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Effects of the AirLift PTTD Brace on Foot Kinematics in Subjects With Stage II Posterior Tibial Tendon Dysfunction

Orthotic devices are commonly recommended in the conservative management of stage II posterior tibial tendon dysfunction (PTTD) to correct abnormal foot kinematics.[1,5,11,14,18,25,26,32] Evidence of posterior tibialis muscle weakness,[27,34] combined with tendon degeneration (tendinosis),[16] suggests that patients with stage II dysfunction have impaired active structures used to control foot and ankle kinematics. In addition, damage to passive support structures, such as the spring and talocalcaneal interosseus ligaments, has been observed, further contributing to abnormal foot kinematics.[2,8,21] Orthotic devices indicated for individuals with stage II dysfunction may unload or prevent further attenuation of both active (muscular) and passive (ligamentous) support structures by limiting abnormal foot kinematics. Although some foot kinematics may be coupled (hindfoot position may influence forefoot position), specific brace components may be necessary to limit abnormal kinematics across different phases of stance in individuals with stage II PTTD.

STUDY DESIGN: Experimental laboratory study.

OBJECTIVES: To investigate the effect of inflation of the air bladder component of the AirLift PTTD brace on relative foot kinematics in subjects with stage II posterior tibial tendon dysfunction (PTTD).

BACKGROUND: Orthotic devices are commonly recommended in the conservative management of stage II PTTD to improve foot kinematics.

METHODS AND MEASURES: Ten female subjects with stage II PTTD walked in the laboratory wearing the AirLift PTTD brace during 3 testing conditions (air bladder inflation to 0, 4, and 7 PSI [SI equivalent: 0, 27 579, and 48 263 Pa]). Kinematics were recorded from the tibia, calcaneus (hindfoot), and first metatarsal (forefoot), using an Optotrak motion analysis system. Comparisons were made between air bladder inflation and the 0-PSI condition for each of the dependent kinematic variables (hindfoot eversion, forefoot abduction, and forefoot dorsiflexion).

RESULTS: Greater hindfoot inversion was observed with air bladder inflation during the second rocker (mean, 1.7°; range, –0.7° to 6.1°). Less consistent changes in forefoot plantar flexion and forefoot adduction occurred with air bladder inflation. The greatest change toward forefoot plantar flexion was observed during the third rocker (mean, 1.4°; range, –3.8° to 3.9°). The greatest change towards adduction was observed during the third rocker (mean, 2.3°; range, –3.4° to 6.5°).

CONCLUSIONS: On average, the air bladder component of the AirLift PTTD brace was successful in reducing the amount of hindfoot eversion observed in subjects with stage II PTTD; however, the effect on forefoot motion was more variable. Some subjects tested had marked improvement in foot kinematics, while 2 subjects demonstrated negative results. Specific foot characteristics are hypothesized to explain these varied results.

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KEY WORDS: *biomechanics, orthotic device, tendinopathy*

Orthotic devices should target abnormal foot kinematics identified in individuals with stage II dysfunction to unload active and passive support structures. The abnormal foot kinematics identified using biomechanical models include hindfoot eversion, forefoot abduction, and loss of medial longitudinal arch (MLA) height. Complicating the design of orthotic devices, these abnormal foot kinematics occur at different phases of gait. During the first rocker (heel contact until end of double-limb support) and second rocker (single-limb support), ex-

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cessive hindfoot eversion has been identified in subjects with stage II PTTD.[18,33] In contrast, abnormal forefoot kinematics (forefoot abduction and forefoot dorsiflexion [contributing to lowering the MLA]) are greatest during the third rocker (start of double-limb support until toe-off).[18,25,26,34] The third rocker is also a time when high loads are being transmitted through the forefoot after the heel is off the floor, making controlling forefoot motion with orthotic devices potentially challenging. The clamshell component used in ankle braces has been shown to limit hindfoot eversion in subjects with pronated foot postures[9,29] but may have limited ability to control forefoot posture. How specific device components complement the clamshell design and improve forefoot control is less studied.

The need for specific strategies/components to control forefoot kinematics is underscored by recent in vitro data.[3] Unloading passive and active support structures by altering forefoot kinematics may be partially dependent on hindfoot position; however, current evidence[3] suggests some independence of forefoot kinematics. Hindfoot inversion is thought to contribute to locking the midtarsal joint providing bony stability to limit forefoot motion. When tested in a cadaver model, hindfoot inversion limits sagittal plane forefoot motion (plantar flexion/dorsiflexion) but has no effect on transverse (abduction/adduction) or frontal plane (internal/external rotation) forefoot motion.[3] Although not tested in vivo, this result suggests that orthotic components which reduce hindfoot eversion may also limit forefoot dorsiflexion in individuals with stage II PTTD. The same is not true of forefoot abduction, which may be unchanged with hindfoot inversion control. Attenuation of the posterior tibialis musculotendon occurring due to excessive forefoot abduction at the end of stance may require specific orthotic device components.[20]

The AirLift PTTD brace (DJO Inc, Vista, CA) is an off-the-shelf ankle brace with a clamshell ankle component (hindfoot component) and an air bladder component (midfoot component), located along the medial midfoot, that can be custom filled by the user. It is assumed that the lateral side of the shoe will interact with the air bladder component to control forefoot kinematics. Although patients typically assume higher inflation of the air bladder will improve its effectiveness, testing of specific orthotic device components has resulted in high variability in subject responses.[17,19] For example, the effect of a medial heel wedge has been shown to increase hindfoot inversion in 1 subject, while increasing hindfoot eversion in another.[30] Nevertheless, if effective clinically, inflation of the air bladder component of the AirLift PTTD brace would be expected to limit or correct abnormal foot kinematics associated with stage II PTTD.

The purpose of the current study was to investigate the effect of inflation of the air bladder component of the AirLift PTTD brace on relative foot kinematics in subjects with stage II PTTD. It was hypothesized that air bladder inflation would result in hindfoot inversion, forefoot adduction, and forefoot plantar flexion (reducing flatfoot kinematics); however, the effect of inflation would be dependent on the stance phase of gait. This correction of abnormal kinematics due to air bladder inflation would target the second rocker for hindfoot inversion and the third rocker for correction of forefoot kinematics (plantar flexion and adduction). These hypotheses were motivated by observed excessive hindfoot eversion early in stance contributing to attenuation of the posterior tibialis musculotendon and abnormal forefoot kinematics during the end of stance as a result of high loads being transferred through the forefoot after the heel is off the floor.

TABLE 1 Demographics for Subjects With Stage II PTTD (n = 10)*

Variables	Subjects
Age (y)	52.7 (6.2)
Height (cm)	162.3 (7.1)
Mass (kg)	90.1 (21.5)
BMI (kg/m^2)	34.4 (8.8)
Arch height index	0.311 (0.036)
Gait speed (m/s)	1.13 (0.20)

Abbreviations: BMI, body mass index; PTTD, posterior tibial tendon dysfunction.
** Values are mean (SD).*

METHODS

Ten female subjects with stage II PTTD volunteered for this study (**TABLE 1**). Subjects with unilateral PTTD were referred by a local orthopedic surgeon and were clinically classified as having stage II PTTD, based on clinical exam and radiological evaluation. The inclusion criteria for classification of stage II PTTD required subjects to have 1 or more signs related to tendinopathy, including (1) palpable tenderness of the posterior tibial tendon, (2) swelling of the posterior tibial tendon sheath, and (3) pain during single-limb heel raise. Additionally, 1 or more signs of flexible flatfoot deformity were required for classification of stage II PTTD. Clinical signs of flexible flatfoot deformity included excessive nonfixed rearfoot valgus deformity during weight bearing, excessive forefoot abduction, or loss of height in the MLA. Signs of flatfoot deformity included (1) excessive motion, defined as greater on the involved compared to uninvolved side (subjects were required to have unilateral involvement to allow comparisons between sides), (2) objective measurements using the arch height index, as described by Williams et al[36] and Powell,[24] and (3) radiographic comparison of the involved side to normal values.[37]

The arch height index is described as the ratio of dorsum height at 50% of the foot length, divided by the foot length from the heel to the base of the distal first metatarsal head. Greater values indicate a higher arch, with a mean (SD) of 0.335 (0.040) reported for 72 healthy subjects.[24] The subjects with PTTD tested in this study averaged (SD) 0.311 (0.036), indicating a lower MLA (**TABLE 1**). The lateral talar-first metatarsal angle, measured on radiographs of the weight-bearing foot, was used to describe foot posture, consistent with previous studies of subjects with foot pronation.[28,37] The mean (SD) lateral talar-first metatarsal angle for the 10 subjects was 15.4° (5.4°). All but 1 subject demonstrated a talar-first metatarsal angle outside the confidence interval of healthy subjects (3.0°-11.2°) reported by Younger et al.[37] The 1 subject falling within this confidence interval exhibited greater hindfoot eversion on the involved side in standing on visual inspection. Subjects were excluded if they had a history of pain or pathology in the foot or lower extremity that prevented them from ambulating greater than 15 m. All subjects were informed of the experimental procedures and signed a consent form approved by Ithaca College and the University of Rochester Research Subjects Review Boards.

Due to the potential repetitive stress that results from walking with a flatfoot posture, a small 2° change may be clinically important. A previous study suggests that a 2° change in hindfoot inversion may be associated with clinical benefit in patients with pronated foot postures.[12] Larger changes would indicate more effective device components but small changes of 2° may unload foot structures that control kinematics in patients with PTTD. The power analysis completed for this study suggested that in the presence of consistent 2° responses a sample of 10 subjects would provide 80% power to address the stated hypotheses.

Kinematic Measurements

Kinematic data were collected using a 3-segment foot model, including the tibia, calcaneus (hindfoot), and first metatarsal (forefoot), as described previously.[33] Briefly, sets of 3 infrared-emitting diodes (IREDs) were mounted on rigid thermoplastic platforms, and then attached using double-sided adhesive tape. Anatomic landmarks were digitized by a single examiner (C.N.) to establish local anatomically based coordinate systems for each segment. For this investigation, motion of the most distal foot segment was then calculated relative to the adjacent proximal segment, based on the Euler rotation sequence of flexion/extension, inversion/eversion, and abduction/adduction, as suggested by Cole et al.[6] Two banks of infrared cameras (Optotrak model 3020; Northern Digital Inc, Waterloo, Ontario, Canada), in conjunction with Motion Monitor software Version 7.24 (Innsport Training Inc, Chicago, IL) were used to track IRED sets on each segment at a sampling rate of 60 Hz. The field of view of the Optotrak is 2.25 m^2 at a distance of 2 m. The manufacturer reports accuracy of tracking an individual IRED at ±0.1 mm, with additional studies also reporting excellent precision and repeatability using the Optotrak system.[15,31] Using a 10-N threshold of vertical forces collected at 1000 Hz from an embedded force plate (model 9286; Kistler Instrumente AG, Winterthur, Switzerland), initial contact and toe-off points of the gait cycle were identified. Kinematic data were smoothed using a fourth-order, zero-phase-lag Butterworth filter with a cut-off frequency of 6 Hz.

Procedures

Subjects were fitted with an AirLift PTTD brace according to manufacturer recommendations (US shoe size: small, 5-8.5; medium, 9-12.5; large, 13-15) and given a pair of standard walking shoes in an appropriate size to be used for walking trials. Shoes were modified to allow visualization of skin-mounted IRED markers by cutting windows over the areas of the posterior calcaneus and medial dorsal first metatarsal. Shoe modifications tested in a similar study have resulted in decrements in heel counter stability of less than 10%.[35] However, to minimize the effect from shoe alterations in this study, windows were maintained as small as possible, and any changes that resulted from altering shoe construction were quantified by testing each shoe before and after the windows were cut. Ideally, kinematic measures recorded before and after altering the shoes would provide the best assessment of the effect of shoe alterations on foot kinematics (the dependent variable in this study). However, the shoes could not be removed without disrupting the kinematic markers, thus as an alternative for this study the percent change in peak force under the heel and forefoot (locations of the windows) were calculated from plantar pressure data collected with a pressure insole (PEDAR; Novel, Inc, Minneapolis, MN), while the subject walked before and after the windows were cut. At the heel, the average (SD) percent change was –1.1% ± 3.7%, while at the forefoot it was 1.9% ± 3.3%, suggesting that the shoe modifications are unlikely to influence the effect of air bladder inflation on foot kinematics.

Three air bladder inflation conditions were randomly tested (0, 4, and 7 PSI, [SI equivalent: 0, 27 579, and 48 263 Pa) in each subject. Inflation of the air bladder was done in a non–weight-bearing position using a 15-PSI pressure gauge (model 595-02; Ashcroft, Inc, Stratford, CT), before each set of walking trials was collected. Following donning the brace, shoe, and IRED markers, subjects were asked to walk down a 10-m walkway to establish their mean, self-selected walking speeds. Subsequently, speed was monitored with the use of a timing system (Brower, Salt Lake City, UT) and maintained during testing to within ±5%. Average (SD) walking speed was 1.13 (0.21) m/s. Each subject completed a minimum of 5 successful trials, consisting of full contact with the force plate for each air bladder inflation level (0, 4, and

TABLE 2	Within-Day Trial-to-Trial Reliability for Each Kinematic Variable of Interest at the Point in Stance in Which Significant Differences Were Observed		
Kinematic Variable	**$ICC_{3,1}$**	**2 SEM***	**Rocker**
Hindfoot ev/inv	0.973	0.7°	Second
Forefoot abd/add	0.980	1.6°	Third
Forefoot pf/df	0.952	2.1°	Third

Abbreviations: abd/add, abduction/adduction; ev/inv, eversion/inversion; ICC, intraclass correlation coefficient; pf/df, plantar flexion/dorsiflexion; SEM, standard error of the measurement.
** Formula for 2 SEM: $2(s_x\sqrt{1 - ICC})$, where s_x = standard deviation.*

TABLE 3	Descriptive Data (Mean ± SD degrees) for Each Kinematic Variable at the Midpoint of Each Rocker*			
	0 PSI	**4 PSI**	**7 PSI**	***P* Value**
Hindfoot ev/inv				
First rocker	–7.8 ± 2.5	–7.0 ± 2.7	–7.3 ± 2.5	.17
Second rocker	–8.1 ± 2.2	–6.5 ± 2.3	–6.4 ± 2.3	.006
Third rocker	–1.0 ± 2.2	–0.4 ± 2.2	–0.5 ± 2.3	.45
Forefoot pf/df				
First rocker	7.0 ± 2.0	7.4 ± 3.6	7.2 ± 3.2	.81
Second rocker	4.7 ± 1.5	4.1 ± 2.9	3.6 ± 2.5	.25
Third rocker	0.6 ± 4.8	–0.9 ± 4.8	–0.3 ± 4.8	.09
Forefoot abd/add				
First rocker	–3.2 ± 4.1	–3.3 ± 4.6	–2.8 ± 4.5	.38
Second rocker	–4.7 ± 2.9	–5.2 ± 3.2	–4.3 ± 3.2	.19
Third rocker	–2.5 ± 5.7	–1.2 ± 6.9	–0.5 ± 7.1	.06

Abbreviations: abd/add, abduction/adduction; ev/inv, eversion/inversion; pf/df, plantar flexion/dorsiflexion.
**The effect of air bladder inflation was dependent on the phase of stance for each of the kinematic variables; therefore, main effects were ignored.* P *values represent results of 1-way ANOVA models for each rocker. Positive values indicate hindfoot inversion, forefoot dorsiflexion, and forefoot adduction.*

7 PSI). To assess variability unrelated to air bladder inflation, within-day, trial-to-trial variability of each kinematic variable was examined in the no-inflation condition. The intraclass correlation coefficient (ICC) and standard error of the measurement (SEM) were calculated from these data to represent variability in the measurement. The SEM represents the total variability in the study from both technical errors and individual variation between trials; therefore, differences greater than 2 SEM were considered above error for each kinematic variable. The 2 SEM was 0.7° for hindfoot inversion (during second rocker), 1.6° for forefoot adduction (during third rocker), and 2.1° for forefoot plantar flexion (during third rocker) (**TABLE 2**).

Data Analysis

The purpose of this investigation was to evaluate the air bladder component of the AirLift PTTD brace on foot kinematics in subjects with stage II PTTD. A repeated-measures research design was used with air bladder inflation levels (0, 4, and 7 PSI) tested in each subject during the stance phase of gait. Raw kinematic patterns were inspected and, in general, each inflation condition produced an offset pattern from the no-inflation condition across stance. For this reason, the midpoint of each rocker was chosen as representative of the different functional demands placed on the foot across the stance phase. The rockers also represent distinct periods where the functional demands on the foot have been shown to be altered in subjects with PTTD.[26] The midpoint of each rocker was defined consistent with previous studies (10%, 50%, and 90% of stance).[7,23] Analysis was completed using 2-way repeated-measures analysis of variance (ANOVA) models for each dependent variable (hindfoot eversion, forefoot abduction, and forefoot dorsiflexion). In each ANOVA model, air bladder inflation level (0, 4, and 7 PSI) served as the first factor, while phase of stance (first, second, and third rocker) served as the second factor. In the presence of a significant interaction, main effects were ignored and repeated-measures 1-way ANOVA models were pursued at each phase of stance, with preplanned pairwise comparisons to determine the effect of each level of air bladder inflation.

RESULTS

The effect of air bladder inflation was dependent on the phase of stance for hindfoot eversion/inversion (P = .001). Following a significant phase-by-inflation interaction a repeated-measures 1-way ANOVA was pursued at each phase of stance. A difference between inflation conditions was observed at the second rocker (P = .006), while no differences were observed at the first (P = .17) or third (P = .45) rocker. At the second rocker, pairwise comparisons between inflation levels revealed differences between 0 and 4 PSI were 1.6° (P = .04), differences between 0 and 7 PSI were 1.8° (P = .002), and differences between 4 and 7 PSI were 0.2° (P = .72) (**TABLE 3, FIGURE 1**).

The effect of air bladder inflation was dependent on the phase of stance for forefoot plantar flexion/dorsiflexion (P = .031). Following a significant phase-by-

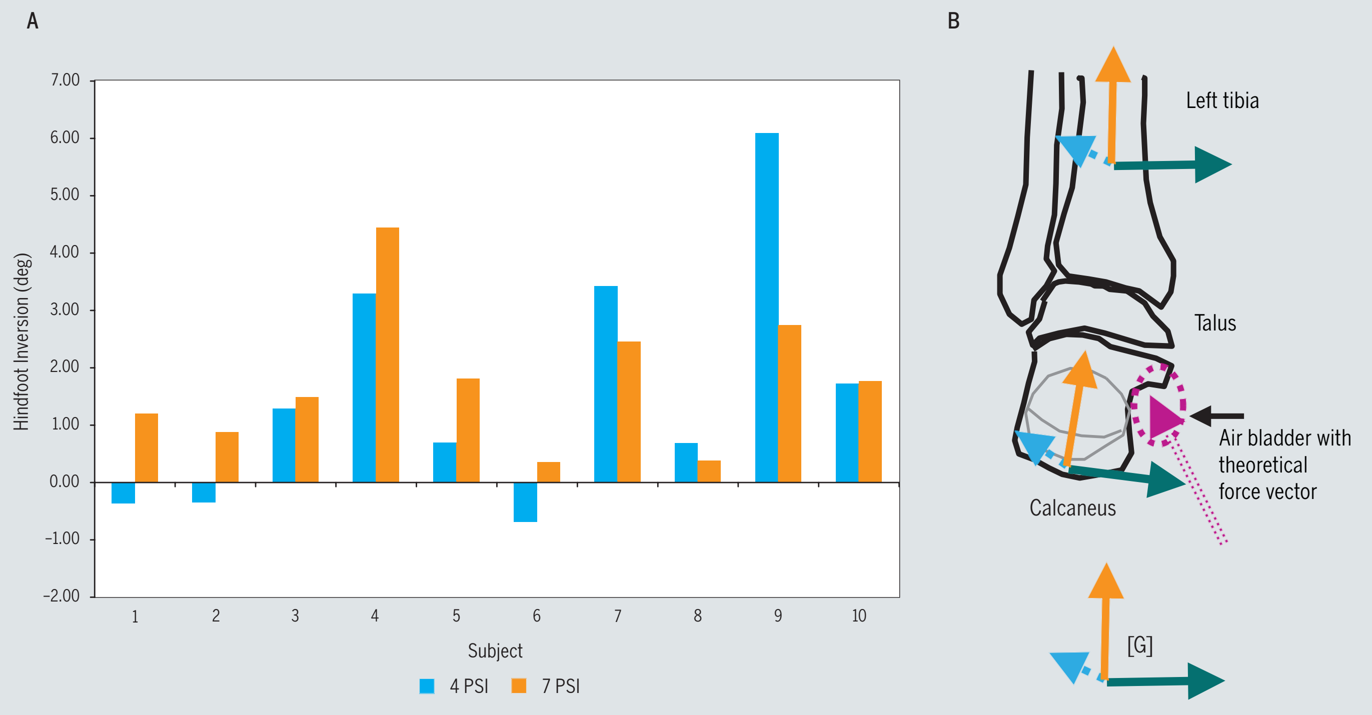

FIGURE 1. (A) Changes in frontal plane hindfoot motion with air bladder inflation. Positive values indicate hindfoot inversion. (B) Schematic representation of how air bladder inflation influences hindfoot kinematics in subjects with posterior tibial tendon dysfunction.

inflation interaction, a repeated-measures 1-way ANOVA was pursued at each phase of stance. The difference between inflation conditions at the third rocker had a significance level of $P = .09$, while the level of significance at the first and second rocker were $P = .81$ and $P = .25$, respectively. At the third rocker, pairwise comparisons between inflation levels revealed a difference between 0 and 4 PSI of 1.5° ($P = .02$), between 0 and 7 PSI of 0.9° ($P = .23$), and between 4 and 7 PSI of 0.6° ($P = .46$) (**TABLE 3, FIGURE 2**).

The effect of air bladder inflation was dependent on the phase of stance for forefoot abduction/adduction ($P = .002$). Following a significant phase-by-inflation interaction a repeated-measures 1-way ANOVA was pursued at each phase of stance. The level of significance for the difference between inflation conditions was $P = .06$ at the third rocker, $P = .38$ at the first rocker, and $P = .19$ at the second rocker. At the third rocker, pairwise comparisons between inflation levels revealed a difference between 0 and 4 PSI of 1.3° ($P = .12$), between 0 and 7 PSI of 2.0° ($P = .08$), and between 4 and 7 PSI of 0.7° ($P = .15$) (**TABLE 3, FIGURE 3**).

DISCUSSION

As hypothesized, inflation of the air bladder in the AirLift PTTD brace was associated with improvement in abnormal foot kinematics; however, air bladder inflation had a greater and more consistent effect on hindfoot motion than forefoot motion. Air bladder inflation produced hindfoot inversion during the second rocker limiting excessive hindfoot eversion observed in subjects with PTTD. Reducing hindfoot eversion may limit attenuation of the posterior tibialis musculotendon and may increase midfoot stability.[3,10] Air bladder inflation had less effect on forefoot motion, with the greatest effect occurring during the third rocker. Forefoot control may further contribute to unloading the posterior tibialis musculotendon, as well as the passive support structures of the foot such as the spring ligament. Interestingly, 2 of the subjects tested demonstrated responses in forefoot motion that were inconsistent from trends in the remaining 8 subjects. Subject-specific responses may be attributed to foot structure and are observed in other studies of orthotic devices.[19,31] If foot kinematics provide an indication of the overall outcome with use of the brace, these results would suggest that higher levels (7 PSI) of air bladder inflation are no more beneficial than lower levels (4 PSI). It is unclear from this study if inflation to levels below 4 PSI has any effect on foot kinematics.

On average, changes in hindfoot and forefoot kinematics were small, but obvious variability in responses were also observed. Changes in foot kinematics, although small, may provide clinical benefit by unloading support tissues (tendon and ligament). Hindfoot kinematic changes of 2° have been argued to be related to clinical improvement with the use of orthotic devices,[12] but the clinical benefits from forefoot and midfoot control are less studied. With this in mind, clinical interpretation of the study results should

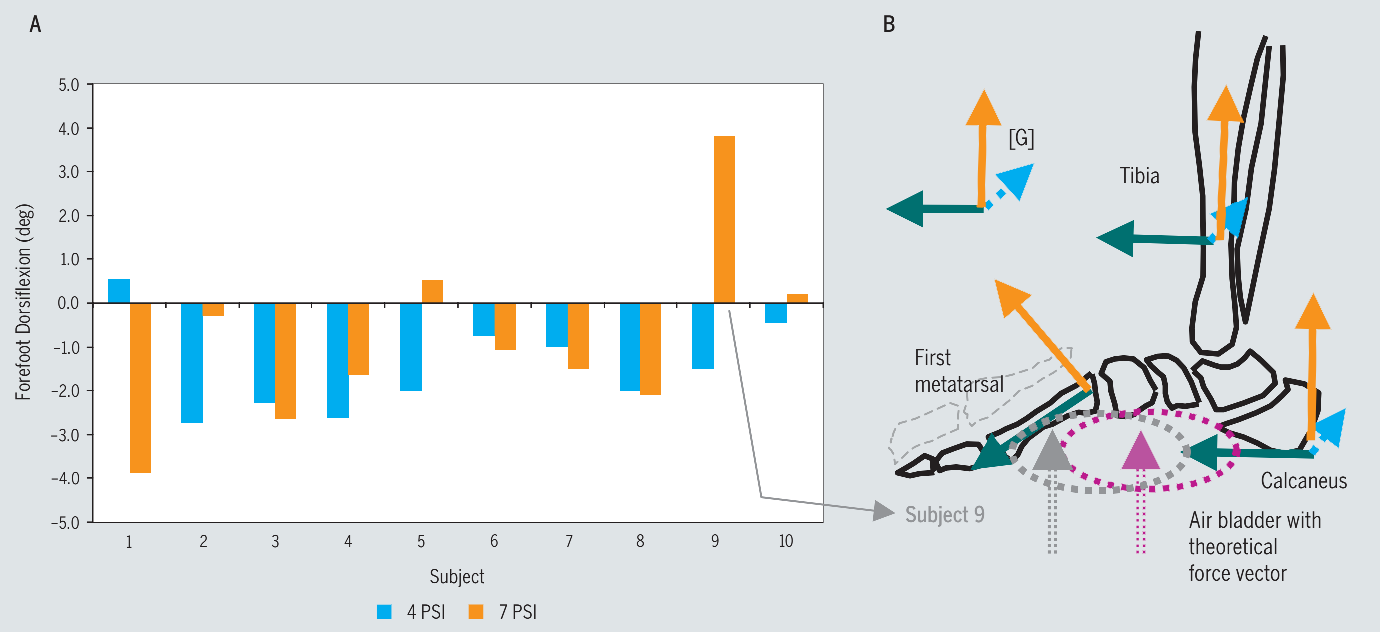

FIGURE 2. (A) Changes in sagittal plane forefoot motion with air bladder inflation at the third rocker. Positive values indicate forefoot dorsiflexion (inflated conditions relative to no inflation). (B) Schematic representation of how air bladder inflation influences forefoot kinematics in subjects with PTTD with shadowed air bladder and force vector indicating possible faulty location in subject 9.

recognize that, although on average the addition of the air bladder component had a small but positive effect, individual responses were variable, with some marked positive and negative responses. As an example, with air bladder inflation, subject 4 demonstrated improved hindfoot inversion of 4.4°, followed by improved forefoot plantar flexion of 2.6° and forefoot adduction of 6.5°. Success in this subject should be contrasted, however, with subject 10 who, despite small but measurable improvement in hindfoot inversion of 1.8° at the second rocker, had no change in forefoot plantar flexion (0.5°) and worsened forefoot abduction by (3.4°). These responses suggest clinical benefit may vary widely from inflation of the air bladder component of the AirLift PTTD brace.

Addition of the air bladder component to the AirLift brace provides an overall small but positive effect on hindfoot motion, which may provide clinical benefit by stabilizing the midfoot and unloading support structures. All 10 subjects tested demonstrated improved hindfoot inversion with inflation of the air bladder to one of the tested levels (4 or 7 PSI). However, these changes were on average small (mean, 1.7°; range, 0.69° to 6.10°), making the clinical benefit of the air bladder unclear. Three of the 10 subjects had changes that exceeded 2°, which may be a clinically important change for these subjects. Small changes attributable to the air bladder may add to changes from the clamshell component to further enhance clinical benefit.[9,29] Hindfoot inversion has been shown to stabilize the midfoot and contribute to unloading the posterior tibialis musculotendon supporting the clinical use of the air bladder component of the AirLift PTTD brace.[10,20]

On average, the effect of air bladder inflation on forefoot plantar flexion was small and variable, with the largest effect occurring during the third rocker. The air bladder location along the medial midfoot was designed to impart a force to raise the MLA when inflated (**FIGURE 2**). Forefoot plantar flexion relative to the hindfoot is consistent with raising the MLA in the foot model used in this study. Unloading of the passive ligamentous structures, such as the spring ligament, and altered dynamic function of the posterior tibialis muscle are potential effects of raising the MLA.[13,22] Foot size, in addition to abnormal foot kinematics, is likely to influence the location of the force imparted under the MLA by the air bladder and may explain some of the variable responses observed. The AirLift PTTD brace comes in 3 sizes to accommodate variability in foot size. Truncated foot length represents the length of the MLA (distance from posterior heel to first metatarsal-phalangeal joint line) and was recorded to describe subjects enrolled in the study (used to calculate the arch height index). Subject 9 had the smallest truncated foot length in the group and was fitted with a small brace, according to manufacturer recommendations (shoe size, 8.5). An increase in forefoot dorsiflexion with air bladder inflation could occur if the location of the force imparted on the MLA in subject 9 was too distal in the foot (relative to the axis of rotation) due to the subject's small foot size. Although other subjects also wore a small brace (subjects 2, 3, 5, 6, and 8-10), their truncated foot lengths were greater. For off-the-shelf braces, alternative sizes may

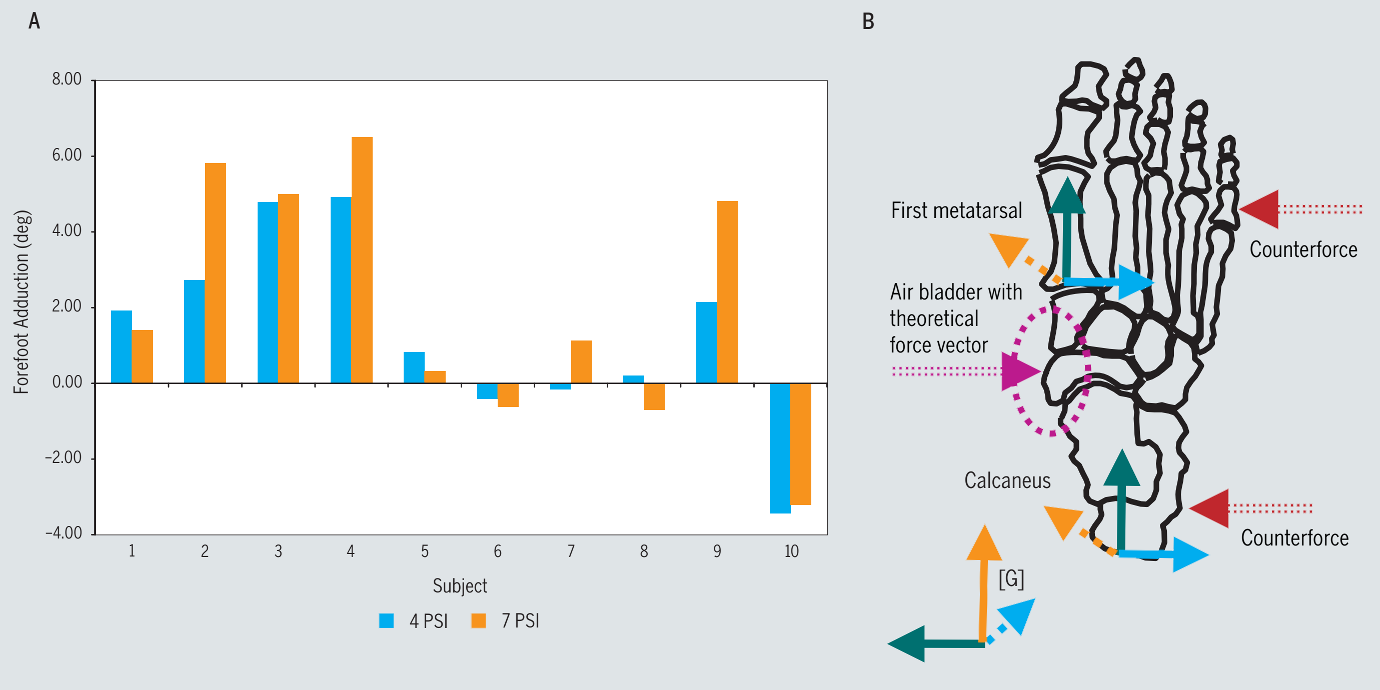

FIGURE 3. (A) Changes in transverse plane forefoot motion with air bladder inflation at the third rocker. Positive values indicate forefoot adduction (inflated conditions relative to no inflation). (B) Schematic representation of how air bladder inflation influences forefoot kinematics in subjects with posterior tibial tendon dysfunction with theoretical force and counter forces provided by the air bladder and lateral wall of the shoe, respectively.

be necessary to ensure that design components like the air bladder influence abnormal foot kinematics as intended.

Even greater variability in subjects' responses was observed with air bladder inflation and its effect on forefoot adduction. On average, the effect was small, with the largest effect during the third rocker. A force directed from medial to lateral at the midfoot with air bladder inflation could reduce excessive forefoot abduction, if counter forces were provided by the shoe at the lateral heel and lateral fifth metatarsal (**FIGURE 3**). Excessive forefoot abduction identified in subjects with stage II PTTD contributes to lengthening the posterior tibialis musculotendon.[10] One subject (subject 10) demonstrated an increase in forefoot abduction with air bladder inflation. Although the same shoe (size, 8.5) was used in testing 2 other subjects (subjects 3 and 9), the dynamic function of subject 10's foot differed from that of the others. Subject 10 exhibited the greatest average forefoot abduction across all phases of stance (10.4°; group average ± SD, 3.5° ± 3.8°) during the no-air-bladder-inflation condition. And, with air bladder inflation, forefoot abduction increased (which is theoretically detrimental to subjects with PTTD) in this subject, the brace being unable to correct the subject's advanced deformity. Perhaps more aggressive or custom-bracing options are necessary to correct advanced deformity. Clinical measures to identify subjects who may require alternative brace strategies to mitigate abnormal foot kinematics do not exist and are recommended for future research.

Limitations to this study are related to subject selection, biomechanical modeling, and research design. The classification of stage II PTTD includes a wide range of patients with varying severity of foot deformity. Refined classification schemes have been proposed to divide stage II into more substages.[4,14] Provided the relatively small sample of 10 subjects tested in this study, it would be warranted to further investigate orthotic device response from subgroups of subjects. This study set forth to investigate the air bladder component of the AirLift PTTD brace using a biomechanical model of the foot. Numerous kinematic models have been used to study foot and ankle function, with results affected by the choice of segmentation, joint alignment, and marker location. Other components are incorporated into the design of the brace and may also provide benefits to subjects with stage II PTTD but were not evaluated in this study. Effects from air bladder inflation were variable with some marked improvements in some subjects, while others had a negative response, suggesting that clinical use of the air bladder may also result in variable responses. The research design used in this study allowed for only a brief time for subjects to accommodate to the current brace and air bladder inflation level. It remains unclear if accommodation over days or weeks would change the kinematic effects of air bladder inflation. Additionally, it should be noted that changes in forefoot motion were variable and significant at the 0.06-to-0.09 level, suggesting that the effects of the brace on specific subjects should be interpreted with caution.

Clinical Implications

Variability in the kinematic responses observed from the 10 subjects tested in this study suggest that, although the effect of the air bladder component in the AirLift PTTD brace was positive, some subjects may be better served with alternate designs. The goal of the air bladder in the AirLift PTTD brace is to unload active and passive support structures by correcting abnormal flatfoot kinematics. This goal was achieved in some subjects but not in others. As a cost-effective and convenient option that can be dispensed in the clinic, this off-the-shelf brace may serve as a good first orthotic treatment option for some patients with stage II PTTD. Positive effects from air bladder inflation may combine with effects from other device components (ankle clam shell)[29] to explain the positive outcome observed clinically with use of the AirLift brace. Further development of device components to optimize patient responses plus research to clinically identify subjects who will be successful candidates will advance the treatment of patients with stage II PTTD.

CONCLUSIONS

Air bladder inflation produced small but positive effects in correcting flatfoot kinematics in subjects with stage II PTTD. The effect was more consistent for hindfoot control compared to forefoot control. Improved foot kinematics are theorized to unload active and passive support structures. However, subject specific responses suggest that foot size and degree of deformity may play important roles in the effectiveness of off-the-shelf braces. Individual patient responses should guide clinical recommendations for air bladder inflation, as kinematic responses did not always improve with higher inflation levels. Although further research is needed to optimize outcomes with this orthotic device, the results from this study identify an efficient and cost-effective orthosis to treat flatfoot kinematics in patients with stage II PTTD. ◉

KEY POINTS

FINDINGS: Air bladder inflation in the AirLift PTTD brace provides small but positive changes in flatfoot kinematics in subjects with stage II PTTD. Changes in hindfoot inversion were more consistent than changes in forefoot plantar flexion and forefoot adduction.

IMPLICATIONS: As a cost-effective and easily used orthotic device, the AirLift PTTD brace is associated with biomechanical changes that are theoretically beneficial to patients with stage II PTTD.

CAUTION: This study examined a limited sample of subjects with stage II PTTD, with noted variability in the kinematic responses, and no short- or long-term clinical outcome measures were included. This suggests variability in the clinical outcomes from use of the brace is expected across patients.

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