

# ARE ULTRASOUND-BASED ESTIMATES OF ACHILLES TENDON KINEMATICS CONSISTENT WITH THE EXPECTED BEHAVIOR OF A PASSIVE ELASTIC TISSUE IN SERIES WITH MUSCLE?

Emily S. Matijevich, Lauren M. Branscombe and Karl E. Zelik

Vanderbilt University, Nashville, TN, USA  
email: emily.matijevich@vanderbilt.edu, web: my.vanderbilt.edu/batlab

## INTRODUCTION

The Achilles tendon (AT) is an important passive elastic structure that facilitates safe and economical human locomotion, and whose behavior informs the development of assistive technologies and rehabilitative interventions. However, quantifying AT kinematics and kinetics *in vivo* is challenging, leading to inconsistent estimates of length change, stiffness and hysteresis in literature [1]. Ultrasound imaging offers one way to non-invasively estimate AT kinematics *in vivo* during human movement, but critical questions remain about which ultrasound methods are most accurate, and if/when each method yields physiologically plausible AT estimates [2]. Two questions motivated this study: (I) Do commonly used ultrasound tracking methods yield similar estimates of AT length change? (II) Are these estimates consistent with the expected behavior of a passive elastic tissue acting in series with a contracting muscle?

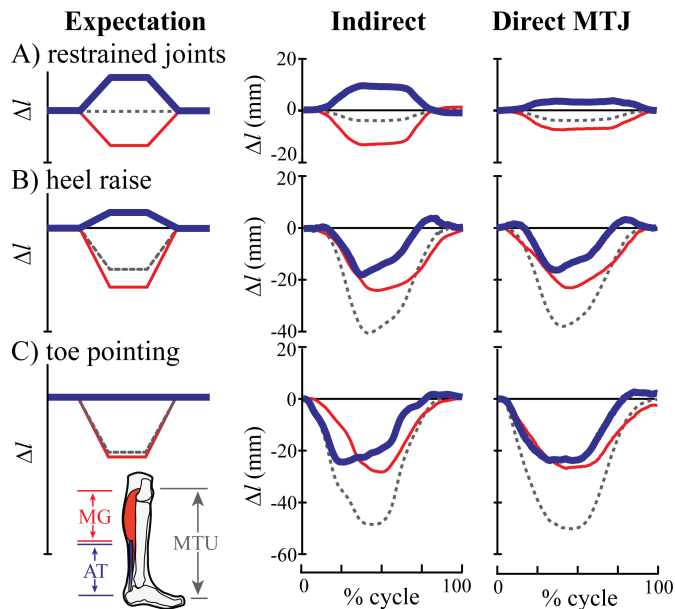
## METHODS

Three healthy subjects ( $20 \pm 2$  years,  $75 \pm 10$  kg) performed various movement tasks, during which unilateral lower-limb kinematics (100 Hz, Vicon) and ground reaction forces (1000 Hz, Bertec) were collected synchronously with B-mode ultrasound (~60 Hz, 50 mm depth, Telemed). Subjects provided informed consent prior to participation. To address question (I), we compared AT length change estimates from two commonly used ultrasound methods. For the first method, termed *Indirect*, the ultrasound probe (7 cm linear transducer) was placed on the medial gastrocnemius (MG) muscle belly to track muscle fascicle length changes. Fascicle length was corrected for pennation angle to estimate total muscle length

change. AT length change was then approximated indirectly as the difference between the overall muscle-tendon unit (MTU) length change (estimated from a regression equation using knee and ankle joint angles [3]) and muscle length change. For the second method, termed *Direct Muscle-Tendon Junction (MTJ)*, the ultrasound probe was placed over the MG-AT MTJ. Using optical motion capture and a custom-fixture attached to the probe to track its position, AT length change was more directly estimated as the linear distance between the calcaneus marker (AT insertion) and MTJ. MG muscle length change was also approximated using this method, by subtracting AT from MTU length change (from [3]).

To address question (II), subjects completed three simple tasks in which empirically-estimated AT length changes could be compared to the expected behavior of a passive elastic tendon acting in series with muscle. Tasks were chosen to test combinations of high/low MTU force and large/small MTU length changes. Tasks: (A) Restrained joint calf contractions were performed while seated with a rigid bar affixed above the knees, restricting ankle and knee rotation. Expectation: Small MTU length change and high MTU force would result in substantial AT lengthening, equal and opposite to MG shortening. (B) Heel raises involved contracting the calf muscles while standing to rise onto the toes. Expectation: Large MTU length change and high MTU force would result in AT lengthening. (C) Toe pointing required subjects to hold their foot in the air and plantarflex their ankle. Expectation: Large MTU length change and low MTU force would result in minimal AT length change. Each cycle began/ended with the MG relaxed and the foot in neutral position (i.e., perpendicular to shank).

## RESULTS AND DISCUSSION



**Figure 1:** AT (thick blue), MG (thin red) and MTU (dashed gray) length changes for one subject during 3 tasks. Data averaged over 5 cycles.  $\Delta l$  = change from relaxed length.

AT length change estimates were strongly correlated between the Indirect and Direct MTJ tracking methods. We found correlation coefficients of  $r = 0.82 \pm 0.06$ ,  $r = 0.89 \pm 0.09$ ,  $r = 0.75 \pm 0.21$  for tasks A, B, and C, respectively (N=3, Figure 1). AT length change estimates were qualitatively consistent with the expected behavior of a series elastic tissue during task A, which involved

minimal changes in MTU length. However, AT length changes were drastically different from expectations for tasks B and C, in which the MTU underwent substantial shortening.

## CONCLUSIONS

Preliminary findings suggest that Indirect and Direct MTJ methods yield similar estimates of AT kinematics for the tasks tested. However, estimated AT kinematics were highly inconsistent with the expected behavior of a passive elastic tissue in series with muscle. In this ongoing study we seek to understand the reasons for and implications of this inconsistency.

## REFERENCES

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## ACKNOWLEDGMENTS

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