The Effect of Medical Insoles on the Kinematics of Lower-Limb Joints in People with Flexible Flatfeet during Walking

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Abstract

Introduction: Since the height of the medial longitudinal arch decreases in people with flatfeet, thereby resulting in biomechanical changes in the foot-ankle complex, the use of medical insoles as a common treatment has been of interest for therapists. The aim of the present study was to investigate the effect of using medical insoles on the kinematics of lower-limb joints during walking in male athletes with flexible flatfeet. **Materials and Methods**: A total of 15 male athletes with flexible flatfeet with mean ± standard deviation (SD) of age of 21.33±3.39 years, height of 178.72±5.28 cm, and weight of 71.76±8.04 kg participated in the study. The peak angles of ankle, knee, and hip movements in the stance phase of gait in three conditions (bare feet, sandals with insoles, and sandals without insoles) were assessed by eight motion analysis capture cameras (VICON UK). Data analysis was carried out by repeated measures ANOVA and Bonferroni post-hoc test in SPSS software. *P*-value≤0.05 was considered as the significance level. **Results**: The findings showed that in individuals with flatfeet, the variables of the peak points of the ankle dorsiflexion (*P*=0.001) in mid-stance and knee flexion (*P*=0.001) in loading response were significantly different between test conditions. However, there was no significant difference between the peak points for the ankle plantar flexion (*P*=0.24), knee extension (*P*=0.92), and hip extension (*P*=0.87). **Conclusion**: The results showed that controlling the foot motion during walking using sandals and custom medical insoles can make changes in the kinematics of the ankle and knee joints. However, it did not have a significant effect on hip kinematics.

Keywords: Flatfeet; Kinematics; Medical insole; Walking

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Introduction

The foot is the most distal segment in the lower extremity chain that has a relatively small level of support, and therefore, and any slight structural and biomechanical changes may affect the musculoskeletal structure and balance (1, 2). Flatfoot is one of the most common musculoskeletal disorders. The height of the medial longitudinal arch decreases in this disorder and causes problems for the person that these problems are not limited to the foot with effect on other parts in the form of a kinematic chain. These problems usually include hallux valgus, hammer toe, Morton's neuroma, knee and back pain, *etc.* (3, 4), which even affect a person's performance and increase the risk of injury in people, especially athletes (5). This deformity causes involvement in all three planes including frontal (heel valgus), sagittal (equinus, and plantar-flexed first ray), and horizontal (metatarsal adduction) (6). Since the foot arch absorbs shock, adapts to surfaces, and maintains stability during walking, any disturbance in it may affect these functions and increases mechanical stress on the lower extremity (7). During walking, pronation occurs in the subtalar joint at initial contact, then the stance phase continues for about 25%, and then the foot goes to the supination at the end of the mid-phase to enable the heel off phase. In people with flatfeet, the frequency of initial pronation is abnormally high and therefore supination is either delayed or does not occur at all (8).

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Figure 1. Right image: 3D scan, left image: Semi-rigid custom insoles with fabric cover

One of the common treatments for this disorder is the use of a medical insole (orthosis) expected to reduce the risk of injury among individuals (9). The biomechanical effect of medical insoles on the structure and control of subtalar eversion and tibial rotation has been expressed in many studies (10, 11). Results of studies investigating the effect of insoles on the foot function and movements showed that kinematics of the lower extremities can change after using the medical insoles (10, 12). Insoles are usually designed to perform pronation and supination appropriately and controllably during walking. McLean *et al.* (11) showed that insoles significantly reduced heel eversion angle and its speed during walking, thereby resulting in a reduction in the maximum inversion moment. Kudo *et al.* (13) also stated that a suitable insole may have a positive kinematic and kinetic effect on each plane of motion and in addition to considering the medial longitudinal arch, the lateral arch should also be considered in the insole design (14).

All these features in insole design depend on the designer's experience, insole material, and the effect of this design on the kinematics and kinetics of the lower extremities. Overall, the purpose of using insoles is to reduce the likelihood of injuries of mechanical origin (15). Bonanno *et al.* (14) stated that 75% of runners with symptoms such as knee pain, plantar fascia inflammation, calcaneal spur, and sole pain had a better feeling with the use of insoles and their symptoms were reduced up to about 80%. Bonanno *et al.* (16) also concluded that insole may reduce the additional load on the joints and tissues by modifying the foot structure alignment which can be effective in reducing the symptoms of structural disorders. Therefore, while designing insoles, the adverse mechanical effects of the flatfeet must be considered in order to make a more accurate design for the insoles.

During dynamic evaluation, foot motions are quantitatively observed, therefore, its information can be used to design more appropriate insoles. Most of studies have investigated the role of insole as one of the therapeutic interventions on the ankle joint (10, 17). However, there are limited studies on the effect of medical insoles on other parts of lower extremities. For example, Telfer *et al.* (15) investigated the effect of insole on the kinematics and kinetics of lower extremities and stated that insole was effective on the function of the muscles around the ankle and knee joints as well as the distribution of plantar pressure. Since athletes are more prone to injuries than non-athletes and the risk of these injuries may increase due to flatfeet, the aim of the present study was to investigate the effect of using insoles on the kinematics of lower-limb joints among people with flatfeet during the stance phase.

Materials and Methods

Subjects

This was a quasi-experimental study. The statistical population of the present study consisted of 18-25-year old healthy male athletes with severe and flexible flatfeet who had been exercising regularly for about three years. The sample size was determined using G Power software (http://www.gpower.hhu.de/), test power of 80%, type I error rate of 0.05, and the effect size of 0.80. From the statistical population, 15 people with mean standard deviation of age of 21.33±3.39 years, height of 178.72±5.28 cm, and weight of 71.76±8.04 kg participated in the study. Before any measurement, all study steps were explained to individuals. Additionally, subjects received full information regarding study procedure, their submitted consent to participate in the study, and completed the relevant forms. Finally, demographic characteristics were recorded in a questionnaire. Individuals were reassured that this study did not have any risk and injury for them both in terms of intervention or measurement methods.

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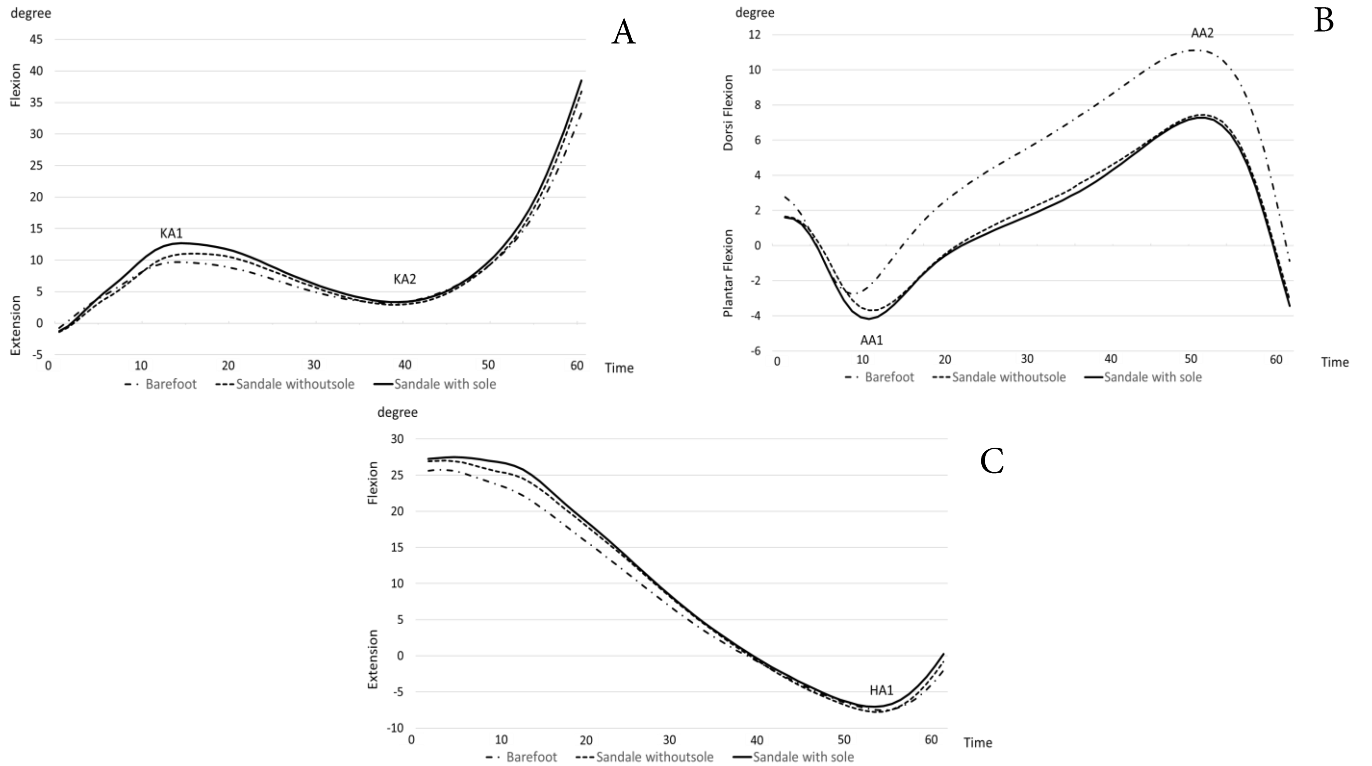

***Figure 2**. A*) Angular changes in ankle; *B*) Knee; C) hip joints during walking in the stance phase in three conditions: bare feet, sandals without insoles, and sandals with insoles

Inclusion criteria included having flatfeet and no history of having ankle sprains, lower-limb fractures in the last six months, surgery, especially in the lower extremities during the past year, and diseases that can affect a person's performance (walking, balance). Exclusion criterion also included having a normal foot structure or rigid flatfeet and not meeting the inclusion criteria.

Foot posture index (FPI) was used to evaluate the foot structure. This index consists of six variables assessed from both posterior and anterior views of the foot. The score range for each variable is -2 to +2 and the overall score is -12 to + 12. Negative and positive scores indicate supination and pronation disorders, respectively (18). In this study, people whose FPI was above 8 (in terms of arch, heel deviation, Talus rotation, and anterior adduction, navicular protrusion of +1 or +2) were selected for the next stages of the research. If the flatfeet were confirmed, to determine its type (flexible or rigid), individuals were asked to stand on their toes. If the foot arch was formed and the heel valgus was eliminated, the person was allocated as flexible flatfoot. These steps would be performed by an expert occupational therapist (19).

Instruments and Methods

Marker clustering was used to record kinematics data. In the lower-limb model, light-reflecting markers were placed on the upper anterior iliac spine, upper posterior iliac spine, ilium protrusion, greater trochanter, medial and lateral condyle, medial and lateral ankle, heel and the end of the first, second, fifth metatarsal bones, and two clusters with 4 markers were also placed on the left and right sides of the thighs and legs (20).

In the present study, a pair of custom-made medical insoles was used designed using CNC cutting machine based on structural examinations and scanning (SL Digitizer, Amfit Inc., USA) by CAD-CAM method. The insoles were made of semi-rigid thermoplastic polypropylene with fabric cover (Figure 1). This type of insole supported the medial longitudinal arch of the foot and had a little depth on the lateral side to further support the heel. When performing the test, the insoles were used inside the sandals made in three sizes: 40-42-44. Kinematic data was recorded in three conditions including bare feet, use of sandals without insoles, and sandals with custom-made medical insoles with three repetitions for each condition. Eight Vicon motion capture cameras were arranged in a circle at 45-degree angle to each other so that each marker was captured by at least three cameras at a time. To this end, individuals were asked to walk in the walkway (7 meters in length) at their self-selective speed.

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Table 1. Mean (SD) and F statistic, and significance of the results of the selected peak points of the angle charts of the ankle, knee, and hip joints during walking at their normal speed under different test modes

Variable		Group	Mean (SD)	Minimum	Maximum	F Statistics	*P*-value
Ankle (degree)	AA1	Sandals with medical insoles	-4.05 (3.69)	-11.12	2.40	1.36	0.24
		Bare feet	-2.88 (4.77)	-10.46	4.77		
		Sandals without insoles	-3.69 (3.33)	-11.52	1.37		
	AA2	Sandals with medical insoles	7.42 (5.39)	1.29	15.60	5.90	0.001*
		Bare feet	11.27 (4.50)	3.31	17.94		
		Sandals without insoles	7.61 (5.43)	1.48	15.85		
Knee (degree)	KA1	Sandals with medical insoles	12.87 (4.58)	3.55	20.34	5.44	0.001*
		Bare feet	9.90 (3.93)	1.66	18.27		
		Sandals without insoles	11.27 (3.34)	4.28	17.41		
	KA2	Sandals with medical insoles	2.89 (3.50)	-5.99	10.04	0.22	0.92
		Bare feet	2.59 (3.61)	-8.21	9.36		
		Sandals without insoles	2.60 (3.30)	-5.62	7.77		
Hip (degree)	HA1	Sandals with medical insoles	-7.21 (3.84)	-17.14	-0.83	0.30	0.87
		Bare feet	-7.63 (4.29)	-16.03	-0.36		
		Sandals without insoles	-7.91 (3.39)	-16.70	-2.63		

Significance level: $P \leq 0.05$, AA1: ankle plantar flexion angle during loading response, AA2: ankle dorsiflexion angle during mid-stance, KA1: knee angle flexion during loading response, KA2: knee extension angle in the mid-stance, and HA1: hip extension angle in the mid-stance*

Steps of data implementation and processing

Data processing was performed in four stages of data check, filtering, normalization, and analysis. After being collected, the data were first analyzed to ensure the accuracy of the sampling. Then, in order to reduce noise and error, a fourth-order low-pass Butterworth filter was used. In order to homogenize and compare the data, the data were normalized as a percentage based on a complete gait cycle. To compare different test conditions in this study, the peak points of kinematic variables of the lower-limb joints during walking were considered. These points are functionally important selected based on the results of similar relevant studies (21). The present study evaluated the peak angles in the stance phase for the ankle including the first peak of (ankle plantar flexion angle (AA1) in loading response, second peak of ankle dorsiflexion angle in mid-stance (AA2), maximum knee flexion in loading response(KA1), maximum knee extension in the mid-stance phase (KA2), and maximum hip extension in the mid-stance (HA1). Finally, Visual3D software was utilized to analyze the data.

Statistical analysis

Shapiro-Wilk test was used to determine the normal distribution of data. Leven test was used to examine the homogeneity of data variance, and repeated measure ANOVA test was used to compare different walking conditions (bare feet, sandals without insoles, and sandals with custom insoles). Where there was a significant difference between the means of the test conditions, pairwise comparison of conditions was carried out using Bonferroni post hoc test. Data analysis was carried out using SPSS ver. 20. *P*-value≤0.05 was considered as the significant level in all tests.

Results

Table 1 shows mean±SD and results of repeated measured ANOVA for the desired variables in different test conditions. A significant difference between the test conditions in terms of the peak point variables of the joint angle curves including the maximum ankle dorsiflexion in mid-stance (AA2) and the maximum knee flexion (KA1) in loading response was observed. However, there was no significant difference between the conditions in terms of the maximum ankle planter flexion (AA1), the maximum knee extension (KA2), and the maximum hip extension (HA1).

The results of Bonferroni post hoc test showed a significant decrease in the maximum ankle dorsiflexion (AA2) during walking with bare feet and sandals (with insoles (P=0.02) and without insoles (P=0.001)). However, the maximum ankle dorsiflexion demonstrated no significant difference between wearing sandals with insoles and sandals without insoles (P=1.00). Finding also indicated a significant increase in maximum knee flexion (KA1) using sandals with medical insoles compared to bare feet and sandals without insoles (P=0.04). However, there was no significant difference between bare feet and sandals without insoles in this regard (P=0.08) (Figure 2).

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Discussion

The main purpose of the present study was to investigate the effect of using insoles on the kinematics of the lower-limb joints in people with flexible flatfeet during walking. Finding revealed that insoles were effective on the kinematics of the lower-limb joints including the ankle and knee angles with reduced maximum ankle dorsiflexion in the mid-stance phase and increased maximum knee flexion in loading response phase. However, those had no significant effect on the hip joint.

These findings were consistent with the results of studies on the effect of medical insole use on the kinematics of lower-limb joints. These studies demonstrated that use of medical insoles in people with flatfeet caused the angular changes in the knee and ankle joints (6, 22, 23) and also its use of could improve the control of foot motions during walking (22-24). Telfer *et al.* (15) demonstrated the positive effect of insole use on ankle and knee kinematics.

According to previous studies, the ankle joint is in the plantar flexion position at heel strike during walking, which is a mechanism for absorbing shock as well as the immediate acceptance of body weight at this phase. The plantar flexion gradually decreases to reach a normal position and then goes to the dorsiflexion from the mid-stance phase to reach plantar flexion again at heel off. The findings of the present study showed that use of sandals with insoles reduced plantar flexion (AA1) compared to bare feet walking, but it did not reach a statistically significant difference According to the findings regarding the ankle maximum dorsiflexion (AA2), which is related to the mid-stance phase, dorsiflexion was significantly reduced when using sandals with insoles and without insoles compared with bare feet, which can be due to the control of foot motion when using sandals. Considering its significant difference with the bare feet walking, sandals along with insoles can be considered as one of the factors limiting the foot dorsiflexion at this stage. this finding is not consistent with the results of Chen *et al.* study (23). The possible reasons between the results of Chen's study and our study could be age group of the participants, difference in testing method, and study population. However, the results were consistent with the results of another study which showed the use of insoles had an positive effect on ankle kinematics (25).

To improve the shock absorption at heel strike, the knee bends slightly (flexion) and then extends in the mid-stance phase of the gait. These movements are performed to support the weight and shift the center of gravity. Factors such as gait speed affect the knee flexion. As the gait speed increases, the knee flexion increases (26, 27). Previous researches have shown that insoles can increase gait speed (21). In the present study, the maximum knee flexion (KA1) was significantly increased when using sandals with medical insoles compared to the bare feet walking, which can be due to increased gait speed using insoles. Moreover, results of previous studies, which investigated muscle activity in people with flatfeet, showed an increase in the activity of the quadriceps and tibialis anterior muscles in these people compared to normal people (28). Merley *et al.* (28) revealed that sandals and insoles reduced the activity of these muscles. By reducing eccentric contraction rate of quadriceps, the knee flexion may increase when using insoles. Increasing the maximum flexion in the loading response phase can improve the shock absorption mechanism and thus prevent musculoskeletal injuries related in the knee, which is in line with the findings of the study by Mikesky *et al.* (29). These findings are also consistent with the findings of the study by Shih *et al.* (30). They investigated the kinematics of the lower extremities during walking in affected and healthy individuals and concluded that knee flexion was reduced in people with flatfeet and insoles can increase the flexion angle.

Few studies have investigated movements of the proximal joints to ankle including the hip joint in people with flatfeet. Some studies have shown that hip movements among people with flatfeet is lower than healthy people, which can be due to the effect of the kinematic chain of the distal joints (31, 32). The present study did not show a significant difference for this joint in test different conditions, and the only small differences were observed between bare feet and the use of sandals (with insoles and without insoles) which can be due to increased limb length when using sandals.

The present study investigated the immediate effect of using the insole on the kinematics of the lower-limb joints during walking and only in the stance-phase. It is better to consider short-term and long-term uses of medical insoles as well as the effect of using insoles on the function of lower-limb muscles, especially the proximal muscles to the ankle joint (knee and hip) in future research.

Conclusion

The results showed that the use of sandals and medical insoles can cause changes in the ankle and knee movement pattern. Reducing the ankle dorsiflexion and increasing the knee flexion may improve the mechanism of shock absorption during walking, which can prevent injuries due to inefficacy of shock absorption in the knee. The use of sandals and insoles had no significant effect on hip kinematics.

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All authors made substantial contributions to the conception, design, analysis, and interpretation of data.

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