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Original article

Effects of customized foot orthoses on lower limbs kinematics in adults with highly pronated foot

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Background: Previous studies have assumed that pronated foot may cause mechanical deviations of the lower limbs. Foot orthoses have been used for management to elevate the arch of the foot and alter the kinematic variables during walking.
Objective: The purpose of this study was to examine changes in lower limb kinematic variables during the subphases of the gait stance of individuals with highly pronated foot after wearing customized foot orthoses (CFO).
Methods: Thirteen adults (five women and eight men, average age 23.3 ± 3.0 years) with asymptomatic highly pronated foot were included in the study. Participants with Foot Posture Index (FPI-6) scores between 10 to 12 were recruited. Changes in the kinematics of lower limbs in the stance period were measured using an eight-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA). All participants walked at self-selected speeds over a 10-meter walkway with three force platforms in two conditions between barefoot (BF) and wearing CFO. Statistical analysis was performed by Wilcoxon signed-rank test for selected rearfoot, ankle, knee and hip kinematics in a 3 dimensional gait cycle.
Results: The important effects of CFO were seen in the initial contact phase (ICP) for ankle (P = 0.028) joint excursion, the forefoot contact phase (FFCP) for rearfoot (P = 0.001), ankle (P = 0.002), and hip (P = 0.039) joint excursions, the footflat phase (FFP) for ankle (P = 0.002) and hip (P = 0.003 - 0.046) joint excursions as well as the forefoot push off phase (FFPOP) for ankle (P = 0.003) joint excursion.
Conclusion: These findings demonstrate the immediate effect of CFO for promoting good alignment of the rearfoot, ankle and hip joint excursions during walking among individuals with highly pronated foot.

Keywords: Pronated foot, foot orthoses, kinematics, walking.

The pronated foot is an abnormal foot posture with a lowered medial longitudinal arch (MLA), and over pronation of the subtalar joint that results in increased calcaneal valgus, increased plantarflexion of talus, and lowered navicular height.(1) Various physical factors including laxity of spring ligament, lengthening of plantar fascia, tightness of gastrocnemius and peroneal muscles, and weakness of tibialis posterior are linked to pronated foot.(2) Individuals with pronated foot may be subject to excessive foot motion when walking or running. This excessive motion can alter the kinematics acting on lower extremity structures, the biomechanical characteristics of the longitudinal arch, and the distribution of pressure acting on the plantar fascia; it can also increase demand on intrinsic foot muscles that regulate arch deformation.(3) Levinger P, *et al*. reported that persons with pronated foot demonstrated a greater peak forefoot plantarflexion, forefoot abduction, and rearfoot internal rotation during walking compared with normal foot posture.(4) Furthermore, Tateuchi H, *et al*. showed that individuals with calcaneal eversion presented increased hip flexion and medial rotation, and pelvic anterior tilt during the stance phase.(5) Consequently, these excessive motions may lead to overuse injuries.(6) Therefore, in order to prevent or reduce risk of lower extremity problems, it

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is essential to additionally consider the structure and functions of the MLA of the foot. Evidently, the applications of functional foot orthoses (FO) are frequently used in combination with taping and therapeutic exercise programs to manage flexible pronated foot.(3, 7)

Recent systematic reviews suggested the use of FO for supporting the arch of the foot.(8 - 10) A systematic review has shown good to moderate level evidence that FO can improve physical function (medial-lateral sway in standing).(11) Biomechanics studies have shown that FO improves arch alignment.(12) Structurally, the pronated foot posture is controlled. The orthoses can overcome the eversion of the talocalcaneal joint, elevate the MLA, and suppress elongation of the foot.(7) Lower extremities alignment is promoted due to the coupling mechanism of the subtalar joint and tibia.(13) Functionally, orthoses can aid in improving the direction and function of the arch during gait.(14) Wearing FO may clinically correct abnormal load distribution. One study showed that FO shifted the load from forefoot and rearfoot toward the midfoot area, while the midfoot contact area had been increased.(15) Moreover, FO may adjust lower extremity functions during gait including promoting shorter time between heel contact to single leg stance, increasing ankle joint angles in the frontal plane during the midstance phase, decreasing internal tibia rotation, increasing peak hip flexion/extension during the stance phase, as well as reducing the difference of the pelvic rotation between the left and right limbs.(12, 16 - 18)

Functional FO for flexible pronated foot can be classified into two types: customized foot orthoses (CFO) and prefabricated foot orthoses (PFO). In clinical practice, CFO are made to a mold of the patient's feet with individualized prescription.(19) In contrast, PFO are manufactured to a generic shape, and are issued based on a patient's foot size. The types of material used for FO vary depending on the clinical objectives and production process. It is necessary to consider the physical properties of the material regarding temperatures, hardness, density, flexibility, and durability.(20) Commonly, orthoses can be made up of several materials such as thermoplastic, silicone gel, acrylic, foam, leather and corks.(21) However, medial arch support requires a specific design and materials to stabilize the lowered arch, thus hard materials are considered effective.(22)

Many previous studies showed that application of CFO can significantly alter foot, ankle, knee, hip and pelvic kinematics among individuals with pronated foot.(2, 3, 12, 16, 17, 23 - 27) CFO could significantly reduce forefoot eversion,(23, 24) improve forefoot dorsiflexion, and increase dorsiflexion of the first metatarsophalangeal (1st MTP) joint.(3, 23) They also significantly decreased rearfoot eversion and dorsiflexion.(3, 25) Additionally, they significantly decrease ankle eversion but increase ankle dorsiflexion.(12, 16, 26) Orthoses significantly reduce internal tibial rotation and increase knee flexion.(12, 17) Regarding the hip range of motion, a significant reduction in hip adduction and hip internal rotation were reported.(27) Moreover, Park K, *et al*. suggested that the pelvic angle during the mid-stance and mid-swing periods significantly decreased after wearing the orthoses.(2)

Because physical therapists commonly deal with various orthopedic patients with pronated foot, it is essential that they have full knowledge about the benefits of FO. Suitable types of FO may provide more effective physical therapy treatment outcome for such a patient population. Understanding of FO application is critical. Thus, the objective of this study was to examine the changes of rearfoot, ankle, knee and hip joint excursions in each subphase of the gait stance among individuals with highly pronated foot during the wearing of CFO. Doing so will help us understand the effect of CFO on lower limbs motion during the stance phase.

Materials and methods

An experimental study of pre- and post-tests design was used in this study.

Participants

Participants with unilateral or bilateral asymptomatic highly pronated foot were recruited for the study. The recruited participants were screened by the main researcher. The subjects aged range between 20 to 35 years. Potential participants were recruited into the study if they had a Foot Posture Index (FPI-6) score between 10 and 12. The FPI-6 was used to assess the overall participant's foot posture using the procedures described by Redmond AC, *et al.*(28) To determine inter-rater reliability, the study had scored by the experienced physical therapist and the main researcher. The study reported excellent agreement between raters (ICC = 0.9) for FPI-6 scores. Agreement between raters for categories the foot type was showed perfect agreement (Kw = 1.0). The intra-rater reliability between two repeated measurements by the main researcher had shown good reliability (ICC = 0.9). Individuals were excluded if they had a previous history of traumatic lower extremity injury and body mass index over 30 kg/m^2. Moreover, participants were excluded if they had lower extremity pain during the experiment. All participants signed their informed consent form as approved by the Ethics Committee for Research Involving Human Research Participants (Group 1), Chulalongkorn University. The serial number of human research approval was 150.1/61.

Experimental setup

Kinematic variables were collected using an eight-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA) with a sampling rate of 120 Hz. The cameras were synchronized with three force platforms (BERTEC, Columbus, OH, U.S.A.) which were mounted in the center of a 10 – meter walkway. The force platforms were set to a sampling frequency of 1,200 Hz and fourth-order Butterworth filter with a cutoff frequency of 6 Hz. Cortex version 3.1.1.1290 was the main software with the functions of calibration of capture volume and collecting data.

Static and dynamic calibrations were performed before the data collections. The L-frame was placed on the corner of the force plate that was designed as an origin of the global coordinate system (0, 0, 0) for the static calibration. The wand with three located markers was waved 60 seconds entire the volume for the dynamic calibration. An acceptable wand length is ranged from 499.98 to 500.02 mm.

Orthoses

The CFO (Figure 1A) is a rigid foot orthosis three-fourths the length of an individual foot. The materials include leather and thermoplastic materials, which are auto-adhesive at high temperatures. During the molding process, the subject was in a passive position, the hip and knee flexion approximately 90° without rotation and the subtalar joint in a neutral position with the slight extension of the big toe. The CFO was heated by oven at 70 degrees Celsius for approximately 3 minutes. Then the main researcher inserted the warm CFO under the foot. The participant was asked to transfer weight to the leg during the CFO molding process. To mold the foot orthoses, the main researcher manually held pressure on the dorsum of the foot for about 2 minutes.[29] Afterwards, the main researcher immersed the CFO into water until the heat dissipated. Consequently, the CFO (Figure 1B) was ready for use in the experiment. The orthoses are designed to position the heel bones vertical to the ground, bring the calcaneus back to normal alignment with the shank, and to maintain the subtalar joint in neutral position; thus it can be used to prevent pronation and excessive movement of the whole foot.[30]

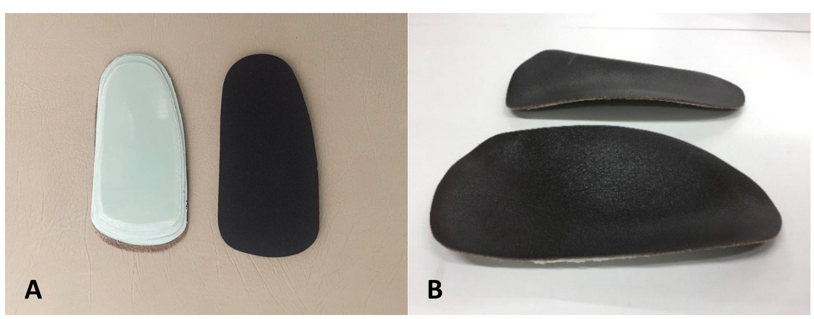

Figure 1. Customized foot orthoses (CFO) (A) unmolded (B) molded.

Protocol

The objective and process of the study were explained by the main researcher to all participants prior to the experiment. Each participant was required to have the CFO inserted beneath his/her foot during walking. Additionally, the CFO was attached to the plantar area by double-sided adhesive tape plus elastic socking. As for gait assessment, 47 reflective markers were placed on anatomical landmarks on each participant following the Helen Hayes marker set [31] and multi-segment foot model.[32, 33] Both static and dynamic trials were collected under 2 conditions, namely, the BF and CFO conditions. All participants were required to start the BF condition, followed by the CFO condition, respectively. For participants to become accustomed with the study protocol, they were required to walk 2 - 3 trials before collecting data in each condition. This was to increase the researcher's confidence that the participants could walk with a consistent gait pattern. For each condition, they had to walk along a 10-meter walkway at their preferred walking speed. A successful trial involved the complete contact of both feet on the force platforms.

Once the marker attachments were completed (Figures 2A and 2B), the participant was asked to walk for 5 trials without CFO and 5 trials with CFO on the same day. In the BF condition, the participants were asked to walk barefoot without wearing the sock. After the BF condition, they could take a break for 3 minutes or until without muscle fatigue. With respect to the CFO condition, the participant was asked to wear socks with the CFO inserted on the plantar area. The characteristics of the socks were light, breathable, and matching the participant's foot length. Moreover, each sock was punched to produce several little holes at the bony prominence where the markers were attached (Figure 2C).

Data analysis

Raw kinematic data were processed using Cortex version 3.1.1.1290 software. The mean of the final three walking trials from each test condition with complete marker tracking was used in the analysis. Kinematic data were low-pass filtered using a fourth-order Butterworth filter with cutoff frequency of 6 Hz. During the stance phase, foot initial contact and forefoot push off were identified using the difference between the first and last vertical ground reaction force (GRF). The joint angles, three-dimensional joint angles of the hip, knee, ankle, rearfoot, midfoot and forefoot were analyzed using Matlab (MATLAB R2018b; The Math Works, Natick, Massachusetts, U.S.A.). Pronated foot with higher FPI-6 score was used for data analysis. If both legs had equal score, the selection of the main side was randomized by computer.

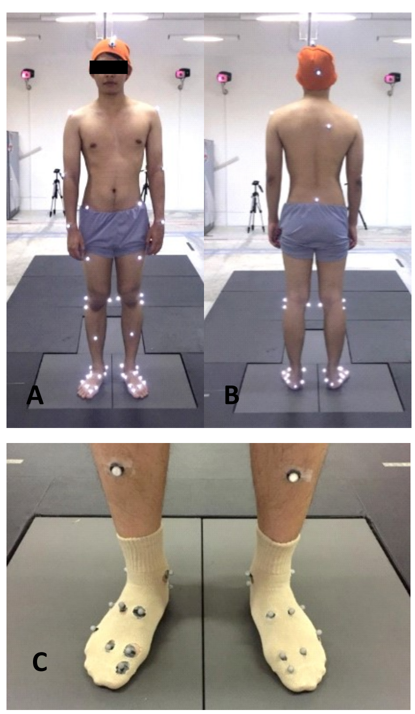

Figure 2. Fully placed markers (A) Anterior (B) Posterior and (C) CFO inserted within the socks.

The kinematic variables were reported in 4 subphases: initial contact phase (ICP), forefoot contact phase (FFCP), footflat phase (FFP) and forefoot push off phase (FFPOP). The first phase (ICP) was the duration between heel contact and base of first metatarsal contact; FFCP was the duration between base of first metatarsal contact and forefoot being flat; FFP was the duration between the forefoot being flat and heel off; and the last phase (FFPOP) was the duration between heel off and last foot contact. Each subphase was separated by ground reaction force (GRF). The duration between the first contact to first peak GRF was the ICP subphase. Next, the duration between first peak GRF to second peak GRF was midstance, which consisted of the FFCP and FFP subphases. The FFCP was the duration between the first peak GRF to minimum GRF, as well as the FFP was the duration between minimum GRF and the second peak GRF. Also, the duration between the second peak GRF to foot off from the ground was the FFPOP subphase. Changing of GRF was analyzed in three planes: the sagittal, frontal and transverse planes. In each subphase, the representative of averaged joint excursion (in degrees) that the quantity of the motion of the markers throughout subphase duration was applied to data analysis.

Statistical analysis

Statistical analyses were performed using SPSS 22.0 (SPSS, Inc., Chicago, IL). Demographic data of the subjects and Spatio - Temporal measurements were expressed as mean and standard deviations (SD) for numerical data. For inferential analysis, the Shapiro-Wilk test was used to detect the normal distribution of the data. For normal distribution of the data, the paired *t* - test was used to compare before and after wearing the CFO. For data outside normal distribution, the Wilcoxon signed-rank test was used to determine the difference between before and after wearing the CFO within the group. Statistical significance was set at $P < 0.05$.

Results

Thirteen adults (five women and eight men, average aged 23.3 ± 3.0 years, height 165.5 ± 8.9 cm, weight 65.0 ± 13.5 kg, body mass index (BMI) 23.5 ± 3.2 kg/m^2, FPI-6 10.7 ± 0.6) with asymptomatic highly pronated foot participated in the study. Demographic data of the participants are presented in Table 1.

Spatio-temporal walking measurements are shown in Table 2. There were no significant differences in gait speed (m/s) and stride length (m) between BF and CFO conditions.

Table 1. Participant demographics.

	Minimum	Maximum	Mean	Standard deviation
Age (years)	20.0	32.0	23.3	3.0
Height (cm)	150.3	180.9	165.5	8.9
Weight (kg)	51.5	96.3	65.0	13.5
BMI (kg/m^2)	19.0	29.8	23.5	3.2
FPI-6 (scores)	10.0	12.0	10.7	0.6

Table 2. Spatio-temporal measurements.

	Conditions		*P* - value
	BF	CFO	
Gait speed (m/s)	1.2 ± 0.1	1.2 ± 0.1	0.675
Stride length (m)	0.5 ± 0.3	0.5 ± 0.3	0.625

* Significant level at $P < 0.05$

Table 3. Summary of the mean range of joint excursion and standard deviation (in degrees) during the four subphases of stance before and after wearing customized foot orthoses (CFO).

		Initial contact phase			Forefoot contact phase			Footflat phase			Forefoot push off phase		
		BF	CFO	P – value	BF	CFO	P - value	BF	CFO	P - value	BF	CFO	P - value
Rearfoot													
Sha-Cal	Sagittal	9.7	8.7	0.650[a]	5.8	4.1	0.001*	4.9	4.7	0.749	25.6	24.1	0.080
	(DF/PF)	(3.2)	(1.7)		(2.1)	(1.2)		(2.1)	(1.8)		(3.8)	(3.7)	
	Frontal	4.4	4.5	0.762	2.4	2.3	0.748	3.9	4.0	0.884	4.9	4.8	0.463[a]
	(Inv/Eve)	(1.2)	(1.1)		(1.0)	(0.7)		(1.5)	(1.1)		(1.7)	(2.0)	
	Transverse	6.9	7.4	0.408	4.9	4.5	0.211	4.8	4.7	0.644	6.5	6.7	0.972[a]
	(Add/Abd)	(2.2)	(2.4)		(2.0)	(1.6)		(1.8)	(2.1)		(2.7)	(3.7)	
Ankle													
Sha-foot	Sagittal	9.3	8.0	0.028*[a]	6.2	4.3	0.002*	4.6	4.1	0.341	27.5	27.2	0.770
	(DF/PF)	(2.7)	(2.0)		(2.2)	(1.2)		(1.6)	(1.8)		(4.9)	(3.7)	
	Frontal	8.7	8.2	0.612	2.0	1.7	0.345[a]	5.8	4.2	0.002*	10.6	5.8	0.003*[a]
	(Inv/Eve)	(2.9)	(4.0)		(1.0)	(0.7)		(1.1)	(1.3)		(3.5)	(2.2)	
	Transverse	6.9	7.7	0.133	5.0	4.6	0.101[a]	5.1	4.8	0.355	6.7	6.4	0.607
	(Add/Abd)	(2.4)	(3.0)		(1.7)	(1.5)		(2.1)	(2.2)		(2.4)	(3.3)	
Knee													
	Sagittal	13.4	13.7	0.783	8.8	8.3	0.361	4.5	4.4	0.799	37.1	38.6	0.290
	(E/F)	(7.3)	(4.5)		(3.2)	(3.2)		(1.5)	(1.9)		(4.6)	(5.3)	
	Frontal	6.7	7.0	0.523	2.0	1.9	0.972[a]	2.1	2.1	0.917[a]	4.9	3.9	0.088
	(Add/Abd)	(2.0)	(2.0)		(0.7)	(0.6)		(0.9)	(0.6)		(1.4)	(1.4)	
	Transverse	3.6	3.5	0.600	1.8	1.9	0.693	1.4	1.3	0.390	5.8	6.1	0.279[a]
	(IR/ER)	(1.0)	(1.0)		(0.7)	(0.6)		(0.5)	(0.4)		(2.2)	(2.2)	
Hip													
	Sagittal	10.5	9.7	0.442	15.3	14.7	0.433	14.5	15.4	0.003*	7.8	9.0	0.109
	(E/F)	(3.2)	(2.9)		(3.5)	(3.4)		(2.6)	(2.6)		(2.4)	(3.2)	
	Frontal	9.5	9.1	0.329	3.0	2.8	0.210	2.2	2.0	0.046*[a]	12.7	12.3	0.507[a]
	(Add/Abd)	(2.2)	(2.8)		(1.2)	(0.8)		(1.2)	(1.1)		(2.9)	(2.5)	
	Transverse	7.2	7.3	0.843	4.0	3.4	0.039*[a]	2.7	2.7	0.975	9.9	10.0	0.837
	(IR/ER)	(2.4)	(2.5)		(2.0)	(2.0)		(1.2)	(1.4)		(3.0)	(2.2)	

* Significant level at $P < 0.05$, [a] Non-parametric analysis

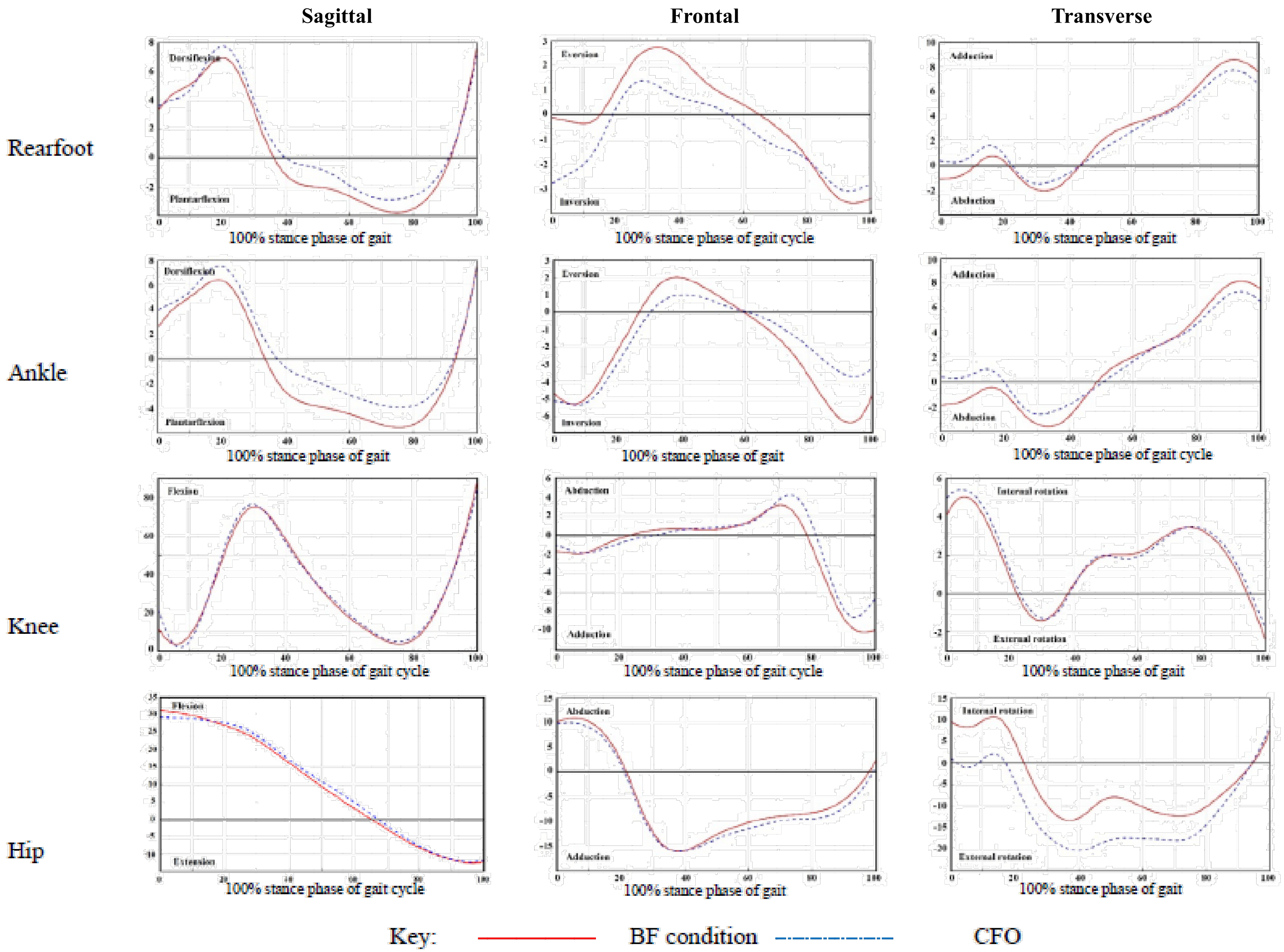

Figure 3. Segmental excursions (in degrees) for the BF and CFO conditions during the stance phase of the gait cycle. Positive values of the rearfoot and ankle motion indicate dorsiflexion, eversion, and adduction; and negative values of the foot segment and ankle indicate plantarflexion, inversion, and abduction. While, positive values of the knee and hip motions indicate flexion, abduction and internal rotation; and negative values of the knee and hip motions indicate extension, adduction, and external rotation. The scale on the vertical axis for the sagittal, frontal and transverse plane is altered compared to other graphs.

Table 3. shows the averaged joint excursion for the rearfoot, ankle, knee and hip in the BF condition and CFO condition in each subphase of the gait stance. The current result showed that the CFO condition could significantly change rearfoot, ankle and hip joint excursions in the stance phase. For the ICP, there was a significant decrease of ankle joint excursion in the sagittal plane (P = 0.028). For the FFCP, there was a significant decrease of rearfoot joint excursion in the sagittal plane (P = 0.001), and also a decrease of ankle joint excursion in the sagittal plane (P = 0.002) as well as a decrease of hip joint excursion in the transverse plane (P = 0.039). For the FFP, significant change was found in the ankle and hip joint excursions. The averaged joint excursion in the ankle joint significantly decreased in the frontal plane (P = 0.002), while the hip joint excursion significantly increased in the sagittal plane (P = 0.003) and significantly decreased in the frontal plane (P = 0.046). As for the FFPOP, there was a significant change only in ankle joint excursion in the frontal plane (P = 0.003). The comparative results for the BF and CFO conditions are presented in Table 3.

The patterns of averaged joint excursion in all three planes for rearfoot, ankle, knee, and hip joint angles between BF and CFO conditions are shown in Figure 3. The averaged joint excursion during the BF condition was represented in the red line, and the averaged joint excursion during the CFO condition was represented in the blue line. Furthermore, Figure 3 visually supports the results as depicted in Table 3.

Discussion

The present study investigated the kinematics change of the lower limb during the stance phase with the CFO in participants with asymptomatic highly pronated foot. The kinematics changes of the lower limb were observed between BF and CFO conditions compared. The participants with highly pronated foot had excessive lower limb motions, of which one of the most widely used management is wearing orthoses.(11) The highly pronated foot causes various unwarranted motions of the rearfoot, ankle, knee and hip joints. Abnormal rearfoot motion includes excessive plantarflexion, eversion, and abduction; abnormal ankle motion includes increased plantarflexion and eversion; abnormal hip motion includes increased femoral internal rotation and adduction. Additionally, increased tibia internal rotation is also found in highly pronated foot as a consequence of femoral internal rotation. Therefore, our aim in using CFO was to inhibit the excessive motions of the lower limb during weight-bearing in the stance phase. Under the CFO condition, there were significant changes in the rearfoot, ankle and hip joint excursion of the participants with pronated foot during the stance phase. A decrease in the rearfoot excursion occurred in the FFCP. A decrease in the ankle joint excursion occurred in every subphase in the stance phase. Moreover, changes in hip joint excursion were found in the FFCP and FFP. Therefore, the CFO used in the present study could possibly alter the alignment of the lower limb during walking.

Evidently, the rigid CFO made from a thermoplastic material in this study can provide benefits for the highly pronated foot and then change the gait pattern. This result is in line with those of some previous studies. In the study by Seo K, *et al.*,(16) their CFO were molded with ethylene-vinyl acetate (EVA). The authors showed their CFO could maintain the normal plantar arch, reduce eversion of the ankle joint, with move inversion closer to the normal angle. They explained that the CFO could increase the ankle motion by reducing foot muscle tension and plantar fascia that were stressed in the midstance phase. Additionally, Chen YC, *et al.*(12) used customized orthoses made by EVA with a special purpose to reduce the pronation of the foot. The effect of their CFO showed a significant reduction in the peak of the ankle plantarflexion angle and moment. However, their CFO could not alter knee and hip motions.

During the use of the applied CFO, a decrease in joint excursion of rearfoot and ankle in the sagittal plane during the FFCP might indicate that the CFO could limit excessive plantarflexion of rearfoot and ankle joint in pronated foot. Simultaneously, the decrease of rearfoot and ankle joint excursions were related to the decrease in the hip joint excursion in the transverse plane, as a decrease in the excessive hip internal rotation was observed in the subjects.

During the FFP, the ipsilateral leg was weighted on only one side, joint stability of the lower limb is needed to maintain the balance of the body. The current finding showed that CFO could significantly decrease ankle joint excursion in the frontal plane; indicating a decrease in eversion of the ankle joint. This motion might encourage arch lifting and subsequently increased hip flexion and decreased hip adduction of the lower limbs. Previous studies have suggested that the effect of orthoses on the hip may be related to the mechanical alteration of the foot segmental motion. Hsu WH, *et al.* studied the effect of semi-rigid orthoses designed to lift up the arch height in 15 adults with bilateral forefoot varus abnormality and found a significant decrease of hip adduction angle in their subjects.(24) Lack S, *et al.* used prefabricated varus posted orthoses in 20 subjects and found decreased hip adduction during a step-up task.(34) Hip adduction angle may be significantly reduced with orthoses due to the performance of the gluteus medius muscle. This muscle becomes longer in a less adducted hip position.(24) Orthoses with arch support may increase muscle power and then possibly restore body stability during the stance phase.

The reduced ankle joint excursion in the frontal plane during the FFPOP that was found in this study additionally supported the benefit of using the CFO for a highly pronated foot. The CFO supported the arch of the foot in the FFP when moving into the FFPOP, the ankle joint was in an appropriate inversion position, leading to sufficient calf muscle performance in pushing off.(35)

This study found that the CFO did not change the knee kinematic variables in the participants with highly pronated foot. The current result is in contrast to a previous study of Lack S, *et al*. reporting reduced knee internal rotation in the individuals wearing FO. The study by Lack S, *et al*. found that the effect of foot orthoses was significantly reduced knee internal rotation during a step-up task in individuals with patellofemoral pain.(27) They described that a decrease in knee kinematics might be associated with a decrease in the rearfoot kinematics, as the subtalar joint provides an anatomical related between talus to the tibia. While the current study showed that there was no significant change of the rearfoot motion in the transverse plane. Therefore, any consequence of a change of rearfoot motion was inhibited. Furthermore, the knee joint is a hinge type synovial joint, which mainly allows for motion in the sagittal plane and a small amount of motion in frontal and transverse planes. While the hip and ankle joints have angular motion in many directions and rotational movements. Thus, the changes possibly occur in the hip and ankle more than the knee joint.

Although the different results between conditions were small, the changes of joint excursion in degrees were also slight suppression of the unwarranted motion among participants with highly pronated foot. The relative result of the CFO compared with the BF conditions during the stance phase of the gait cycle might represent a clinically relevant change. Considering the human tasks in daily life, the movement of the limbs occurred via joint motions that overlapping between segments. Each segment was linked whereby motion at one segment affected motion to other segments via the kinetic chain. A small amount of bone alternation after wearing the CFO may develop progressively result in a significant change during the gait stance. The improvements of the kinematic variables observed in this study may still have benefits in the clinical treatment for participants with highly pronated foot. Therefore, the clinical implication of our findings given the relationship between foot and hip kinematics is that the limit unwarranted movement of the foot and ankle subsequence to the hip motion would increase the stability when wearing the CFO. Furthermore, the test-retest reliability of kinematic variables was calculated to determine the standard error of measurement (SEM). The SEM indicates the expected variation in observed data between two repeated measurements due to measurement error. In the present study, the intra-rater reliability testing of lower extremity and multi-segment foot kinematics during the four subphases showed SEM of multi-segment foot model in rearfoot ranged from and 0.1 to 0.3, as also the SEM of Helen Hayes marker set in ankle ranged from 0.1 to 0.2, knee ranged from 0.1 to 0.6 and hip ranged from 0.1 to 0.4, respectively.

The experimental methodology adopted in the current study had some limitations that should be described and considered. Markers were placed on the skin to collect the kinematics data. This method is suitable for analyzing the gait cycle during walking. However, the method can only have represented structural movement due to the skin moving over the bony landmarks during locomotion. Another limitation of this study was the small number of participants and this may account for the lack of any significant difference in the results. In addition, while the results presented in this study provide a useful insight into the immediate effects of the CFO, it is not clear whether these effects persist or are likely to change over a longer-term accommodation period. Thus, further investigation is required to examine the long-term effects of an orthotic intervention. Moreover, this study made custom-molded orthoses according to the height of MLA suitable for inhibiting the unwarranted motion of the ankle, while few differences were reported in the limitation of the rearfoot joint excursion. However, previous studies have reported the benefit of medial wedged orthoses in controlling rearfoot motion. Future research may study the effect of CFO combined with a medial wedge on changes in the lower extremity kinematic variables in the highly pronated foot.

Conclusion

The present study demonstrated the effect of CFO on the rearfoot, ankle and hip joint excursions during dynamic movements and weight-bearing activities in participants with highly pronated foot. The CFO significantly decrease rearfoot plantarflexion, decrease ankle plantarflexion, decrease ankle eversion, increase hip extension, decrease hip adduction and decrease hip internal rotation in such population. The benefits of CFO may be due to the ability of such devices to increase the arch height during the stance phase. This application would serve as an additional treatment in combination with other physical therapy interventions. Additionally, the CFO used in the current study was cheap and simple but easy to apply in the clinical setting.

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Conflict of interest

The authors, hereby, declare no conflict of interest.

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