USTIM: A novel method to assess subject-specific architecture of the Achilles tendon *in vivo* in humans

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Summary

The Achilles tendon (AT) comprises three subtendons whose relative locations, and respective lines of action, can vary individually. Here we demonstrate the efficacy of a novel method, combining Ultrasound and electrical sTIMulation (USTIM), to identify the *in vivo* location of individual subtendons in cross-sections of the human free AT. We individually stimulated the three heads of the triceps surae muscle and imaged localized tissue movement on a distal transverse plane using B-mode ultrasonography. Movement induced by muscle stimulation was presumed to arise from movement in the respective subtendon. Changes in grayscale values were analyzed to detect localized tissue movement, thus establishing subtendon locations from 14 healthy adults. From 12 successfully assessed legs, 83% were identified as low twist type I. The subtendon centroids identified by USTIM method had moderate to excellent reliability and close correspondence to those identified via high-field MRI method (N=2) by Cone et al. [1].

Introduction

Currently, our knowledge of AT architecture is derived from cadaver studies [2,4], and there is a lack of *in vivo* methods for study in humans. Knowledge of the three subtendon locations, arising from soleus (SOL) and medial (MG) and lateral gastrocnemius (LG), may contribute to understanding the etiology of different pathologies and facilitating personalized training and rehabilitation interventions. Here, we introduce and demonstrate the efficacy of a new method - USTIM (i.e., Ultrasound and electrical STIMulation) - to identify the *in vivo* location of individual subtendons from a cross-section of the human AT.

Methods

For participants (N=14, mean age 30y) in a prone position with their ankle at 90º, we individually stimulated SOL, MG, or LG [3]. For SOL, the electrodes were placed on the lateral side between muscle-tendon junctions of SOL and LG. Stimulation intensity was at or slightly above the motor threshold. B-mode ultrasound videos (at 75fps, 38mm probe, Aixplorer Supersonic Imagine, France) during each 0.7 s stimulation train were acquired transversely ~1 cm proximal to the calcaneus. Two individuals were also assessed using the 7T MRI method of Cone et al. [1].

Ultrasound videos were analyzed for frame-by-frame changes in grayscale with the assumption that locations of earliest tendon tissue displacements were anatomically associated with the stimulated muscle. Two raters analyzed all trials independently following a predetermined decision-making strategy. Geometrical centroid points of the entire tendon cross-section and those of each subtendon were extracted.

Results and Discussion

From 12 successfully assessed legs without movement artefacts, test-retest reliability was excellent (ICC=0.93, N=3), and intra- and inter-rater reliability was good for subtendon centroid locations (ICC>0.77, N=12). Reliability for identifying subtendon area was good for test-retest (ICC=0.77) and intra-rater assessments (ICC>0.70) but moderate between raters (ICC=0.53). Subtendon centroid locations assessed using USTIM showed strong association (N=2; $r^2 = 0.80$, $p<0.001$) with those identified via 7T MRI.

Of the 12 tendons (10 individuals), 83% were identified as type I, and 17% as type II/III following Pękala et al. [4] (Fig. 1). The prevalence of structure type I aligns with in vivo study by Cone [1] but is higher than in cadaver studies [2,4].

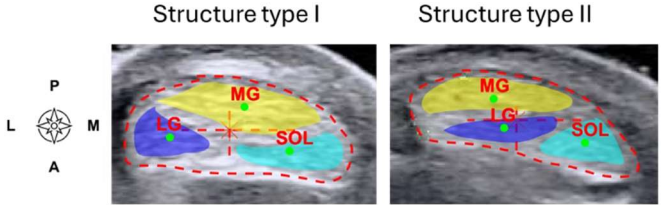

Figure 1: Examples of the final analysis outputs, showing the three subtendon areas (SOL, MG, LG) identified within the entire tendon cross-section. Geometrical centroids are shown for the entire tendon (red cross) and for each subtendon (green dots).

Conclusions

We successfully used a novel USTIM method combining ultrasonography and electrical stimulation to identify the locations of the three AT subtendons in humans *in vivo*. The method was shown to be feasible with results comparable to high-field MRI with moderate to excellent-reliability. This method may be used to unravel intricacies of structure-function relationships in the Achilles tendon.

Acknowledgments

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References

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