Tendon Loads Measured over 2 Weeks of Daily Living are Associated with Achilles Tendinopathy Patient Outcomes

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Introduction

Achilles tendinopathy is a debilitating chronic condition prevalent in physically active adults.[1] Exercise rehabilitation can effectively reduce symptoms in a short term,[2] yet long-term outcomes vary greatly among patients[3] as 35–60% still experience pain and up to 50% seek alternative treatments including surgery.[4,5] A major challenge for improving rehabilitation outcomes is to determine the cumulative effects of tendon loading due to exercises and patient-specific daily living. The purpose of our study was to develop a strategy to measure cumulative tendon loads in Achilles tendinopathy patients and determine their associations with patient outcomes and characteristics including age, severity of tendinopathy, and self-reported activity level.

Methods

We enrolled 8 patients diagnosed with Achilles tendinopathy and 3 pain-free controls after informed consent in this IRB-approved study. We continuously measured loads in each patient's most painful tendon (random side for controls) over a 2-week span using an instrumented force-sensing insole (Loadsol) and a physics-based algorithm.[6] We computed cumulative tendon loads over the entire monitoring period above 2 pre-defined thresholds: "*overall*" load as $\geq$ 0.3 body weight ($\times$BW) that results from any non-trivial daily living activities,[7] and "*high*" load as $\geq$ 3.0$\times$BW which is above walking level and thus primarily due to dynamic exercises.[7] We computed cumulative loading time as the total time when tendon load is over the *overall* and *high* thresholds, and cumulative loading impulse as the integral of *overall* and *high* load over their cumulative loading time (**Figure 1, insets**). We defined *overall* cumulative loading time ($\geq$ 0.3$\times$BW) as the "Total Active Hours", and normalized the *overall* and *high* cumulative loading impulse by Total Active Hours to control for the variable total periods that participants wore the instrumented insole. We also normalized *high* loading time by Total Active Hours to represent the percentage of time when the tendon was loaded above a *high* level. To determine whether these 3 normalized metrics (*overall* and *high* loads per Active Hour; percentage of time over *high* load) are associated with patient outcomes, we calculated Pearson correlations between these metrics and participant age, self-reported severity of Achilles tendinopathy,[8] and a self-reported current Physical Activity Scale (PAS).2 We defined a correlation coefficient of $|r| \geq 0.7$ as strong, 0.4 – 0.7 as moderate, and 0.1 – 0.4 as weak.[9] We combined data from the patients and controls for these preliminary analyses (n = 11).

Results

Eleven participants (age: 43.5 $\pm$ 17.2 y/o, BMI: 30.5 $\pm$ 7.0 kg/m2) logged insole data over 10.3 $\pm$ 2.3 days (range: 6 – 13), capturing 21.4 $\pm$ 9.5 Total Active Hours (11.6 – 46.9) and cumulating 23.5 $\pm$ 11.3 $\times$BW*hours of *overall* tendon loading impulse (9.8 – 53.5). As a subset of *overall* load, participants had highly variable *high* loading time (0.9 $\pm$ 0.9 hours, 0 – 2.4) and impulse (3.2 $\pm$ 3.3 $\times$BW*hours, 0 – 9.3). Per Active Hour, participants cumulated 1.10 $\pm$ 0.17 $\times$BW of *overall* load (0.82 – 1.28) and 0.14 $\pm$ 0.12 $\times$BW of *high* load (0 – 0.38). Percentage of time over *high* load was 3.8 $\pm$ 3.1% (0 – 10.0). *Overall* load per Active Hour was weakly correlated to age ($r = -0.247$) and severity of tendinopathy ($r = 0.367$), and moderately to self-reported activity level ($r = 0.458$, (Figure 1, left). In contrast, reduced *high* load per Active Hour was strongly correlated to older age ($r = -0.733$) and a lower self-reported activity level ($r = 0.705$, (Figure 1, center), while moderately correlated to more severe tendinopathy ($r = 0.548$). Likewise, a lower percentage of time over *high* load was strongly correlated with older age (r = -0.744) and less self-reported activities ($r = 0.707$, (Figure 1, right) and moderately with disease severity ($r = 0.558$).

Discussion

Our study is the first we know to experimentally measure Achilles tendon loads

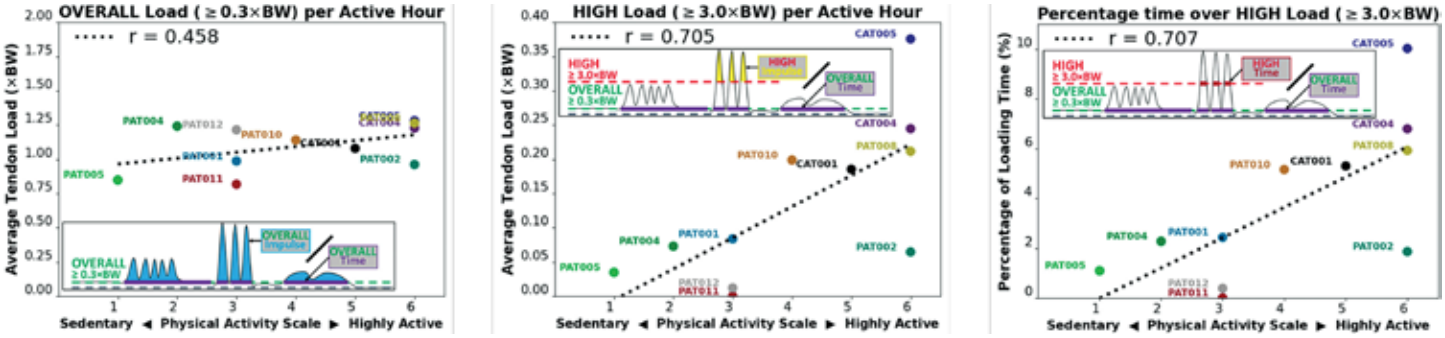

Figure 1. Self-reported activity level vs. normalized Achilles tendon loads measured over 2 weeks of force-sensing insole monitoring: (left) overall tendon load (≥ 0.3×BW) per Active Hour, (center) high load (≥ 3.0×BW) per Active Hour, and (right) percentage of time over high load. Cumulative high load showed stronger correlations ($r > 0.7$) to self-reported activity level than overall load likely because it varied more substantially among individuals due to occupations and lifestyles. Each marker represents a patient (PAT) or control (CAT). Inset diagrams depict the definitions of each normalized load metric.

during daily living over a weeks-long duration. While the cumulative loading time and impulse are confounded by the inherent variability of data amount available, they also denote the variation of real-world tendon loading profiles due to patient-specific characteristics (age), lifestyles (activity level), and tendon health (severity of tendinopathy). The associations between measured cumulative tendon loads and patient outcomes became more pronounced when loading time and impulse were normalized by Total Active Hours. We found that reduced cumulative *high* Achilles tendon loads are associated with older age, more severe tendinopathy, and more sedentary lifestyle (Figure 1, center and right). Measured cumulative tendon loads generally matched both self-reported activities and tendon health status. For example, among the 4 individuals who reported the highest current activity level (PAS = 6), the 2 patients had less cumulative *high* load than the 2 controls. Although preliminary, our data also reveal links between sensor metrics and daily living events, as the patient who cumulated more *high* load (PAT008, yellow marker) frequently self-reported running via daily text surveys, while the other patient (PAT002, teal marker) did not. Our ongoing research is recruiting a larger homogeneous patient cohort to explicitly define how cumulative tendon loads throughout patient-specific daily living influence the biological health of the Achilles tendon.

Significance

Tendon loading during daily living is a major contributor to Achilles tendinopathy. Our results confirm the clinical benefits of using self-reported activities and disease severity to guide exercise rehabilitation, while also establishing a rigorous strategy to quantify cumulative Achilles tendon loads throughout daily living. Our wearable sensing paradigm provides clinicians with a powerful tool to identify unique loading profiles that govern patient-specific outcomes, customize rehabilitation exercises, and monitor their impacts out of the clinic to promote the therapeutic effects of tendon loading.

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