VIDEO

Differential Motion and Compression Between the Plantaris and Achilles Tendons

A Contributing Factor to Midportion Achilles Tendinopathy?

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Background: The plantaris tendon (PT) has been thought to contribute to symptoms in a proportion of patients with Achilles midportion tendinopathy, with symptoms improving after PT excision.

Hypothesis: There is compression and differential movement between the PT and Achilles tendon (AT) during ankle plantarflexion and dorsiflexion.

Study Design: Descriptive laboratory study.

Methods: Eighteen fresh-frozen cadaveric ankles (mean ± SD age: 35 ± 7 years, range = 27-48 years; men, n = 9) were mounted in a customized testing rig, where the tibia was fixed but the forefoot could be moved freely. A Steinmann pin was drilled through the calcaneus, enabling a valgus torque to be applied. The soleus, gastrocnemius, and plantaris muscles were loaded with 63 N with a weighted pulley system. The test area was 40 to 80 mm above the os calcis, corresponding to where the injury is observed clinically. Medially, the AT and PT were exposed, and a calibrated flexible pressure sensor was inserted between the tendons. Pressure readings were recorded with the ankle in full dorsiflexion, full plantarflexion, and plantargrade and repeated in these positions with a 5 N·m torque, simulating increased hindfoot valgus. The pressure sensor was removed and the PT and AT marked with ink at the same level, with the foot held in neutral rotation and plantargrade. Videos and photographs were taken to assess differential motion between the tendons. After testing, specimens were dissected to identify the PT insertion. One-way analysis of variance and paired *t* tests were performed to make comparisons.

Results: The PT tendons with an insertion separate from the AT demonstrated greater differential motion through range (14 ± 4 mm) when compared with those directly adherent to the AT (2 ± 2 mm) ($P < .001$). Mean pressure between the PT and AT rose in terminal plantarflexion for all specimens ($P < .001$) and was more pronounced with hindfoot valgus ($P < .001$).

Conclusion: The PT inserting directly into the calcaneus resulted in significantly greater differential motion as compared with the AT. Tendon compression was elevated in terminal plantarflexion, suggesting that adapting rehabilitation tendon-loading programs to avoid this position may be beneficial.

Clinical Relevance: The insertion pattern of the PT may be a factor in plantaris-related midportion Achilles tendinopathy. Terminal range plantarflexion and hindfoot valgus both increased AT and PT compression, suggesting that these should be avoided in this patient population.

Keywords: midportion Achilles tendinopathy; Achilles tendon; plantaris tendon; compression; differential motion

Midportion Achilles tendinopathy has an incidence of 9% to 11% among runners[11] and affects 2.35 per 1000 persons of the general population.[6] Twenty-nine percent of patients with midportion Achilles tendinopathy may fail to improve with nonoperative management, such as strengthening exercises, activity modification, and analgesia. Surgery can also have unpredictable results, and up to 5% of professional athletes are forced to end their careers prematurely as a result of the condition.[9,12,15]

In the majority of patients with midportion Achilles tendinopathy, the medial part of the tendon is affected. This pattern of tendinopathy is thought to occur secondary to increased stress associated with hindfoot valgus.[25] It is

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now recognized that for a subgroup of patients with midportion Achilles tendinopathy, the plantaris tendon (PT) may be responsible for focal, medially located Achilles tendinopathy pain approximately 4 to 8 cm from insertion into the os calcis.[16,21] This condition is a significant problem for elite track-and-field athletes, who have an annual injury incidence of up to 9.3%, with sprinters having an annual incidence of 22%.[16] Clinical improvements have been reported for this population after PT excision,[2] despite the absence of tendinosis in the excised PT.[3,26] Interestingly, it is the bend sprinters who are particularly affected, with the right leg being predominantly affected, which suggests some form of mechanical interaction between the PT and the Achilles tendon (AT).[16] Specifically, repetitive valgus hindfoot motion during push-off is a known risk factor for midportion Achilles tendinopathy.[13,16] It is therefore hypothesized that differential motion and compression of the PT against the AT, rather than the PT itself, may cause symptoms and pain for these patients. This was previously thought to occur as a result of different material properties of the tendons, with PT fibers significantly stiffer than AT fibers when accounting for cross-sectional area.[10]

The plantaris is a vestigial muscle, present in approximately 80% to 100% of individuals,[18,25] and it arises from the lateral aspect of the supracondylar line of the femur, passing from lateral to medial, deep to the medial gastrocnemius, and superficial to the soleus and inserting onto the medial aspect of the calcaneus or directly to the AT.[25] However, the anatomy of its distal insertion is highly variable,[5] with 3 to 9 distinct insertion patterns.[7,25] PT attachment directly onto the calcaneus is reported in 80% to 90% of cases, with direct adherence to or insertion into the AT reported among 10% to 20%.[5,25] There is variability in findings between fresh-frozen and formalin-fixed specimens, with 23% of fresh-frozen specimens found to attach directly to the AT.[25] It is not known whether insertion site affects the likelihood of developing plantaris-related midportion Achilles tendinopathy.

The purpose of this study was to investigate differential movement between the AT and PT during simulated loading and ankle plantar dorsiflexion range of motion and to determine whether this movement was influenced by the insertion site of the PT. A secondary purpose was to investigate compression between the AT and PT during ankle motion and whether this was influenced by the presence of hindfoot valgus.

METHODS

Specimen Preparation

Twenty-two fresh-frozen cadaveric feet and ankles (age: mean ± SD = 39 ± 11 years, range = 27-59 years; men, n = 10) with no history of surgery or disease were obtained from a tissue bank after approval from the local research ethics committee. Specimens consisted of whole feet and approximately 400 mm of tibia, were stored in a freezer at –20°C before use, and thawed on the day of experimentation. Testing on each specimen took place in a single day. The tibia was cut to 300 mm in length, and an intramedullary rod was cemented into the tibia. A Steinmann pin was drilled medial to lateral through the calcaneus, at a position 200 mm from its posterior and inferior margins, while the foot was resting flat on the bench and the tibia was held at 90° to the bench surface.

The gastrocnemius, soleus, and plantaris muscles were identified. Cloth material was used to surround and stitch the gastrocnemius and soleus to load the AT, and the plantaris was wrapped separately. Cables were attached to the cloth to apply muscle load. A customized testing rig (Figure 1) was developed and used to mount specimens and enable muscle loads to be applied with a weight-and-pulley system. The ankle was mounted in the testing rig with the AT facing upward and the second metatarsal pointing downward, aligned with the shaft of the tibia.[28] The muscle tensions were applied in their physiologic directions in relation to the tibial axis. The AT was set to pull along the posterior shaft of the tibia, and the PT insertion was measured from magnetic resonance imaging scans from 2 in vivo healthy volunteers and taken 1° anterior and 2° lateral to the tibial shaft. With application of previous in vitro methodology[4,8] and prior studies on muscle cross-sectional area,[27] the PT and AT were loaded with a ratio of 62:1. Therefore, 1 N was applied to the PT and 62 N to the AT. This load represents an unloaded open kinetic chain calf raise with the knee extended. Higher load levels were not used to avoid damaging the soft tissues across the tests performed on each ankle. Heavier loads were applied during pilot testing, which revealed that increasing the load did not affect pressure or differential motion outcomes. Closed kinetic chain motion (by placing a board across the foot) was also assessed during pilot testing and gave results similar to those of open kinetic chain assessment. This testing setup and Tekscan sensors have been used extensively to assess soft tissue structures of the knee joint.[22,23]

Tendon Compression Measurements

A Tekscan 4011 pressure sensor (Tekscan; I-Scan) was used to measure pressure between the AT and PT. The sensor dimensions were 40.1 × 24.9 mm and 0.1 mm thick, and they contained 273 sensel measurement points (each 0.8 mm^2) with a saturation pressure of 3.45 MPa. Calibration of each sensor was undertaken with a materials testing machine (model 5585; Instron). The sensor was compressed to produce an area of uniform pressure. Ten preconditioning cycles to 0.9 MPa were performed, ~20% greater than anticipated pressures based on pilot study testing and according to manufacturer guidelines. Each sensor was equilibrated to 10%, 50%, and 90% of the maximal anticipated load to normalize the readings and ensure identical output from each sensel with a uniform pressure applied. An identical 2-point power law calibration was performed to each sensor at loads ~20% and 80% of the expected maximum tendon compression pressure based on pilot testing with Tekscan software. The system was determined to have a test-retest difference of 0.03 ± 0.05 MPa, which was deemed acceptable for the present study.

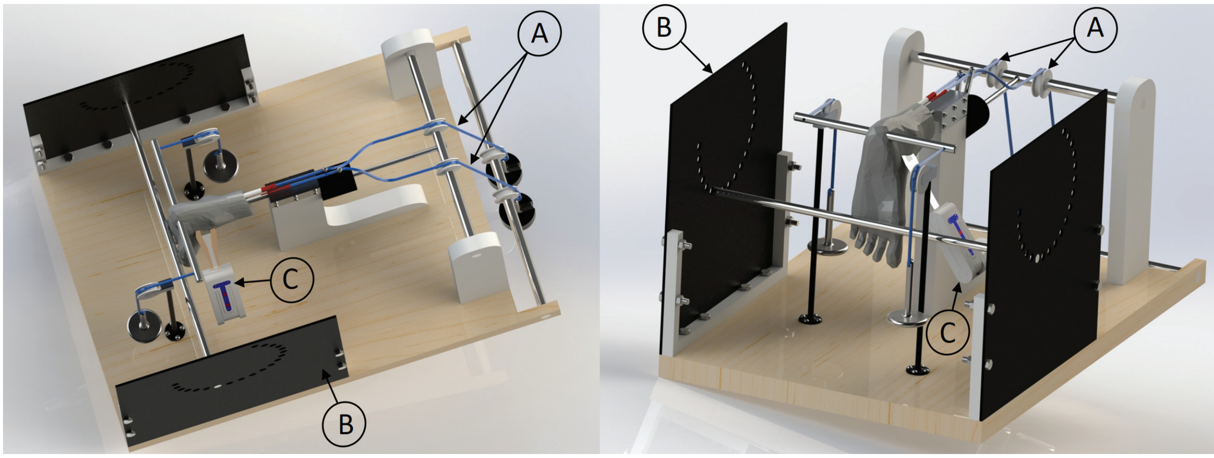

Figure 1. The ankle test rig: muscle loading system (A), a slot-and-bar system (B) to allow the ankle to be dorsiflexed and plantarflexed and to enable it to be held in a standardized position for testing, and Tekscan film and handle (C).

The skin and subcutaneous fat overlying the AT were carefully opened to expose the posterior aspect of the AT and tissue medial to it. The AT was measured, and the level 40 to 80 mm proximal to the os calcis in each specimen was marked, corresponding to the zone where the pathologic changes are typically observed clinically.[2] The PT was identified in 18 specimens. In 4 specimens, the PT was absent, so these specimens were excluded. When present, the PT and AT were separated, and the Tekscan sensor was inserted between the tendons and sutured into place to the skin, with the base of the sensor 50 mm above the os calcis. The sensor position relative to the tendon was marked to ensure consistency in sensor placement during testing. Mean ankle range of dorsiflexion was 19° ± 4° (range = 14°-28°), and mean plantarflexion range was 44° ± 7° (range = 40°-54°), similar to prior ankle ranges of motion reported among younger populations.[17]

Measurements were taken with the foot in neutral alignment in 5 angles: plantargrade, 10° dorsiflexion, full dorsiflexion, 20° plantarflexion, and full plantarflexion. These measurements were then repeated in full dorsiflexion, full plantarflexion, and plantargrade with a 5-N·m torque in the direction of valgus rotation applied to the calcaneus. The order of the tests was randomized to avoid an order effect.

Differential Tendon Motion

After compression testing, the Tekscan sensor was removed. The ankle was held in neutral position, with the foot in plantargrade and neutral alignment. A mark with a surgical marker pen was made on the AT and PT at the same level. Photographs were then taken of marks on the tendons from a standardized distance while the ankle was held statically in full plantarflexion and dorsiflexion, with a ruler in the photographs to allow correction of magnification. ImageJ (National Institutes of Health) was used to make measurements of the distance between the points. This method had a test-retest difference of 0.1 ± 0.2 mm, which was deemed acceptable for the current study. Last, a video was recorded of the ankle being moved through range to enable visualization of the differential movement between the tendons. We decided to present differential values as the complete motion rather than as the direction-specific motion, since this represents what AT + PT motion would go through during gait cycle and when symptoms are elicited clinically. Hindfoot valgus alignment was simulated during the motion assessments in pilot testing but did not demonstrate any additional changes to those determined with the neutral alignment; therefore, it was not added to the full study protocol. Finally, at the conclusion of testing, specimens were dissected, and the location of the distal attachment of the PT was recorded.

Analysis

Custom-written Matlab scripts (MathWorks) calculated mean pressures between the PT and AT. Data were analyzed in SPSS (v 20; IBM). After a Shapiro-Wilk test, the pressure data were normally distributed and analyzed with parametric analysis; however, the differential motion data were not found to be normally distributed and therefore were analyzed with nonparametric analysis. The dependent variables were mean pressure between the AT and PT and the distance between the reference marked points on the AT and PT. Specimens were allocated to 2 groups for comparison of differential motion—the first consisting of the PT fused or adherent to the AT and the second of that inserting separately on the calcaneus. The following analyses were performed: (1) a Mann-Whitney U test was performed to compare the 2 insertion groups in terms of differential motion measurements between the tendons; (2) a repeated-measures analysis of variance was performed on the mean pressure data to compare PT and AT compression over different flexion angles and in hindfoot neutral and hindfoot valgus. Post hoc paired t tests with Bonferroni correction at individual flexion angles were applied. Significance level was set a priori to $P < .05$.

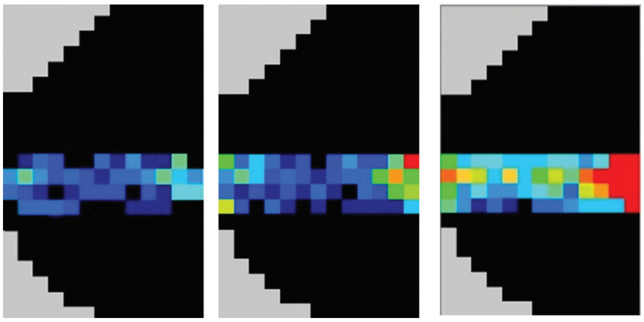

Figure 2. Screen Tekscan image of the pressure reading from 1 ankle: on the left, in plantargrade and neutral hindfoot alignment; in the center, in full plantarflexion and neutral alignment; on the right, in full plantarflexion with valgus hindfoot alignment. Pressures rise during plantarflexion and then further with valgus combined. This was a typical pattern observed for most ankles. Scale: dark blue, close to zero pressure; midgreen, 0.4 MPa; red, 0.6 MPa.

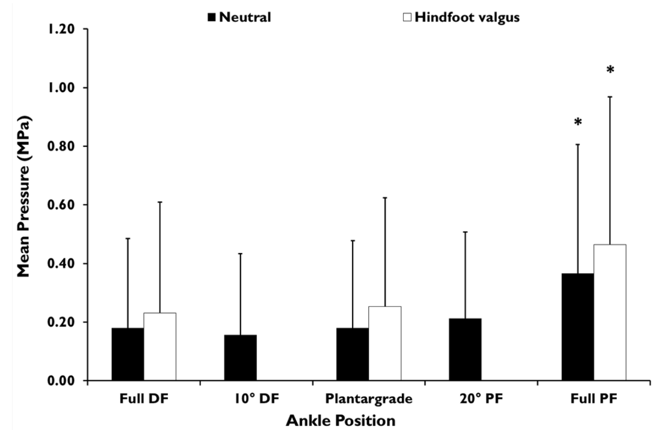

Figure 3. Mean pressure between the plantaris and Achilles tendons (MPa) during ankle motion with the ankle in neutral (black) and the hindfoot in valgus (white). *$P < 05$. DF, dorsiflexion; PF, plantarflexion. Error bar indicates SD.

RESULTS

Plantaris Insertion

Of the 22 specimens, 18 (82%) had a PT (age: 35 ± 7 years, range = 27-48 years; men, n = 9). Of these PTs, 39% (7 of 18, 3 men) directly adhered or fused with and terminated onto the AT, and 61% (11 of 18, 6 men) attached medial or medial and anterior to the AT, terminating on a separate insertion on the calcaneus.

Mean Pressure Between AT and PT

Flexion angle had a significant effect on mean pressures between the AT and PT. The mean contact pressures significantly increased from 0.18 ± 0.3 MPa to 0.37 ± 0.44 MPa during plantarflexion ($P < .001$). Applying a hindfoot valgus torque to specimens further increased compression in all positions (Figure 2), with the greatest effect observed in terminal plantarflexion (mean pressure = 0.47 ± 0.49 MPa, $P < .001$) (Figure 3).

Differential Motion

PTs inserting independently onto the calcaneus had significantly greater motion in relation to the AT (14 ± 4 mm) during ankle motion (Appendix Video 1, available in the online version of this article) as compared with the PT that inserted and terminated directly onto the medial AT fibers (Appendix Video 2) (2 ± 2 mm, $P < .001$).

DISCUSSION

This study provides the first direct quantitative evidence of differential motion and compression between the PT and AT, which is thought to be a contributing factor to symptoms in a subgroup of patients with midportion Achilles tendinopathy. Only 18 of the 22 specimens had a PT (82%). Of these, 39% directly adhered to or fused with and terminated onto the AT, with the remaining 61% attaching medial or anteromedial to the AT with a separate direct insertion on the calcaneus. Specimens in which the PT attached directly onto the calcaneus displayed significantly greater differential motion between the 2 tendons. Compression between the tendons was greatest in plantarflexion and further increased when a valgus torque was applied to the calcaneus. These findings provide a rationale for modification of rehabilitation programs to minimize terminal plantarflexion loading and to address valgus alignment where indicated. Currently, it is known that plantaris excision clinically helps to reduce pain and improve function; however, it is not known why. It could be a placebo effect of surgery or the ventral stripping and denervation performed at the time of plantaris excision; however, as we hypothesize and provide support for in this article, it may be the removal of differential motion and compression between the AT and PT. The findings of this study therefore provide a clinical rationale to study whether such patients' symptoms may be resolved simply by sectioning of the PT. If successful, this approach could have significant benefits for the patient and potential cost benefits if done in the outpatient setting.

A prior descriptive study observed differential PT and AT motion with an unloaded cadaveric model.[20] In contrast to the current findings, this study found proximal-distal differential movement between the AT and PT in all 20 of its specimens. However, the authors did not investigate plantaris insertion, so the influence of anatomic variation was unknown. The contrasting findings likely result from differing test protocols. The present study used a loaded ankle model to simulate motion. The observational study, however, used an unloaded limb; thus, there was no tension in the soleus or plantaris muscle during manual ankle movements performed by the testers. Potential slack in the system when the tendons were relaxed could therefore have resulted in an overestimation of apparent tendon motion.

Interestingly, 4 specimens in the current study did not have a PT. In those cases, we dissected the specimens proximally to be sure that the PT was absent. Our findings differ from a recent study examining 107 specimens that reported a 100% presence of PT.[25] However, other investigators reported an absence of 4% to 20%,[14,19] similar to findings from the current study. During testing, it was evident that the differential tendon motion was influenced by the PT insertion. As compared with previously reported studies based on formalin-fixed specimens, there was a higher proportion of specimens in which the PT adhered to or fused with the AT. Van Sterkenburg et al[25] reported that in 23% of fresh-frozen specimens, the PT had direct attachments to the AT.

It has been widely hypothesized that friction and compression between the PT and AT are potential drivers of pain and inflammation in PT-related midportion Achilles tendinopathy.[2] This is the first time that direct evidence supporting this theory has been shown with a loaded cadaveric model. The movement has been hypothesized to result as a difference in the mechanical properties and stiffness of the tendons, with the PT stiffer than the AT.[10] However, this study suggests that it may depend on the distal insertion site of the PT. When the PT was found to adhere directly to or fuse with the AT, very little differential movement was evident between the tendons during ankle motion; the tendons practically moved as 1 unit. The small motion difference observed in this group may be the result of the differences in tendon properties previously reported.[10] However, in specimens where the PT adhered anterior or anteromedial to the AT, significant differential movement was evident. The videos demonstrate that this differential movement is the result of the PT insertion moving more distal to that of the AT during plantarflexion and then proximal to the AT insertion during ankle dorsiflexion. Because there is a greater range of ankle motion during plantarflexion, the biggest differential motion is observed from plantargrade to full plantarflexion, as highlighted in Appendix Video 1. Currently, there is no information on the insertion patterns of patients who develop PT-related midportion Achilles tendinopathy; however, this may be of interest to study in the future.

There are no articles describing optimal nonoperative management for patients with PT-involved midportion Achilles tendinopathy. However, there are many reports on managing cases of Achilles tendinopathy with loading programs. These utilize either eccentric or heavy resisted loading, through full ankle range of motion.[1,9] Interestingly, the compression data identified that pressure between the AT and PT is greatest in terminal plantarflexion, where differential tendon motion was also greatest. We acknowledge that this was not the case for all specimens, as in some, the tendons separate in terminal plantarflexion (see Appendix Video 1B). Since the PT and AT run within the same paratenon sheath,[24] it is possible that increased separation of the tendons occurred artificially as a result of the limited dissection necessary to enable access for the Tekscan sensor. However, the findings suggest that modifying loading to avoid terminal plantarflexion range may be beneficial by reducing tendon friction/compression in the subgroup of patients with PT-related midportion Achilles tendinopathy. Last, over all ranges, hindfoot valgus caused increased pressure between the AT and PT, suggesting that attention to overpronation through strengthening, stretching, or orthotic intervention may be beneficial for these patients if this is identified clinically.

Limitations of this study include those inherent to in vitro testing. Care was taken to load the muscles in physiologic directions, but the tensions were constant and lower than those estimated to occur in vivo. Although the forces in this experiment may be exceeded in vivo, the analysis examined a direct comparison of the tendon attachment or within the same subject, the nature of those changes is unlikely therefore to alter, but they may be larger in vivo. The Tekscan was placed with minimal disruption to the tendons, but it did require opening the paratenon within which both tendons lie, which may have affected the pressure readings and tendon motion. The test-retest repeatability of the Tekscan system meant that small pressure changes may not be identified. However, the changes that were identified as the ankle was taken to plantarflexion were larger, and we believe that they could be reliably identified. Last, the sample size was low, meaning that differences could be subject to a type II error. However, there was a significant difference between tendon site groups for the differential motion, leaving little scope for type II errors.

In conclusion, this study presents evidence of differential motion between the AT and PT during ankle range of motion, which is significantly influenced by the insertion site of the PT. Tendons attaching separately to the calcaneus appear to display greater differential motion than those directly attaching into the fibers of AT. Furthermore, compression between the PT and AT is evident, being maximal in terminal plantarflexion as the PT is forced against the AT. It further increased when the hindfoot was positioned in valgus to simulate foot pronation. The implications for clinical practice are a rationale for the excision of the PT among patients with PT-related midportion Achilles tendinopathy that is unresponsive to nonoperative measures, on the basis that this will cease any compression and differential tendon motion. A potential role for restriction of excessive hindfoot valgus and conservative loading programs in this patient population would be to restrict loading into terminal plantarflexion, where the PT and AT compression was greatest. Future studies should investigate more specific loading protocols for this population to establish if there is a benefit to modifying the range of loading to minimize compression during rehabilitation. The attachment site of the PT in patients with clinical manifestations of PT-related midportion Achilles tendinopathy should also be investigated with modern imaging techniques, which may be more sensitive, as current findings suggest that it could be a contributing factor in midportion Achilles tendinopathy. Last, as discussed, a clinical study would now be merited to compare sectioning with excision of the PT. If results were comparable, it would support the current hypothesis that it is the reduction in motion and compression between these tendons that results in clinical improvement, rather the neovascularization stripping undertaken during plantaris excision.

A Video Supplement for this article is available online.

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