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MEASUREMENT OF TRANSIENT ACHILLES TENDON DYNAMICS DURING MUSCLE TWITCH CONTRACTIONS

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SUMMARY

The purpose of this study was to assess the feasibility of using high frame rate ultrasound data to measure transverse motion of the Achilles tendon during twitch contractions. To achieve this aim, we used a programmable research ultrasound system to collect radiofrequency (RF) sound waves from distinct locations along the Achilles tendon at over 14,000 frames/sec. We then used a cross-correlation method to track transverse tendon displacements based on the time varying phase of the RF signals. We show that micro tendon motion can be measured using this technique with a high degree of repeatability. Peak frame-to-frame and cumulative displacements were approximately 0.1 µm and 100 µm respectively, with the magnitude of motion found to increase monotonically with twitch intensity. The transverse tendon motion exhibited a regular spatial and temporal pattern, in which the largest displacements were observed in the proximal free tendon. These data demonstrate the potential of using high frame rate ultrasound RF collections to noninvasively track transient tendon dynamics. Such data can be used potentially to characterize dynamic phenomena such as shear wave speed and resonance frequency which are highly dependent on tissue stiffness. The noninvasive characterization of *in vivo* tissue material properties, therefore, may be possible with this novel method.

INTRODUCTION

Ultrasound is increasingly being used to evaluate *in vivo* musculotendon motion and estimate tissue strains [1]. Although conventional approaches use B-mode imaging to track the motion of anatomical landmarks within tissue, recent advances in high frame rate ultrasound techniques have emerged that can assess tissue material properties by tracking dynamic phenomena. Shear wave elastography, for example, induces shear waves with a concentrated RF pulse, and then tracks the resulting tissue motion using plane wave imaging. Although these plane wave collections allow for very high frame rates, current shear wave imaging systems are still limited to being able to measure shear wave speeds less than 17 m/s [2]. Although this speed range may be sufficient for muscles and other soft tissues [3], stiffer tissues, such as stretched tendon, can exhibit shear wave speeds that substantially exceed this range. In contrast to plane wave imaging, conventional clinical ultrasound machines collect data in a sequential manner from a fixed number (e.g. 128) of focused acoustic transmissions from elements spaced along the transducer. This leads to an inherent tradeoff between lines of data collected and frame rate, which typically limits frame rates to less than 100 frames/sec when all elements are sampled. In this study, we programmed a research ultrasound machine to collect RF data at much higher frame rate by limiting the collections to only two lines of data. The purpose of this study was to investigate the feasibility of using the high frame rate RF data to track micro motion in the tendon during dynamic twitch contractions. We first evaluated the repeatability of tendon motion over sequential trials, and then assessed spatial and temporal variations in the transverse motion patterns induced within the tendon tissue.

METHODS

Data were collected from a healthy young adult. Stimulating electrodes were placed over the medial gastrocnemius muscle to induce an isolated twitch. A low intensity twitch was defined based on the smallest stimulus voltage that produced visible motion at the ankle. Medium and high intensity twitches were then defined by increasing the input voltage by 15% and 30% respectively. A linear array transducer (L14-5, 10 MHz, Ultrasonix Corp., Richmond, BC) was positioned longitudinally over the Achilles tendon, with the most distal aspect of the transducer located approximately 1 cm from the posterior superior surface of the calcaneus. For all experiments, the transducer was fixed in place with a rigid transducer holder affixed to a stationary bench, and a standoff pad placed between the transducer and the Achilles tendon to facilitate imaging (Figure. 1).

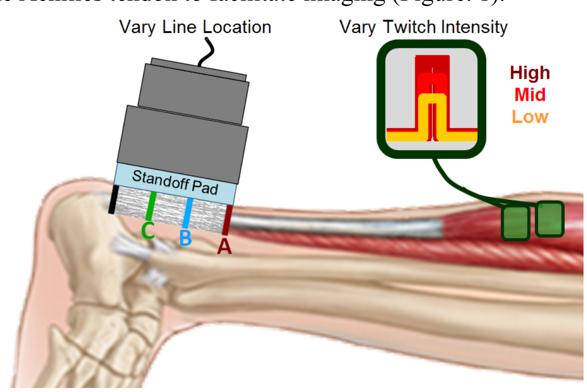

Figure 1: Ultrasound data were collected from specific lines along the distal Achilles tendon while varying intensities of twitches were induced in the medial gastrocnemius. *Image adapted from Healthwise, Inc.*

Ultrasound RF data were collected with a SonixTOUCH (Ultrasonix Corp., Richmond, BC) machine, which was triggered to collect high frame rate (14,124 frames/sec) data from two distinct lines along the transducer. We collected data from four different positions along the tendon, each line spaced 12 mm apart (Figure 1). The most distal line was maintained at the same spatial location for all collections. Five trials at each twitch intensity and each line combination were collected, such that 45 trials were collected in total. Conventional B-mode images were also collected after each trial to anatomically identify the location of the tendon along a single line of RF data.

Tendon motion was measured from the ultrasound RF data using a speckle tracking methodology [4]. A line of interest was manually defined to span the tendon thickness (line lengths=3.5-3.8 mm) based on the collected B-mode image. Incremental displacements of the line between successive frames were tracked by computing the normalized cross-correlation function, with subpixel motion estimated via a cosine fit to the correlation function at the lag corresponding to peak correlation [5]. Incremental displacements were then low-pass filtered using a third order 200 Hz butterworth filter. Cumulative displacements were obtained by integrating the incremental data over time.

RESULTS AND DISCUSSION

Distinct and repeatable transverse tendon motion was observed in response to the induced muscle twitches. There was a high degree of repeatability between trials (Figure 2), with intraclass correlation coefficients (ICCs) ranging from 0.86 to 0.98 for the high intensity twitch cases. The magnitude of tendon motion was observed to increase with twitch intensity. For example, the average peak incremental displacement of the proximal tendon increased from 0.02 to 0.13 µm for low and high twitch intensities, respectively. ICCs were lowest for the low intensity twitch cases where the smallest amount of motion was noted. When integrated over time, cumulative tendon displacements reached up to ~100 µm. We also noted a regular spatial pattern of the displacements with the largest motion observed in the proximal tendon (Figure 3).

CONCLUSIONS

This study shows the capability of measuring transient dynamic motion in the Achilles tendon by collecting ultrasound RF data from specific locations at very high frame rates. The high temporal and spatial resolution may make it feasible to characterize the dynamic properties of tendon, such as shear wave speed or tendon vibration frequencies. A prior *ex vivo* study showed that the resonance frequency of tendon increases monotonically with load [6], likely reflecting the strain-stiffening behavior of tendon tissue. Further studies will be conducted to see if similar phenomena are observable *in vivo*, which, if true, would provide a noninvasive approach for ascertaining tendon tissue stiffness.

ACKNOWLEDGEMENTS

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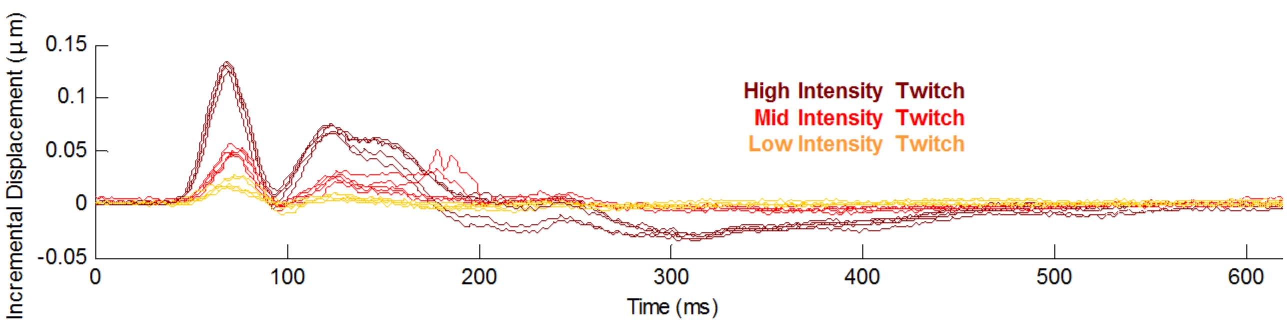

Figure 2: Incremental displacements of the proximal free tendon measured during different twitch intensities. These data show an increase in twitch displacement as the twitch intensity increases, as well as very good repeatability between trials.

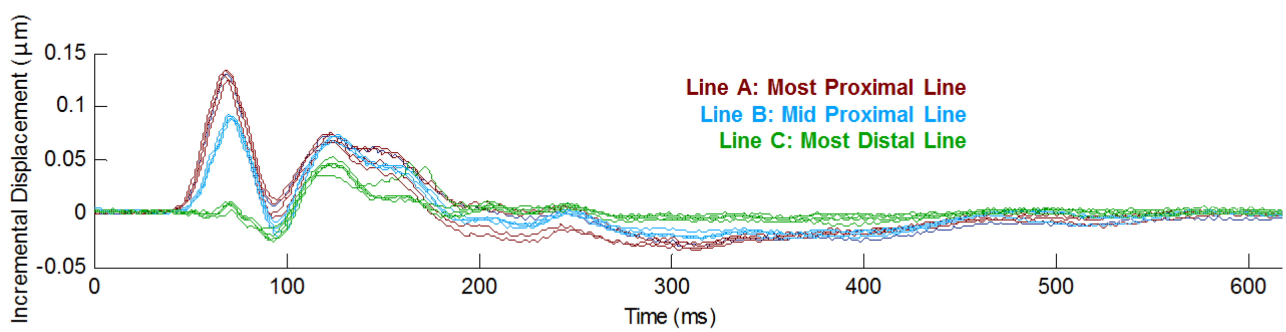

Figure 3: Incremental displacements measured during the high intensity twitch from three different spatial locations. The phase and magnitude of the displacements vary systematically with position along the Achilles tendon.