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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™ (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

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[☆] 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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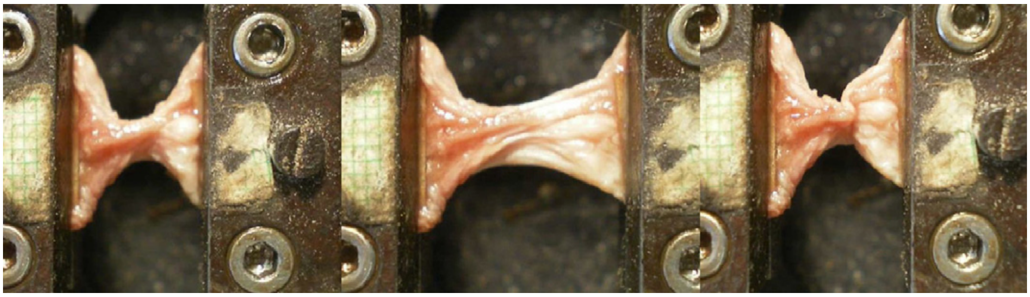

Fig. 1. Clamped Achilles tendon sample before stretching, at maximum stretch and after failure.

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 2000^{TM}, 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

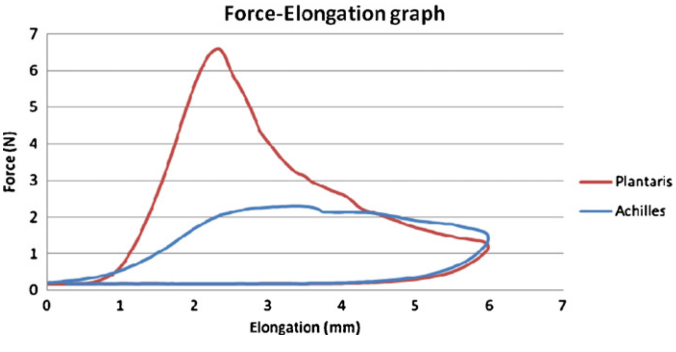

Fig. 2. Typical force–elongation graphs.

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Table 1
Results for strain, stress at failure and stiffness and statistical significance.

	Strain at failure (%)		Stress at failure (N/mm^2)		Stiffness (N/mm)	
	PLT	AT	PLT	AT	PLT	AT
Mean	14.1	21.8	1.4	0.20	5.7	1.7
Max	16.8	37.9	2.2	0.25	6.6	2.2
Min	11.5	14.9	0.9	0.15	4.7	1.4
SD	02.0	9.5	0.6	0.03	0.8	0.3
p value	<0.05		<0.005		<0.00005	

role in the pathogenesis of the inflammatory processes. The mechanical properties of Plantaris have the potential to create repeated shear stresses to the peritendinous tissues, and/or to the Achilles tendon itself. Our results demonstrate that, under similar tensile stresses, the Achilles elongates a greater distance than Plantaris. As a consequence the two surfaces could trap peritendinous tissues between them, which would be subject to shear stresses. The precise strains encountered by these two tendons *in vivo* are unknown, but it is likely that they would be in proportion to the ultimate strains measured at failure (Table 1), so that Achilles would be strained more than Plantaris during most activities.

Our results may also provide a biomechanical explanation for the presence of an intact plantaris tendon in cases of acute Achilles tendon rupture, as is frequently observed in clinical practice and reported in the literature [4–6].

Although this study showed significant differences, it is recognized that since it was carried out on frozen cadaver samples rather than *in vivo*, the results should not be overinterpreted. Repeated freeze–thaw cycles as used for the present work did not alter significantly the mechanical properties of ligaments [12] which have very similar mechanical properties as tendons. If freeze–thaw cycles, or any other post-mortem processes, did influence mechanical properties, they would be expected to have a similar effect on both tendons, so that comparisons between them are not invalidated.

The authors do acknowledge that although we have shown a difference in the mechanical properties of the two structures, we can only hypothesize as to the effects of this on the surrounding tissues. The theory that differential movement between the two tendons produces an inflammatory reaction in the surrounding tissues has not been explored in this study. Recent published work however suggest that repeated mechanical loading may trigger the secretion of inflammatory mediators which in turn induces degenerative changes in tendon cellularity [13].

A further limitation of our study is that we used tendon samples without a history of tendinopathy *ex vivo*. It is reasonable to assume that *in vivo*, degeneration occurring in one or both of the two tendons may alter their biomechanical properties, either primarily or through tethering and swelling. This was recently reported by Arya for Tendo Achilles alone [14]. Our observations would therefore only apply to the paratendonitis group.

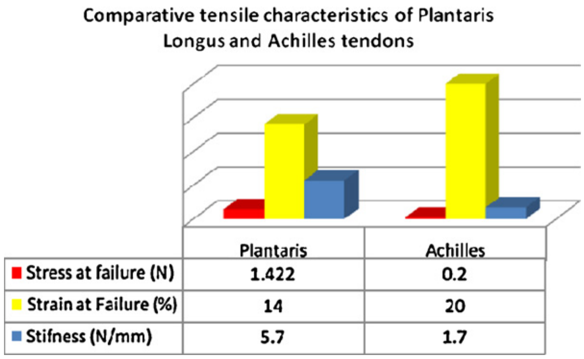

Fig. 3. Comparative tensile characteristics of PLT and AT.

The Plantaris Longus (PL) is a biarticular muscle which is present in approximately 90% of the general population [5]. It has a short muscular belly innervated by a branch of the tibial nerve and a very long, thin tendon which runs distally and medially along the gastro-soleus complex. Its proximal origin is on the lateral supracondylar line of the posterior distal femur [1]. Its distal insertion is on the posterior calcaneal tuberosity, on the medial border of the Achilles tendon (AT) insertion. The Plantaris Longus Tendon (PLT) has been rarely studied and is mostly known generally as a potential source of tendon autograft or augmentation in the case of AT repair [2,15].

Little is known about the role of the PLT in the pathogenesis of Achilles tendinopathy. One report mentioned a lower incidence of PLT in patients with acute AT rupture [5]. Also, concurrent rupture of both AT and PLT has been reported in only one case: PLT is usually preserved [6] in acute AT rupture, suggesting different *in vivo* visco-elastic properties and resistance to stress and strain.

Another observation as to the function of the plantaris tendon is that it remains redundant with an intact tendoachilles, but in cases of acute AT rupture, provides a protective role and undergoes load induced hypertrophy [4]. Mechanical properties are known to vary from tendon to tendon and along the length of tendons [8,16,17]. In addition, other neighboring tendons such as semi-tendinosus and gracilis have been shown to display significantly different visco-elastic behavior [8]. Although Plantaris has never been directly mentioned as a potential cause in Achilles tendinopathy, other structures such as the accessory soleus muscle have. Accessory soleus muscles, another inconstant structure medial to the AT, has been reported to be associated with chronic Achilles tendinopathy [7,18], suggesting the possibility for a similar pathological interaction between it and the Achilles tendon.

The AT and PLT are surrounded by peritendinous tissues which are supported by loose connective tissue and abundant cellularity that can predispose to inflammatory processes [2,3]. Also, mechanical stresses are known to induce a myofibroblast response within the peritendinous tissues, with an associated increase in collagen production. This in turn results in thickening and retraction of the affected tissue. Repeated microtrauma arising from exercise overuse [2] or inadequate gait (overpronation) [19] or even tight shoe external pressure [9] can trigger such inflammatory reactions in the paratenon. All these observations, could imply that Plantaris rubs against the Achilles, creating inflammatory changes in the latter or in the peritendinous tissue.

Implications of this work for clinical practice are that MRI or ultrasound imaging should describe more closely and more systematically the PLT and its relation to the AT. Further research will need to be aimed at understanding this process.

5. Conclusions

The Plantaris Longus and Achilles tendons demonstrate different mechanical properties in response to similar tensile stress. Differential movement and shear stress between them could trigger an inflammatory response in or near the Achilles tendon.

Conflict of interest statement

The authors report no conflict of interest and disclose any financial and personal relationships with other people or organisations that could inappropriately influence (bias) their work.

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The authors state that each of them was actively involved in the process of the present work.

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