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Ankle and Foot Kinematics Associated with Stage II PTTD During Stance

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Abstract

Background—Subjects with stage II posterior tibial tendon dysfunction (PTTD) exhibit abnormal foot kinematics; however, how individual segment kinematics (hindfoot (HF) or first metatarsal (first MET) segments) influence global foot kinematics is unclear. The purpose of this study was to compare foot and ankle kinematics and sagittal plane HF and first MET segment kinematics between stage II PTTD and controls.

Materials and Methods—Thirty patients with stage II PTTD and 15 healthy controls were evaluated. Kinematic data from the tibia, calcaneus, and first MET were collected during walking using three dimensional motion analysis techniques. A three segment foot model (HF, calcaneus; first MET, first metatarsal, and tibia) was used to calculate relative angles (ankle, HF relative to tibia; midfoot, first MET relative to HF) and segment angles (HF and first MET relative to the global). A mixed effect ANOVA model was utilized to compare angles between groups for each variable.

Results—Patients with PTTD showed greater ankle plantarflexion ($p = 0.02$) by 6.8 degrees to 8.4 degrees prior to or at 74% of stance; greater HF eversion ($p < 0.01$) across stance (mean difference = 4.5 degrees); and greater first MET dorsiflexion ($p < 0.01$) across stance (mean difference = 8.8 degrees). HF and first MET segment angles revealed greater HF dorsiflexion ($p = 0.01$) during early stance and greater first MET dorsiflexion ($p = 0.001$) across stance.

Conclusion—Abnormal HF and first MET segment kinematics separately influence both ankle and midfoot movement during walking in subjects with stage II PTTD.

Clinical Relevance—These abnormal kinematics may serve as another measure of response to clinical treatment and/or guide for clinical strategies (exercise, orthotics, and surgery) seeking to improve foot kinematics.

INTRODUCTION

Posterior tibial tendon dysfunction (PTTD) has been cited as a leading cause of adult acquired flatfoot deformity.^{6,16, 21-50} The classification scheme in current use, places subjects into 3 stages depending on symptoms and degree of deformity.^{6,21} Subjects with stage I PTTD present with signs of tendinopathy without foot deformity, while stage II disease presents with both signs of tendinopathy and flexible flatfoot deformity. In stage III PTTD the deformity is fixed. Recent reports suggest that the flexible flatfoot deformity in subjects with stage II PTTD

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includes a lower medial longitudinal arch (MLA) height, excessive hindfoot (HF) eversion, and excessive forefoot abduction in stance.^{11·14·50·52} In addition, magnetic resonance imaging studies demonstrate abnormal signal in important foot ligaments (eg. spring ligament, deltoid ligament)¹³ and atrophy of the posterior tibial (PT) muscle.^{41·47·49} Breakdown of foot ligaments and muscle atrophy are thought to contribute to abnormal foot kinematics leading to progression of PTTD. Recent studies associate abnormal foot kinematics with increased friction of the PT tendon suggesting this as a cause of tendinopathy.^{2,45} These observations partly drive clinical recommendations to employ bracing/orthotic devices to control abnormal kinematics^{3,4,10,35} and surgical methods to correct bony alignment in subjects with PTTD.^{29,30,42} Yet, there are few studies of in-vivo ankle and foot kinematics typical of PTTD during walking.^{20,32,39,40,44}

To assess foot kinematics in normal controls and those with PTTD, the metatarsals (forefoot segments (FF)) are frequently referenced to the calcaneus (hindfoot segment (HF)) for FF plantarflexion/dorsiflexion.^{20,32·39·40·44} Some studies isolate the medial FF by tracking the first metatarsal segment (first MET) separate from other metatarsal bones.^{25,44} In addition, the HF is referenced to the tibia for HF eversion/inversion.^{20·32·39·40·44} Blackwood et al. showed that sagittal plane metatarsal motion increased with HF eversion suggesting an unlocking of the midtarsal joint or a more flexible foot.⁵ In healthy participants, in-vivo foot models suggest HF eversion and first MET dorsiflexion (arch lowering) occur during early stance, confirming that the foot is flexible, which enables it to adapt to uneven surfaces.^{25·28} This is followed, at approximately 75% of stance, by HF inversion and first MET plantarflexion (arch rising) converting the foot into a rigid lever for push off.^{25·28}

Patients with PTTD display greater relative HF eversion and FF dorsiflexion than controls across the stance phase of gait, suggesting even greater foot flexibility.^{20,32,44} These abnormal foot kinematics increase the length of the PT muscle and reliance of the foot on ligaments for support during push off.^{13·15·34} Because both segments (HF or first MET) may influence relative first MET dorsiflexion angles independently, it remains unclear if one or both segments should be targeted to correct abnormal foot kinematics. Recent studies examined the isolated motion of the HF and first MET segment in healthy controls, identifying the contribution of each segment to relative first MET plantarflexion/dorsiflexion.⁵² However, a similar analysis has not been completed on participants with PTTD. Isolated motion of the HF segment and first MET segment in healthy patients revealed a stationary first MET across the midstance phase of gait, confirming that plantarflexion of the HF segment alone contributes to arch lowering (first MET dorsiflexion) during midstance.⁵² In participants with PTTD, it is possible that greater HF segment plantarflexion may lead to greater relative first MET dorsiflexion with less of a contribution from the first MET segment. This analysis was not explored in previous descriptions of abnormal movement in patients with PTTD.

Changes in the HF segment that contribute to first MET dorsiflexion may also lead to altered ankle kinematics in stage II PTTD. Normal sagittal plane ankle motion is partially directed by the triceps surae which is the primary muscle responsible for effective push off.³¹ In healthy controls, ankle motion follows a pattern of plantarflexion during early stance, allowing the foot to contact the ground, followed by dorsiflexion as the tibia progresses over the foot.^{9,19,26,39} Peak ankle dorsiflexion occurs at approximately 75% of stance, followed by rapid ankle plantarflexion. The decreased calcaneal pitch angle, observed from radiographs, in PTTD suggests an increase in plantarflexion and shortened triceps surae.^{42,54} Some recent studies^{20,32} confirmed an increase in ankle plantarflexion across the stance phase in PTTD compared to healthy controls. Other studies either did not report ankle position⁴⁴ or did not observe altered ankle plantarflexion.⁴⁰ Further, previous studies did not track the HF segment separately which demonstrates the contribution of abnormal foot kinematics to ankle kinematics.

The purpose of this study was to compare ankle and foot kinematics between patients with stage II PTTD and healthy controls. Specifically, this study extends previous studies by evaluating the influence of isolated HF (HF with respect to the global) and first MET segment (first MET with respect to the global) kinematics on relative ankle and foot kinematic angles. Patients with stage II PTTD were chosen because the tendinopathy is accompanied by foot deformity in this stage. The relative ankle and foot angles included ankle dorsiflexion/plantarflexion, HF inversion/eversion, and first MET dorsiflexion/plantarflexion. It was hypothesized that patients with stage II PTTD would demonstrate greater ankle plantarflexion (HF relative to the tibia), HF eversion (HF relative to the tibia) and first MET dorsiflexion (first MET relative to the HF) compared to controls. First, greater HF segment plantarflexion was hypothesized to contribute to greater ankle plantarflexion. Second, a combination of greater HF segment plantarflexion and first MET segment dorsiflexion were hypothesized to result in first MET dorsiflexion (medial longitudinal arch lowering) in stage II PTTD.

MATERIAL AND METHODS

Participants

Thirty patients with PTTD (22 female, eight male) and 15 controls (14 female, one male) volunteered. These participants are distinct from previous studies;^{18,44} however, similar methods were used. 17 Patients were referred from a local orthopedic surgeon that fit the classification of unilateral stage II PTTD. Similar to previous studies,^{18,44} patients had one or more signs of tendinopathy. The signs of tendinopathy included: (1) palpable tenderness of the posterior tibial tendon, (2) swelling of the posterior tibial tendon sheath, and (3) pain along the course of the PT tendon during a single limb heel raise. Additionally, patients had one or more signs of flexible flatfoot deformity while standing, including excessive non-fixed HF eversion deformity, excessive first MET abduction, or loss of height in the MLA. Assessment of flatfoot deformity was based on visual comparisons of the involved to the uninvolved side. Clinically this was quantified using the arch height index (Table 1).⁵³ This assessment required that all patients in the PTTD group had unilateral involvement. Patients that had a history of pain or pathology in the foot or lower extremity that prevented them from ambulating greater than 15 meters were excluded.

In an attempt to match the control group for age, height, and mass, the average of the first 15 patients recruited for the stage II PTTD group were used. Because of this matching, there were no significant differences in age, height, weight or body mass index (BMI) between groups (Table 1). The control participants were required to have no history of foot and ankle problems (absence of tendinopathy), a normal arch height index and normal foot posture. The arch height index has been validated using radiographs and used to describe foot posture in large samples.^{8,53,55} The arch height index is a ratio of the height of the dorsum of the foot divided by the length. The dorsum height is taken at 50% of foot length, then divided by the foot length from the heel to the base of the distal first MET head to calculate the arch height index.^{8,53,55} Reliability of the arch height index is high with intraclass correlation coefficients reportedly greater than 0.9.^{8,53} Greater values indicate a higher arch. A normal arch was defined as equal to, or greater than the average arch height index as reported by Butler et al.⁸ Use of the arch height index excluded those participants with asymptomatic flatfoot deformity. The participants were informed of the study procedures and risks consistent with an approved protocol.

Kinematic measurements

The foot segments used to track foot and ankle motion were the tibia, calcaneus, first MET and hallux. Three infrared emitting diodes (IRED) were mounted on a thermoplastic molded platform, and placed directly on the skin overlying the calcaneus (HF segment), first MET

(first MET segment), second to fourth metatarsals and hallux (Figure 1). The hallux and second to fourth metatarsal segment data were not used in this analysis. The placement of the thermoplastic platforms was based on previous studies that reported good repeatability and validity of tracking these HF and first MET segments using skin mounted sensors.^{33,46,51} Movement was tracked at 60 Hz using a 6 camera Optotrak™ Motion Analysis System (Northern Digital, Inc, Ontario, Canada). Subsequently, the kinematic data was smoothed using a fourth order, zero phase lag, Butterworth filter with a cut-off frequency of 6 Hz.

Bony landmarks were digitized to establish local anatomically based coordinate systems consistent with previous studies.¹⁷ The conventions used resulted in right hand Cartesian reference system, where the positive z axis of each coordinate system was oriented to the right, perpendicular to the sagittal plane of each segment (tibia, HF, & first MET). Once reference frames were established, a Z-X-Y sequence¹² of rotations was used to calculate five angles including HF with respect to (w.r.t.) the tibia (HF Inv/Ev, ankle Pf/Df), first MET w.r.t. to the HF (first MET Pf/Df), HF w.r.t. the global reference frame (HF global) and first MET w.r.t. to the global reference frame (first MET global). The HF Inv/Ev angle was a rotation around an anterior/posterior axis. The ankle Pf/Df angle and first MET Pf/Df angle were rotations around a medial/lateral axes. The global 3D orientations (HF global and first MET global) were rotations around the medial/lateral axis (Pf/Df) of the global or laboratory coordinate system for each segment.

A significant problem when describing foot kinematics is identifying a common zero position for participants with normal and abnormal foot postures.^{17,18,36,37} The subtalar neutral (STN) position when used as a common zero in a recent study was reliable and valid for detecting differences in the kinematic patterns of asymptomatic participants with foot pronation.¹⁷ Therefore, the STN position was used in this study as a zero reference position for the HF and first MET variables. To establish the STN position, the examiner asked the participants to roll their HF into inversion and eversion while palpating the talo-navicular joint. Using palpation, the examiner identified the STN position as the mid position of the talar head with respect to the navicular bone.^{36,43} Studies suggest examiners can reliably reproduce this position to within 2 to 3 degrees.^{17,36,37} Once the STN position was established by the examiner, participants were asked to hold that position while a 1-second trial was collected.¹⁷

Procedures

Participants walked down a 10-meter walkway at a target speed of 1 m/s. Speed was monitored with a timing system (Brower, Salt Lake City, UT) and maintained during testing to within $\pm 5\%$ of the target speed. The slow walking speed was used to accommodate participants with PTTD. Using a 10 N threshold, an embedded force plate (Model 9286, Kistler, Switzerland) was used to identify initial contact and toe-off points during stance with data collected at 1000 Hz. Each participant completed a minimum of five successful trials consisting of full contact with the force plate.

Analysis

Five walking trials per subject were averaged and used in the statistical analysis. Each of the five kinematic variables (HF Inv/Ev, ankle Pf/Df, first MET Pf/Df, HF global, first MET global) were interpolated to 101 points (0% to 100%) across stance and then the 5 walking trials were averaged to gain a representative pattern for each subject. The key features of the PTTD group patterns across stance were then used to identify stance points that described each pattern. The same stance points were used for each group. Once discrete stance points were established a mixed two-way ANOVA model was used to assess each kinematic variable. The two factors of the two-way ANOVA model included group and stance points. The two levels of the fixed factor group were the PTTD group and control group. The second factor, stance

points, was a repeated factor with four levels. For ankle Pf/DF the stance points used included initial contact, peak plantarflexion (13%), peak dorsiflexion (74%) and toe off. For HF Inv/Ev the stance points used included initial contact, peak eversion (25%), peak inversion (92%) and toe off. For first MET Pf/Df the stance points used included initial contact, peak dorsiflexion (12%), peak dorsiflexion (78%) and toe off. For HF global and first MET global initial contact, 15% of stance, 75% of stance and toe off were used. For each two-way ANOVA analysis if significant interactions were detected (Group $\times$ Stance Point) they were followed by pair wise comparisons (comparison between groups for each phase of stance) and main effects were ignored. A significance level of $\alpha = 0.05$ was used for each ANOVA analysis. Because the distribution of gender was not equivalent for the two groups (control group = 93% female and PTTD group = 73% female) the ANOVA analyses were also run with gender as a covariate.

RESULTS

Relative ankle, hindfoot and midfoot angles

The ankle Pf/Df ($p = 0.02$) angle was dependent on group and stance point (group $\times$ stance point interaction), while HF Inv/Ev ($p < 0.01$) and first MET Pf/Df ($p < 0.01$) angles were only dependent on group (main effect for group) (Table 2). The ankle Pf/Df angles pair wise comparisons indicated significantly greater peak plantarflexion at IC ($p < 0.01$), 13% of stance ($p < 0.01$) and 74% of stance ($p < 0.01$) by 6.8 degrees to 8.4 degrees (Figure 2A). The HF Inv/Ev patterns showed significantly greater eversion across stance with the mean difference across all stance points equal to 4.5 degrees (95% CI = 2.4 degrees to 6.6 degrees) (Figure 2B). Consistent with HF Inv/Ev, first MET Pf/Df showed consistently greater first MET dorsiflexion by a mean difference across all stance points equal to 8.8 degrees (95% CI = 4.3 degrees to 13.2 degrees) (Figure 3A). There was no change in significant findings (main effects or interaction effects $p < 0.05$) when including gender as a covariate.

Hindfoot and forefoot segment angles

The HF global angles depended on group and stance point (group $\times$ stance point interaction, $p = 0.01$), however, the first MET global angles only depended on group assignment (group main effect, $p < 0.01$) (Table 2). For HF global angles pair wise comparisons between groups revealed significantly greater plantarflexion at IC ($p < 0.01$) and 15% ($p < 0.01$) of stance in participants with PTTD by 4 degrees and 4.5 degrees, for each stance point respectively (Figure 3B). In contrast, for first MET global angles there was a significant bias toward greater dorsiflexion with a mean difference across all stance points equal to 13.7 degrees (95% CI = 8.4 degrees to 18.9 degrees) in the PTTD group (Figure 3C). There was no change in significant findings (main effects or interaction effects $p < 0.05$) when including gender as a covariate.

DISCUSSION

Findings from this study identify the separate contributions of the HF and first MET segments to ankle (ankle Pf/Df) and first MET (first MET Pf/Df) kinematics and document alterations in foot kinematics in participants with stage II PTTD compared to healthy controls. New to this study, the HF segment kinematics (HF global) explained the abnormal ankle angles (ankle Pf/Df) during stance. The relative first MET dorsiflexion angles were the result of both abnormal HF segment kinematics (HF global) during early stance and first MET segment kinematics (first MET global) throughout stance. The key features of the abnormal patterns in stage II PTTD included greater ankle Pf, HF Ev and first MET Df compared to controls.

The abnormal ankle angles in stage II PTTD is evidence of altered ankle function. Previous studies using radiographs to align the HF segment showed greater ankle plantarflexion by greater than 10 degrees from heel strike to late stance and near 20 degrees of HF eversion

throughout stance in PTTD.^{20,32} In contrast, the greater ankle Pf and HF Ev in this study was more modest, 6.8 degrees to 8.4 degrees greater ankle Pf/Df across stance points up to 74% and an average 4.5 degrees greater HF Ev across stance points in PTTD (Table 2 and Figure 2A). Because abnormal ankle Pf and HF Ev are theoretically linked to progression of foot deformity, it is possible that previous studies^{20,32} included patients with more severe stage II PTTD. However, alternative kinematic modeling approaches may also contribute to differences across studies. Further studies are necessary to determine if abnormal kinematics using the *in-vivo* methods of these studies are an effective marker of disease severity and progression in PTTD.

In this study, greater ankle plantarflexion only contributed to arch lowering during early to mid stance. The HF global kinematic patterns from 0% to 50% of stance showed greater plantarflexion compared to controls (Table 2), confirming the HF segment was contributing to greater ankle plantarflexion. This habitual posture of HF segment plantarflexion may lead to shortening of the triceps surae muscle which over time may alter its force length relationship, weakening the muscle during push off. In a study of 5 patients with PTTD, Ringleb et al.⁴⁰ demonstrated decreased push off power compared to controls. Further, Ness et al.³² suggested late heel off is a characteristic of stage II PTTD. At least two functional adaptations may explain these gait changes: 1) ankle plantarflexion starts later to optimize the triceps surae force length relationship for push off; and/or 2) ankle plantarflexion is near the start of double support, which would decrease the need for a strong push off power.²² These data suggest the effects of current treatment (bracing^{3,22,23} or exercise¹ or surgery²⁴) on ankle Pf/Df kinematics deserve exploration separate from medial longitudinal arch kinematics.

Associated with alterations in ankle kinematics, the sagittal plane first MET Pf/Df angles confirmed an increase in first MET Df, and therefore MLA lowering, in stage II PTTD compared to healthy controls (Figure 3A). These data are consistent with previous studies with more modest differences between groups than observed by others.^{20,32} The participants with PTTD in this study demonstrated first MET dorsiflexion (MLA lowering) at 10% of stance that equals or exceeds the peak dorsiflexion occurring at 75% of stance observed in healthy controls. The greater first MET dorsiflexion of PTTD extended throughout stance and did not return to a subtalar neutral position at toe off (Figure 3A). This gross kinematic modeling of the foot was unable to attribute the HF and first MET movements to specific midfoot joints. However, it is possible that an association may exist between these foot kinematics and ligaments of midfoot joints involved in PTTD. Similar associations were found between posterior tibial muscle length and foot kinematics.^{15,34} In addition, abnormal kinematics not occurring in the sagittal plane (first MET abduction) assessed in previous studies may also load the midfoot joints.^{32,44}

The HF global and first MET global angles help partition the contribution of each foot segment to abnormal first MET dorsiflexion. Wilken et al.⁵² suggested that HF global plantarflexion on a stationary first MET accounted for MLA lowering during midstance in controls. In this study, the HF global angles of the PTTD participants contributed to lowering the MLA (greater HF Pf) during stance at the IC, 15% and 74% stance points. In contrast, the greater first MET global dorsiflexion was an offset, suggesting the first MET segment is dorsiflexed throughout stance. Current studies of walking suggest forward progression and support during walking depend on ankle push off, not a controlled roll off or contributions from the contralateral swing leg as described previously.³¹ This emphasis on ankle push off assumes that the midfoot will achieve stability through muscle control, soft tissue restraints or bony interactions to transform the foot into a rigid lever for push off.⁴⁸ In this study the foot kinematic data suggests a lower MLA, however, the patterns are not exaggerated by late stance push off. Decreased push off power in PTTD is one explanation.^{7,40} Alternative explanations including higher reliance on ligament loading and muscle control to stabilize the foot are also possible.

Previous studies using alternative definitions of neutral foot posture demonstrate a strong effect on offsets in kinematic patterns across studies. The definitions of neutral foot posture include applying global axes,⁴⁰ standardized jig,⁹ radiographs³² and the STN position^{17,36,37} as used in this study. Using global axes has resulted in no differences in foot kinematics across controls and patients ($n = 5$) with PTTD.⁴⁰ A recent study demonstrated that the use of the STN position for defining angles was more consistent with clinically defined asymptomatic flatfoot than global axes.¹⁷ This study underscores the importance of aligning segment axes with foot posture. Which methods are used to achieve alignment with foot posture (i.e., radiographs or standardized jigs) affects the definition of neutral and therefore may result in offsets.^{20,32,44} For example when comparing the results of this study to previous studies that used radiographs to align segment axes, larger differences in joint angles are apparent.^{20,32,44} This difference could arise from offsets caused by definitions of segment axes or the severity of PTTD samples used across these studies.^{20,32,44}

Valid approaches to foot kinematic modeling continue to evolve. Critics of in-vivo foot models point at errors of up to ~ 5 degrees when comparing bone and surface mounted markers.^{33,51} However, these studies note that the influence of bone mounted markers on skin movement prohibit simultaneous recordings (bone and surface markers), possibly overestimating errors.^{33,51} For example, an in-vitro study of skin artifact suggests errors may be smaller (less than 3 degrees) than those from consecutive recordings for the first MET.⁴⁶ Nevertheless, these studies are the best estimate of errors, influencing marker placement and segmentation of the foot. Errors in tracking the calcaneus, from consecutive recordings, reported peak errors of 5.7 degrees and average errors across a walking cycle of ± 2.6 degrees.³³ The HF Inv/Ev and HF Df/Pf movements reported in this study should be viewed with respect to these errors. Although some foot kinematic models segment the first MET,^{26,28} studies involving PTTD patients have not reported the first MET segment separately.^{20,32,39,40,44} The first MET in this study was emphasized to capture MLA changes⁴⁴ and because an in-vitro study estimated low (less than ± 2.3 degrees) bone tracking errors specific to the first MET.

Further limitations are associated with the study design and subject sample. The study design was cross sectional, making inferences of cause effect speculative. However, cross sectional data are typically used for theory development.³⁸ The description and classification of patients with PTTD is continually evolving with recent clinical guidelines suggesting a division of stage II into sub-stages based on clinical presentation.²⁷ The need for further classification may be underscored by the differences in foot kinematics between the various studies^{20,32,40,44} and this sample. While the groups of this study were equivalent for age and BMI, there was a larger percentage of females in the control (93%) group compared to the PTTD group (73%). However, when gender was entered as a covariate the results were unchanged, suggesting gender did not influence the results. In addition, barefoot walking may not represent the participant's shod gait patterns. Finally, comparisons to the uninvolved side, rather than a control group may reveal different kinematic patterns.

CONCLUSION

When compared to healthy controls, patients with Stage II PTTD demonstrated alterations in both ankle and forefoot kinematics. Using an in-vivo foot kinematic model, the HF and first MET segments were found to contribute separately to abnormal foot kinematics in stage II PTTD. Because of differences across studies, further evaluation of the progression of abnormal kinematics in patients with PTTD is warranted. These data may prove useful in evaluating therapeutic approaches to either limit progression or correct abnormal HF and first MET kinematics in participants with stage II PTTD.

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Fig. 1. Infrared emitting diode (IRED) placement used to establish rigid bodies for each segment and schematic diagram of anatomic reference frames used.

Fig. 2. Average (±SD) ankle (Ankle Pf/Df) (2A) and hindfoot (HF Inv/Ev) (2B) for the healthy control subjects (grey) and stage II posterior tibial tendon dysfunction (PTTD) subjects (black).

Fig. 3. Average ($\pm$ SD) sagittal plane first metatarsal (first MET Pf/Df) (3A), hindfoot global (HF Global) (3B) and first metatarsal global (FF Global)(3C) for the healthy control subjects (grey) and stage II posterior tibial tendon dysfunction (PTTD) subjects (black).

Table 1

Subject characteristics and clinical variables

Variable	PTTD Group(<i>n</i> = 30)	Control Group(<i>n</i> = 15)	<i>p</i> Value *
Age (y)	59.3 (10.8)	56.5 (7.7)	0.39
Height (cm)	167.8 (9.3)	164.9 (7.3)	0.29
Mass (kg)	83.8 (16.0)	83.2 (10.8)	0.89
BMI (kg/m ²)	29.6 (4.8)	30.5 (3.6)	0.52
Arch Height Index	0.314 (0.026)	0.376 (0.026)	< 0.01
Foot Function Index (%)			
Activity	15 (12)		
Disability	34 (18)		
Pain	36 (17)		

Abbreviations: BMI, body mass index; PTTD, posterior tibialis tendon dysfunction.

* No significant differences using an independent t-test between groups with the exception of the arch index

Table 2

Means (SD) of kinematic variables during stance

Kinematic Variables	Points of Stance Used for Analysis*				p Value for Overall Differences
	IC	13%	74%	TO	
Ankle P/Df					
PTTD	-1.8 (5.3) ^f	-10.5 (4.2) ^f	8.0 (5.4) ^f	-7.5 (8.6)	Group < 0.01
Control	5.9 (2.4)	-2.1 (2.5)	14.8 (3.2)	-4.2 (3.8)	Group × Stance Point 0.02
HF Inv/Ev					
PTTD	IC -3.4 (4.0)	25% -11.2 (4.3)	92% -9.8 (4.3)	TO -1.4 (5.0)	Group < 0.01
Control	-0.7 (2.4)	-6.1 (2.2)	-4.8 (2.2)	3.8 (2.6)	Group × Stance Point 0.09
1st Met P/Df					
PTTD	IC 6.3 (8.4)	12% 12.2 (7.9)	78% 16.4 (8.5)	TO -0.3 (9.9)	Group < 0.01
Control	-1.7 (3.5)	2.4 (3.5)	7.3 (4.2)	-8.5 (6.0)	Group × Stance Point 0.56
HF Segment Global					
PTTD	IC 11.0 (4.4) ^f	15% -5.7 (3.1) ^f	75% -13.7 (4.6)	TO -55.3 (6.9)	Group 0.02
Control	15.0 (3.3)	-1.2 (1.8)	-12.6 (3.0)	-55.7 (4.1)	Group × Stance Point 0.01
1st Met Segment Global					
PTTD	IC 24.7 (9.5)	15% 12.1 (7.5)	75% 8.1 (9.7)	TO -51.4 (14.5)	Group < 0.01
Control	12.2 (3.1)	-0.1 (2.2)	-6.7 (4.2)	-66.7 (7.1)	Group × Stance Point 0.27

Abbreviations: Pf, plantarflexion; Df, dorsiflexion; Inv, Inversion; Ev, eversion; HF, hindfoot; 1st Met, 1st Metatarsal.

* Points used to describe key features of PTTD group pattern with corresponding points for controls.

^f denotes significant difference (p < 0.051) in pair wise comparison between groups