Original Research

Medical Journal of the Islamic Republic of Iran.Vol. 21, No.2, August 2007. pp. 91-97

Effects of rigid and soft foot orthoses on dynamic balance in females with flatfoot

M. Akbari, PhD.[1], M. Mohammadi, MSc.[2], and H. Saeedi, PhD.[3]

Department of Physical Therapy, School of Rehabilitation Sciences, Iran University of Medical Sciences , Tehran, Iran.

Abstract

Background: Various types of foot orthoses are prescribed for people with flatfoot. It has been reported that orthoses not only improve the biomechanics of the lower limb, but also have good effects on some balance parameters in these subjects. It is hypothesized that the latter effect is dependent on the rigidity of the orthoses.

The aim of this study was to evaluate and compare the effects of rigid and soft foot orthoses on dynamic balance in females with flatfoot. The Biodex Balance System was used in a clinical trial study.

Methods: 20 healthy students with bilateral flatfoot were randomly assigned to two equal groups. Each participant was tested on two days with 2-week interval. On each day, dynamic stability test was performed while standing in single-leg stance on an unstable platform of the balance system in 3 conditions (barefoot, with shoe, shoe with orthosis). SPSS11.5 was used for statistical analysis.

Results: A significant group-by-day-by-condition interaction was found. Both groups on day 2 testing had a decreased overall stability index while wearing orthoses. Overall stability index was significantly lower on day 2 testing.

Conclusion: Foot orthoses, depending on the amount of rigidity, were associated with some improvements in dynamic balance in subjects with flatfoot.

Keywords: dynamic balance, female, flatfoot, orthoses.

Introduction

Foot orthoses have been reported to improve symptoms in lower extremity and foot pathologies such as patellofemoral pain syndrome, lateral ankle sprain, plantar fasciitis and flatfoot [1-4]. These devices are most commonly prescribed in individuals with flatfoot in an effort to limit the range and speed of abnormal pronation in subtalar joint along with subsequent rotations of the lower limb [5-8]. Recently, it has been proposed that the foot orthoses have positive effects on the sensory-motor system and in this way, they can improve neuro-muscular function of the lower limb [8]. In this topic, a number of studies have reported beneficial effects of these devices on some balance parameters in both injured and uninjured subjects [2,9,10, 11,12]; however, others suggest no significant changes [13-15]. Dissimilar results of the available literature might be due to different morphological foot types of the subjects [16]. It has been shown that postural stability is affected by foot type [17-19]. Therefore, the effects of foot orthoses on balance in subjects with dif-

1. **Corresponding author**, Assistant Professor , Department of Physical Therapy, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran. P.O.Box: 15875-4391, Tel: +9821 22227124, Fax: +9821 22220946, akbarimo43@yahoo.com.
2. MSc, Department of Technical Orthopedics, Iran University of Medical Sciences, Tehran, Iran.
3. Associate Professor, Department of Technical Orthopedics, Iran University of Medical Sciences, Tehran, Iran.

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ferent morphological foot types might better clarify the function of these devices [15]. Olmsted and Hertel [20] reported that orthoses significantly improved some of static and dynamic balance indices of subjects with cavus feet, however they did not observe any beneficial effects in participants with planus feet. In contrast, Rome and Brown found a significant reduction in medial-lateral sway in subjects with excessively pronated feet after four weeks of wearing foot orthoses [16]. The differences in opinion from the current literature necessitate some new studies in this regard.

Percy and Menz [15] have suggested that the rigidity of the orthoses might affect postural stability in subjects with different foot types. In this topic, it has been reported that shoes with thin and hard soles provide better stability for men than that with thick and soft midsoles [21]. However, there are not any systematic studies for estimating the effects of rigidity of the foot orthoses on balance ability in people with different foot types. Therefore this study was designed with the purpose of investigating and comparing the effects of rigid and soft foot orthoses on dynamic balance in asymptomatic females with bilateral flat foot over a two-week period.

Methods

Subjects

The study was a randomized clinical trial. All female students of a college were identified as potential participants for the study. Among them only persons with bilateral flexible flatfoot were included in the study. Arch ratio was used to describe the foot type [22]. The ratio is derived from dividing the height of the midpoint of the foot from the base to the it's truncated length. Truncated length of the foot is the distance between the most posterior aspect of the calcaneus and the center of the medial joint space of the first metatarsal phalangeal joint. In the current study the ratio was determined while quiet standing in double-leg stance. All participants for inclusion had a ratio less than or equal to 0.275 [23].

The subject pool was screened to eliminate all participants with a history of fracture or surgery of the lower limb in the one year prior to testing, a neurological condition/deficit/or impairment, an uncorrected visual deficit, a vestibular and/or internal ear abnormality, a limitation in motion of the lower limb joints, a weakness of the ankle muscles or anyone who had worn foot orthoses in the six months prior to testing.

Finally, 20 healthy subjects were recruited to participate in this study. Then, half of them were assigned to group one (age 21.60±2.63 years, mass 58.85±7.63 kg, height 163.25±3.37cm) and another half were placed in group two (age 22.00±2.05 years, mass 57.60±7.23 kg, height 161.05±3.43cm) by the use of randomized tables by an independent observer. All subjects were informed about the procedure and signed a consent form.

Shoe and orthoses

Each subject was provided with an arch support orthosis and a pair of comfortable low-top basketball shoes. The sole of the shoes used (All Star®) was about the 5-mm-thick and had moderate rigidity. Orthoses were prefabricated and were purchased according to each subject's shoe size and her group. Half of the participants that were placed in group one wore and were evaluated with rigid orthoses and the other half of the subjects that were placed in group two wore and were evaluated with soft orthoses. Rigid orthoses were made from EVA (ethyl vinyl acetate) foam with density of 0.2626 gr/cm^3. Soft orthoses were constructed from EVA foam with density of 0.0746 gr/cm^3. Orthoses spanned all of the foot length and their thickness was nearly 6mm under the calcaneus and was about 15-18mm in the peak of the medial longitudinal arch depending on the orthotic length. Fitting of the orthoses was performed in

MJIRI.Vol. 21, No.2, August 2007. pp. 91-97

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a separate session prior to testing. In this session each subject was asked to sit on a chair and her foot was held in non-weight bearing position. In this situation the orthosis was placed against the sole of her foot. Then, appropriate modifications were done based on where the supportive pad of the orthosis fit relative to the subject's medial longitudinal arch.

Participants were given an overview of the testing procedure on the fitting day. Also, they became acquainted with the instrument on this day.

Data collection was achieved by using the Biodex Balance System (BBS, Biodex, Inc., Shirley, New York). BBS is a commercially available dynamic postural stability assessment system [24]. This device is designed to stimulate joint mechanoreceptors and to promote reflex muscular activation necessary for joint stability [25]. The platform of the BBS on which the individual stands provides up to 20° of surface tilt in a 360° range. This platform has eight different stability-levels.

The resistance of the foot platform changes at each level. Level 8 is virtually stable and level 1 is the most unstable. The platform is interfaced with a computer and uses dedicated software (Biodex, version 3.1, Biodex, Inc.). The software provides the overall, anteroposterior and mediolateral stability indices [26]. In the current study we chose to use overall stability index as the stability measure because this index is believed to be the best indicator of the overall ability of the patient to balance the platform [26]. This index is calculated online and quantified the variance of platform deviation in degrees from reference position in all motions during a test.

A high index is indicative of a lot of movement during a test and therefore less stability. In contrast, a lower index reflects less time spent away from reference position and is therefore interpreted as a better balance score [25]. The reliability of the BBS has been established with intraclass correlation coefficients (ICC) ranging from 0.6 to 0.95 [27].

Procedure

Each subject was tested individually on two separate days with two-week interval. Participants performed a single leg balance test of both lower extremities while standing on the unstable platform of the BBS under 3 testing conditions (barefoot, shoe and shoe with orthosis) on each day. Consistent with other literature, level 4 was selected for use during testing because level 2 would be too unstable for some subjects. Conversely, levels 6 through 8 might not be sufficiently challenging to allow subtle differences in stability in healthy asymptomatic participants to be observed [28].

The subject was instructed to keep the platform as stable as possible during the dynamic stability test. For this reason, the participant was informed from platform position through a cursor on the visual feedback screen directly in front of her. The cursor represents the center of the platform. Keeping the cursor at the center of the bull's-eye on the screen equated to a level platform [25].

Two practice trials on each leg were completed on the first day before the first test trial in order to familiarize subjects with the task and reduce any learning effects. Prior to practice trials, the participant was asked to find a position for each stance limb on the center of the unstable platform that allowed her to easily maintain single-leg stance with as little platform tilting as possible and keep the cursor at the center of the bull's-eye on screen. These foot placements were used as reference positions and maintained throughout all practice and test trials for the stance limb to obtain consistency between the trials.

For each trial, the subject was instructed to keep the platform level for 20sec with arms folded across her chest and with the nonstance leg held in a comfortable position so as not to touch the stance leg or the test platform. A single trial was used for each condition to reduce

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	1st session of evaluation			2nd session of evaluation		
	Bare foot	with shoe	with orthosis	Bare foot	with shoe	with orthosis
Group1	1.83(.33)	1.79(.09)	1.78(.2)	1.72(.1)	1.71(.09)	1.51(.21)
Group2	1.82(.48)	1.84(.37)	2.15(.69)	1.81(.46)	1.84(41)	1.52(.21)

Table 1. Mean (standard deviation) of overall stability index.

the potential effects of learning and fatigue. Test leg (left, right) and condition (barefoot, with shoe, and shoe with orthosis) were counterbalanced among all participants to control for any learning or order effects. The trial was terminated and repeated after 5 minutes if the participant lost her balance during the course of a trial.

Upon completion of day 1 testing, the subject was instructed to wear the orthosis for a 2-week interval between testing sessions according to a written instruction so that at the end of this period 40 hours of wearing time would be completed. After 2 weeks, the participant returned to the laboratory for day 2 of testing and the above procedure was repeated, with the order of test leg (left, right) and condition (barefoot, with shoe, and with orthosis) the same as day 1 testing.

Results were analyzed using SPSS version 11.5. Paired t-tests were performed to compare right and left overall stability indices on day 1 testing under all 3 conditions (barefoot, with shoe and shoe with orthosis) for both groups. Because no significant side-to-side differences were identified, mean of the right and left overall stability index was used for further analyses. A repeated-measures analysis of variance (ANOVA) with 1 between factor (group) and 2 within factor (day, condition) was run on the overall stability index. Bonferoni t-testing was used to determine significant differences. An alpha level of 0.05 was set for all analyses.

Results

The means and standard deviations for all overall stability indices are presented in Table 1. The ANOVA showed a significant group-by-day-by-condition interaction ($P<0.036$, $F2.76= 3.460$). Bonferrone t-test revealed that both groups on day 2 testing had a decreased overall stability index when wearing orthoses compared with the other conditions ($P<0.035$). A main effect for day was also found ($P<0.0001$, $F1.38 = 16.288$). Overall, stability index significantly decreased on day 2 testing for both groups under all three conditions ($P<0.043$).

Conclusion

Our results show that after a two-week period of wearing rigid orthoses, subjects in group one had improved dynamic balance while standing with rigid orthoses. Previous studies have proposed that application of the foot orthoses might increase tactile stimulation to the bottom of the foot. This can improve the somatosensory feedback necessary for postural control [2,9, 11]. On the other hand, orthoses might add structural support to the medial side of the foot or support the foot in a proper alignment for weight bearing and limit the magnitude of its maximal pronation. This can enhance mechanical stability at the ankle mortise [2,9,11] and through it, decrease postural sway. This claim is rational with respect to the results of McPoil et al [29]. In their study, overall migration of the center of pressure significantly decreased while walking with orthoses designed to counter hyperpronation in females with forefoot varus deformities. Proper alignment of the talocrural joint might also improve proprioception and kinesthetic awareness through relief of excessive stresses applied on muscle spindles, tendons and bony structures. On the other hand, it might decrease reliance on the activity of supporting musculature for maintenance of joint stability [2,9,11]. Researchers support this contention, finding changes in muscle activity at the ankle,

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knee, and hip when the degree of pronation is altered sufficiently [19]. These proposed mechanisms are all possible explanations for the postural sway improvements we saw. However, it must be noted that the effects of orthoses on neuromechanical function of the lower extremity might change over time with accommodation of the individuals to their presence [12]. This can explain the lack of any differences between different conditions on day 1 testing.

The results of the current study also reveal that in spite of reduced but non-significant dynamic balance at baseline, after 40 hours of wearing orthoses participants in group two had increased balance ability with orthoses. However, similar to group one, such an improvement wasn't seen at baseline. These findings were surprising, as participants in group two were assessed with soft orthoses made from low-density EVA foam. There is evidence to suggest that postural stability is impaired when the supporting surface is constructed from soft, compliant materials [30]. Previous studies have discussed that mechanoreceptors are stimulated by rigid materials and could provide better feedback and therefore improve stability [16]. Also, it has been proposed that soft surfaces cause high amplitude movements of the plantar surface of the foot with respect to the leg. This factor can induce decline in foot position awareness and hence increase postural sway. A postulated interpretation for this phenomenon in the literature is that frontal plane movements of the foot with respect to the leg principally require intense contraction of the tibialis anterior and peroneal muscles. Intense voluntary contraction of muscle is associated with "post contraction sensory discharge" of intrafusal elements of muscle receptors. It persists for a considerable time and results in underestimating actual joint position [31].

There are three possible explanations for the insignificant effect of the soft orthoses at baseline. First, as cited by Percy and Menz [15], it isn't improbable that the ability of our healthy subjects in controlling the degree of platform deviation was such that small perturbations provided by soft material of the orthoses could be corrected within the segments of the closed kinetic chain without producing a significant high overall stability index. Analysis of individual trends confirmed this conjecture.

According to our testing protocol during each trial total body weight was being exerted only on one leg. It is possible that applied weight has maximally compressed the low-density EVA foam for the duration of the trial and therefore, has eliminated any destabilizing effect caused by returning of the material to its original state. The current statement is supported by the evidence that if the shoe sole remains compressed between steps, it has little effect on sway, whereas if it recoils, it might impair stability [15]. This could be the second explanation for the null result observed with the soft orthoses on day 1 testing.

Absence of a significant difference with the soft orthoses at baseline could also be attributed to the special shape of the orthoses. The foot orthoses used in the current study had medial longitudinal arch support. The cradling effect of this support could stabilize the talocrural joint in a suitable alignment for weight bearing and so, enhance mechanical stability at this joint. Improved alignment might also allow joint mechanoreceptors to detect postural perturbations. Orthoses might also alter pressure distribution on the bottom of the foot that could lead to enhanced plantar cutaneous receptor activity, thus decreasing postural sway. It is possible that these mentioned effects have neutralized any postural instability caused by the soft orthoses.

Improvement seen in the performance of our participants with the soft orthoses on day 2 testing could be attributed to either the wearing of the orthoses between testing sessions and therefore, accommodation of the sensory-motor system or the permanent compression of the soft orthoses. It isn't improbable that the low-density EVA foam of the orthoses has been com-

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pressed and thus, become more rigid after 40 hours of wearing. Olmstead and Hertel [20] examined the effects of foot type and orthotic intervention on postural control. They reported that some static and dynamic balance measures improved in subjects with cavus feet while wearing orthoses. However, they found no substantial benefits or detriments in participants with planus feet while wearing orthoses. Although the latter finding is different than our current result, it must be noted that the measurement technique of Olmstead and Hertel for the dynamic balance was the star excursion balance test. For this test, participants stand on a stable surface and maintain a single-leg stance on the stance leg while reaching with the opposite leg to touch as far as possible along the different directions determined on the surface. It seems that performance of the star excursion balance test is easier than the dynamic stability test used in our study, as it was done on an unstable platform as opposed to a stable surface. Observed differences could also be related to moderate reliability of the star excursion balance test. The ICC that is reported for reliability of measures taken during two testing session ranged from 0.67 to 0.87 depending on reaching direction [32]. The foot type classification system used by Olmstead and Hertel was also different than that which we used in the current study. Their subjects' feet were evaluated visually by three independent examiners. Contrary to our evaluation method, this technique is subjective and might provide limited information. The ICC for level of agreement between different examiners for the visual non-quantitative assessment of the MLA has been found to be poor [33].

Rome and Brown [16] investigated the impact of rigid foot orthoses on static balance in participants with clinically diagnosed excessively pronated feet. At baseline their participants were randomly assigned to either an intervention or control group. Subjects in the intervention group were assessed with orthoses. Balance testing was performed in two sessions. There was no significant difference in balance scores between two groups at baseline. However after four weeks, medial-lateral sway of intervention group considerably reduced. In spite of differences in balance measurement technique and also foot classification system, these findings are identical to our current results.

The current study was designed to evaluate the rigidity of foot orthoses, but it didn't include a range of orthoses with variable rigidity. So, it wasn't possible to determine orthoses rigidity levels that are optimal for balance. It was one of the limitations of this study. Although the reliability of foot classification is in question, future research on the effects of a wide range of foot orthoses or surfaces with variable hardness among populations with flat, cavus and rectus feet is warranted.

Arch support orthoses improve dynamic stability in asymptomatic females with flatfoot. Such an improvement might be caused by a combination of a change in body mechanics and neuromuscular re-education. However, in case of soft orthoses, enhanced dynamic stability might also occur as a result of material compression and therefore, being constantly more rigid. This could eliminate any destabilizing effects of soft materials. Clinically, although foot orthoses are commonly prescribed in individuals with flatfoot in an effort to limit hyperpronation, their special effect on balance should be considered. Also, our result could inform clinicians that for prescription of orthoses special attention should be paid to their rigidity. For participants with flatfoot the more rigid orthoses are preferable to soft ones which performed poorly under our experimental condition for day 1 testing. So, elimination of soft material of orthoses and use of more rigid technology will result in orthoses that provides high stability for these people.

Acknowledgment

We would like to thank the Research Center of Rehabilitation Sciences, Faculty of Iran University of Medical

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Sciences for use of their equipment and facilities.

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