Biomechanical and Clinical Factors Related to Stage I Posterior Tibial Tendon Dysfunction

Posterior tibial tendon dysfunction (PTTD) is a progressive and debilitating condition that is estimated to affect nearly 5 million people in the United States.\(^7\) In the early stages (stage I) of the condition, PTTD is a common running-related injury.\(^3\) While the aetiology of PTTD has not been established, it is considered multifactorial in nature and has generally been related to progressive alterations in arch structure, muscular strength, and gait biomechanics.

Few studies have been conducted to understand how arch structure may play a role in the progressive nature of PTTD.\(^4,15,24\) Williams et al\(^3\) conducted a retrospective analysis of running injuries in runners with high and low planter arch and reported that the low-arch group had a 3-fold higher incidence of stage I PTTD compared to the high-arch group. Dyal et al\(^4\) also reported that a lower arch height was associated with the symptomatic PTTD foot compared to the uninvolved foot. In contrast, Shibuya et al\(^6\) reported that radiographic and MRI scans of patients with PTTD at various stages showed damage to the spring ligament, with a lower arch height only present in patients with stages III and IV PTTD. Thus reduced arch height may be a predisposing factor related to stages III and IV PTTD, while a more typical arch height would be expected in stage I PTTD. Moreover, stage I PTTD is characterized by tendon inflammation, with no change in foot shape, while stage II PTTD is characterized by the tendon’s elongation and dysfunction, as the foot develops adult acquired flatfoot disorder.\(^13\) Thus it can be hypothesized that no differences in arch shape would be expected for patients with stage I PTTD, and, consequently, other factors, such as reduced ankle muscle strength, should be considered.

There is a paucity of research regarding differences in ankle invertor muscle strength for individuals with PTTD. Alva-\(\)rez et al\(^1\) reported significant concentric and eccentric ankle invertor strength reductions for the involved compared to the uninvolved ankle. Following a 10-week

**STUDY DESIGN:** Case control.

**OBJECTIVES:** To investigate differences in arch height, ankle muscle strength, and biomechanical factors in individuals with stage I posterior tibial tendon dysfunction (PTTD) in comparison to healthy individuals.

**BACKGROUND:** PTTD is a progressive condition, so early recognition and treatment are essential to help delay or reverse the progression. However, no previous studies have investigated stage I PTTD, and no single study has measured static anatomical structure, muscle strength, and gait mechanics in this population.

**METHODS:** Twelve individuals with stage I PTTD and 12 healthy, age- and gender-matched control subjects, who were engaged in running-related activities, participated in this study. Measurements of arch height index, maximum voluntary ankle invertor muscle strength, and 3-dimensional rearfoot and medial longitudinal arch kinematics during walking were obtained.

**RESULTS:** The runners with PTTD demonstrated significantly lower seated arch height index (\(P = .02\)) and greater (\(P = .03\)) and prolonged (\(P = .05\)) peak rearfoot eversion angle during gait, compared to the healthy runners. No differences were found in standing arch height index values (\(P = .28\)), arch rigidity index (\(P = .06\)), ankle invertor strength (\(P = .49\)), or peak medial longitudinal arch values (\(P = .49\)) between groups.

**CONCLUSION:** The increased foot pronation is hypothesized to place greater strain on the posterior tibialis muscle, which may partially explain the progressive nature of this condition. J Orthop Sports Phys Ther 2011;41(10):776-784. Epub 12 July 2011. doi:10.2519/jospt.2011.3545

**KEY WORDS:** foot kinematics, gait, tendinopathy
strengthening program, the PTTD group exhibited a 58% increase in strength, concomitant with significant reductions in pain. Houck et al. also reported that patients with PTTD exhibited 30% reduced ankle invertor strength compared to age-matched controls. However, while these 2 studies indicate that ankle invertor strength may be associated with PTTD, the individuals with PTTD in the aforementioned studies were at stages II to IV of the condition, and no study has investigated individuals with stage I PTTD for potential differences in ankle invertor strength. Because stage I PTTD involves mild swelling to the tendon and pain upon palpation, it is reasonable to hypothesize that reduced force output would be present in these individuals.

Few studies have investigated differences in gait biomechanics for individuals with PTTD. Ness et al. reported increased rearfoot eversion throughout stance in patient with PTTD compared to controls; however, all their study’s patients with PTTD had failed conservative treatment and were scheduled for operative intervention. Tome et al. also reported that individuals with stage II PTTD demonstrated significantly greater peak rearfoot eversion and a lower medial longitudinal arch (MLA) angle during walking. Finally, Houck et al. investigated patients with stage II PTTD and reported increased rearfoot eversion compared to controls. Thus, increased rearfoot eversion is present in individuals with stages II to IV PTTD when walking; however, no studies have investigated whether increased rearfoot eversion is present in stage I of the condition. Because PTTD is a progressive condition, identifying if potentially contributing factors related to static foot structure, ankle invertor muscle strength, and gait biomechanics may be present in individuals with stage I PTTD could lead to interventions aimed at early detection and prevention of PTTD progression.

The purpose of this study was to investigate differences in arch height, ankle muscle strength, and kinematic factors in individuals presenting with stage I PTTD in comparison to healthy individuals. Compared to the control group, we hypothesized that the PTTD group would demonstrate (1) no differences in static arch height, (2) decreased ankle invertor muscle strength, and (3) greater and prolonged peak rearfoot eversion and lower peak MLA during the stance phase of walking.

### METHODS

#### Subjects

Subjects were recruited through the Running Injury Clinic at the University of Calgary and various sports medicine clinics, including local practitioners such as pedorthists, podiatrists, and medical doctors. All subjects were actively involved in running and running-related sports and provided informed, written consent. The study protocol was approved by the Conjoint Health Research Ethics Board of the University of Calgary.

A Canadian certified athletic therapist, who is also a Canadian certified pedorthist, screened potential subjects through a clinical assessment that included a detailed history, differential diagnosis for other tendinopathies and musculoskeletal injuries, muscle strength testing, and manual palpations. Several steps were taken to differentiate between individuals with stages I and II PTTD. Typically, individuals with stage I PTTD exhibit signs of tendinopathy without postural changes in the foot, whereas those with stage II PTTD exhibit tendon elongation, acquired flatfoot deformity, and fixed rearfoot deformities. Moreover, with stage I PTTD, individuals generally exhibit pain superior and posterior to the medial malleolus, whereas those with stage II PTTD exhibit pain near the distal insertions of the tendon. Thus a clinical examination of passive rearfoot eversion and midfoot mobility was conducted and location of pain was evaluated to initially screen potential subjects. Once selected, potential subjects were screened according to specific inclusion and exclusion criteria.

Each subject was required to meet the following inclusion criteria to qualify for the PTTD group: (1) mild swelling and/or tenderness posterior to the medial malleolus, (2) pain posterior and/or superior to the medial malleolus, aggravated by recreational activity, (3) pain that had been present for at least 3 weeks, and (4) participation in recreational running or walking a minimum of 3 times per week and 30 minutes per session. Subjects were excluded from the PTTD group if they met any of the following exclusion criteria: (1) previous surgery on the affected foot, leg, or knee; (2) osteoarthritis in the knee of the affected side; (3) fixed rearfoot deformities; (4) recurrent ankle sprains on the affected side; (5) ligament tears or boney abnormalities of the affected foot; (6) a physical or medical condition that contraindicated the testing protocol; (7) pregnancy; or (8) flexor hallucis longus or flexor digitorum longus tendinopathy.

In total, 15 individuals with PTTD presented for consideration, 3 of which...
were excluded from the study, 1 due to incorrect location of pain (presentation of lateral ankle pain), another who met all the inclusion criteria but whose data were deemed unusable after processing, and a third due to multiple confounding injuries, including plantar fasciitis and metatarsalgia. Based on a 0-to-10 visual analog scale, with 0 representing no pain and 10 extreme pain, the PTTD group reported an average pain score of 5 during running activity and 3.5 during activities of daily living. The visual analog scale has been established as a reliable and valid measure of self-reported pain.29 No individuals with stage II PTTD were screened, most likely because the sample was recruited primarily from sports medicine clinics, which typically see patients involved in recreational sports that demand a level of activity limited by stage II PTTD.11,13,14

Control subjects (9 females and 3 males) were matched to individuals with PTTD (9 females and 3 males), based on age, gender, and body mass index (BMI), and screened by the same exclusion criteria as those used to screen the PTTD group. There were no statistical differences between groups for the variables listed in Table 1 and other demographic variables.

Structure
Arch height index (AHI) was measured using a custom-built arch height index measurement system2 (Figure 1). Two boards were placed under the foot, 1 under the calcaneus and 1 under the forefoot, to allow the midfoot to achieve maximum deformation. AHI was defined as the ratio of dorsum height at 50% of total foot length, divided by the foot length from the back of the heel to the head of the first metatarsal (truncated foot length).35 Seated AHI was obtained with the subject seated, hips and knees flexed to 90°, and approximately 10% of total body weight on the foot. Standing AHI was obtained with the subject standing, with equal weight on both feet. Arch rigidity index (ARI) is defined as the ratio of standing AHI divided by seated AHI.27 AHI and ARI were deemed appropriate measurements of static foot structure, as their reliability has been previously demonstrated.2,15

Additionally, and to better understand the anatomical structure of the foot, goniometric measurement of passive rearfoot range of motion was obtained. With the subjects in a prone position, the calcaneus was passively and maximally everted by the therapist (Figure 2). The mean ± SD passive and maximal rearfoot eversion for the subjects with PTTD was 6.5° ± 3.1° and 4.8° ± 2.0°, respectively. Pilot testing was conducted on 7 control subjects, and the test-retest reliability for the measurement of passive rearfoot eversion was r = 0.94.

Strength
To assess the strength of the ankle invertor muscles, the subjects were seated on the ground, with their knee fully extended and their foot in a plantar-flexed and inverted position (Figure 3). They were instructed to use only their ankle invertor muscles to produce a force against the stationary force dynamometer (Lafayette Instruments, Lafayette, IN). During the contraction, the investigator palpated the tibialis anterior tendon to ensure that this muscle was not being recruited. The movements of subtalar inversion and forefoot adduction were based on strength testing, as described by Kendall et al.28 to best isolate the ankle invertor muscles. Four trials of ankle invertor maximum voluntary isometric contraction were collected and the average of these 4 trials was recorded. Force measurements from the dynamometer were normalized to body mass.29 Pilot testing, using the aforementioned 7 control subjects, indicated a test-retest reliability for ankle invertor strength of r = 0.86.

Biomechanics
Three-dimensional walking data were collected using an 8-camera motion analysis system (Vicon Motion Systems Ltd, Oxford, UK). All subjects were barefoot and fitted with 9-mm retroreflective markers, adhered to the skin at the anatomical landmarks of the tibia, fibula, and foot (Figure 4). A standing calibration of 1 second was obtained with the feet 0.30 m apart and pointing directly forward. Following the standing calibra-
tion, the subjects were provided a 1-minute warm-up walk on the treadmill at 1.2 m/s. Following the familiarization period, marker trajectory data were captured at a rate of 120 Hz.

Ten continuous footfalls of the walking trial were selected for analysis. Raw marker trajectory data were filtered using a fourth-order low-pass Butterworth filter at 12 Hz. Anatomical coordinate systems were created for the shank and rearfoot using Visual 3D software (C-Motion Inc, Germantown, MD). Only the stance phase of gait was analyzed, and all kinematic data were normalized to 100 data points. Stance phase was defined as initial heel contact to toe-off and these events were identified using the velocities of the superior calcaneal and hallux markers.

Cardan angles were used to calculate 3-dimensional angles for the rearfoot and shank. Rearfoot eversion was expressed as frontal plane motion relative the shank segment. The MLA was calculated in a manner similar to the method used by Tome et al. The MLA was defined as the angle subtended by 2 lines, one from the marker on the medial aspect of the calcaneus (MCAL) to the navicular tuberosity (FIGURE 5).

CUSTOM LABVIEW software (National Instruments Corp, Austin, TX) was used to calculate discrete kinematic variables of interest, which included peak rearfoot eversion, peak MLA, and the time of peak rearfoot eversion.

Statistical Analysis

An a priori power analysis was conducted using kinematic rearfoot data previously published. Individuals with stage II PTTD, compared to healthy controls, had a significant difference in rearfoot eversion angle (PTTD, 10.4° ± 4.5°; control, 5.4° ± 3.6°). Using these values, the following calculation was used to estimate the required number of subjects to adequately power this study: 

\[
n = \left[ \frac{2 \cdot SD^2 \cdot (Z_a + Z_b)^2}{\Delta^2} \right]^{\frac{1}{2}}
\]

where SD is the pooled standard deviation, \(Z_a\) is the \(z\) score of alpha (.05), \(Z_b\) is the \(z\) score of beta (.80), and \(\Delta\) is the difference between the 2 means. Applying this calculation gives an estimation of 10 subjects per group, with a statistical significance of 0.05. Thus 12 subjects per group was considered appropriate for the study.

The following biomechanical variables obtained during walking were compared between the PTTD and control groups: (1) peak rearfoot eversion, (2) eversion excursion, (3) time to peak rearfoot eversion, and (4) peak MLA. The following anatomical and strength variables were compared between groups: (1) seated AHI, (2) standing AHI, (3) ARI, (4) passive rearfoot eversion range of motion, and (5) ankle invertor strength. Because the biomechanical and strength variables were associated with directional hypotheses, independent 1-tailed \(t\) tests were employed. Because no differences in static arch height were hypothesized, independent 2-tailed \(t\) tests were employed. All comparisons were conducted using an alpha of .05, in SPSS, Version 17 (IBM Corporation, Armonk, NY) software.

RESULTS

Structure

The PTTD group demonstrated significantly lower seated AHI (PTTD, 0.36 ± 0.01; control, 0.38...


**TABLE 2**

<table>
<thead>
<tr>
<th>Biomechanical Variables*</th>
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<tr>
<td><strong>PTTD (n = 12)</strong></td>
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<tr>
<td>Peak eversion, deg</td>
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<tr>
<td>Eversion excursion, deg</td>
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<tr>
<td>Time to peak eversion, percent stance</td>
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<td>Peak MLA, deg</td>
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*Abbreviations: MLA, medial longitudinal arch; PTTD, posterior tibial tendon dysfunction.*

*Values are mean ± SD unless otherwise specified.

The PTTD group exhibited significantly greater rearfoot eversion (6.0° ± 4.6°; P = .03) compared to controls (2.9° ± 2.6°) and significantly greater time to peak eversion (45.8% ± 8.1%; P = .05) compared to controls (38.1% ± 12.9%) (TABLE 3, FIGURE 6). There were no between-group differences in rearfoot eversion excursion (PTTD, 6.6° ± 2.9°; control, 5.9° ± 1.5°; P = .24) or peak MLA (PTTD, 12.5° ± 8.0°; control, 13.0° ± 9.4°; P = .49) (TABLE 3, FIGURE 7).

FIGURE 6 shows the PTTD rearfoot inversion/eversion curve to be in a more everted position throughout the stance phase of gait as compared to that of the control group. Therefore, to better understand the significantly greater peak eversion between groups, we conducted a post hoc analysis of rearfoot angle at heel strike and found that the PTTD group landed in significantly less inversion (0.1° ± 2.5°; P = .01) compared to controls (3.9° ± 2.7°). In addition, there was a significant positive correlation between rearfoot angle at heel strike and peak rearfoot eversion angle for both the PTTD (r = 0.81; P = .02) and control (r = 0.86; P = .01) groups.

**DISCUSSION**

The purpose of this study was to investigate differences in arch height, ankle muscle strength, and biomechanical factors in patients with stage I PTTD in comparison to healthy individuals. While PTTD is considered a progressive condition, most studies have focused on stage II of the condition in subjects who were predominantly overweight and relatively sedentary women, as opposed to patients with stage I PTTD who were generally younger and active. To our knowledge, no study has investigated these factors for stage I PTTD.

The PTTD group demonstrated a lower arch height in a seated position but no differences in standing AHI measurements or ARI, compared to controls. Because the differences in seated AHI were minimal and no other structural differences were measured between PTTD and controls, these findings support our hypothesis and indicate that there were no differences in static foot measures between groups. Moreover, the AHI values for both the PTTD and control groups fell within the normative ± SD value of 0.34 ± 0.03 for a group of 100 recreational runners reported by Butler et al., suggesting overall typical static arch height measures.

Shibuya et al. also reported no differences in talar declination angle, or Meary’s angle, between individuals with stage I PTTD and healthy controls, as measured using radiographs. However, these authors did not measure AHI, so comparisons are difficult. Both Neville et al. and Houck et al. measured AHI in individuals with stage II PTTD and found significantly lower values than in healthy controls. Therefore, the results of the current study suggest that arch structure, while perhaps not a contributing factor in stage I PTTD, may be more apparent in later stages of the condition.

In contrast to our hypothesis, there were no differences in ankle inverter strength between the 2 groups. These results are in contrast to the findings of Alvarez et al. and Houck et al., who reported that individuals with PTTD exhibited significantly reduced ankle inverter strength compared to healthy controls. However, these authors investigated persons with a mean age of 50 and 61 years, respectively. Our subjects were classified as having stage I PTTD, were 30 years old on average, and were regularly ac-
tive in either running, exercise walking, or running-based sports for a minimum of 30 minutes per day, 3 times per week. Thus the similarities in ankle invertor muscle strength between the PTTD and controls in the current study seem reasonable, considering that both groups were involved in regular physical activity and those with PTTD exhibited only minor swelling and pain to the posterior tibialis region.

In support of our hypothesis, the PTTD group exhibited greater peak rearfoot eversion while walking, compared to the control subjects, which is similar to the findings of previous studies involving stages II to IV PTTD. Moreover, those with PTTD demonstrated approximately 4° less inversion at heel strike compared to controls, and a significant positive association was found between rearfoot angle at heel strike and peak rearfoot eversion angle. These data suggest that the PTTD group exhibit altered rearfoot kinematics throughout the entire stance phase of gait. It is possible that greater rearfoot eversion is associated with early identification of the PTTD; however, prospective studies are necessary to answer this question.

Interestingly, when calculated with respect to the amount of passive maximal rearfoot eversion, the PTTD group utilized 92% of their available rearfoot range of motion, reaching a peak eversion value of 6° out of 6.5° of available range of motion. In contrast, the control group used only 60% of their available eversion range of motion, reaching 2.9° out of a possible 4.8°. These results are similar to those reported by Youberg et al., in which healthy subjects used 68.1% of their available passive rearfoot eversion range of motion while walking. Thus the results of the current study suggest that individuals with stage I PTTD exhibit atypical and excessive pronation mechanics. While speculative, these data also suggest that they may be at risk for ligamentous damage, which is consistent with the progressive nature of PTTD.

Although both groups reached the peak eversion in the first half of stance, the PTTD group reached peak eversion at 45.8% of the stance phase as compared to 38.1% of stance for the control group. These findings are in contrast to the data by Tome et al., who reported that individuals with PTTD reached peak eversion earlier in the stance phase compared to controls. Thus, we postulate that the increased rearfoot eversion measured in the present study places greater strain on the posterior tibialis muscle, which may partially explain the progressive nature of this condition. While no strength deficits were found in the PTTD group, other elements of muscle control, such as improper activation timing, lack of eccentric control, and atypical fiber recruitment, may contribute to the altered rearfoot eversion. Future research is necessary to better understand the interrelationship of muscle function and biomechanical movement patterns.

Because the posterior tibialis muscle is a major inverter and stabilizer of the MLA, we also expected a greater MLA value (lower arch) in those with PTTD while walking. However, no differences in MLA angle between the groups were measured, which is consistent with the finding of no difference in standing AHI between groups and no differences in strength. These results are in contrast to those of Tome et al., who measured the difference between standing MLA, normalized to subtalar neutral position, as compared to the peak MLA value in gait. Because we did not obtain MLA values in a subtalar neutral position, we are not able to directly compare our results to those of Tome et al. In addition, the present study was limited, in that the vertical height of the medial calcaneal marker from the plantar surface was not standardized, which might have masked between-group differences.

The biomechanical results of the current study provide support for PTTD being a progressive condition. For example, the stage I PTTD group exhibited a 3.1° increase in rearfoot eversion compared to controls, whereas Tome et al. reported that patients with stage II PTTD demonstrated a 6.2° increase compared to

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**FIGURE 6.** Representative rearfoot eversion patterns for posterior tibial tendon dysfunction (orange) and controls (blue, shaded area is standard deviation) during the stance phase of gait. Positive values indicate rearfoot inversion, negative values eversion.
controls. Moreover, while discrete values were not reported, Ness et al\(^2\) provided data showing that an approximately 10° increase in rearfoot eversion throughout the stance phase of gait could be observed in individuals with stage II PTTD compared to controls. Thus, increases in frontal plane rearfoot kinematics appear to be associated with PTTD severity. Interestingly, a strong positive association was found between rearfoot angle at heel strike and peak rearfoot angle in the current study. Ness et al\(^2\) reported a similar eversion offset throughout stance. These results suggest that individuals with PTTD exhibit altered rearfoot kinematics throughout the stance phase of gait, regardless of stage I or II of the condition. Moreover, the lack of differences in MLA between groups for the present study and a reported 8° change in MLA for stage II PTTD\(^3\) suggest that stage I PTTD may not involve midfoot or forefoot changes in walking kinematics, whereas these factors may be apparent in stage II and beyond.\(^4,5,7,13\) Thus, PTTD progression may be best understood by rearfoot kinematic measures during stage I, whereas altered midfoot and forefoot kinematics may play a role in stage II and beyond.\(^19,20\) Finally, the results of the current study also suggest that patients with stage I PTTD exhibit similar arch structure and ankle invertor strength as compared to healthy controls and that these variables may not be associated with early identification of the condition.\(^5,19\) In contrast, individuals in the more severe stages of the PTTD progression generally exhibit marked differences in arch height, strength, and gait kinematics.\(^19,24\)

Several limitations are acknowledged. First, this study did not include the classically defined PTTD demographic of sedentary women over the age of 40, who are diabetic or obese.\(^15,16\) However, the use of a younger, more active population is supported by previous research demonstrating PTTD that is a common injury among runners.\(^31,36\) It is also possible that stage I PTTD is distinct and only associated with tendon overload due to the altered rearfoot mechanics reported in the current study. In contrast, tendon overload in stages II to IV PTTD may be associated with other factors, such as obesity, altered MLA and rearfoot mechanics, as well as neuromotor and muscular strength deficits. Second, due to the placement of markers directly on the skin, participants had to undergo the biomechanical analysis barefoot, and foot kinematics have been shown to be different between barefoot and shod gait.\(^7\) Third, the examiner responsible for determining inclusion/exclusion criteria, data collection, and analysis of the data was not blinded to group allocation. However, a different clinician initially screened all patients over the phone, and all subjects were assigned a research number to blind the examiner during statistical analysis and to help minimize potential bias. As well, the present investigation was designed as a case control study; yet we sought to theorize about the interrelationships between variables. In addition, we powered the study based only on potential differences in rearfoot eversion. Thus future research, involving multiple covariates, with a sample size calculated considering a variance inflator factor, is necessary to better understand the multifactorial nature of biomechanical, strength, and structural factors for patients with PTTD.

**CONCLUSION**

The results of the current study suggest that runners with stage I PTTD are likely to present with normal inversion ankle muscle strength, significant differences in rearfoot pronation during walking gait, and no differences in foot posture as compared to healthy controls. The increased foot pronation is hypothesized to place greater strain on the posterior tibialis muscle, which may partially explain the progressive nature of this condition. Future investigations should be directed towards assessing the effects of rehabilitation programs for individuals in the early stages, to shed light

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**FIGURE 7.** Representative medial longitudinal arch (MLA) patterns for posterior tibial tendon dysfunction (orange) and controls (blue, shaded area is standard deviation) during the stance phase of gait. Values closer to 0 indicate arch deformation.
on the clinical and biomechanical factors that can be altered to prevent PTTD progression.

**KEY POINTS**

**FINDINGS:** Runners with stage I PTTD exhibited significant differences in rearfoot pronation during walking gait, along with normal inversion ankle muscle strength and foot posture, as compared to healthy controls.

**IMPLICATION:** The increased foot pronation is hypothesized to place greater strain on the posterior tibialis muscle, which may partially explain the progressive nature of this condition.

**CAUTION:** This study involved a group of healthy runners that does not represent the classic PTTD demographic of middle-aged, sedentary women with diabetes and obesity, which are often identified as primary risk factors.

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