Ultrasound Echogenicity is Associated with Fatigue Damage and Failure of Achilles Tendon in a Cadaveric Loading Model

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Introduction

Achilles tendon disorders are one of the most common conditions observed by sports medicine physicians and one of the most difficult to predict with current clinical tools.[1] One in twenty patients with tendinopathy will eventually sustain an Achilles tendon rupture.[2] Clinical diagnoses currently rely on patient-reported symptoms of pain, a reduction in ankle range of motion, and tendon swelling. However, by the time Achilles tendinopathy becomes symptomatic, many degradative changes to the tendon have already been initiated.[3] Developing clinical imaging tools sensitive enough to detect and quantify markers of Achilles tendon damage may lead to better treatment and improved outcomes for patients. Therefore, the purpose of this study was to determine whether clinical ultrasound images can be assessed with computational algorithms to detect in vitro fatigue-induced degradation of Achilles tendon mechanical properties. We hypothesized that slight alterations in mean echogenicity (ME) could be linked to changes in vitro tendon fatigue life.

Methods

Achilles tendons were harvested from 10 fresh-frozen cadaveric feet (3 matched pairs, 7 unmatched; 4M, 3F; 60 ± 15 years old). Calcanei were potted in surgical cement and tendons were cut into dog-bone shapes to ensure failure at the mid-substance. The proximal end of the tendon was secured in custom 3-D printed clamps. Tendons were tested in a 37°C circulating PBS bath and were loaded using a universal test frame (Fig 1A). To fatigue the tendon, we utilized the following cyclic loading protocol: First, 500 sinusoidal cycles were applied under load control between 10-20 MPa at 1 Hz (Fig 1B). Next, we applied 2 'stress test' loads at 0.25 Hz and acquired continuous ultrasound images at 41 Hz using an 18MHz transducer. This two-step process was repeated until tendons failed at mid-substance (Fig 1C). Using a custom MATLAB script, we analyzed the change in mean echogenicity (%ME) of ultrasound images captured during stress tests throughout testing. To determine if this echogenicity measurement differed between tendons that failed and tendons that survived the fatigue loading, we compared the two groups using an unpaired t-test ($P < 0.05$)

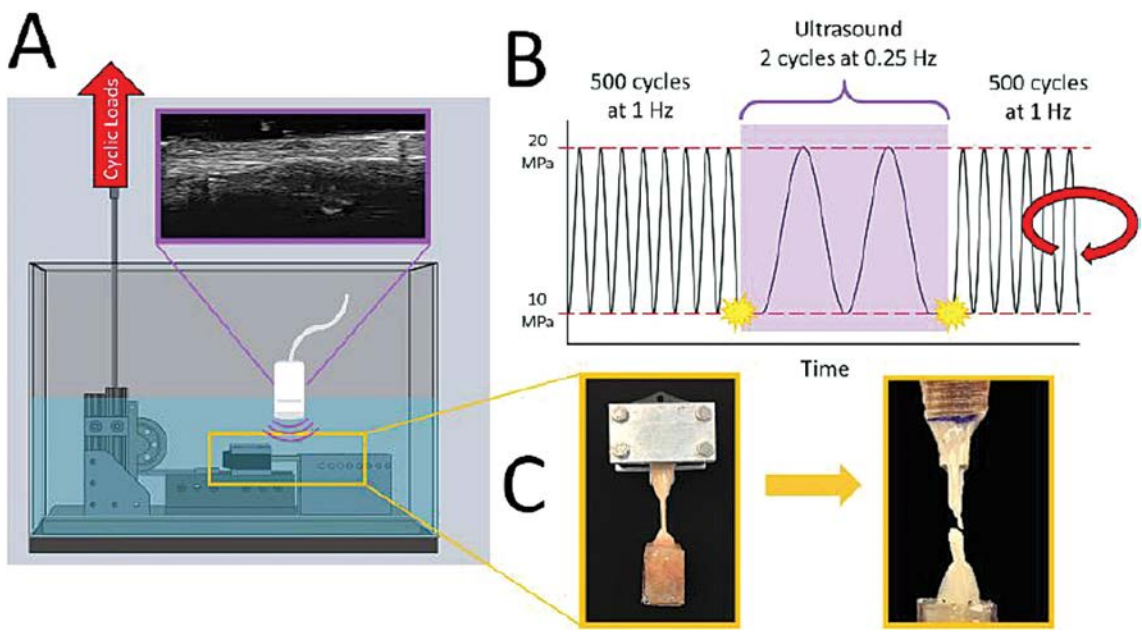

Figure 1. (A) Computer-aided representation of tank water bath testing setup, showing pulley, linear track, and tendon carriage setup. **(B)** Cyclic testing protocol applied to tendon. Ultrasound (purple) was captured every 500 cycles and initiated via a trigger signal (yellow bursts). **(C)** This protocol was repeated until tendon failure or until 150,000 cycles was achieved.

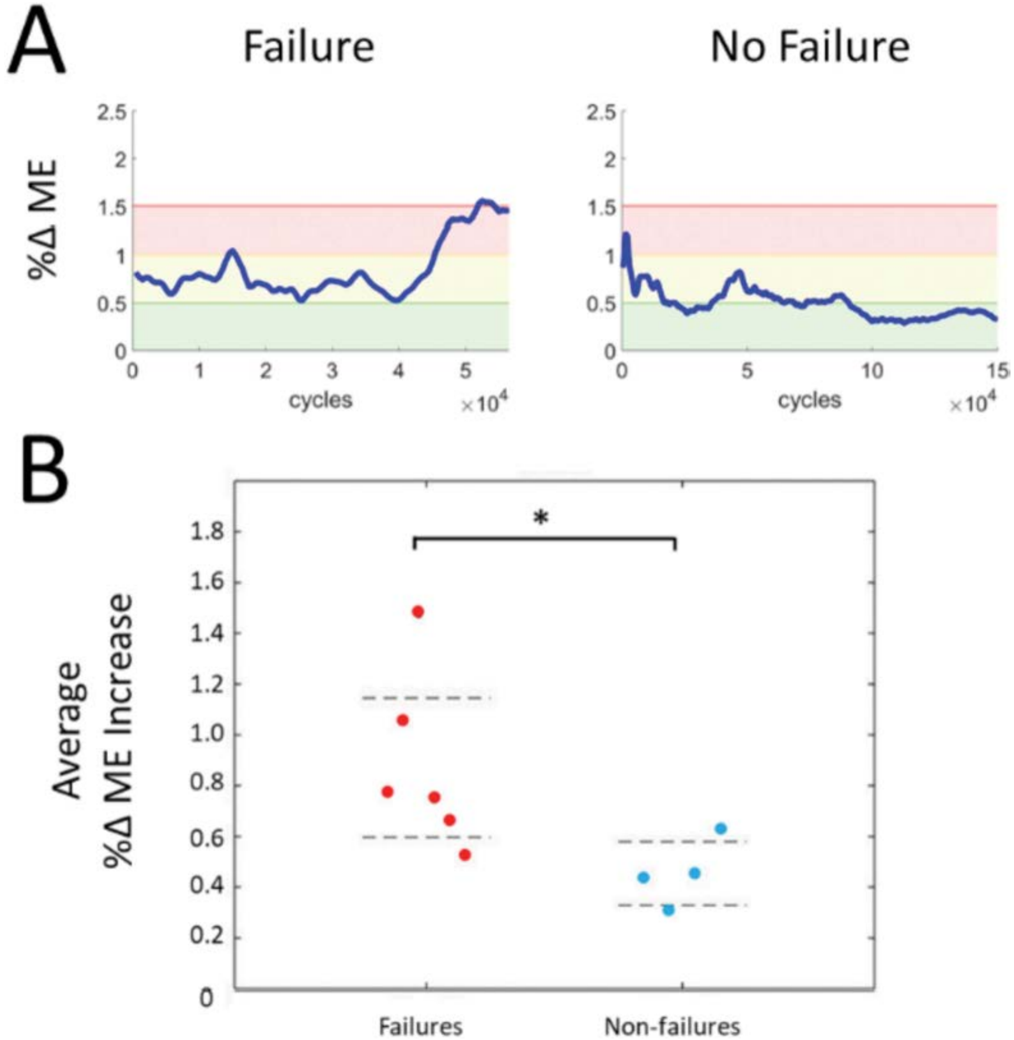

Figure 2. (A) The percent change of mean echogenicity (%ME) profile over fatigue life for a tendon that failed and a tendon that survived. **(B)** Statistical differences between the failure (red datapoints) and non-failure (blue data points) groups for average % ME (left). Dashed lines indicate 95% confidence intervals. Asterisks indicate $p < 0.005$.

Results

Of the ten tendons that were tested, six failed at the mid-substance and four did not fail after 150,000 cycles. On average, the tendons that failed did so at 12.5±1.1% strain while the tendons that survived the fatigue loading protocol underwent less strain (7.1 ± 1.6%). Tendons that did fail spent more time in the zone above 0.5 %ME and eventually surpassed 1.0 %ME(Fig 2A). Conversely, tendons that survived the fatigue loading "settled" below 0.5 %ME (Fig 2A). The average increase in %ME was greater in the tendons that failed compared to those that did not ($p = 0.031$) (Fig 2B).

Discussion

In this study we combined biomechanical loading with ultrasound imaging to assess the fatigue life behaviors of cadaveric Achilles tendons. We found that changes in mean echogenicity measurements increased under tension with increased tendon damage. Ultrasound imaging is an attractive clinical tool because it is relatively inexpensive, portable, and non-invasive. Using ultrasound to identify patients that are at risk of Achilles tendon rupture based on quantitative metrics would be a highly convenient and cost-effective way to alleviate the physical and healthcare costs of these debilitating injuries. The magnitude of change in mean echogenicity that was found in this study was relatively small (< 1.5%ME) and would not be visible to the clinician's eye. Therefore, machine learning may be the next logical direction for future work on establishing a predictive model for Achilles tendon injuries.

Significance/Clinical Relevance

Mean echogenicity is a promising marker for quantifying fatigue damage in Achilles tendons. Future work will focus on developing computer-based predictive tools to assess Achilles tendinopathy risk in physically active adults.

References

1. McAuliffe et al. Can ultrasound imaging predict the development of Achilles and patellar tendinopathy? A systematic review and meta-analysis. *British J Sports Med.* 2016 Dec;50(24):1516-1523.

2. Yasui et al. The Risk of Achilles Tendon Rupture in the Patients with Achilles Tendinopathy: Healthcare Database Analysis in the United States. *Biomed Res. Int.* 2017;2017:7021862. Epub 2017 Apr 30.

3. Sunding et al. Evaluation of Achilles and patellar tendinopathy with greyscale ultrasound and colour Doppler: using a four-grade scale**.** *Knee Surg Sports Traumatol Arthrosc.* 2016 Jun;24(6):1988-96.