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Foot orthoses improve kinematic measurement in young women with biomechanical abnormality

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ABSTRACT

BACKGROUND
Foot pronation causes biomechanical abnormalities in the form of functional leg-length disparity. Foot orthoses are often used in the treatment of abnormal pronation. The aim of the study was to evaluate the effect of foot orthoses on abnormal kinematic chain the differences of pelvic height, step length, and walking distance on walking test in young women with biomechanical abnormality.

METHODS
A randomized double blind controlled clinical trial was conducted on 27 young adult women having abnormal biomechanical abnormalities. By random allocation the subjects were divided into the intervention group (14 subjects) receiving correction of foot pronation using foot orthoses, and the control group (13 subjects) receiving no orthoses. Before and during use of foot orthoses, we determined pelvic height difference (mm), step length difference (cm), and walking distance at maximal walking speed for 15 minutes.

RESULTS
Correction of foot pronation resulted in decreased pelvic height difference from 4.7 ± 2.1 mm to 1.7 ± 1.3 mm ($p<0.001$) and in a reduction in step length difference, from 4.9 ± 2.9 cm to 2.1 ± 1.5 cm ($p=0.002$). Walking test distance of the intervention group was 1318.5 ± 46.3 m, as compared with that of the control group of 1233 ± 114.7 m ($p = 0.05$). Walking distance of the intervention group rose steadily in the second test to 1369.3 ± 27 m, and in the third test to 1382.14 ± 10.5 m ($p<0.001$).

CONCLUSIONS
Foot orthoses improved the kinematic chain, resulting in a more symmetrical pelvic height, reduced step length difference, and increased functional walking ability.

Key words: Foot orthoses, biomechanical disorder, kinematic chain, young women

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Ortosis kaki memperbaiki pengukuran kinematik pada wanita muda dengan kelainan biomekanikal

ABSTRAK

LATAR BELAKANG
Adanya kelainan biomekanik berupa kaki pronasi dapat berhubungan dengan terjadinya disparitas panjang tungkai fungsional.. Ortosis kaki seringkali digunakan untuk mengatasi kaki pronasi abnormal. Penelitian ini bertujuan untuk menilai pengaruh penggunaan ortosis kaki terhadap kelainan rantai kinematik selisih tinggi pelvis, panjang langkah, serta jarak tempuh saat uji jalan pada perempuan muda dengan kelainan biomekanik.

METODE
Rancangan eksperimental tersamar ganda ini mengikutsertakan 27 perempuan muda dengan kelainan pronasi. Randomisasi menempatkan 14 subjek pada kelompok intervensi yang menggunakan ortosis kaki, dan 13 subjek kelompok kontrol yang tidak menggunakan ortosis kaki. Ukuran kinematik berupa selisih tinggi pelvis (mm), selisih panjang langkah (cm) dan jarak tempuh saat berjalan pada kecepatan maksimal selama 15 menit diukur sebelum dan selama penggunaan ortosis kaki.

HASIL
Penggunaan ortosis kaki menurunkan selisih tinggi pelvis secara bermakna dari 4,7 ± 2,1 mm menjadi 1,7 ± 1,3 mm (p<0,001). Penurunan secara bermakna juga terjadi pada selisih panjang langkah dari 4,9 ± 2,9 cm menjadi 2,1 ± 1,5 cm (p=0,002). Uji jalan pada kelompok perlakuan jarak tempuhnya sebesar 1318,5 ± 46,3 m, yang lebih jauh dibandingkan kelompok kontrol sebesar 1233,0 ± 114,7 m (p=0,05). Jarak tempuh uji jalan pada kelompok intervensi meningkat secara bermakna menjadi 1369,3 ± 27,0 m pada uji jalan kedua dan 1382.14 ± 10.5 m pada uji jalan ketiga (p<0,001).

KESIMPULAN
Penggunaan ortosis kaki mampu memperbaiki kelainan biomekanik yang menghasilkan tinggi pelvis yang simetris, penurunan selisih panjang langkah dan meningkatkan kemampuan berjalan.

Kata kunci : Ortosis kaki, kelainan biomekanik, rantai kinematik, perempuan muda

INTRODUCTION

According to previous studies, the most prevalent biomechanical abnormality in the population is functional leg-length disparity (60% to 90%). Previous studies have also found an association between functional leg-length disparity and foot pronation. The prevalence of flexible foot pronation in the population is 20-30%.(1) Foot pronation is a combination of subtalar eversion, anterior abduction and dorsiflexion of the foot, and flat foot.(2) Foot pronation may result in other biomechanical abnormalities, i.e. increased knee Q angle, pelvic tilt, and lumbar postural scoliosis. Pelvic tilt causes functional leg-length disparity, which may lead to abnormal walking. The latter may be due to walking kinematics in the sagittal plane, in the form of asymmetry in right and left step lengths.(3) Foot pronation accompanied by functional leg-length disparity without subsequent intervention may lead to structural joint damage, such as damage to cartilage of the subtalar, knee, and facet joints, along with damage to the intervertebral discs.[4,5] These findings support other studies demonstrating that subjects with low back pain had higher prevalence of functional leg-length disparity than controls. A disparity of more than 5 mm was found in 75% of patients with low back pain, and in 44% of the control group.[6] Previous studies also found that cases of back pain and leg pain were closely associated with asymmetrical leg-length.[7,8]

Individuals with foot pronation and functional leg-length disparity may experience vertebral-pelvic-hip kinematic chain abnormalities. The kinematic chain abnormalities may increase the activity of skeletal muscles around the joints during activity, increasing the mechanical tension of the muscular tissue of the lower limbs, and possibly resulting in skeletal muscle injury.[7,8]

Correction of foot pronation is indicated to prevent muscle injury in biomechanical disorders. Conservative management of flexible foot pronation consists in advising the patient to frequently walk without footwear on a soft surface, such as sand, turf, or a thick carpet, to perform active and passive contraction exercises on the Achilles tendon, and to use foot orthoses. The latter is the most effective conservative management of foot pronation, as it ensures the stability of correction of foot pronation posture in the performance of daily activities. Correction of foot pronation may result in pelvic equality, which will improve functional leg-length disparity, thus improving the kinematic measures of walking, i.e more symmetrical right and left step lengths.[9,10]

The assessment of foot pronation is performed by means of foot prints, pelvic height difference by means of bodyworks body scan, and kinematic evaluation of walking activity in the sagittal plane by means of the Biodex Gait Trainer 2 (230 VAC).[11-12] Based on the above description, there is a need for a study to evaluate the effect of foot orthoses on kinematic measurements in young women with biomechanical abnormalities. Gender and age affect the occurrence of muscle injury and degenerative processes, thus to obtain a homogenous sample of subjects without degenerative problems, this study was conducted on young adult women aged 20-29 years.[13-15]

METHODS

Research design

This study was a randomized double blind controlled trial and was conducted from October 2010 to February 2011 in three locations. History taking (anamnesis), physical examination, and fitting of foot orthoses were performed at Trisakti Medical Center *(Pusat Medis Trisakti)*. Walking tests were conducted by means of the Biodex Gait Trainer 2 at a private hospital in East Jakarta. Three-dimensional body scans were performed at the Ergonomics Laboratory, Faculty of Industrial Technology, University of Indonesia, Depok.

Study subjects

The study subjects were female students of universities in West Jakarta with biomechanical abnormalities in the form of functional leg-length disparity accompanied by foot pronation. The sample size calculation was according to the formula for the difference between two means, to detect a 25% difference of mean change in kinematic measures, and the obtained estimation of sample size was 14 subjects for each group.

Intervention

Research subjects were randomly divided into two groups, i.e. the control group and the intervention group. The intervention group was given foot orthoses for correction of foot pronation whereas the control group was not. We evaluated the differences in pelvic alignment with and without foot orthoses. The assessment was conducted using three-dimensional body scans to meassure pelvic heights. Subjects in both groups performed the walking test to assess step length differences and walking distance on the Biodex Gait trainer 2. The intervention group performed the walking test twice, both with and without foot orthoses. To meassure step length differences, the walking test was performed at normal speed for 2 minutes, whereas to meassure walking speed, the test was performed by both groups at the maximum speed that could be tolerated by the subjects for 15 minutes. The walking test to measure walking distance in the intervention group was performed three times, i.e at the start of the study, at day seven, and at day fourteen, whereas walking distance in the control group was assessed only once.

The type of ready-made polyethylene orthoses used in this study as shown in Figure 1 are relatively expensive and not freely sold on the Indonesian market. Mean height of the medial arch supports in these foot orthoses is 1.30 ±0.15 cm. Prescribing foot orthoses with identical heights of medial arch supports resulted in elevation of both subtalar joints to a relatively similar level in all subjects of the intervention group.[9,10]

Protocol of assessment

Assessment of foot pronation was performed by means of foot prints to find the medial contour of the foot prints, from which the grade of foot pronation was determined (grades 1-3).[4] Assessment of pelvic alignment was by means of body scans obtained by laser beam technology projected on the human body. The light sensors act concurrently on the simple geometric principle of triangulation, and will measure the surface of the human body. A special optical system and glass are used to obtain a linear reflection of the single laser beam. The laser scanning unit, consisting of the laser, optical system, and light sensor, moves across the human body to obtain digital measures of the body surface. Three scanning units move vertically and synchronously along three posts and are aimed at the center where the subject is standing. The light sensor, optical system and electric motor can be detached and reattached. The scanning unit has to be calibrated such that the positions of the geometric elements may be accurately determined. A disadvantage of this instrument is that it is expensive and rare. When scanning is performed, the body has to be immobilized for a few seconds. The values obtained by digitalization consist of anthropometric measurements expressed in centimeters and millimeters. The use of the scanner for anthropometric measurements of the human body has been demonstrated to be valid and reliable.[11]

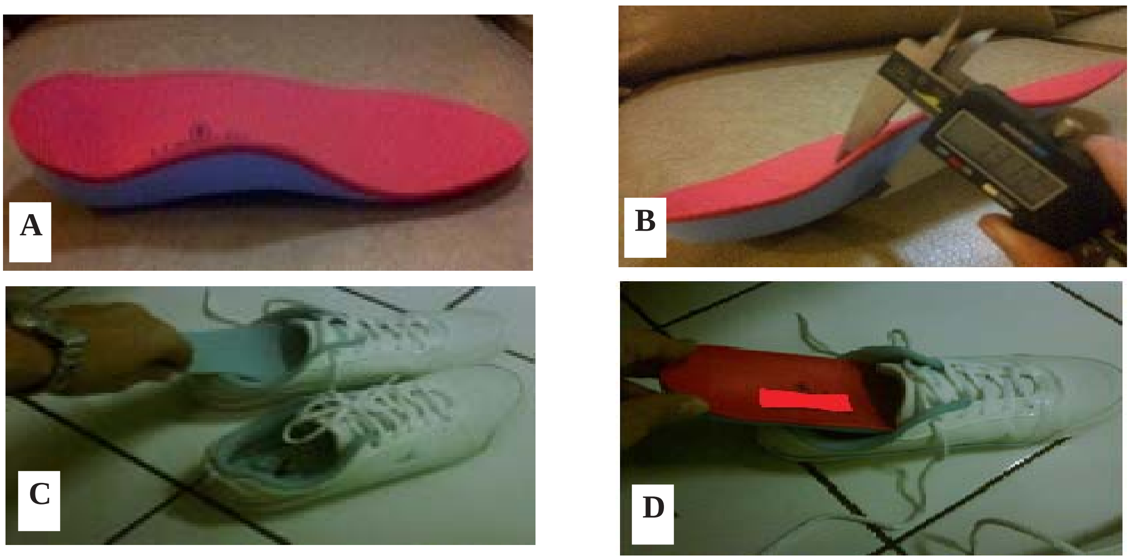

Figure 1. (A) Foot orthoses; (B) Height of medial arch measured by digital caliper; (C) Type of shoes used; (D) Inserting orthosis into shoe

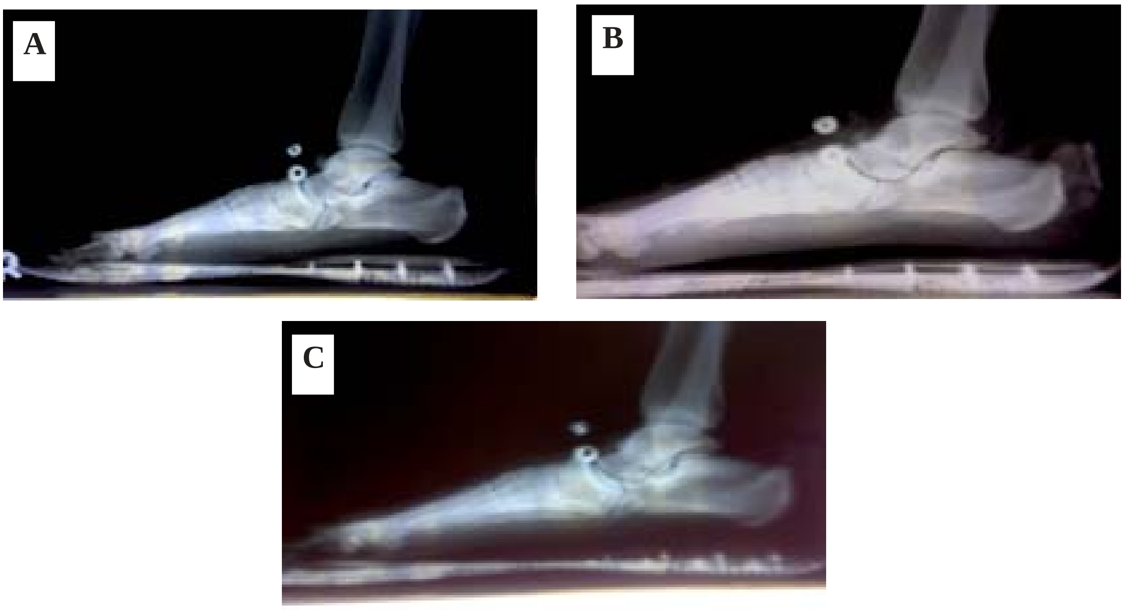

Figure 2. (A) Right subtalar position without orthoses; (B) Right subtalar position with orthoses; (C) Difference in right subtalar height with and without orthoses

The anthropometric measurement used for assessment of pelvic height is the distance from the hip (iliac crest) to the ball of the foot. The pelvis is considered to be straight when the difference between the right and left pelvic heights is small.

The assessment of walking step length was performed in subjects with foot pronation and functional leg-length disparity, both without and during use of foot orthoses. The computer of the Biodex Gait Trainer 2 automatically measures the distance between two contralateral heel strikes and calculates the mean right and left step lengths.[12] Assessment of step lenght by means of the Biodex Gait Trainer 2 was performed in our previous study investigating the effect of step

Figure 3. (A) Left subtalar position without orthoses; (B) Left subtalar position with orthoses; (C) Difference in left subtalar height with and without orthoses

length on body posture and low back pain in 77 young adults.[8] The walking test was evaluated by a research assistant was blinded to the use of foot orthoses by the subjects.

In the present study, improvement of subtalar joint height when using foot orthoses was determined from X-ray radiographs. The radiographs were taken from the medial sides of both feet, with the foot supporting the weight of the body on the stance phase in the walking cycle. The radiographs were taken both with and without foot orthoses. Both radiographs were then compared to find the difference in the heights of the subtalar joints with and without using foot orthoses, as shown in Figures 2 and 3.

Data analysis

Tests of normality for all variables were performed according to the Saphiro-Wilk method. Intervention groups were compared with respect to baseline demographic and clinical characteristics. Independent t test was performed to compare all variables at baseline the kinetic measurements after foot correction. Repeated ANOVA was performed to evaluate the effect of the intervention on pulse rate and walking distance. Analyses were conducted at the 0.05 á level. All analyses were performed with SPSS software (version 17: SPSS Inc, Chicago, IL).

Ethical clearance

In this study all components of ethical validity have passed the test of ethics by the Research Ethics Committee of the Faculty of Medicine, University of Indonesia.

RESULTS

Screening of the 177 subjects obtained 27 subjects meeting the inclusion criteria Figure 2.

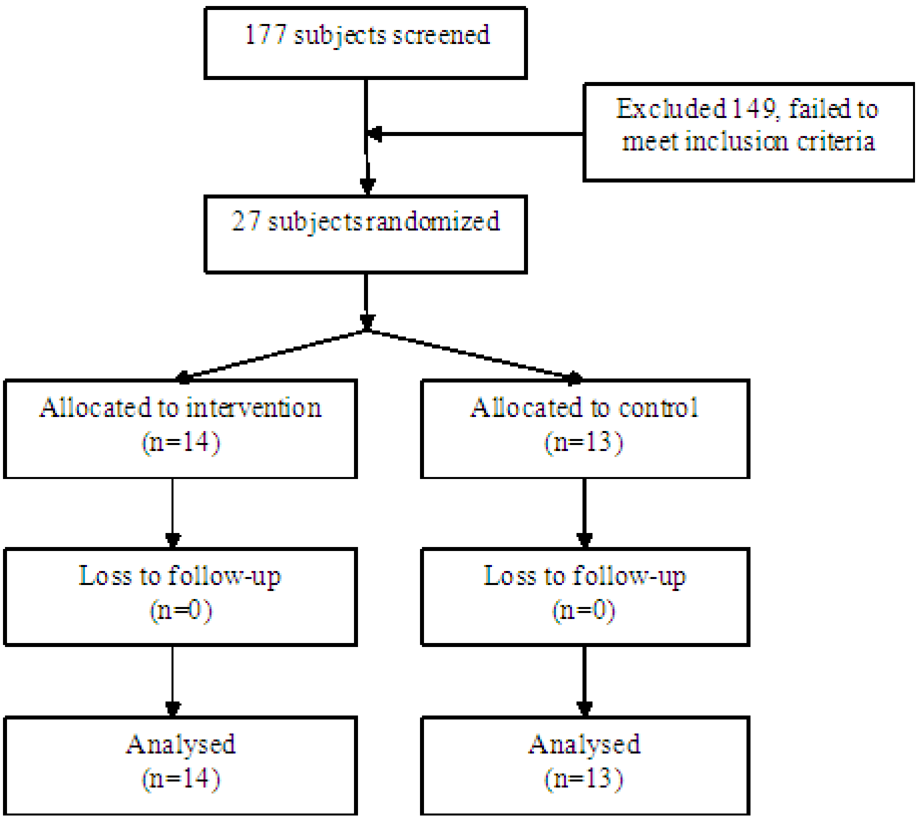

Figure 4. Flowchart of the study subjects

Table 1. Baseline characteristics of the subjects

Characteristics	Intervention (n= 14)	Control (n=13)	p
Age (years)	20.5 ± 0.5	20.3 ± 0.5	0.328
Height (m)	1.5 ± 0.4	1.5 ± 0.5	0.577
Body Weight (kg)	56.7 ± 9.5	56.0 ± 4.7	0.825
Body Mass Index (kg/m^2)	22.7 ± 2.0	23.4 ± 2.3	0.414
Kinetic measures			
Left pelvic height (cm)	98.3 ± 3.6	99.9 ± 1.9	0.156
Right pelvic height (cm)	98.6 ± 3.6	100.0 ± 1.8	0.209
Pelvic height difference (mm)	4.7 ± 2.1	4.3 ± 1.7	0.595
Left step length (cm)	41.6 ± 5.0	42.5 ± 5.3	0.678
Right step length (cm)	45.6 ± 3.6	46.4 ± 3.8	0.603
Step length difference (cm)	4.9 ± 2.9	4.4 ± 2.3	0.647

The baseline characteristics of the study subjects are shown in Table 1. The mean age of the intervention group was 20.5 ± 0.5 years, and the mean age of the control group was 20.3 ± 0.5 years. The mean height was 1.5 ± 0.4 m in the intervention group and was 1.5 ± 0.5 m in the control group. At the beginning of the study, there were no significant differences of the various physical and kinematic variables between the intervention and control groups. This suggested that randomization had been performed successfully to spread evenly all variables between the two groups, except the intervention variable. The fitting of foot orthoses decreased significantly the differences in pelvic height (1.7 ± 1.3 cm) in the intervention group as compared with the control group (4.7 ± 2.1 cm) (p <0.001). The same effect is shown in the significantly smaller differences between right and left step lengths in the intervention group (2.1 ± 1.5 cm) compared with the control group (4.9 ± 2.9 cm) (p = 0,002) (Table 2). To determine walking intensities performed by the subjects on walking tests, the achieved of walking distance was measured. The measurement results of walking distance achieved in walking tests 1, 2, and 3 are presented in Table 3.

To determine walking distance difference in walking test 1 between both groups, the Mann-Whitney test was performed. The results showed that in walking test 1 the walking distance of 1318.5 ± 46.3 m in the intervention group was longer than the walking distance of 1233.1 ± 114.7 m in the control group (p=0.05). Analysis of walking distance in walking tests 1, 2, and 3 in the group with foot orthoses, was conducted by means of the Friedman test and found a significant difference in walking distance (p<0.001). Subsequently the Wilcoxon test was performed, with the results indicating that walking distance in walking test 3 was longer than that in walking test 1 (p=0.001). Similarly, walking distance in walking test 2 was longer than that in walking test 1 (p=0.002), while walking distance in walking test 3 was longer than that in walking test 2 (p=0.048).

Table 2. Effect of foot orthoses on kinematic variables in the two experimental groups

Kinetic variables	Intervention (n= 14)	Control (n=13)	p
Left pelvic height (cm)	101.0 ± 3.4	98.3 ± 3.6	< 0.001*
Right pelvic height (cm)	101.0 ± 3.5	98.6 ± 3.6	< 0.001*
Pelvic height difference (mm)	1.7 ± 1.3	4.7 ± 2.1	< 0.001*
Left step length (cm)	49.2 ± 5.7	41.6 ± 5.1	0.006
Right step length (cm)	50.9 ± 6.5	45.6 ± 3.6	0.009
Step length difference (cm)	2.1 ± 1.5	4.9 ± 2.9	0.002

Table 3. Distance of the walking test between the intervention and control groups

Walking distance	Intervention (n=14)	Control (n=13)	p
Walking test 1	1318.5 ± 46.3	1233.1 ± 114.7	0.05
Walking test 2	1369.3 ± 27.1		
Walking test 3	1382.1 ± 10.5		

DISCUSSION

The fitting of foot orthoses in young adult women with foot pronation and functional leg-length disparity was demonstrated to improve pelvic alignment (pelvic alignment in the horizontal plane), as the pelvic height difference became smaller, from 4.7 ± 2.1 mm to 1.7 ±1.3 mm. The results of measurement of left and right pelvic height, with and without foot orthoses showed that the left pelvic height increased from 98.3 ± 3.6 cm to 101.0 ± 3.4 cm, and right pelvic height increased from 98.6 ± 3.6 cm to 101.0 ± 3.5 cm.

The presence of functional leg-length disparity due to foot pronation, which results in pelvic height difference, has been demonstrated in previous studies conducted by Knutson, Lenvinger et al., and Rothbart.(1,4,5) Knutson states that the mean functional leg-length disparity was 5.2 ± 4.1 mm.(1) Our study results showing that the pelvic becomes more aligned when using foot orthoses, demonstrates the occurrence of a biomechanical improvement of the feet, knees, and of the sacroiliac joints. The results of this study support those of a study conducted by Shorten and Bishop et al., in that the use of foot orthoses in foot pronation is capable of enhancing foot posture, which may improve rotation in the knee and sacroiliac joints.(9,11)

The occurrence of improved pelvic alignment from use of foot orthoses is due to the fact that foot orthoses support the low medial arches of the feet in foot pronation. The use foot orthoses elevates the medial arch of the foot to the level of the orthotic arch.(4,5) The use of foot orthoses with identical support heights of the medial arches on both sides causes the subtalar heights to be more symmetrical. The improved subtalar position leads to improvement of tibial and sacroiliac rotation. The ensuing correction of joint position results in better alignment of the subtalar, knee, and sacroiliac joints and promotes more symmetrical pelvic heights.

In foot pronation, the subtalar joint is in a valgus position, causing rotation of the knee and sacroiliac joints. The resulting series of biomechanical abnormalities causes tilting of the pelvis and functional shortening of one of the lower extremities. The pelvic tilt promotes the occurrence of functional lumbar scoliosis, with its convexity in the direction of the shorter one of the lower extremities. The occurrence of functional lumbar scoliosis leads to structural imbalance of the vertebrae and promotes the formation of a compensatory curve towards the longer one of the lower extremities. The resulting rotation of the joints in the series of biomechanical abnormalities in uncorrected foot pronation, may cause damage to the cartilage of the knee and sacroiliac joints, and of the intervertebral disks.(4,5) The results of this study support the study conducted by Weiner et al.(7) and Nourbakhsh et al.,(8) who state that the presence of biomechanical abnormalities in the lower extremities and the vertebral column increases the risk of back pain. The occurrence of back pain in biomechanical abnormalities is due to tension and strain in the ligaments and muscles, during activities of the lower extremities, such as standing, walking, and running, thus stimulating nociceptors for the afferent pain-conducting nerve fibers to the brain.(1,13)

The study results demonstrated that the use of foot orthoses improves pelvic alignment (alignment of the pelvis in the horizontal plane) in young adult women with foot pronation and functional leg-length disparity.

The use of foot orthoses in young adult women with foot pronation and functional leg-length disparity resulted in more symmetrical right and left step lengths, due to decreased step length difference, from 4.9 ± 2.9 cm without foot orthoses to 2.1 ± 1.5 cm with foot orthoses. In addition, with foot orthosis use there was an increase in mean left and right step lengths, where mean left step length increased from 41.6 4 ± 5.1 cm to 49.2 ± 5.7 cm, while mean right step length increased from 45.6 ± 3.6 cm to 50.9 ± 6.5 cm.

Assessment of the difference in left and right step lenght, with and without foot orthoses, was performed using the Biodex Gait Trainer 2.(12) The computer system of the Biodex Gait Trainer 2 automatically calculates mean step length, thus allowing the evaluation of the mean differences in left and right step lengths, with and without foot orthoses. Functional leg-length disparity, manifesting as a difference in left and right step lengths on walking, will increase the risk of back pain. Improved step length symmetrical will improve biomechanical vertebral-pelvis-hip abnormalities, and may decrease the incidence of back pain. This conclusion supports a previous study on 77 young adults, that there is a relationship between step length differences, incidence of back pain and postural abnormalities.(6) According to the previous study, a more symmetrical step length decreases the risk of back pain.(6-8)

Murley et al.(15) demonstrated decreased activity of the tibialis anterior, tibialis posterior, and peroneal muscles on heel strike while using orthoses. Shorten (12) and Bishop et al.(13) obtained an increase in dorsiflexion and a decrease in shifts between the bones of the foot at heel strike, when using special shoes with bulit-in foot orthoses. The decreased work intensity of the muscles, increased kinematics symmetrical, and decreased shifts between the soles of the foot on walking with foot orthoses, may decrease the risks of muscle injury.(14,15) The symmetrical step lenghts that occur during using foot orthoses, is due to the fact that the foot orthoses support the medial arches. This support improves the kinematic chain at the knees and hips, to yield a more aligned pelvic posture, and also improves foot posture, thus improving the gravitational axis. A better aligned pelvic posture and normal foot posture improves functional leg-length disparity, and improves musculoskeletal system balance on walking. Improvement of musculoskeletal system balance in the foot-hip-pelvis-vertebral chain causes a more symmetrical and longer step length. The use of foot orthoses also results in elevation of right and left pelvic heights, thus increasing walking distance.(5)

An increase in walking distance of 1319.3 ± 44.6 m occurred in the group of foot orthosis users, as compared with a walking distance of 1233.0 ± 114.7 m in controls. These study results indicate that the use of foot orthoses improved the effectiveness of intrinsic and extrinsic muscular activity of the lower extremities on walking activity. These results support the results of previous studies indicating that using foot orthoses in foot pronation decreases muscular activity and improves kinematic measures.(9,10)

The clinical implication of the results of this study is that young adult women with the biomechanical abnormality of foot pronation, accompanied by functional leg-length disparity, are recommended to use foot orthoses to improve their walking ability. A limitation of the study was the assessment of kinematic measurements in one plane only, because of limitations of the equipment.

CONCLUSIONS

Correction of foot pronation accompanied by functional leg-length disparity, through the use of ready-made polyethylene foot orthoses, results in more symmetrical pelvic height and step length. The use of foot orthoses in foot pronation enhances the functional capacity of the lower extremities, as evidenced from the longer step lenghts and walking distance. Further research needs to be done to assess kinematic measurements in other planes and the effectiveness of foot orthoses in young adult men.

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