis would result in all tag lines displacing by the same amount. Experimental observations confirmed previous observations that the aponeurosis does not move uniformly, exhibiting displacements which suggest some regions of the aponeurosis stretch while other regions undergo compression (Fig. 2). Furthermore, some tags on the calcaneus showed a greater displacement than the displacement of the aponeurosis, consistent with the well recognized phenomenon that Achilles tendon stretches under load.

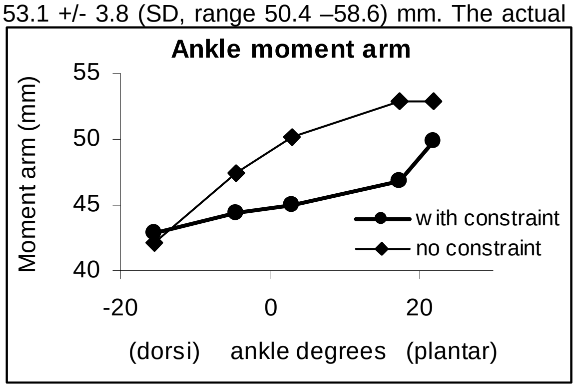

Fig. 1: Achilles tendon moment arm showing the moment arm measured from MRI data (with constraint) and a theoretical moment arm based upon the Achilles tendon lever arm and a constant direction of pull set to the direction measured at full dorsiflexion (no constraint). The lack of constraint would also require the Achilles tendon to move posteriorly by ~1.5 cm.

The alternative explanation for the differences between calcaneus and aponeurosis displacement may be an amplification mechanism due to the constraint on posterior movement of the Achilles tendon. These MRI experiments suggest that the major point of action of this constraint is 61.6 +/- 5.1 (SD, range 52.7 -65.6) mm superior to and 33.5 +/- 6.9 mm posterior to the ankle center of rotation.

Conclusions: Computations of the potential amplification by this configuration suggests a maximum gain of ~1.1 [1]. While apparently quite small, this could have a significant impact on experimentally observed Achilles tendon strain. For example, ultrasound measurements of aponeurosis excursion during a maximum voluntary contraction typically report a displacement of 20 – 30 mm. If a significant proportion of this movement involves rotation of the ankle, this could account for a significant portion of the observed strain.

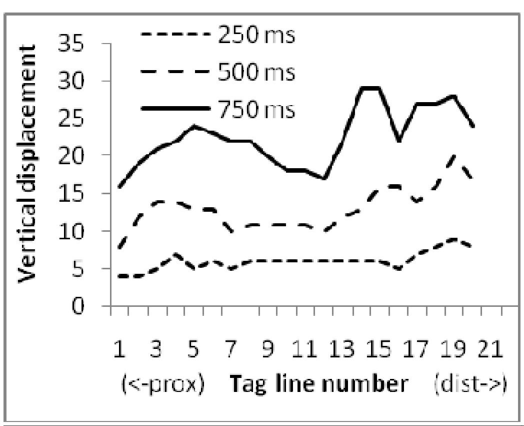

Fig.2-A: Starting at maximum dorsiflexion

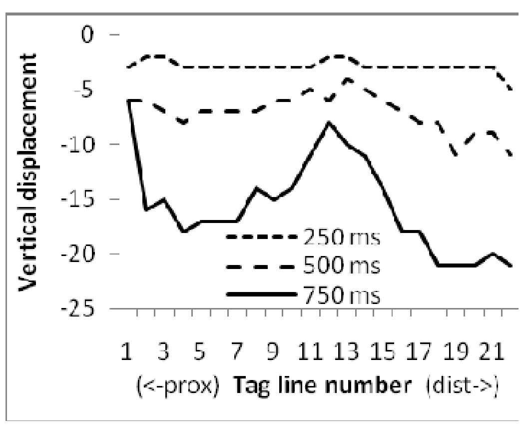

Fig.2-B: Starting at maximum plantarflexion

References: [1] Hodgson JA, Finni T, Lai AM, Edgerton VR, Sinha S. J Morphol. 2006;267(5):584-601. [2] Shin D et al. Proceedings of 16th ISMRM, Toronto, 2008; pg 3671. [3] Rugg SG, Gregor RJ, Mandelbaum BR, Chiu L. J Biomech. 1990;23(5):495-501. **Acknowledgement:** NIAMS Grant RO1 AR-53343.