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ORIGINAL RESEARCH

Effects of Medially Wedged Foot Orthoses on Knee and Hip Joint Running Mechanics in Females With and Without Patellofemoral Pain Syndrome

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We examined the effects of medially wedged foot orthoses on knee and hip joint mechanics during running in females with and without patellofemoral pain syndrome (PFPS). We also tested if these effects depend on standing calcaneal eversion angle. Twenty female runners with and without PFPS participated. Knee and hip joint transverse and frontal plane peak angle, excursion, and peak internal knee and hip abduction moment were calculated while running with and without a 6° full-length medially wedged foot orthoses. Separate 3-factor mixed ANOVAs (group [PFPS, control] x condition [medial wedge, no medial wedge] x standing calcaneal angle [everted, neutral, inverted]) were used to test the effect of medially wedged orthoses on each dependent variable. Knee abduction moment increased 3% ($P = .03$) and hip adduction excursion decreased 0.6° ($P < .01$) using medially wedged foot orthoses. No significant group x condition or calcaneal angle x condition effects were observed. The addition of medially wedged foot orthoses to standardized running shoes had minimal effect on knee and hip joint mechanics during running thought to be associated with the etiology or exacerbation of PFPS symptoms. These effects did not appear to depend on injury status or standing calcaneal posture.

Keywords: kinetics, kinematics, rehabilitation, gait

Patellofemoral pain syndrome (PFPS) is one of the most common orthopedic conditions,[1–3] particularly in active, young females.[3,4] Murray et al[2] reported that PFPS accounted for 34% of knee injuries and 10% of all injuries among individuals seeking treatment at a sports injury clinic. Due to the high recurrence rate of PFPS and a potential association with the future development of patellofemoral osteoarthritis this condition warrants further study.[5,6]

The etiology of PFPS is likely multifactorial yet appears to be related to abnormal patellar alignment relative to the femoral trochlea during weight bearing activities and elevated patellofemoral joint stress.[7–10] Altered foot posture and foot and ankle kinematics may contribute to hip and knee joint mechanics thought to increase patellofemoral joint stress.[9,11] Specifically, increased foot pronation has been suspected by these authors to contribute to increased compensatory femoral internal rotation, hip adduction, and knee abduction, resulting in decreased patellofemoral contact area and increased retropatellar stress. In addition, individuals with PFPS have been reported to display a greater rearfoot valgus posture and increased navicular drop than subjects without PFPS[12,13] as well as greater hip internal rotation, hip adduction, and knee external rotation during running.[14–17] Additionally, individuals with greater foot mobility during weight bearing appear twice as likely to develop PFPS.[18]

Medially wedged foot orthoses are often prescribed to reduce knee and hip joint mechanics thought to increase retropatellar stress by reducing calcaneal eversion and tibial internal rotation during the stance phase of running.[19,20] However, inconsistent effects of medially wedged foot orthoses on knee joint running mechanics have been reported in previous studies[20–22] and the effects of medially wedged foot orthoses on hip joint mechanics during running have yet to be investigated. Further, recent evidence suggests individuals with PFPS demonstrate unique static and dynamic measures of foot mechanics.[23] This suggests it is possible that the effect of medially wedged foot orthoses on knee and hip joint mechanics may be different between females with and without PFPS. If so, these previous studies of the effects of foot orthoses on gait mechanics that include only healthy participants may not generalize well to individuals with PFPS.

Although the specific rationale remains elusive, medially wedged orthoses for PFPS may reduce pain and

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hasten recovery time compared with therapeutic exercise alone or use of a flat shoe insert as an intervention.[24–27] It is conceivable that the mechanism for these positive effects is a reduction of hip and knee joint transverse and frontal plane kinematics and kinetics believed to increase patellofemoral joint stress. However, hip and knee joint mechanics have not been evaluated in previous clinical studies among people with PFPS and it is not clear that these effects observed using healthy subjects generalize well to people with PFPS. Thus, the purpose our study was to evaluate the effects of medially wedged foot orthoses on hip and knee joint transverse and frontal plane joint mechanics during running in females with and without PFPS. Based on previous reports of unique foot postures and hip and knee joint mechanics during running among females with PFPS, it was hypothesized that medially wedged orthoses would have a greater effect on transverse and frontal plane hip and knee joint mechanics during running in females with PFPS than females without PFPS. It was also hypothesized that the effects of medially wedged orthoses would be greatest among females with the most standing calcaneal eversion.

Methods

The study protocol was approved by the university institutional review board and all subjects provided informed consent before participation. Using an alpha level of 0.05 and a beta level of 0.2, 19 participants per group were calculated to be necessary to identify group × condition interaction effect sizes greater than 0.7 for the dependent variable with the greatest variability (peak knee external rotation). For this sample size calculation, variability of the dependent variables was estimated from previous studies of running mechanics that used similar methodology.[16,28] All participants were female runners, 18–35 years old, who ran at least 10 miles per week and reported their activity level as greater than or equal to 5 out of 10 on the Tegner activity scale (a measure of regular participation in recreational sports activities that require running or jumping).[29] All subjects who were pregnant or reported known cardiovascular pathology, foot or ankle pain, surgery to either lower extremity in the last 12 months, or traumatic injury to either knee joint within 6 months of the study were excluded from participation. Control group subjects had to be free of lower extremity symptoms during running for the last two years.

Forty-two potential participants with complaints of knee pain during running were screened by a licensed physical therapist for specific criteria to be included in the PFPS group. These criteria included a verbal pain score of at least a 3 (moderate) on a 10 point verbal pain scale during running and during one additional activity such as squatting, prolonged sitting, ascending or descending stairs, or jumping. The potential participants must have also described pain behind or adjacent to the patella and not solely at the iliotibial band, patellar tendon, or knee joint line. Symptoms were required to be of insidious onset and of at least 2 months in duration. Participants with PFPS had to report that their symptoms were exacerbated with manual compression of the patella into the trochlear groove with the knee in 15° of flexion or with palpation of the medial or lateral patellar retinaculum against the posterior patellar surface. Lastly, participants with PFPS were required to score less than 85/100 on the Anterior Knee Pain Scale.[30] Fifteen points on this scale has been determined to be the minimum clinically important difference from healthy controls.[31] Potential participants were excluded from participation if they presented for screening tests with signs and symptoms of meniscus or ligament pathology or were currently receiving physical therapy for PFPS.

Screening of potential participants continued until 20 females with PFPS and 20 healthy females were identified and agreed to participate in this investigation (Table 1). For participants with bilateral PFPS symptoms, the more symptomatic lower extremity was chosen for analysis (9 right legs, 11 left legs were analyzed). The right leg was used for comparison among females without PFPS. All participants wore the same type of shoe (model 629, New Balance, Boston, MA) with and without the medially wedged orthoses to reduce variability that may be caused by different shoe absorption properties or other design characteristics.

Procedure

Before motion analysis testing, standing calcaneal angle was recorded for all participants during single leg stance using methods similar to those previously described.[32,33] These data were recorded to determine if foot orthoses influence on knee and hip kinematics may partly depend

Table 1 Average (SD) subject demographics for females with and without patellofemoral pain (PFPS)

	n	Age (y)	Weight (kg)	Height (m)	Miles run per week	Calcaneal angle (deg)
No PFPS	20	21.6 (4.5)	62.1 (8.9)	1.69 (0.09)	21.1 (12.2)	90.1 (4.9)
PFPS	20	21.3 (2.6)	62.9 (7.7)	1.68 (0.06)	15.6 (8.1)	89.6 (3.1)
P		0.83	0.75	0.86	0.10	0.73

on whether a person demonstrates clinical signs of foot pronation. Participants were asked to lie prone with the plantar aspect of the uninvolved foot against the medial side of the involved knee and the foot of the involved limb (PFPS group) or right limb (control group) positioned in 0° ankle dorsiflexion and the long axis of the foot oriented vertically off the end of a plinth. In this position, marks were drawn at the insertion of the Achilles tendon and midpoint of the distal calcaneus. Next, three digital images of the calcaneal markers were recorded as participants stood on one leg with their foot on a line with a digital camera placed 3 m posterior to the subject. Participants stood on a raised platform such that the middle of the calcaneus was at the same height as the lens of the camera. Participants were allowed to use the wall for balance as necessary during the image capture. Images were transferred to a computer and analyzed using CorelDraw (Ottawa, Ontario). Standing calcaneal angle was measured by a single rater and defined as the angle of a line connecting the calcaneal markers in these images relative to horizontal (Figure 1). The average of the three images was used for analysis. Levinger et al[33] reported an intrarater ICC of 0.97 between three measurements of standing calcaneal angle using video images among females with PFPS.

Subjects were prepared for 3D motion analysis testing by attaching reflective markers on the leg and pelvis of the target limb. The 3D coordinates of these markers were used to record motion of the pelvis, femur, shank, and foot, each modeled as a rigid body. Anatomical markers used to establish the segmental coordinate systems were placed over the most lateral aspect of each iliac crest, the greater trochanters, medial and lateral femoral condyles, medial and lateral proximal tibia, medial and lateral malleoli, the first and fifth metatarsal heads, and the tip of the shoe. Tracking markers, which remained in place for all of the running trials, were positioned as a cluster of 3 markers on the rearfoot of the shoe, a cluster of 4 markers on the posterior shank, a cluster of 4 markers on the lateral thigh, and 3 markers for the pelvis on each anterior superior iliac spine and at the L5-S1 interspace. The knee joint center was assumed to be the midpoint of a line between the femoral condyle markers. Ankle joint center was assumed to be the midpoint of a line between the two malleoli markers. The hip joint center was identified using a Newton iterative spherical fitting algorithm on data recorded during a standing trial where the instrumented leg was moved in a prescribed fashion before the running trials.[34] During this trial, participants stood on their contralateral leg while moving the target leg through two arcs of approximately 80° hip flexion and two arcs of 50° hip abduction. Following both the standing calibration trial and hip center movement trial, the anatomical markers were removed.

Running mechanics were recorded as participants ran along a 20 m (65 foot) runway between 3.52–3.89 m/s as indicated by the average forward velocity of a marker on the sacrum in the laboratory coordinate system during 9 video frames before first contact with the force platform. A 10 N threshold was used to determine foot contact based on the onset of the vertical ground reaction force. After at least 5 practice trials, 5 trials were collected without orthoses for further analysis. Next, 6° EVA medial wedges (65 Shore A hardness, Foot Management, Inc., Pittsville, MD) that extended beyond the metatarsal heads for each participant were inserted under the sock liner of each shoe and the running trials were repeated. To accommodate to the orthoses, subjects were asked to repeat the 5 practice trials before the motion trials for the orthoses condition.

During each running trial, marker data were collected at 120 Hz using 8 Eagle digital cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) positioned around the runway. Marker trajectories were digitally filtered at 12 Hz using a low-pass, fourth-order Butterworth recursive filter. Hip and knee transverse and frontal plane joint angles during the stance phase for each running trial were calculated with Visual 3D software (C-Motion Inc, Rockville, MD) using a sequence of rotations that first calculated flexion-extension, followed by abduction-adduction, and internal-external rotation, respectively. Joint kinematic conventions were defined using the right-hand rule. Hip and knee frontal and transverse plane joint excursions were calculated as the change in joint angle from the time of initial contact with the force plate to peak joint position for each running trial using custom software (LabView 8.6, National Instruments, Austin, TX). Kinematic data were not normalized to the static neutral trial, such that zero degrees corresponded to a position where thigh and shank coordinate systems were aligned.

Ground reaction forces were recorded at 1080 Hz by a force platform (Model 4080, Bertec Corporation,

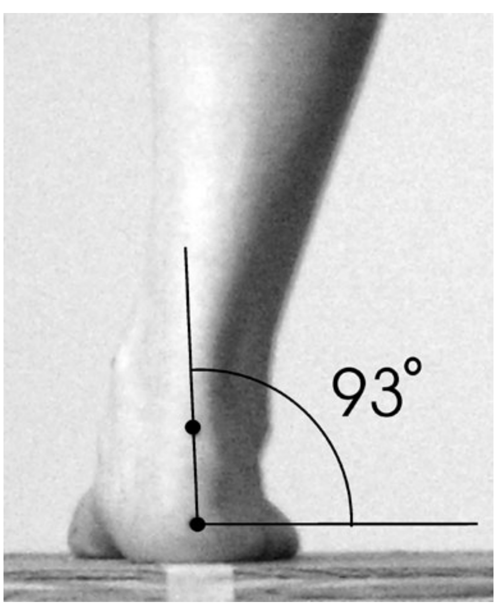

Figure 1 — Standing calcaneal angle relative to horizontal.

Columbus, OH) flush with the surface of the runway. The ground reaction force data used to identify specific gait events (initial contact and toe off during running) were digitally filtered at 50 Hz using a low-pass, fourth-order Butterworth recursive filter. Internal joint moments during running were calculated by Visual 3D using an inverse dynamics approach, normalized to participant height and mass, and reported in the reference frame of the distal segment. Ground reaction force data for calculating hip and knee joint moments were digitally filtered using a low pass, fourth order Butterworth recursive filter at the same cut off frequency as the kinematic data (12 Hz).[35]

Kinematic and kinetic dependent variables of interest included hip and knee transverse and frontal plane peak angles and joint excursion during the stance phase of running as well as peak internal hip and knee abduction moment. The average of these variables of interest from all five running trials for each condition were calculated and used for analysis. The effect of medially wedged orthoses on each kinematic and kinetic dependent variable of interest was analyzed using separate 3 factor mixed ANOVAs (group (PFPS, control) × condition (medial wedge, no medial wedge) × standing calcaneal angle [eversion, inversion, neutral]). For this analysis, the 14 participants with the greatest and smallest standing calcaneal angles were defined as "everted" and "inverted," respectively. The remaining 12 participants were defined as "neutral" (Table 2). Standing calcaneal angle was compared between females with and without PFPS with an independent *t* test. All statistical procedures were performed in SPSS with alpha set to 0.05 (version 18, SPSS Inc., Chicago, IL).

Results

Participant demographics and standing calcaneal angle were similar between groups of females with and without PFPS (Table 1). No participant in either group reported knee pain during the motion analysis trials.

No three way interactions (group × condition × calcaneal angle) were observed for any hip or knee joint kinematic or kinetic variable examined. Similarly, no statistically significant group × condition interactions or condition × calcaneal angle interactions were observed. Therefore, the effects of medially wedged orthoses on hip and knee transverse and frontal plane running mechanics was similar among females with and without PFPS and was not influenced by standing calcaneal angle.

Main effects of foot orthoses were not observed for peak knee and hip transverse and frontal plane joint angles during running after pooling data from all 40 subjects (Table 3). However, a small yet statistically significant

Table 2 Standing calcaneal angle by group for participants who demonstrate eversion, neutral, or inversion standing calcaneal posture

	Sample size (injury status)	Average (deg)	SD (deg)	Range (deg)
Eversion	14 (7 PFPS, 7 No PFPS)	93.8 (2.8)	2.8	91.0–100.6
Neutral	12 (7 PFPS, 5 No PFPS)	89.9 (0.6)	0.6	88.9–90.8
Inversion	14 (6 PFPS, 8 No PFPS)	85.8 (2.7)	2.7	80.4–88.9

Table 3 Mean peak joint angles (SD) during running organized by main effects (units = degrees)

	Hip		Knee	
	Internal rotation	Adduction	Internal rotation	Abduction
No wedge	2.5 (7.9)	18.2 (4.3)	5.6 (7.4)	4.4 (3.8)
Medial wedge	2.6 (8.1)	17.8 (4.4)	5.9 (7.3)	4.7 (3.9)
P	0.75	0.20	0.49	0.16
No PFPS	1.9 (8.6)	19.2 (4.4)	5.9 (7.7)	5.0 (4.2)
PFPS	3.3 (7.3)	16.8 (3.9)	5.6 (7.0)	4.1 (3.4)
P	0.53	0.06	0.33	0.17
Calcaneal eversion	3.6 (7.0)	17.5 (5.1)	6.1 (8.7)	5.1 (3.8)
Calcaneal neutral	1.3 (8.2)	19.0 (4.1)	4.8 (7.5)	4.9 (4.0)
Calcaneal inversion	2.7 (8.7)	17.7 (3.5)	6.2 (5.6)	3.7 (3.7)
P	0.71	0.56	0.74	0.39

decrease in hip adduction excursion (0.6°, $P < .01$) and a 3% greater internal knee abduction moment was identified while running with medially wedged orthoses ($P = .03$) (Tables 4, 5).

No group main effects were observed for knee or hip transverse and frontal plane peak angles or joint excursion between females with and without PFPS during running (Tables 3, 4). However, females with PFPS produced 12% less ($P = .05$) hip abduction moment during running relative to females without PFPS (Table 5).

Finally, average standing calcaneal angle was 8° greater among participants with the highest calcaneal eversion compared with those with the highest calcaneal inversion (effect size = 3.9) (Table 2). However, no main effect of standing calcaneal angle was observed for knee or hip transverse or frontal plane kinematics or joint moments during running.

Discussion

The purpose of our study was to examine if medially wedged foot orthoses influence knee and hip joint mechanics during running. We also tested if medially wedged orthoses affect knee and hip joint mechanics during running of females with PFPS differently than females without PFPS. Our findings suggest that medially wedged foot orthoses have little effect on knee and hip joint mechanics during running and that these effects are similar among females with and without PFPS. Thus, although medially wedged orthoses may reduce PFPS symptoms or hasten recovery time, a biomechanical explanation for this effect was not identified.[24–27] Finally, we tested if the effect of these orthoses on knee and hip joint mechanics during running depended on the magnitude of calcaneal eversion observed while standing.

Table 4 Mean joint angle excursions (SD) from initial contact to peak angle organized by main effects (units = degrees)

	Hip		Knee	
	Internal rotation	Adduction	Internal rotation	Abduction
No wedge	2.9 (2.8)	7.7 (2.8)	8.0 (3.6)	2.2 (2.4)
Medial wedge	2.8 (2.7)	7.1 (2.7)	8.4 (3.5)	2.6 (2.6)
P	0.34	<0.01	0.09	0.47
No PFPS	2.9 (2.6)	7.9 (2.8)	8.2 (3.2)	1.5 (1.9)
PFPS	2.8 (2.9)	6.8 (2.6)	8.2 (3.8)	3.0 (2.8)
P	0.88	0.21	0.45	0.10
Calcaneal eversion	2.6 (2.4)	7.8 (2.2)	8.7 (2.6)	2.6 (2.6)
Calcaneal neutral	2.7 (2.4)	6.9 (2.6)	7.1 (3.3)	2.7 (2.8)
Calcaneal inversion	3.3 (3.4)	7.4 (3.3)	8.7 (4.2)	1.5 (2.0)
P	0.77	0.80	0.54	0.47

Table 5 Mean peak internal joint moments (SD) during running organized by main effects (units = N·m/m·kg)

	Hip abduction	Knee abduction
No wedge	1.22 (0.23)	0.60 (0.21)
Medial wedge	1.19 (0.26)	0.62 (0.23)
P	0.20	0.03
No PFPS	1.29 (0.27)	0.64 (0.24)
PFPS	1.13 (0.20)	0.58 (0.20)
P	0.05	0.32
Calcaneal eversion	1.23 (0.27)	0.59 (0.25)
Calcaneal neutral	1.17 (0.18)	0.58 (0.18)
Calcaneal inversion	1.22 (0.28)	0.66 (0.21)
P	0.82	0.78

With respect to the dependent variables examined in this study, we conclude that the effect of medially wedged orthoses appears to be independent of standing calcaneal eversion angle.

To our knowledge, this is the first investigation to examine knee and hip joint mechanics during running in response to medially wedged foot orthoses among females with and without PFPS. Individuals with PFPS have been reported to demonstrate a more pronated foot type.[12] Increased foot pronation may be associated with more rapid rearfoot eversion during walking, but only among those with PFPS.[23] As altered timing and magnitude of rearfoot eversion are theorized to elicit compensatory effects in the transverse and frontal plane of the knee and hip during gait,[9,11] we anticipated that medially wedged foot orthoses to reduce rearfoot eversion may have unique effects on knee and hip joint mechanics during running among females with PFPS. However, the effects of these orthoses were not different among females with and without PFPS. It is possible that this finding is unique to our sample or that the medially wedged orthoses did not produce the anticipated effect within the shoe. Conversely, these results may reveal that proximal effects of medially wedged orthoses are similar between groups despite unique associations between foot posture and foot motion among individuals with PFPS.

Our hypothesis that the medially wedged foot orthoses would have a greater effect on running mechanics in subjects with the most everted, static calcaneal posture was also not supported. No previous studies that have compared the effects of foot orthoses on knee and hip mechanics during running classified their participants based on foot type. However, these results appear consistent with a previous study that showed no change rearfoot peak joint angles, excursions, and velocities with foot orthoses with a medial rearfoot post during walking among recreational runners with either high or low arch types.[36]

Clinical signs of foot pronation such as increased standing calcaneal eversion are often considered indications for use of medially wedged orthoses for treatment of PFPS.[20,37,38] However, it is not clear that greater pronation is associated with improved clinical outcomes due to foot orthoses. If increased pronation does improve clinical outcomes for individuals with PFPS, our data appears to suggest the benefits are not likely to be a consequence of changes in knee or hip joint angles or moments during running. This finding supports the conclusion of Nigg et al[39] who stated that the primary function of foot orthoses may not be skeletal realignment during gait. Rather, the primary function of foot orthoses may be to support the preferred movement of the skeleton by decreasing lower extremity muscle activity, minimizing fatigue, and reducing energy expenditure.[39]

There does not appear to be a generally accepted clinical method used to evaluate standing foot posture and we may have obtained different results had we used another measure to classify foot type. For example, the Foot Posture Index or the arch height index determined using the Arch Height Index Measurement System may be more comprehensive and reliable measures of standing foot posture compared with standing calcaneal angle.[23,40] However, many static measures of foot pronation have been found to have inconsistent relationships with dynamic foot motion.[33,41–43] As a result, our findings may simply reflect this inability to comprehensively describe the influence of foot posture on knee and hip mechanics during running.

It is also possible that increased foot mobility, rather than foot posture, has a stronger association with changes in knee and hip joint mechanics during running with a medially wedged foot orthoses. In a recently derived clinical prediction rule, increased mobility of the forefoot increased the likelihood of marked improvement in PFPS symptoms after a 12 week foot orthoses intervention.[44] Although knee and hip joint gait mechanics were not measured in their study, improvement of altered knee and hip transverse and frontal plane joint mechanics that increase patellofemoral joint stress is a possible explanation for their subjective improvements. Future studies of knee and hip joint gait mechanics among people who respond favorably to foot orthoses appear to seem justified.

No foot orthoses main effects were observed in our study with respect to transverse or frontal plane knee joint running kinematics. The intended effect of the full-length 6° medially wedged orthoses was to decrease calcaneal eversion, elevate the first metatarsal head, and to shift the center of pressure of the foot medially. The theoretical results of these mechanical changes due to this intervention at the foot are thought to reduce tibial internal rotation and foot abduction.[9,11] However, experimental studies of medially wedged foot orthoses on running mechanics show inconsistent effects on both center of pressure and proximal segment kinematics. Full-length laterally wedged orthoses appear to shift the center of pressure laterally during running.[22] However, a medial shift of the center of pressure during running was not observed in most participants when running with a full-length medially wedged orthoses.[22] A small (<2°) average decrease in peak tibial internal rotation during running with medially wedged foot orthoses has been reported by some authors,[20,45,46] but no change or an increase (4°) has been reported by others.[47,48] Similarly, a small (2-3°) increase in peak knee adduction has been reported by some,[48] while no change in peak frontal plane knee angle or excursion has been reported by others.[20,47] Though the statistical differences related to these kinematic effects in previous studies may vary, the magnitude of these effects is in every case unlikely to exceed the bounds of measurement error.[49] The results of our study are consistent with the previous studies that have reported both statistically and clinically insignificant changes in knee transverse or frontal plane peak angles or joint excursions while running using medially wedged foot orthoses. Therefore, clinicians should not expect a systematic and consistent effect on knee kinematics during running in response to medially wedged orthoses in those with and without PFPS.

Foot orthoses main effects were observed for the frontal plane knee moment during running. Specifically, the internal knee abduction moment increased by 3.3% among all participants during running with the use of a medially wedged foot orthoses. Williams et al[48] and Nigg et al[22] identified larger increases in knee abduction moment while running with medially wedged foot orthoses (approximately 18% and 11%, respectively). Although we observed smaller effects, this increased internal knee abduction moment may shift tibiofemoral compressive loads toward the medial compartment while increasing strain to the lateral knee joint structures such as the iliotibial band. Such changes are not intuitively beneficial to patellofemoral joint mechanics. In fact, increased knee abduction moment with use of a medially wedged orthoses may be an undesirable effect based on previous research which identified knee abduction moment impulse as a potential risk factor for PFPS development among runners.[50] Therefore, although the effect to knee abduction moment in this study was small, a repeated exposure to these increased moments during a prolonged run may actually represent a mechanism for exacerbation of PFPS symptoms due to the use of medially wedged foot orthoses.

To our knowledge, the effects of medially wedged foot orthoses on hip joint mechanics during running have not been previously reported. However, hip joint internal rotation and abduction have been observed among females with PFPS and are frequently implicated in the etiology and exacerbation of patient symptoms.[9,11,14–16,51] We observed a small but statistically significant decrease in hip adduction excursion among all subjects when running with medially wedged orthoses. Theoretically, this may reduce PFPS stress by decreasing iliotibial band tension since a portion of the iliotibial band inserts on the lateral patella through the lateral retinaculum as well as into Gerdy's tubercle of the tibia.[52,53] Through these attachments, greater iliotibial band tension may result in increased lateral patellar force or displacement[54,55] and tibial external rotation;[52] each potentially increasing retropatellar stress.[54,56] Decreased hip adduction excursion may also reduce PFPS stress by decreasing lateral quadriceps muscle forces.[57] However, it is important to reiterate that the effect of medially wedged orthoses on hip adduction motion was small and it is not clear that such a small effect would cause meaningful changes in patellofemoral joint stress.

Medially wedged foot orthoses did not affect hip transverse plane kinematics during running. Knowledge of factors that may decrease hip internal rotation may be particularly beneficial for the treatment of PFPS since increased hip internal rotation may increase patellofemoral joint stress due to decreased patellofemoral contact area during weight bearing activities.[58] Both theoretical and experimental studies alike suggest that hip internal rotation coincides with foot pronation and tibial internal rotation during weight bearing activities.[11,59] Further, increased hip internal rotation and foot pronation have been identified among females with PFPS, supporting an intuitive link between increased foot pronation and the etiology or exacerbation of PFPS.[12,15] However, the consistency of an association between the timing and magnitude of foot pronation and hip internal rotation during gait has been questioned in previous studies.[60,61] Our results appear to contradict the proposed association between foot pronation and hip internal rotation since medially wedged foot orthoses used to decrease calcaneal eversion did not result in a meaningful systematic reduction in hip transverse plane peak angles or joint excursion during running. In addition, a post hoc analysis of individual responses to medially wedged foot orthoses revealed that peak hip internal rotation decreased greater than one degree for only seven of the 40 participants, while eight participants increased hip external rotation greater than one degree, and 25 participants demonstrated virtually no change. Only one participant demonstrated a reduction in peak hip internal rotation greater than 3 degrees in response to the orthoses.

Limitations of the current study may include that the foot orthoses provided to females with and without PFPS were not full-contact foot orthoses. Full-contact foot orthoses may provide important sensory input to the foot that may influence foot loading patterns as well as vastus medialis and gluteus medius muscle activity during gait.[62–64] As such, our results may not generalize well to custom foot orthoses used by individuals with PFPS. In addition, the amount of wedging necessary to influence proximal joint motion has not been well described and varies considerably throughout the literature.[20,21,48,65,66] It is possible that wedging greater than 6° may be necessary to produce more substantive effects at proximal joints during running.[48] Another potential limitation was our choice to exclude foot and ankle kinematic and kinetic data from our analysis of running mechanics. We felt that reflective markers placed on the outside of the shoe would not provide a valid measure of foot motion within the shoe. Thus, although previous studies using similar methods have suggested that medially wedged foot orthoses may decrease peak calcaneal eversion during running,[22,45,46] we cannot be sure that these same effects were achieved in our investigation. To decrease participation time we did not randomize the order of the conditions which may have imparted an order effect in our results. Finally, transverse and frontal plane hip and knee kinematics are quite variable and susceptible to soft tissue movement artifact during high impact activities such as running.[67] Thus, it is likely such errors may exist in our results.

Despite these limitations, we conclude that full-length medially wedged foot orthoses yield minor effects on transverse and frontal plane knee and hip joint mechanics during running among both females with and without PFPS, regardless of standing calcaneal posture. Therefore, clinicians should not expect meaningful changes in knee and hip joint transverse and frontal plane mechanics during running in response to medially wedged foot orthoses. Decreased pain that has been previously reported following prescription of these types of foot orthoses for PFPS may not be due to an improvement in altered knee and hip joint mechanics during running.

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