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SCIENTIFIC ARTICLE

Tenosynovial fluid as an indication of early posterior tibial tendon dysfunction in patients with normal tendon appearance

Felix M. Gonzalez[1] · Elie Harmouche[1] · Douglas D. Robertson[1] · Monica Umpierrez[1] · Adam D. Singer[1] · Yara Younan[1] · Jason Bariteau[2]

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Abstract

Objective Our primary aim was to quantify the posterior tibial tendon (PTT) sheath fluid volume in individuals with the clinical diagnosis of stage 1 posterior tibial tendon dysfunction (PTTD) and no MRI-detectable intra-substance tendon pathology and compare them with patients with other causes of medial ankle pain, also without MRI-detectable intra-substance PTT pathology and with normal controls. We also wanted to determine if there is a fluid measurement that correlates with the clinical diagnosis of PTTD.

Materials and Methods A total of 326 individuals with medial ankle pain and no intra-substance PTT pathology were studied. Group 1 included 48 patients with a clinical diagnosis of stage 1 PTT dysfunction, group 2 comprised 278 patients with other causes of medial ankle pain, and a third control group consisted of 56 patients without any medial ankle pain. MRI-based geometric measurements included PTT fluid volume, maximum cross-sectional fluid area, and fluid width. Fluid measurements were compared between groups and measurement reliability was tested.

Results Group 1 showed greater PTT fluid volume, area, and width compared with groups 2 (other causes of medial ankle pain) and 3 (asymptomatic controls) (all p values < 0.001). A 9-mm threshold maximum fluid width was associated with PTTD (sensitivity 84%, specificity 85%). Measurements were reliable (all p values < 0.03) among three observers blinded to the gold standard.

Conclusion Patients with stage 1 PTT dysfunction displayed greater volumes of tendon-sheath fluid than those with other causes of medial ankle pain and compared with asymptomatic controls. A threshold maximum fluid width greater than or equal to 9 mm distinguishes those with PTTD. An association between tendon sheath fluid distension and the clinical diagnosis of stage 1 posterior tibial tendon disease in the setting of no MRI-detectable intra-substance tendon pathology may allow for differentiation of medial ankle pain from other sources and may allow for early intervention aimed at preventing progressive PTTD. The level of evidence was prognostic (level III).

Keywords Ankle · Tibialis posterior tendon · Tendon sheath fluid · Tendon dysfunction · MR imaging

Introduction

Posterior tibial tendon (PTT) dysfunction is a clinical diagnosis commonly confirmed by magnetic resonance imaging (MRI) [1–4]. Individuals with posterior tibial tendon dysfunction (PTTD) frequently present with pain and swelling around the medial malleolus, pain on the plantar aspect of the medial foot, and progressive ambulatory intolerance [5, 6]. On physical examination, tenderness along the tendon from the medial malleolus to the navicular bone shows high correlation with PTTD. In PTTD stages 2 through 4 there is tendon elongation, degeneration, and tearing [7]. In stage 1, there may be tendon degeneration, tenosynovitis, and/or paratendinitis [7].

The accuracy of clinical examination regarding the diagnosis of stage 1 PTTD has been reported to be moderate, which highlights the significance of imaging-based diagnostic clues [8]. Much has been written about the MRI appearance of the tendon in PTTD [1–4]. MRI is considered the imaging

✉ Felix M. Gonzalez
Felix.m.gonzalez@emory.edu

1 Department of Radiology and Imaging Sciences, Emory University Hospital, Atlanta, GA, USA

2 Emory University Orthopaedic and Spine Center, 59 Executive Park S, Suite 2000, Atlanta, GA 30329, USA

modality of choice for evaluating PTT morphology and pathology, confirming the clinical diagnosis of PTTD, and including or excluding other diagnoses [1, 4, 9–11]. MRI can confirm the diagnosis of PTTD by detecting intra-substance tendon degeneration, partial and complete tendon tears, and tendon subluxations and dislocations [1–3, 12, 13]. MRI is also able to detect tenosynovitis/paratendinitis, which typically appears as increased signal intensity on fluid-sensitive pulse sequences around the tendon [1, 3, 10]. However, the significance of increased signal adjacent to the tendon in individuals with the clinical diagnosis of stage 1 PTTD [7] and no MRI-detectable intra-substance tendon pathology (a subset of stage 1 PTTD) is unknown. In these individuals, an MRI-based confirmatory finding separate from intra-substance tendon pathology could be clinically useful to assist with the difficulty in differentiating other sources of medial ankle pain. However, there is no consensus on what constitutes a clinically significant amount of fluid adjacent to the PTT [1, 3, 5, 10, 12, 14].

The purpose of this study is to quantify the amount of fluid adjacent to the tendon in individuals with the clinical diagnosis of stage 1 PTTD (test group) and in controls (those with and without medial ankle pain), and to determine if there is a threshold value that could reliably identify patients with early PTTD. We hypothesize that in individuals with a clinical diagnosis of stage 1 PTTD and no MRI-detectable intra-substance tendon pathology, increased signal adjacent to the tendon is an independent confirmatory imaging finding. Confirmation of stage 1 when there is no MRI-detectable intra-substance tendon pathology may allow for early intervention aimed at preventing progressive PTTD and the associated deformities.

Materials and methods

Patients

After obtaining Institutional Review Board approval, a database search was performed for consecutive patients who had had a foot and ankle clinic visit for medial ankle pain and an ankle MRI obtained within 2 months of the clinic visit. Clinical diagnoses (tenderness along the inframalleolar course of the posterior tibialis tendon and positive single heel rise and first metatarsal rise sign tests) were made by foot and ankle specialists (6 years of experience as foot and ankle surgeons). Individuals younger than 30 years of age or with foot or ankle fracture, tumor, osteomyelitis, soft-tissue infection, or recent surgery were excluded. Individuals were also excluded if they had stage 2 or higher PTTD [7] and if they had MRI-detectable intra-substance PTT pathology or tendon dislocation (as determined by the MRI examination). The underlying pathological condition in patients with clinically diagnosed PTTD was secondary to overuse stress according to the clinical histories. Enrolled patients were split into three groups: those with the clinical diagnosis of stage 1 PTTD; those with other causes of medial ankle pain; and those without any medial ankle pain treated as asymptomatic controls.

Image acquisition and analysis

Unenhanced ankle MRI examinations were performed using a 3.0-T magnet (GE Medical Systems, Waukesha, WI, USA), which included high-resolution sagittal proton density-weighted fat saturation (repetition time [TR] 3,000 ms; echo time [TE] 40 ms; echo train length [ETL] 8), T1-weighted images (TR 500 ms; TE 15 ms; ETL 5), coronal proton density-weighted fat-saturated images, axial proton density-weighted fat saturation, and T1-weighted images with a field of view of 16 × 18 cm, a matrix of 512 × 512, and slice thickness of 3 mm, with a gap of 1 mm and number of excitations 2.

Two fellowship-trained musculoskeletal radiologists, each with over 15 years of clinical experience, reviewed all MRI studies to qualify the individuals, identify MRI-detectable pathology associated with PTT dysfunction (spring ligament, os navicularis, sinus tarsi, plantar fasciitis or deltoid ligament pathology [1, 3, 12, 15]) and make the fluid measurements. The two observers were blinded to age, gender, and clinical diagnosis.

The length of the tendon from the tibial plafond to the attachment at the navicular was measured, in addition to the length of the major and minor axes of the tendon and sheath ellipses (Fig. 1). Utilizing the axial MR images, ellipse axis lengths were measured at the level of the tibial plafond and along the PTT. The PTT fluid volume (ml) was calculated as a truncated ellipsoid. Fluid volume was the difference between PTT fluid volume and tendon volume along the measured length. The maximal cross-sectional area (mm^2) was measured as an ellipse on the axial image that had the most fluid. The PTT fluid cross-sectional area was the difference between the PTT fluid area and the tendon area on the measured image. Also on the axial images at the level of maximal fluid collection, the maximum fluid width was calculated as the difference between the maximum lengths of the elliptical tendon and the PTT fluid.

To measure the effect of the axial MRI plane being off axis to the cylindrical PTT, the axial image elliptical cross-sections were corrected using analytical geometry to calculate their true circular cross-sections (Fig. 2). From the corrected circular cross-sections, volumes of a tapered cylinder were calculated. Thus, corrected fluid volumes and cross-sectional areas were calculated. The correction process was simple as the axial MR images are only off in one plane about the tendon's long axis; thus, the ellipse's minor axis length (tendon or sheath) was identical to the diameter of the circular cross-section of the tendon or PTT fluid.

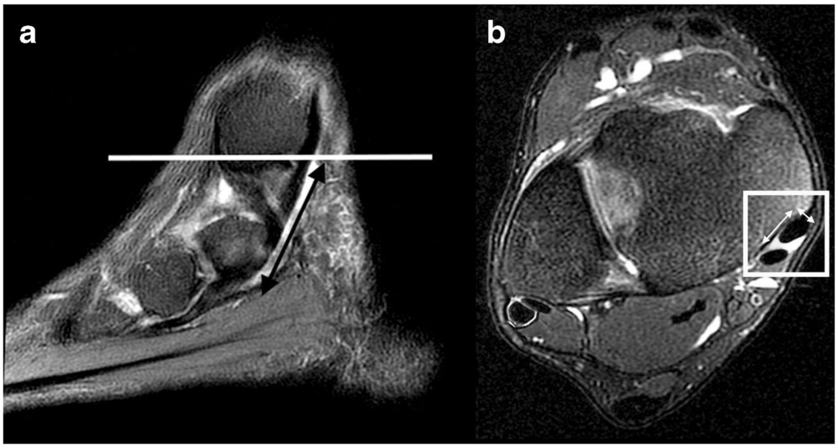

Fig. 1 Posterior tibial tendon (PTT) fluid in an individual with PTT dysfunction. **a** Sagittal magnetic resonance image (MRI). *Horizontal line* corresponds to the axial level depicted in **b**. *Double-headed arrow* illustrates the PTT length studied. **b** Axial MR image at the level of the tibial plafond. Major and minor axis tendon sheath ellipse lengths are illustrated by *double-headed arrows*. Similar measurements of the tendon were made

Statistical analysis

Pearson's Chi-squared test compared gender, associated findings, and clinical diagnosis of PTT dysfunction. Unpaired two-sample *t* test tested for the difference between the groups with regard to age, fluid volume (truncated ellipsoid or tapered cylinder), maximum cross-sectional fluid area (ellipse and circle), and maximum fluid width. Receiver operating characteristic (ROC) analysis of the maximum fluid width data was used to calculate the sensitivity, specificity, and width predictive threshold value. Original and repeat tendon and fluid measurements were made twice by the three observers (the two experienced readers and a fellow). The time between the two sets of measurements made by each observer was at least 3 weeks and image order was shuffled for the second reading. Test–retest reliability (precision) was defined as the mean difference between repeated measurements. Intra-class coefficients (ICC) were used to assess inter- and intraobserver variability for the three reviewers. All statistical analyses were carried out with the level of significance set at 0.05.

Results

For the 3-year period included in the database search, 326 patients met the inclusion criteria. These were categorized into two groups: group 1, including 48 patients with clinical diagnosis of stage 1 PTTD, and group 2, which consisted of 278 patients with other, clinically confirmed, causes of medial ankle pain. A third group included 56 patients with no history of medial ankle pain treated as normal controls. The patient group was also evaluated to exclude pathological conditions other than PTT dysfunction-associated abnormalities. In the PTTD group, there were 28 females and 20 males, the mean age was 55 ± 20 (range, 31–79) years compared with group 2 with 150 females and 128 males with a mean age of 50 ± 22 years (range, 30–88), and group 3 (asymptomatic controls) with 29 females and 27 males who had a mean age of 51 ± 18 (range, 30–69).

Magnetic resonance imaging studies of patients (second group) with clinical diagnosis of other causes of medial ankle pain, including impingement (9/3%), instability (56/20%),

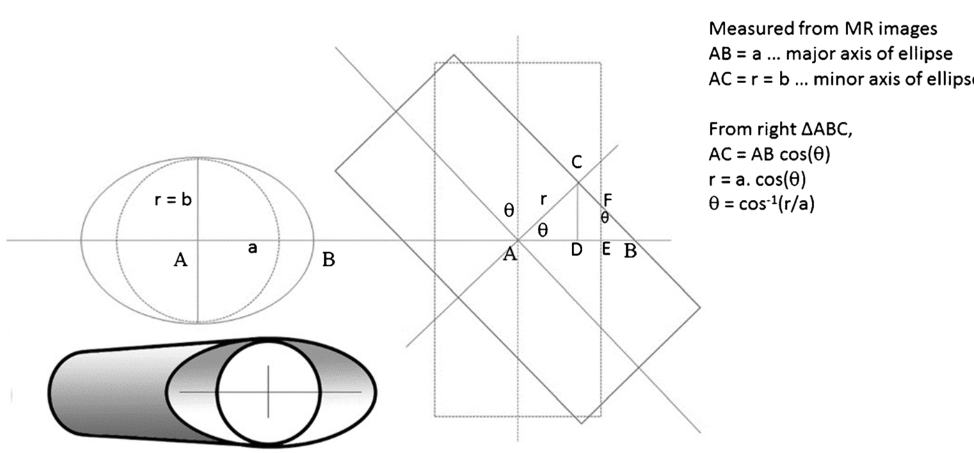

Fig. 2 Correction of the axial MRI plane being off axis to the cylindrical PTT. Tendon and PTT fluid ellipse short axes on the axial images are identical to the diameter of the tendon or sheath calculated for the true circular cross-sections

flexor hallucis longus tendon injury (7/2.5%), medial and lateral ankle sprain (19/7%), ligament disruption (25/9%), subtalar osteoarthritis (25/9%), gout (5/1.8%), and treated Achilles tendon rupture (9/3%), were assessed to confirm the clinical diagnosis and exclude additional pathological conditions.

Gender and age distribution were statistically similar in the groups ($p > 0.1$). Five out of 48 individuals (10%) with clinically diagnosed PTT dysfunction had MRI-detected spring ligament, os navicularis, sinus tarsi, plantar fasciitis or deltoid ligament pathology compared with 83 individuals (30%) in group 2. These diagnoses have been previously described as consequences of PTTD [1, 3, 12, 15]. PTT fluid volume, maximum fluid area, and maximum fluid width were significantly different in the groups with and without PTTD ($p < 0.001$; Table 1 and Fig. 3). Six percent of individuals with PTTD (3 out of 48) and 45 % (125 out of 278) with medial ankle pain (other causes) had MRI-detectable PTT fluid of less than or equal to 1-mm fluid width on two or more axial images or less than or equal to 1-mm fluid width along 1 cm or more on a sagittal image (Tables 2, 3, and 4).

Correction of PTT fluid volume to a tapered cylinder and correction of maximum cross-sectional area to a circle to accommodate for the MR images being off-axis to the PTT produced fluid volumes of 4 ± 1 ml (mean, SD; range, 0–6) and areas of 98 ± 60 mm^2 (mean, SD; range, 0–297) in the PTTD group, whereas in group 2, volumes of 1 ± 1 ml (mean, SD; range, 0–5) and areas of 33 ± 46 mm^2 (mean, SD; range, 0–208) were obtained. The normal control subjects yielded volumes of 2 ± 1 ml (mean, SD; range, 0–4) and areas of 29 ± 31 mm^2 (mean, SD; range, 0–156). The PTTD and the two additional groups (group 2 and the asymptomatic controls) were statistically different with respect to volume and area ($p < 0.001$).

Receiver operating characteristic analysis of the maximum fluid width data calculated the area under the curve to be 87% with a confidence interval of 81–93% and $p < 0.001$. A maximum fluid width of 9 mm predicted the presence of stage 1 PTTD without MRI-detectable intra-substance tendon pathology (sensitivity 84%, specificity 85%). Measurements were reliable and reproducible among the three reviewers, with interobserver ICC of 0.83 ($p < 0.001$). Intraobserver ICCs were 0.73, 0.79, and 0.82 ($p < 0.03$) for the three reviewers.

Discussion

To the best of our knowledge, there is only one previous study on the evaluation of synovial sheath fluid in patients with stage I PTT dysfunction and comparison with the unaffected ankle [16]; however, this was based on ultrasound rather than MRI findings, which is considered the gold standard for tendon assessment. Additionally, there are overall a limited number of research articles evaluating the imaging characteristics of stage I PTTD, and such a diagnosis relies mainly on clinical data.

Although the PTT has clear MRI criteria for classifying intra-substance tendon pathology and tendon dislocation [6, 14, 15, 17], and although it would seem reasonable that individuals with PTTD would have more tendon sheath fluid (or fluid adjacent to the distal tendon) than individuals with and without other causes of medial ankle pain, this has not been previously verified. DeOrio et al. [9] found associated pitting edema along the course of the PTT with PTT fluid detectable on MRI in individuals with later-stage PTTD. They did not study the stage 1 individuals studied by us. In previous reports, there was no consensus regarding what constitutes significant PTT fluid, with different authors suggesting circumferential fluid, fluid observed in the distal 1–2 cm of the tendon, or fluid isolated to the PTT amongst the medial tendons as abnormal [1, 3, 5, 12, 14]. The purpose of this study was to quantify the amount of PTT fluid in individuals with the clinical diagnosis of stage 1 PTTD and no MRI-detectable intra-substance tendon pathology and to test if increased PTT fluid was associated with PTTD.

In this study, fluid amount in individuals without intra-substance PTT pathology was associated with the clinical diagnosis of stage 1 PTTD, whether the fluid was measured as a volume, area, or width. Thus, PTT fluid can be used as an MRI confirmatory finding of stage 1 PTTD when no MRI-detectable intra-substance pathology is present. None of the studied individuals, in either the test or the additional two groups, had MRI-detectable PTT intra-substance pathology. Ten percent of individuals with the clinical diagnosis of PTTD had the non-PT tendon associated findings of the consequences of PTTD (spring ligament, os navicularis, sinus tarsi, plantar fasciitis, or deltoid ligament pathology). However, the group with medial ankle pain (non-PTTD group) had a higher prevalence of these pathological

Table 1 Posterior tibial tendon (*PTT*) fluid measurements (mean ± SD)

	Non-PTT dysfunction	PTT dysfunction	*p*
Fluid volume truncated ellipsoid (ml)	4 ± 6 (range, 0–27)	16 ± 7 (range, 0–31)	< 0.001
Maximal CSA fluid ellipse (mm^2)	133 ± 182 (range, 0–832)	390 ± 241 (range, 0–1,117)	< 0.001
Mean maximal fluid width (mm)	1.5 ± 2 (range, 0–11)	6 ± 2 (range, 0–12)	< 0.001

CSA cross-sectional area

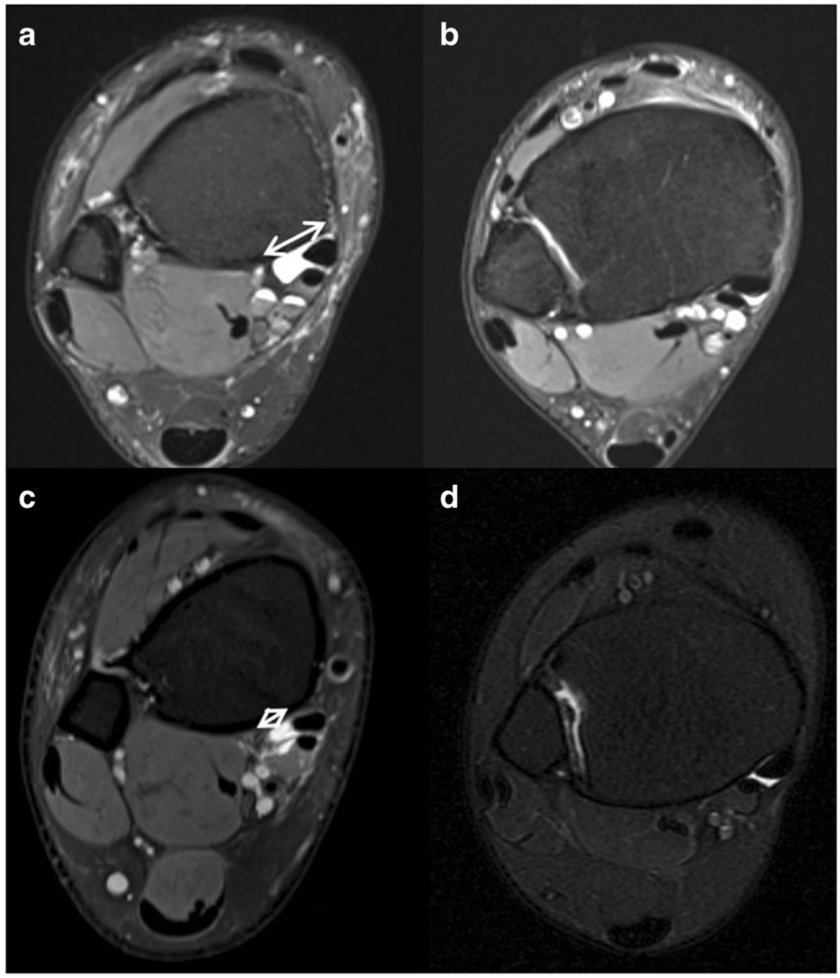

Fig. 3 Examples of different cases illustrating several degrees of tendon sheath expansion by fluid at the level of the retromalleolar groove. **a** PTT tendon sheath distension of approximately 12 mm with a physical examination positive for early PTT dysfunction. **b** Normal minimal tendon sheath fluid in a patient with a negative examination. **c** Tendon sheath fluid expansion of 9 mm in a patient with a positive physical examination. **d** Asymptomatic patient with minimal sheath fluid

conditions (30%). Thus, unlike PTT fluid amount, these non-PTT findings are not helpful for corroborating the clinical diagnosis of stage 1 PTTD individuals without MRI-detectable intra-substance tendon pathology.

To measure the effect of the axial MRI plane being off-axis to the cylindrical PTT, we measured fluid volume both as a truncated ellipsoid (using the axial MR images) and as a correctly tapered cylinder (correction performed for off-axis MRI). Correction of elliptical cross-sections to their true circular cross-section was facilitated by the fact that the axial MRI plane was only rotated one plane about the tendon's cylindrical axis; thus, the length of the short axis of the ellipse was identical to the diameter of the circular cross-section of the tendon or sheath. Although the absolute values of fluid

Table 2 Clinical findings of group 1 (patients diagnosed with posterior tibial tendon dysfunction [*PTTD*] stage 1) and group 2 (patients presenting with other causes of medial ankle pain). Group 3 has not been included because the patients who constituted this group were asymptomatic without any medial ankle pain

Group	Findings					
1, $N = 48$	Tenderness along the PTT, $n = 48$	Positive single heel rise, $n = 48$	Positive first metatarsal rise sign, $n = 48$		Other MRI-detected pathology[a], $n = 5$	
2, $N = 278$	Tenderness along the PTT, positive heel rise or metatarsal rise sign, $n = 0$	Medial ankle impingement/-instability, $n = 65$ (23%)	Medial and lateral ankle sprains, $n = 19$ (7%)	Flexor hallucis longus tendon injury, $n = 7$ (2.5%)	Medial ankle ligament disruption, $n = 25$ (9%)	Subtalar OA/treated Achilles tendon rupture, $n = 34$ (12%)

OA osteoarthritis

[a] MRI-detected spring ligament injury, os navicularis, sinus tarsi, plantar fasciitis or deltoid ligament pathology

Table 3 Summary of patient demographics among the three groups

	Group 1	Group 2	Group 3
Gender	28 female	150 female	29 female
	20 male	128 male	27 male
Mean age	55 ± 20 (range 31–79)	50 ± 22 (range, 30–88)	51 ± 18 (range, 30–69)

volume and area of uncorrected calculations (original off-axis images of the tendon) were different than the corrected calculations, correction was not necessary to demonstrate statistical differences between the PTTD and the other two groups (all p values < 0.001). Thus, measurements from the actual MR images, without correction, work as well as adding the additional computational step of correction.

To make this study more clinically relevant and applicable, we tested whether a simple single maximum fluid width measurement obtained from the axial MR images, as opposed to a fluid volume or area measurement, could be used as a predictor. With good sensitivity and specificity, ROC analysis found a PTT fluid width of 9 mm or more on the axial image containing the maximum fluid to be a predictor for the diagnosis of stage 1 PTTD when no MRI-detectable intra-substance pathology is present. This early identification may allow for behavior modification/therapy such as orthosis wear, stretching, in addition to eccentric and concentric progressive resistive exercises [16, 18–20] to prevent the deformity associated with the later stages of PTTD. Future work will hopefully correlate these findings with either intraoperative findings or help to identify effective treatment protocols for this group of patients.

There are several limitations in this study. First, it was retrospective. Second, the accuracy and reliability of our PTTD clinical diagnoses are unknown. No operative confirmation or long-term follow-up was available. We also recognize that the shape of the tendon in its distal portion is not a perfect cylinder, especially distally (1–2 cm proximal to the navicular insertion), where there is no tendon sheath and fluid adjacent to the tendon indicates paratendinitis [1, 3]. In this region, the tendon transitions to an expanding ellipse in cross-section. Given the short distance when this is true, we estimated that this would not affect our volume measurements. In addition, we used the same methods with their inherent errors to measure both the tendon and the sheath, which should equally affect both volume and area calculations, cancelling out deleterious effects. In future studies, image analysis software could be used to segment and model the fluid and tendon shapes in three dimensions along the length of the studied tendon.

In conclusion, in individuals with the clinical diagnosis of PTTD and no MRI-detectable intra-substance PTT pathology, PTT fluid, whether measured in its volume, area, or width, is associated with the clinical diagnosis of stage 1 PTT dysfunction. However, this requires an accurate diagnosis, which can be helped by fluid on an MRI. The clinical manifestations of stage 1 PTTD are nonspecific without any visible deformity, and being more aggressive early, with physical therapy, orthosis or possibly tendoscopy, can help outcomes. Additionally, MRI-detected fluid amount can be used as a confirmatory finding of PTTD in individuals who do not have MRI-detectable intra-substance pathology. To clinically implement this work, we suggest a maximum fluid width of greater than or equal to 9 mm, which can be easily measured on the axial MR images as a threshold level to confirm PTTD.

Table 4 Summary of PTTD stages

Stage 1	Stage 2	Stage 3	Stage 4
Normal tendon length with tenosynovitis	Elongated tendon with degeneration	Elongated tendon. Tendon disrupted and less painful	Same presentation as stage 3 with the following:
Gradual onset/No deformity	Normal hindfoot-flexible pes planovalgus deformity	Degenerative subtalar joint changes	Degenerative subtalar and ankle joint changes
Mild to moderate pain	Evolves over several months to years	Fixed pes planovalgus deformity. Forefoot abduction when weightbearing	Fixed hindfoot eversion with ankle incongruency
Tenderness around the medial malleolus to its navicular insertion. Mild weakness (able to complete single heel rise with inversion of the hindfoot)	Flexible pes planovalgus deformity. Abnormal single-heel-raise test	Inability to perform a single-leg heel rise.	Valgus tilt of the talus within ankle mortise and lateral tibiotalar degeneration

Compliance with ethical standards

Conflicts of interest None of the authors has a conflict of interest.

Ethics approval This retrospective study was approved by the institution's ethics committee. All authors made substantial contributions to conception and design, and/or acquisition of data, and/or analysis and interpretation of data. Authors also participated in drafting the article and revising it critically for important intellectual content; and the authors gave final approval of the version to be submitted and any revised version.

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