Tracking Day-To-Day Achilles Tendon Loading Progression During Rupture Recovery

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Introduction

Achilles tendon ruptures have increased 10-fold in the past 30 years. Although state-of-art treatments can reduce re-rupture rate to $< 5\%$[1], two-thirds of patients still suffer long-term functional deficits[2]. An effective strategy to improve tendon healing is via progressive loading[3]. Yet, targeted Achilles tendon loading has rarely been prescribed in rehabilitation, largely due to difficulties to reliably measure and track tendon loads outside of clinics.

Recent advances in wearable sensors, including instrumented shoe insoles, provide powerful platforms to measure real-world biomechanics. Using simple algorithms our group developed, these instrumented insoles can quantify Achilles tendon loads in an accuracy comparable to lab-based analysis[4,5]. Despite these technical advances, the feasibility of using wearables as a tool to enhance targeted Achilles tendon therapeutics remain unknown, partly due to the cost and logistics to obtain continuous data over the long recovery process on many subjects. Therefore, our goal was to leverage a case study to verify whether instrumented insoles are able to track the longitudinal progression of Achilles tendon loading in daily life, and relate to clinically relevant events that are otherwise difficult to capture beyond controlled settings.

Methods

A patient (F, 30y/o) who suffered a rupture of her right Achilles tendon was enrolled and provided consent in this IRB-approved study. The tendon was repaired ± days after injury, followed by a standard rehabilitation protocol[3]. An immobilizing boot fit with a 3-sensor instrumented insole (Loadsol) was worn starting from week 4 post-surgery. The insole remained in the footwear after it was changed from boot to subject's own shoe at week 9. Data collection continued until week 22. The patient recorded at least 10 seconds of gait data from the insole each day, and logged daily step count using her mobile device. Patient also documented any specific event that may be related to the health of the healing tendon, including pain, discomfort, notable daily living activities, and clinical visits. We also obtained clinical logs from such visits.

We extracted all steps from the daily insole data. For each step, we estimated Achilles tendon loads using our established algorithm[4,5] and calculated 4 mechanical variables: load peak, impulse over a step, average load rate from heel strike to peak, and maximum load rate. We compared the daily average of these load variables longitudinally to step counts, self-reported events, and clinical events to explore their inter-relationships. We also correlated the 4 load variables to determine whether they provide unique insights into Achilles tendon loading versus each other.

Results and Discussion

The insole recorded up to 70 steps each day on a total of 116 days. In general, peak Achilles tendon loading increased gradually over the course of rehabilitation, but in a non-linear manner with large variations especially between week 12-19 (Figure 1). Many "sharp" changes in peak load corresponded to events possibly causing or resulted from altered tendon health. For example, rapid load increases in late week 12 was immediately followed by days of reported pain and swelling. A particularly high step count (20k+) was followed by a large decrease of the Achilles tendon peak load measured at the end of the same day. The insole was also able to identify tendon load changes according to patient instructions. For example, by intentionally "trying to push off' during gait, the patient increased her peak Achilles tendon load by 65% and peak load rate by 45% (Figure 2). This result supports the feasibility for Achilles tendon load to be modified instantly and interactively via instructions or biofeedback. Finally, Achilles tendon load rates and impulse strongly correlated with peak loads ($R^2 > 0.85$). The strong correlations with other mechanical variables suggest peak load is sufficient for tracking Achilles tendon loading.

Significance

Longitudinally monitoring Achilles tendon loading is challenging because 1) it is limited by the scarce frequency of clinical visits, and 2) lab-based gait measurements do not faithfully

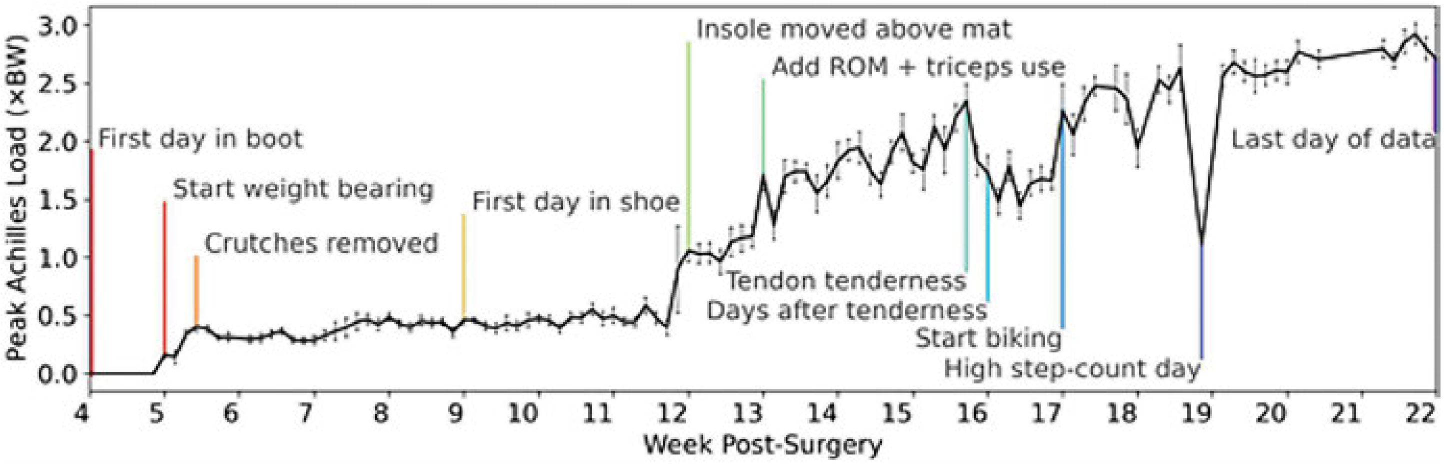

Figure 1. Achilles tendon peak load progression, annotated with selected representative clinically relevant events. Error bars = ± 1 standard deviation (SD) across steps on the same day.

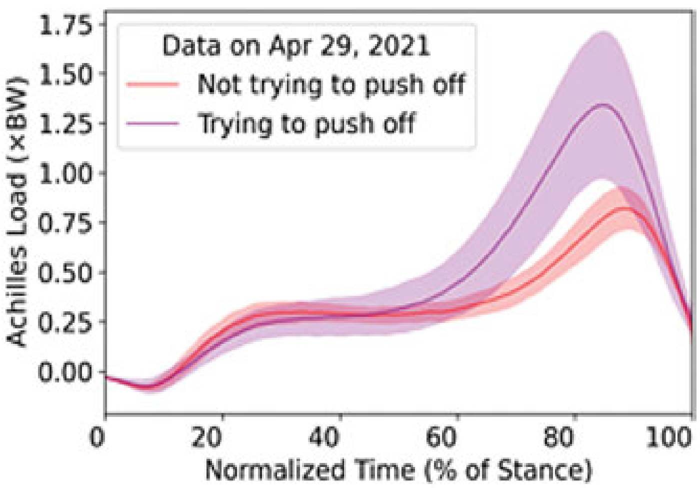

Figure 2. Achilles tendon load over a step with vs without intentional push-off. Shades = ± 1 SD.

reflect real-world biomechanics [6]. This first-of-kind case study shows the value and feasibility of using instrumented insoles to track day-to-day Achilles tendon loading in the real world. Our innovative paradigm can empower future studies to leverage accessible tools (e.g. biofeedback systems) and deliver personalized rehabilitation according to quantitative guidance, thereby optimizing long-term Achilles tendon healing and functional recovery.

Acknowledgments

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