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The role of Plantaris Longus in Achilles tendinopathy: A biomechanical study☆

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ABSTRACT

Background: The Plantaris Longus Tendon (PLT) may be implicated in Achilles (AT) tendinopathy. Different mechanical characteristics may be the cause. This study is designed to measure these.
Methods: Six PLT and six AT were harvested from frozen cadavers (aged 65–88). Samples were stretched to failure using a Minimat 2000^{TM} (Rheometric Scientific Inc.). Force and elongation were recorded. Calculated tangent stiffness, failure stress and strain were obtained. Averaged mechanical properties were compared using paired, one-tailed *t*-tests.
Results: Mean stiffness was higher ($p < 0.001$) in the PLT, measuring 5.71 N/mm (4.68–6.64), compared with 1.73 N/mm (1.40–2.22) in AT. Failure stress was also higher ($p < 0.01$) in PLT: 1.42 N/mm^2 (0.86–2.23) AT: 0.20 N/mm^2 (0.16–0.25). Failure strain was less ($p < 0.05$) in PLT: 14.1% (11.5–16.8) than AT: 21.8% (14.9–37.9).
Conclusions: The PLT is stiffer, stronger than AT, demonstrating potential for relative movement under load. The stiffer PLT could tether AT and initiate an inflammatory response.

1. Introduction

The Plantaris Longus Tendon (PLT) runs alongside the gastrosoleus complex, and continues along the medial aspect of the Achilles tendon (AT) before inserting onto the greater tuberosity of the calcaneus [1]. It is therefore situated within the peritendinous tissues which have been implicated in the pathogenesis of Achilles tendon [2,3]. It has also been observed that PLT is preserved during most acute AT ruptures suggesting that the two structures respond differently to a similar stress [4–6]. Little is known about how PLT might itself contribute to the mechanisms which trigger tendinopathy.

Theories as to the aetiology of Achilles tendinopathy include the effect of neighboring structures such as an accessory soleus muscle [7], and in other sets of synergic tendons different mechanical properties have been demonstrate [8]. Similarly, it has been reported that shear stress could cause inflammation of the peritenon [9].

Although the mechanical properties under load of the Achilles tendon have been previously studied [10], the differential mechanical properties under similar stress in paired Achilles and Plantaris tendons have to our knowledge not previously been reported.

The aim of this study was to describe the comparative mechanical properties in matched pairs of AT and PLT samples with the hypothesis that Plantaris is stiffer and stronger than the Achilles tendon. This variation in response to tensile stress could lead to differential movements between the two structures and therefore be a potential mechanism through which an inflammatory response is created around the Achilles tendons. Furthermore, this study will bring insight into the biomechanical properties of the PLT which to our knowledge has never been reported.

2. Materials and methods

2.1. Cadaveric material and preparation of tendon samples for testing

Six human calf specimens were disjointed at knee level from 4 frozen human cadavers, all male. The age of the specimens ranged from 65 to 88 years (mean 80.5). None of the subjects had died of a condition known to affect tendon metabolism and none of them had sustained an injury or had a surgical procedure to the gastrosoleus complex. The Achilles (AT) and Plantaris Longus (PLT) tendons were dissected. Samples measuring 5–10 cm long of the entire PLT were obtained. Samples of the larger AT were harvested from the distal part of the tendon, between 2 and 10 cm proximal to its calcaneal insertion: these were 5–10 cm long and 2–3 cm

☆ The authors state that the use of human cadaver material for this research was submitted to and approved by the National Health Service North Bristol Trust Research Ethics Committee.

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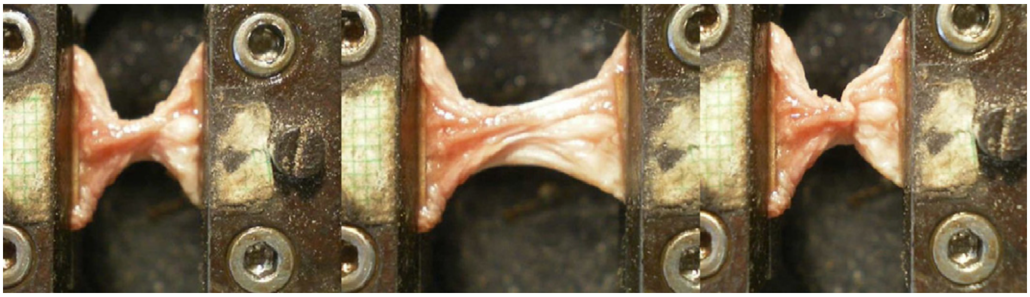

Fig. 1. Clamped Achilles tendon sample before stretching, at maximum stretch and after failure.

wide. Each sample was then divided into three shorter (2–3 cm) samples to fit the testing device. Thus, a total of 18 samples for each tendon were obtained. All samples were wrapped in cling film to minimize water loss and stored at −20 °C.

Each sample was then trimmed to a standard size using a single cutting device consisting of parallel razor blades calibrated to obtain 2.2-mm-thick tendon strips. Slices were cut while the tendons were partially frozen to ensure regular geometry. A second cutting device was used to obtain 'bow-tie' shaped specimens that were narrower in their central region: this ensured that failure would occur here rather than in wider regions that were gripped (and possibly damaged) by the clamps of the testing machine. The narrowed test region was wrapped in a strip of cling film to minimize water loss. Cyanoacrylate adhesive fixed the ends of each specimen to the smooth surfaces of folded strips of sandpaper so that the sandpaper's rough outer surfaces could be held securely in mechanical clamps [11]. The samples were regularly hydrated with 0.09% saline solution using soaked cotton wool.

2.2. Tensile testing of tendons

Specimens were gripped in the clamps of a miniature computer-controlled materials testing machine (Minimat 2000TM, Rheometric Scientific Inc.). The load-beam of the Minimat was calibrated against force using dead weights. Separation of clamps was measured by a displacement transducer (LVDT) and checked by comparison with a graduated scale incorporated in the digital images. As soon as a minimal tensile force was applied to the specimen, the cling film was removed, and a drop of physiologic saline applied to the test region using a pipette [11]. The sample was then measured in length, width and thickness. Typical values for AT samples were 15 mm × 5 mm × 3 mm and 15 mm × 2 mm × 3 mm for PLT. The main precaution against dehydration was then to complete the mechanical testing within 5 minutes and regularly supply the tendon with saline. All specimens were first preconditioned by being stretched once up to approximately 5% strain at a rate of 6 mm/min, once up to 10% strain at a rate of 12 mm/min (to detect any slipping in the clamps) before being stretched to failure at 36 mm/min (Fig. 1). Force and elongation were measured at 10 Hz sampling rate. After failure, samples were refrozen and a slice of the failed region was cut transversely using a razor blade. A digital photograph of the cross-section was taken and its area was measured using digital image analysis software (Image Tool 3.0, UTHSCSA).

2.3. Statistical analysis

Data was exported from Minimat to Excel 2007 (Microsoft Inc.). Averaged properties of each tendon from each cadaver were compared using paired, one-tailed Student *t*-tests. A *p* value of less than 0.05 was considered significant.

3. Results

3.1. Sample characteristics

Specimen sizes differed between the two tendons. Cross-sectional area averaged 6.3 mm^2 (SD 2.1) for PLT specimens and 14.3 mm^2 (SD 3.0) for AT. Average specimen lengths were 15.4 mm for PLT and 13.8 mm for AT.

3.2. Force–elongation graphs

Typical force–elongation graphs (Fig. 2) showed a linear region followed by a turning point (zero gradient) which marked the ultimate tensile strength (UTS). Minimat software was used to calculate tissue stiffness (N/mm) as the gradient of the linear region of the graph, using linear regression. (The coefficient of determination (R^2) was always >0.98, indicating excellent linearity.) UTS was divided by cross-sectional area to give tensile stress at failure (N/mm^2). Elongation was expressed as strain (%), which is elongation divided by initial length (L).

The PLT graphs demonstrated a steep slope followed by a sudden failure point and small elongation, while AT graphs showed a smaller slope with a more gradual failure point and greater elongation.

Force at failure averaged 7.7 N (SD 1.8) for PTL specimens and 2.8 N (SD 0.9) for AT specimens. Elongation at failure averaged 2.2 mm (SD 0.5) for PTL, and 2.8 mm (SD 0.7) for AT. Strain, stress and stiffness data for the two tendons are compared in Table 1. Plantaris was stiffer than Achilles ($p < 0.001$) Plantaris also had a greater failure stress ($p < 0.01$) and reduced failure strain ($p < 0.05$) compared to Achilles.

4. Discussion

Plantaris is a stronger, stiffer and less extensible tendon than the adjacent Achilles (Fig. 3), suggesting potential differential movement between the two structures under load. This may play a

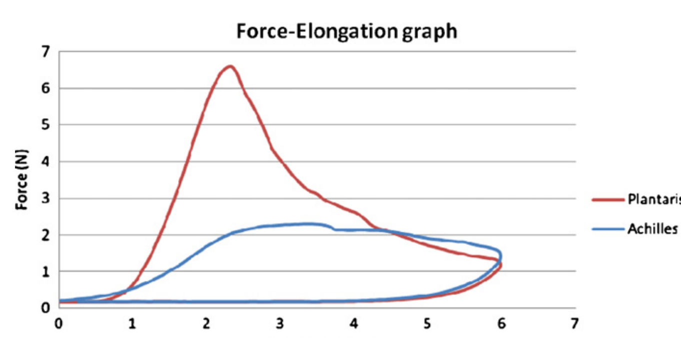

Fig. 2. Typical force–elongation graphs.