Research Report

The Effect of Soft Foot Orthotics on Three-dimensional Lower-Limb Kinematics During Walking and Running

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Background and Purpose. *Although foot orthotics are often prescribed to alter the lower-extremity mechanics during the stance period of gait, there is little documentation of the actual effect of foot orthotics on the movement of the lower-extremity joints during walking and running. This study examined the effect of foot orthotics on the range of motion of the talocrural/subtalar joint and the knee joint in three dimensions during walking and running.* ***Subjects.*** *Ten female adolescent subjects, aged 13 to 17 years ($\bar{X}$=14.4, SD=1.1) who were diagnosed with patellofemoral pain syndrome and exhibited forefoot varus greater than 6 degrees and/or calcaneal valgus greater than 6 degrees participated in the study.* ***Methods.*** *Thirty strides of walking and running on a treadmill were recorded for each of the orthotic and nonorthotic conditions for each subject using an optoelectronic recording technique. Analyses of variance for repeated measures were performed on the range of motion of the talocrural/subtalar joint and knee joint for each plane of motion (ie, six separate analyses). The main factors of each analysis were the effect of the orthotic (orthotic condition versus nonorthotic condition), mode of ambulation (walking and running), and phase of the stance period (contact, mid-stance, and propulsion).* ***Results.*** *No differences were found in sagittal-plane movements. Reductions of 1 to 3 degrees occurred with orthotic use for the talocrural/subtalar joint during walking and running in the frontal and transverse planes. The orthotics reduced knee motion in the frontal plane during the contact and mid-stance phases of walking, but increased the motion during the contact and mid-stance phases of running.* ***Conclusions and Discussion.*** *This study shows that corrections to the static position of forefoot varus and calcaneal valgus can result in changes in transverse- and frontal-plane motion of the foot and knee during walking and running. [Eng JJ, Pierrynowski MR. The effect of soft foot orthotics on three-dimensional lower-limb kinematics during walking and running. Phys Ther. 1994;74:836–844.]*

Key Words: *Foot orthosis, Gait analysis, Kinematics.*

Abnormal foot mechanics during the stance phase of gait may affect the alignment of the lower extremities and predispose a person to overuse syndromes not only of the foot and ankle but also of the knee.[1,2] Foot and ankle motion is often described in terms of pronation (a triplanar rotation of the foot and ankle into abduction, dorsiflexion, and eversion) and supination (a triplanar rotation into adduction, plantar flexion, and inversion).[3] Excessive pronation is thought

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to be one of the major causes of foot and leg problems in runners.[4,5] Foot orthotics, devices inserted between the foot and shoe to modify foot biomechanics, have been used in clinical settings for conditions aggravated by excessive pronation. These conditions include Achilles tendinitis, plantar fasciitis, and posterior tibial tendinitis, as well as knee conditions such as patellofemoral pain syndrome.[4,6–8] Patellofemoral pain syndrome is the leading cause of chronic knee pain in adolescents and has been reported to have a high correlation with excessive pronation.[1,2,9]

Orthotics can be categorized into rigid, semirigid, and soft or temporary orthotics. In our study, the soft or temporary orthotics were selected for subjects experiencing patellofemoral pain syndrome because soft orthotics are inexpensive, quick and simple to fabricate, and easily adjustable, which was important for this adolescent clientele.

To examine the biomechanical effects of the foot orthotic during gait, the effects of the orthotic on joints proximal to the ankle, in addition to the motion of the foot and ankle, should be studied. When defining the motion between the foot and leg, a common center of rotation is assumed with the talocrural (ankle) joint primarily responsible for dorsiflexion/plantar-flexion components; the subtalar joint is primarily responsible for inversion/eversion and abduction/adduction components, although some overlap does occur.[3] For the purposes of this report, we refer to the ankle and foot joints as the talocrural/subtalar (TC/ST) joint.

Previous motion-time studies have produced conflicting reports about the biomechanical effect of orthotics on TC/ST joint motion.[10–13] Although some of the discrepancies may have arisen from the variation in the construction of the orthotic, the procedures used for the gait analysis may also have been a source of variability. The speed of ambulation has been reported to influence the range of motion (ROM) of the TC/ST joint and should be standardized between orthotic and nonorthotic trials.[11,14,15] Additionally, a large number of gait strides should be averaged over each trial. Bates et al[16] reported that the magnitude of the variability of the gait variables indicated a need for calculating representative or average values if subtle differences in lower-extremity function are to be detected.

An estimation of the motion of the calcaneus with respect to the lower leg in the frontal plane is often used to produce a two-dimensional (2-D) estimation of inversion and eversion.[10,11,16] In general, the accuracy of motion description will deteriorate as the number of degrees of freedom considered is reduced.[17] Two-dimensional analyses cannot easily account for errors due to segmental movements out of the plane of motion or due to rotations about a segment's longitudinal axis.[17–19] Engsberg and Andrews[20] reported that inversion/eversion may not necessarily represent the predominant motion of the TC/ST joint and recommended that the dorsiflexion/plantar-flexion, adduction/abduction, and inversion/eversion components be monitored to predict pronation and supination.

Three-dimensional (3-D) analysis of the effect of foot orthotics was performed by Taunton et al,[12] with a follow-up by Smart and Robinson,[13] using a triplanar electrogoniometer to monitor the TC/ST joint as well as the knee joint. Both groups of investigators reported that foot orthotics produced a reduction of the eversion motion of the TC/ST joint during the stance period of running. Smart and Robinson also found that the orthotics caused an increase in the abduction motion at the knee during the stance period.

In our study, we used an optoelectronic technique to find the orientations between the thigh and lower leg and between the lower leg and foot that generate rotations of the knee and TC/ST joint, respectively. The objective of our study was to determine whether soft foot orthotics affect the 3-D motion of the TC/ST and knee joints in female adolescent subjects who were diagnosed with patellofemoral pain syndrome. We wanted to determine whether the effects of the foot orthotic are different in walking and running and whether the effects of the foot orthotic are different in the phases of contact, mid-stance, and propulsion.

Method

Subjects

Subjects examined in this study were 10 female adolescents who had been prescribed foot orthotics for patellofemoral pain syndrome by the same physical therapist and physician. The subjects ranged in age from 13 to 17 years ($\bar{X}=14.4$, SD=1.1) and in mass from 42 to 62 kg ($\bar{X}=50.2$, SD=8.0). Each subject and her parent or guardian provided informed consent. Excessive pronation was a requirement for inclusion in this study and was determined by a measurement of forefoot varus greater than 6 degrees and/or calcaneal valgus greater than 6 degrees (forefoot varus: $\bar{X}=12.4°$, SD=3.7°; calcaneal valgus: $\bar{X}=6.6°$, SD=4.7°). Treatment of forefoot varus or calcaneal valgus greater than 5 degrees is recommended because these amounts are likely to cause foot and/or lower-extremity symptoms.[21] All subjects were measured by the same tester. Calcaneal valgus is the measurement of the angle between the Achilles tendon and the bisection of the posterior calcaneus in a standing position. Forefoot varus is a measurement of the inversion of the forefoot with respect to the hindfoot in a non–weight-bearing position with the subtalar joint in a neutral position.[22] Test-retest trials of 6 subjects conducted by the same physical therapist produced intraclass correlation coefficients[23] (ICC[1,1]) of .71 and .97 for the measurements of forefoot varus and calcaneal valgus, respectively. Excluded from the study were those subjects with leg-length discrepancies greater than 1 cm.

Foot Orthotic Construction

Foot orthotics were made by the same physical therapist for each subject. The orthotics were constructed from a flat Spenco insole* and posted medially in the hindfoot and forefoot with rubber wedges to position the foot closer to a subtalar neutral position. (Information about the compressibility of the rubber wedges was not supplied by the manufacturer.) Subtalar neutral is a position in which the foot is neither pronated nor supinated. The forefoot posting ranged from 4 to 6 cm in length and extended proximally from the heads of the metatarsals. The hindfoot posting ranged from 6 to 8 cm in length and extended distally from the calcaneus. With calcaneal valgus between 4 and 6 degrees, a 2-degree hindfoot posting was used. With forefoot varus between 6 and 10 degrees, a 2-degree forefoot posting was used. If forefoot varus was greater than 10 degrees, 4- to 6-degree forefoot and 2- to 4-degree hindfoot postings were used. The maximal posting was 6 degrees in the forefoot and 4 degrees in the hindfoot, as larger postings were not comfortable for the subjects. The orthotics were posted a mean of 3 degrees in the forefoot and 2.2 degrees in the hindfoot, bilaterally. During the testing, the subjects wore new running shoes† provided by the laboratory. The orthotics were inserted into the running shoe after the original insole of the shoe had been removed to provide space for the orthotic.

Experimental Setup

The data collection took place within the first 3 weeks following the initial fitting of the orthotic. Kinematic data were acquired by a four-camera Waterloo Spatial Motion Analysis and Recording Technique (WATSMART™‡). Because all subjects

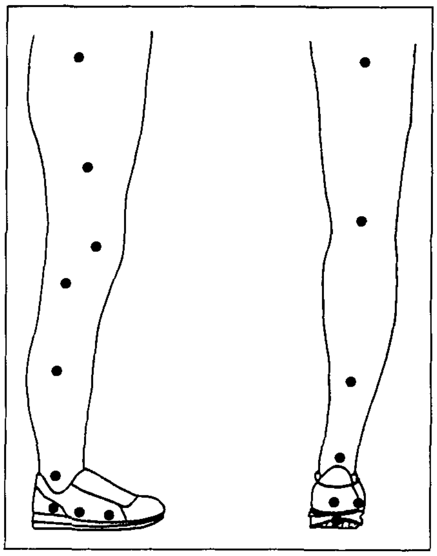

Figure 1. *Lateral and posterior views of the marker location on the right lower limb.*

experienced bilateral knee pain, motion analysis was performed only on the knee that was reported to be the most painful on the initial assessment. Sixteen 3-cm-diameter infrared light-emitting diodes (IREDs) were placed on the leg of the subject: 5 on the thigh, 5 on the lower leg, and 6 on the foot. The positions of the IREDs are shown in Figure 1, and the locations of the cameras are shown in Figure 2. An average of the IRED positions on each segment while in a standing position determined the rigid body segment model. A footswitch was applied to the heel of the shoe to record consecutive heel contacts. To reduce possible reflectiveness of infrared light, black foam banners and carpet of low infrared light reflectiveness were used to cover the head of the treadmill and floor regions surrounding the treadmill.

Calibration of the 3-D system was performed prior to each session using a 1-m cube frame containing 52 IREDs of known 3-D coordinates

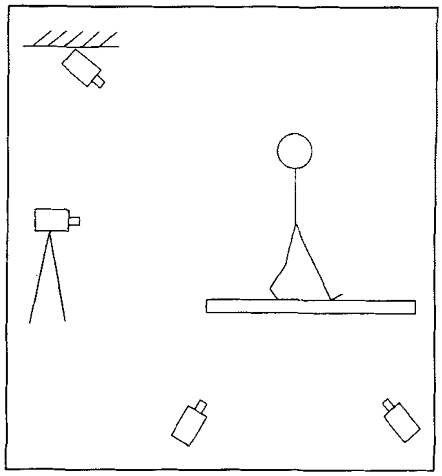

Figure 2. *Camera location for tracking the right lower limb.*

placed on the treadmill. To define the location of the 16 IREDs on the body segments, subjects stood in a relaxed standing position with feet parallel and directed forward. This was referred to as the anatomical position or zero reference, and data were collected in this position to calculate the 3-D coordinates of the IREDs relative to the local coordinate system of the calibration frame. The error to locate the 3-D coordinates of a marker in space using the WATSMART™ system was established to be random and less than 6 mm root mean square (RMS). Random Gaussian noise of this magnitude was mathematically added to simulations that used a computer-driven marker system and experimental setup similar to those shown in Figures 1 and 2. Movements similar to those during walking and running were simulated, and the results predicted that the error in determining a segment's 3-D rotations was less than 2.5, 3.0, and 2.6 degrees RMS for the Z, X, and Y planes, respectively. Because a large number of strides were performed in each trial, the random error component is further reduced by a factor equivalent to the square root of the number of strides.[24] In our study, 30 strides were analyzed for each condition; thus, the error would be reduced by a factor of 5.5. Therefore, the random error in determining a segment's rotations was less than 0.45,

*Spenco Sports Medicine Products, Toronto, Ontario, Canada M4W 3L9.

†Reebok CL600, Reebok Canada, 201 E Stewart Dr, PO Box 27, Ontario, Canada L4G 3H1.

‡Northern Digital Inc, 403 Albert St, Waterloo, Ontario, Canada N2L 3V2.

0.54, and 0.47 degrees RMS for the Z, X, and Y planes, respectively.

Data Acquisition

The walking and running motions on a treadmill of each subject were recorded. Subjects were tested under two conditions: (1) running shoe and flat insole and (2) running shoe and foot orthotic (flat insole with wedges). Subjects were given a 10-minute warm-up period to adjust to the treadmill under the test conditions. Two trials (20 seconds each) of walking at 0.89 $m \cdot s^{-1}$ and running at 1.78 $m \cdot s^{-1}$ under each condition were collected at 75 Hz. These speeds elicited a comfortable walking and running pattern for the subjects.

Data Reduction and Analysis

The kinematic data were analyzed to provide the motions of the knee and TC/ST joints, averaged across a minimum of 30 strides. A body-fixed reference system was used, which means that the reference system was attached to a segment and the X, Y, and Z axes translated and rotated as a segment moved. Specifically, a Z-X-Y rotation sequence was defined[18] and the following definitions used:

> Motion about the X axis occurred in the frontal plane
>
> Motion about the Y axis occurred in the transverse plane
>
> Motion about the Z axis occurred in the sagittal plane
>
> X, Y, Z (+/−) translations: forward/backward, up/down, lateral/medial (external/internal)
>
> Z, X, Y (+/−) knee rotations: extension/flexion, adduction/abduction, medial/lateral rotation
>
> Z, X, Y (+/−) TC/ST joint rotations: dorsiflexion/plantar flexion, inversion/eversion, adduction/abduction

To obtain these time-dependent variables for the knee and TC/ST joints from the 2-D data available from the four cameras, a five-step procedure was used. First, the stationary trial was processed to provide 3-D coordinates of the 16 body IREDs relative to the global laboratory reference system (GRS). Second, the three translations and three rotations that located the thigh, lower leg, and foot segments (origins at the hip, knee, and TC/ST joints, respectively) in 3-D space relative to the GRS were calculated. This procedure did not allow us to calculate the intermediate spatial marker coordinates available from any camera combination; we used a statistical procedure to isolate and remove errant data.[25] Third, relative rotations were determined for the knee (orientation between the thigh and lower leg) and the TC/ST joint (orientation between the lower leg and foot). Fourth, after defining the start and end frames for each stride (right heel contact to right heel contact), the rotations of the two joints were ensemble-averaged across the 30 strides for a given subject. The mean and standard deviation for the joint rotations were then calculated every 2% of the stride. Last, the stance period was divided into phases by observing a 2-D sagittal view of the foot during walking and running.

Previous investigations[12,13] measured the ROM over the entire stance period; however, the TC/ST joint has different functions depending on the phase of the stance period. Thus, an examination of the effect of foot orthotics on the phases of contact (heel contact to foot flat), mid-stance (foot flat to heel-off), and propulsion (heel-off to toe-off) was performed. The non–weight-bearing swing period was not analyzed.

The predominant movement component in each phase was compared between the orthotic and nonorthotic trials by a signed rank test. The predominant movement component was defined as the direction of motion toward one extreme of the ROM. For example, it was to be determined whether the TC/ST joint displayed an eversion component in both the orthotic and nonorthotic trials during the contact phase. Signed rank tests compared the predominant movement of the nonorthotic and orthotic trials for each of the planes of motion of the TC/ST and knee joints during each of the three phases.

The maximum ROM represented the total movement in each plane of motion of the TC/ST and knee joints (eg, the ROM in the frontal plane of the TC/ST joint represents the sum of the maximum degrees of inversion and maximum degrees of eversion attained). A repeated-measures design was used to compare the ROMs because the normal subject-to-subject variation is removed from the error sum of squares; each subject served as her own control. The main factors of the design were the effect of the orthotics (orthotic and nonorthotic conditions), the mode of ambulation (walking and running), and the subphase of the stance period (contact, mid-stance, and propulsion). This analysis was performed six times, once for each joint (knee and TC/ST joints) in each of the three planes of motion.

The significance level was set at .05. The degrees of freedom and error terms are shown in Table 1. *Post hoc* procedures consisted of Tukey's test for significant main effects and the calculation of simple main effects for significant interactions.[26] For example, if the two-way interaction of the independent variables orthotic group and phase of gait (ie, orthotic×phase) was significant, it was to be determined whether the orthotic and nonorthotic trials were significantly different for each of the three phases. All statistical procedures were conducted using the Statistical Analysis System.[§]

Within each analysis of variance (ANOVA), a number of F tests were performed (to test all the main effects and interactions), but the statistical design and *post hoc* procedures (Tukey's) take this into account and we believe the change of a type I

[§]SAS Institute Inc, PO Box 8000, Cary, NC 27511.

Table 1. *F Ratios and Probability Values from Analysis of Variance for Range of Motion of the Talocrural/Subtalar (TC/ST) and Knee Joints in Frontal and Transverse Planes*[a]

				TC/ST Joint				Knee Joint			
				Frontal		Transverse		Frontal		Transverse	
Source	*df*	Error Term	*df*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Orthotic	1	Subject[b]×orthotic	9	34.26	.0002	4.73	.056	1.33	.28	4.18	.071
Mode[b]	1	Subject×mode	9	10.11	.011	3.25	.10	0.45	.52	2.21	.17
Phase	2	Subject×phase	18	10.80	.0008	0.23	.80	1.28	.31	0.12	.88
Orthotic×mode	1	Subject×orthotic×mode	9	1.14	.31	9.12	.014	0.95	.20	2.91	.12
Orthotic×phase	2	Subject×orthotic×phase	18	5.30	.016	3.73	.044	2.06	.16	3.81	.042
Mode×phase	2	Subject×mode×phase	18	3.64	.047	1.61	.23	2.01	.16	3.27	.062
Orthotic×mode×phase	2	Subject×orthotic×mode×phase	18	3.95	.038	1.27	.31	7.15	.005	2.27	.13

[a]No significant orthotic effect in the sagittal plane.

[b]Mode of ambulation (walking and running).

error does not increase with the increase in main effects. It was not feasible, however, to combine all factors into one large ANOVA, and we recognize that performing 6 ANOVAs may increase the probability of a type I error. Due to the complexity of each of the 6 ANOVAs, we treated each ANOVA independently using a probability value of .05 rather than an adjusted value. Using a probability value of .05, however, would mean that with every 20 ANOVA comparisons, 1 ANOVA would be expected to result in a significant difference by chance alone. Hence, we feel that the 6 ANOVAs used in the study with an alpha level of .05 are justified. Furthermore, a relatively conservative *post hoc* procedure (Tukey's) was selected, which makes it more difficult to find a significant difference between the two means.

Results

The ensemble-averaged profiles across the 30 strides for each subject produced standard deviations at each 2% of the stride that were 1 to 2 degrees in the sagittal plane and 1 to 3 degrees in the frontal and transverse planes. The patterns of motion were highly variable across subjects, especially in the frontal and transverse planes. Thus, it was not possible to obtain an average representation across the 10 subjects. Furthermore, averaging across subjects could also introduce systematic errors as the angles and translations were measured with respect to the anatomical position, which could vary between subjects.

No significant differences of the predominant direction of movement between the orthotic and nonorthotic trials were observed in any of the planes of motion of the TC/ST or knee joints during any of the phases. Therefore, if the TC/ST joint demonstrated an eversion component during the contact phase during the nonorthotic trial, an eversion component was also present during the orthotic trial.

The foot orthotic had no significant effects in the sagittal plane, but affected the magnitude of the ROM in the frontal and transverse planes for the TC/ST and the knee joints. The *F* ratios and probability values in the frontal and transverse planes for the TC/ST and knee joints are presented in Table 1. The actual ROMs of the 10 subjects during the orthotic and nonorthotic trials are reported in Tables 2 and 3. The standard deviations in Tables 2 and 3 are large because they provide a representation of the variability across the 10 subjects; however, the repeated-measures analyses were designed to compare the ROMs across the same subject.

Talocrural/Subtalar Joint

In the frontal plane, there was a significant effect of the orthotic on the maximum ROM; a significant two-way interaction of the orthotic group and the phase of gait (ie, orthotic×phase); and a significant three-way interaction of the orthotic group, the mode of ambulation, and the phase of gait (ie, orthotic×mode×phase) (Tab. 1). These findings imply that the effects of the foot orthotic were different across the contact, mid-stance, and propulsion phases and that the effects of the orthotic across the three phases were not the same for the two modes of ambulation in the frontal plane. The *post hoc* procedures showed that the ROM for the nonorthotic trials was different from the ROM for the orthotic trials for the contact and mid-stance phases of walking. The orthotics reduced the ROM by a mean of 1.8 degrees during both of these phases (Tab. 2). During running, the ROMs for the orthotic and nonorthotic trials were different during the contact and propulsion phases, with mean reductions of 2.5 and 1.7 degrees, respectively (Tab. 2).

In the transverse plane, the two-way interaction of the orthotic group and

Table 2. *Means and Standard Deviations[a] of Range of Motion (in Degrees) of Talocrural/Subtalar Joint During Walking and Running (N=10)*

Phase of Gait	Plane of Motion: Frontal		Transverse	
	Nonorthotic	Orthotic	Nonorthotic	Orthotic
Walking				
Contact	11.3	9.5	4.3	4.3
	(3.7)	(3.9)	(2.2)	(2.0)
Mid-stance	6.8	5.0	5.0	5.2
	(2.3)	(2.1)	(1.3)	(1.9)
Propulsion	7.4	7.0	4.7	4.1
	(2.2)	(2.4)	(1.7)	(1.3)
Running				
Contact	9.9	7.4	3.8	3.7
	(3.7)	(3.1)	(0.9)	(1.1)
Mid-stance	3.6	2.8	3.8	3.2
	(1.9)	(1.8)	(2.3)	(2.3)
Propulsion	8.9	7.2	5.4	3.5
	(2.8)	(2.8)	(2.2)	(1.9)

[a]One standard deviation in parentheses.

the mode of ambulation was significant (Tab. 1). The *post hoc* procedures indicated a difference between the orthotic and nonorthotic trials during running. The two-way interaction of the orthotic group and the mode of ambulation was also significant, with the orthotic trials different from the nonorthotic trial during the propulsion phase. In the transverse plane, the orthotic trials reduced the ROM by 1 to 3 degrees.

Knee Joint

In the frontal plane, the three-way interaction of the orthotic group, the mode of ambulation, and the phase of gait was significant (Tab. 1). During the contact and mid-stance phases, the ROM during the orthotic trial was significantly less than that of the nonorthotic trial, with mean reductions of 0.8 and 0.6 degrees, respectively, during walking (Tab. 3). In contrast, mean increases of 0.9 and 0.8 degrees during the contact and mid-stance phases, respectively, were observed during running (Tab. 3). Increases of up to 3 degrees were observed in some subjects. During the propulsion phase, the orthotics caused a 0.8-degree mean reduction of motion at the knee in the frontal plane.

In the transverse plane, only the two-way interaction of the orthotic group and the phase of gait was significant (Tab. 1). The *post hoc* procedures showed that the orthotic and nonorthotic trials were different only during the contact phase.

Table 3. *Means and Standard Deviations[a] of Range of Motion (in Degrees) of Knee Joint During Walking and Running (N=10)*

Phase of Gait	Plane of Motion: Frontal		Transverse	
	Nonorthotic	Orthotic	Nonorthotic	Orthotic
Walking				
Contact	3.6	2.8	5.1	3.2
	(1.5)	(1.2)	(2.0)	(1.5)
Mid-stance	3.8	3.2	5.2	5.2
	(2.6)	(1.7)	(2.0)	(3.1)
Propulsion	4.9	4.8	5.1	4.7
	(2.0)	(2.1)	(2.2)	(2.5)
Running				
Contact	4.2	5.1	5.0	4.6
	(3.0)	(2.5)	(3.0)	(2.2)
Mid-stance	3.5	4.3	3.1	3.1
	(1.8)	(1.7)	(1.1)	(0.8)
Propulsion	4.9	4.1	4.1	3.5
	(2.5)	(2.6)	(2.5)	(2.1)

[a]One standard deviation in parentheses.

Discussion

We partitioned the stance period into the three phases of contact, mid-stance, and propulsion because the foot orthotic acts differently depending on the function of the foot and ankle joints. Generally, the effects of the orthotic on the frontal- and transverse-plane ROMs of the TC/ST and knee joints were modest (1°–3°). The effects in the transverse plane observed in our study may have been missed previously because an inadequate number of strides was used to account for the normal variability of the gait pattern.

Talocrural/Subtalar Joint

Following heel contact, the medial border of the calcaneus and forefoot reach the ground by means of eversion of the TC/ST joint.[3] With a medial posting under the hindfoot and forefoot, the ground has essentially been brought up to reach the foot. The average hindfoot posting was 2.2 degrees, and the average forefoot posting was 3 degrees. Consequently, one would expect that the eversion motion in the contact and mid-stance phases would be reduced by less than 2 to 3 degrees, as some compression of the wedges will occur. This reduction is congruent with the 1- to 2-degree reduction observed during walking. We can conclude from these results that soft orthotics have an effect in reducing the frontal-plane motion of the TC/ST joint. The effect from the soft orthotic is slightly less than the 2- to 4-degree effect reported with rigid and semirigid orthotics.[15,27]

In the transverse plane, the orthotic was most effective in reducing the TC/ST joint motion during running and during the propulsion phase. With the foot planted on the ground, there is minimal TC/ST joint abduction/adduction until the propulsion phase commences. Thus, the use of foot orthotics reduces the TC/ST joint motion in the frontal and transverse planes during dynamic tasks such as walking and running in subjects with excessive forefoot varus and calcaneal valgus measured from a static position.

Talocrural/Subtalar Joint and the Effects on the Knee

During the contact phase of walking, reductions of eversion at the TC/ST joint were accompanied by reductions at the knee joint in the frontal and transverse planes. Hence, reductions of TC/ST joint motion in the frontal plane can affect the knee joint in both the frontal and transverse planes during walking. From these observations, we can conclude that foot orthotics can alter the motion of a joint proximal to the TC/ST joint. Unlike the relationship found in walking, in which a reduction in TC/ST joint motion resulted in a reduction in knee joint motion, the relationship in running is more complex. During the contact and mid-stance phases of running, a reduction of TC/ST joint eversion resulted in an increase in knee motion in the frontal plane. Thus, in running, the foot orthotics increased the motion at the knee in the frontal plane even though a reduction of motion was displayed at the TC/ST joint. Smart and Robinson[13] postulated that a reduction of motion in the frontal plane of the TC/ST joint necessitated a transfer of motion in the frontal plane proximally, which was detected as an increase in the frontal-plane motion at the knee. Because a reduction of motion at the TC/ST joint was accompanied by increased knee joint motion in the frontal plane, one must question whether joints proximal to the knee are also being affected. Is it possible for motion to be reduced at a joint without the expense of excessive motion at another joint? A kinetic or energy analysis of the lower extremities would be useful for gaining further insight into the mechanical effects transferred proximally from the TC/ST joint.

The relationship of the effect of the TC/ST and knee joints may be related to the magnitude of reduction at the TC/ST joint. Very small amounts of reduction at the TC/ST joint (0.4°) did not affect the knee joint. Larger amounts of reduction (0.8°–2.0°) at the TC/ST joint appeared to cause a reduction in knee joint motion. Even larger magnitudes of reduction (2.5°) at the TC/ST joint necessitated a transfer of motion and resulted in an increase in knee motion.

The orthotics were effective in altering the joint motion during the contact phase of walking and running because this is the phase in which the largest eversion movement occurs. During walking, the orthotic is effective in altering the ROM of the TC/ST and knee joints during the contact and mid-stance phases, whereas in running, the contact and propulsion phases were affected. During running, the mid-stance phase has a very short duration, which may be one of the reasons that no effect of the orthotics was observed during this phase. Instead, a reduction of the ROM was observed during the propulsion phase of running. During the propulsion phase, the heel is already off the ground such that only the forefoot postings would have any effects. Additional effects, however, may result from the preceding two phases; because the orthotic reduced the magnitude of the eversion component during the contact phase, the amount of inversion to return to a neutral position may subsequently be reduced.

Clinical Implications

In clinical practice, postings are often based on measurements taken from a static position, however, the intent of the orthotic is to affect the foot position during a dynamic task such as walking or running. In our study, the average forefoot varus was 12.4 degrees, yet the postings were approximately 3 degrees and only partially corrected the subtalar neutral position in a static position. However, these small corrections performed in a static position affected the TC/ST and knee joint motion by 1 to 2 degrees during walking and running. Can such small differences affect the mechanics of the dynamic task and in turn affect the pain experienced by the patient? A recent clinical investigation[8] that followed the same 10 subjects examined in this study in addition to a control group over a 2-month period confirms that these small differences are effective in reducing pain in female adolescents with patellofemoral pain syndrome. The results of this study coupled with our previous findings[8] provide some evidence for alterations in both biomechanical variables and measurements of pain and function.

The results of our study raise a number of issues. A partial correction of the static subtalar position is sufficient to alter the mechanics of the TC/ST and knee joints during a dynamic task. Perhaps the practice of assessing the magnitude of the postings from a single static position (subtalar neutral) should be questioned because the effect of the orthotic on the TC/ST and knee joints is experienced under dynamic loading conditions. Furthermore, measuring the subtalar neutral position has proved problematic to clinicians, as demonstrated by the low intertester reliability recorded.[28] Intertester reliability was not a concern in our study because only one tester was used throughout the study.

The effectiveness of orthotics on the knees is thought to be based on a reduction in TC/ST joint motion and a subsequent reduction of transverse- and frontal-plane knee motion. An increase in knee joint motion, however, was observed in certain phases of the gait cycle. Perhaps it is not so much a reduction of motion but an alteration of the loading of the patellofemoral joints that can result in a reduction of pain. Changes in the transverse- and frontal-plane motion of the knee will affect the patellofemoral contact pressure and the location of the patellofemoral joint reaction force.[29] If the foot is able to function more effectively with a foot orthotic, better shock attenuation may also be achieved.

We believe the proximal translation of the TC/ST joint motion must be considered when fitting a patient with an orthotic. During walking, an alteration of the TC/ST and knee motion joint occurred, but it is possible that the hip joint or lumbar vertebrae were compensating for these changes. The lumbar spine and hip joint of patients fitted with foot orthotics for lower-extremity problems should be closely monitored.

Finally, we can conclude that soft orthotics are effective in generating small alterations in the TC/ST and knee joint ROM during walking and running. Because soft orthotics are relatively easy and inexpensive to fabricate compared with semirigid or rigid orthotics, clinicians may find them a practical alternative for an initial trial in orthotic intervention. A further consideration should be given to the effect of the shoe alone. It has been well documented that certain shoe design parameters (eg, midsole hardness, heel height) can affect the foot mechanics during gait.[30,31] Although the intent of this study was to examine the effect of the soft orthotic with a standard shoe, further investigations should consider the interactions of the orthotic with different shoe design parameters.

Conclusion

This study has provided an evaluation of soft foot orthotics on the three-dimensional kinematics of walking and running in subjects with patellofemoral pain syndrome. Based on the findings of this study, we conclude the following:

1. The effects of the soft foot orthotics were modest; no effects were observed in the sagittal plane, and only 1- to 3-degree differences were found for frontal- and transverse-plane ROM of the TC/ST and knee joints during walking and running.

2. The soft foot orthotic reduced the TC/ST joint motion in the frontal and transverse planes during walking and running.

3. The knee joint was affected by the foot orthotics; the knee motion in the frontal plane was reduced during the contact and mid-stance phases of walking, but was increased during the contact and mid-stance phases of running.

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