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Influence of Bilateral and Unilateral Flatfoot on Pelvic Alignment

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Abstract**—**Background: The change in foot posture can possibly generate changes in the pelvic alignment. There is still a lack of evidence about the effects of bilateral and unilateral flatfoot on possible changes in pelvic alignment. The purpose of this study was to investigate the effect of flatfoot on the sagittal and frontal planes of pelvic postures. Materials and Methods: 56 subjects, aged 18–40 years, were assigned into three groups: 20 healthy subjects, 19 subjects with bilateral flexible second-degree flat foot, and 17 subjects with unilateral flexible second-degree flat foot. 3D assessment of the pelvis using the formetric-II device was used to evaluate pelvic alignment in the frontal and sagittal planes by measuring pelvic inclination and pelvic tilt angles. Results: ANOVA test with LSD test were used for statistical analysis. Both Unilateral and bilateral second degree flatfoot produced significant ($P<0.05$) pelvic anteversion, in comparison to the healthy subjects ($P<0.05$). But the bilateral flatfoot subjects seemed to have more anteversion than the unilateral subjects. Unilateral flatfoot caused a significant ($P<0.05$) lateral pelvic tilt in the direction of the affected side in comparison to the healthy and bilateral flatfoot subjects. Conclusion: The bilateral and unilateral second degree flatfoot changes pelvic alignment. Both of them lead to increases of pelvic anteversion while the unilateral one caused lateral pelvic tilt toward the affected side. Thus, foot posture should be considered when assessing patients with pelvic misalignment and disorders.

Keywords**—**Bilateral flatfoot, foot posture, pelvic alignment, unilateral flatfoot.

I. Introduction

THE pelvic girdle is responsible for the anatomic connection and transmission of forces between upper and lower quadrants of the musculoskeletal system and, thus, is affected by these segments [1], [2]. Pelvic position depends on the alignment of the lower limbs joints, during activities performed in a closed kinematic chain [1]-[5]. Thus, changes in lower limbs posture may lead to the presence of postural alterations of the pelvic girdle and enhance the risk of low back pain progress [1], [6]. The foot is a very complex multi-segmented structure. Shock absorption, stability and propulsion are the main biomechanical functions of the foot [7], [8].

The posture of the feet in standing may have an influence on pelvic alignment spinal posture in standing position [1], [3], [5], [6], [9]. Flatfoot is a frequently encountered pathology and often debilitating chronic foot and ankle condition [10], [11]. Flat foot may affect one or both feet, and not only increase the load acting on foot structure but also interfere with normal foot function [12], [13], and it has characteristics such as decreased medial arch height, talus adduction and medial rotation, calcaneal eversion, and forefoot abduction [14]-[18]. Thus, changes in foot posture may lead to alterations of the pelvic and spine alignment [1], [3], [5], [6], [9], [19]-[21] which resulted from the additional stress placed on the ligaments, joints, and muscles engaged in preservation of standing posture [22].

The presence of adduction of the talus and the eversion of the calcaneus make the lower limb assume an internal rotation position with reduction in limb length and consequently, may alter the pelvis alignment [3], [5], [23], [24]. Bilateral calcaneal eversion produces internal rotation of the lower limb and may lead to increased pelvic anteversion and consequently may cause lumbar hyperlordosis [1], [5], [20]. While, the presence of unilateral calcaneal eversion may produce a functional lower extremities length difference and may produce a lateral tilt of the pelvis to the side with calcaneal eversion, which in it turn may produce a scoliosis of the spine [3]. Thus, the presence of calcaneal eversion as in flatfoot either bilateral or unilateral may lead to alteration in pelvis alignment.

To our best knowledge, there is very limited research investigating the effect of bilateral and unilateral flatfoot on pelvis alignment. Although, [25] reported the effect of second degree flatfoot on spinal and pelvic mechanics in young females but there is no documented evidence describing the effect of bilateral and unilateral flatfoot on pelvis alignment in adult population? Furthermore, previous research investigated the effect of induced calcaneal eversion on the posture of the pelvis [1], [5] in healthy asymptomatic subjects. This study was therefore designed to investigate the effect of flatfoot on the sagittal and frontal planes of pelvic postures.

II. Materials and Methods

Out of 538 volunteers for participation for this study, only 56 subjects who met the inclusion criteria were recruited for this study. Inclusion criteria for all participants were a body mass index (BMI) of 18–25 kg/m2, age ranging between 18–40 years. The participants were diagnosed by physical examination and x-ray radiography and they were classified to 20 healthy subjects with normal feet, 19 bilateral second degree flexible flatfeet, and 17 unilateral second degree flexible flatfeet. The exclusion criteria included subjects with a BMI above 25 kg/m2, recent injury, postural deformities, a neurological deficit or surgery of the lower limbs, pelvis or the spinal column. The study was approved by the ethics

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committee of the Faculty of Physical Therapy, Cairo University. All participants signed the informed consent form, agreeing to participation and publication of the results of the study.

Initial physical examination was performed for each volunteer's both feet for selection of the study participant. The authors observed the volunteer's feet when they were seated with their feet off the ground, standing, and while they were ambulating. The volunteers examined for the positions of their heels, subtalar joint, forefeet, and the medial arches. Observation of the subjects having flatfeet in standing and walking revealed heel valgus, low arch, commonly forefoot abduction and supination. The subtalar joint is commonly in the over pronated position in stance and may be even more so on walking. If any of the volunteers had flatfeet, the authors detected whether it is bilateral or unilateral, while observation of the normal subjects revealed normal heel position and normal arch height.

To differentiate between flexible and rigid flatfeet among the volunteers with flatfeet the authors used the single-heel-raise test. Each subject was asked to stand on tiptoes of one foot then repeat the same procedure for the other foot. In subjects with flexible flat feet, the arch re-appeared and the calcaneus demonstrated normal inversion when viewed from behind [26].

Following the physical examination, the volunteer's feet were scanned with lateral weight-bearing X-ray radiographs to detect whether the volunteers had normal feet, bilateral or unilateral flat feet, and to determine the degree of severity of their flatfoot deformity. Each subject had an X-ray radiograph image taken once for each foot. This study used a Philips view forum 2003 X-ray device to confirm the results of the physical examination.

The degree of flatfoot was determined through measuring the talus–first metatarsal angle on a lateral weight-bearing radiograph. It is the angle between line drawn from the centers of longitudinal axes of the talus and the first metatarsal. In the normal weight-bearing foot, the midline axis of the talus is in line with the midline axis of the first metatarsal. The calculated angle measurement was 0° in the normal foot, 0–15° in participants with mild or first-degree deformities, 15–30° in participants with moderate or second-degree deformity, and greater than 30° in cases of severe deformity or third-degree flatfoot [27], [28].

Following physical examination and lateral weight-bearing radiograph, the volunteers who met the inclusion criteria were assigned to one of the three groups which are participants with normal feet, bilateral second degree flatfeet and unilateral second degree flatfeet.

Assessment of pelvic alignment was done for each participant using Optical 3D spine analysis and posture measurement system. Raster stereography (Formetric II, Diers International GmbH, Schlangenbad, Germany) represents a reliable method for three dimensional back and pelvis shape analysis and reconstruction of spinal deformities without ionizing radiation and without using any markers [29]. It was used to measure pelvic posture in the sagittal and frontal planes.

Each subject in the three groups was examined in standing upright posture with both feet bared in a neutral position at a distance of 2 meter in front of the 3D scanning system camera. The patient's back surface including buttocks lied completely bare in order to avoid disturbing image structures. In female subjects the hair was bound up so that the neck vertebral prominence was uncovered. The column of instrument height was adjusted according to the subject height to move the relevant parts of the patient's back into the center of the control monitor. A multitude of light sections is projected on the patient's back from a different direction than that of the optical measurement unit, thereby compiling shape information along the section line. The best moment for releasing image capture was the slightly breathed out state. Each subject was first asked to breathe normally. The moment of breathing out was observed on the control monitor. The patient was then asked to stop breathing for some seconds while image capture was released. The scanning time was very short (40 ms), in order to eliminate movement artifact.

TABLE I
General Characteristic of the Subjects

Items	Normal Feet	Bilateral Flatfeet	Unilateral latfeet	P-value
Age (year)	24.8±4.96	26.73±5.14	25.64±6.4	0.54
Weight (kg)	68.0±7.26	67.15±7.96	66.05±6.57	0.72
Height (Cm)	171.35±7.46	169.57±8.21	168.0±7.33	0.42
BMI (kg/m^2)	23.12± 0.99	23.25±0.75	23.35±1.51	0.82

*Data presented as mean± standard deviation; p >0.05 (No significant).
* kg = kilogram, cm = centimeter, kg/m^2 = kilogram/meter^2

The automatic anatomical landmarks localization which were the vertebra prominent and the iliac spine in the pelvic region were the basis for an automatic reconstruction of three dimensional dorsal surface of the sagittal back and pelvic shape that provided a set of shape parameters characterizing the back and pelvis profile [29]. The formetric II system analyzed the back and pelvis surface form in a sophisticated, anatomic way with no need for manual fixation of markers on the vertebrae. Anatomical landmarks, vertebral position and rotation were anatomically detected, using the reconstructed high-resolution surface, anatomical, and pathological model. The resulting model showed the complete form and the measured data of the examined spine and pelvis.

The evaluated parameters for participants in the three groups include pelvic alignment in the sagittal plane and frontal plane in the form of pelvic inclination and pelvic tilt angles, respectively, after being calculated and recorded from Formetric II instrument.

III. Statistical Analysis

A statistical power Analysis suggested that sample sizes of 15 subjects per group were required to achieve more than 80% power. Data were first analyzed using the Kolmogorov-Smirnov test to recognize a normal distribution. The differences between the three groups were analyzed using one-way analysis of variance (ANOVA) followed by LSD post hoc test. Level of significance for all tests was set at (0.05). Statistical tests were performed using SPSS version17.

IV. Results

Demographic data of the participant is presented in Table I. Normal feet group consisted of twenty subjects (11 male and 9 female). Bilateral flatfeet group consisted of nineteen subjects (8 male and 11 female). Unilateral flatfeet group consisted of seventeen subjects (7 male and 10 female). No statistical differences were found between groups in demographic data. Statistical diagnostic tests revealed no violations of the assumptions of normality and homogeneity of variance for any of the dependent variables.

A. Pelvic Alignment in the Sagittal Plane (Pelvic Inclination Angle)

Table II shows the pelvic inclination angle in the three groups. There were significant difference among the three groups in pelvic inclination angle (P=0.0001) as revealed by ANOVA test. Bilateral and unilateral flatfeet caused significant pelvic anteversion in comparison to the healthy subject with normal feet as (P=0.0001) and (P=0.001) respectively. Furthermore, bilateral flatfeet subjects seems to have more anteversion than the unilateral subjects (P=0.004).

B. Pelvic Alignment in the Frontal Plane (Pelvic Tilt Angle)

Table II shows the pelvic tilt angle in the three groups. There were significant difference among the three groups in pelvic tilt angle (P=0.02) as revealed by ANOVA test. Unilateral flatfeet caused a significant change in pelvic posture in the frontal plane, in comparison to normal feet and bilateral flatfeet, (P=0.0001) and (P=0.001) respectively, generating a lateral tilt in the direction of the affected feet. Furthermore, no difference was found between normal and bilateral flat feet subjects (P=0.88).

V. Discussion

In this study, subjects with bilateral or unilateral second degree flatfeet showed pelvic anteversion in the sagittal plane. Furthermore, bilateral flatfoot subjects seem to have more anteversion than the unilateral subjects. In addition, unilateral flatfeet subjects had a lateral pelvic tilt in the direction of the affected feet in comparison to the healthy and bilateral flatfoot subjects.

The present study identified larger pelvic anteversion in subjects with bilateral flatfeet than in normal subjects or subjects with unilateral flatfeet. The present study also found a significant pelvic anteversion as a result of the unilateral flatfeet which is sufficient to modify sagittal plane pelvic posture. The identified increase in pelvic anteversion in subjects with bilateral flatfeet is in accordance with the results found by [25] who reported an increase in pelvic inclination and no change in pelvic tilt with bilateral flexible second degree flatfeet subjects.

TABLE II
Pelvic Alignment in the Sagittal and Frontal Planes for the Three Groups

Pelvic alignment	Normal feet	Bilateral flatfeet	Unilateral flatfeet	P-value
Pelvic inclination angle	16.65±4.02	22.87±1.97	19.96±2.13	0.0001*
Pelvic tilt angle	0.77±2.25	0.86±2.59	2.47±0.67	0.02*

*Data presented as mean± standard deviation; *p <0.05(significant)

The change in pelvic alignment towards anterior tilt in subjects with bilateral or unilateral second degree flatfeet can be attributed to the presence of subtalar pronation, coupled with the calcaneal eversion as a result of flat foot which generates an internal rotation of the tibia and femur and consequently at the hip joint [5], [23]. This hip internal rotation may make the head of femur move posteriorly and consequently the pelvis shift posteriorly. In order to regain postural balance the trunk is moved anteriorly to shift the center of mass anteriorly and this forces the pelvis to tilt anteriorly in the sagittal plane. In addition, tension in iliopsoas muscle and hip joint capsule as a result of hip internal rotation also produced anterior pelvic tilt [1], [23]**.** Furthermore, internal rotation of the hip joint brought the greater trochanter forward and outward, and this chronically stretched the piriformis muscle that inserts into the apex of the trochanter. As this muscle's origin is at the anterolateral aspect of the sacrum, the sacrum may be pulled into an anteroinferior position leading to anterior pelvic tilt in the sagittal plane [30].

Thus, the alteration in foot mechanics led to alteration in pelvic alignment. Khamis and Yizhar [5] reported that bilateral induced hyperpronation of the foot using medially tilted wedges led to an increase of the anterior pelvic inclination in healthy subjects. In addition, [1] found that unilateral and bilateral use of medially tilted wedges that produced an increase of calcaneal eversion and foot hyperpronation led to anterior pelvic inclination. Although, [31] reported that internal rotation of the legs caused the pelvis to tilt anteriorly, they found that artificially induced foot pronation did not have a significant relationship with pelvic tilt. It is possible that these differences have occurred due to methodological difference in measurement of pelvic alignment.

While Duval et al. used a 3D motion analysis system with markers attached to body segments to detect the changes in the pelvic alignment, the current study used 3D posture measurement system (formetic II instrument) where there was no need to attach markers to the body. The markers used by Duval et al. may be affected by movement of the skin and soft tissues and thus increase the artifacts of movement. Furthermore, the results of Duval et al. caused by artificially induced foot pronation that led to immediate increase of calcaneal eversion on healthy subjects and those subjects used short-term compensatory mechanisms preventing a change in pelvic posture. While the participants in the current study with flatfeet showed signs of excess pronation for extended period of time and thus may develop compensatory mechanisms overtime leading to change in pelvic alignment in the sagittal plane as long term tissue adaptations may allow greater postural changes to occur [32].

The results of the present study revealed that unilateral flatfeet led to lateral pelvic tilt in the direction of the affected feet while bilateral flatfeet did not generate any change in pelvic alignment in the frontal plane. The lateral pelvic tilt may be due to shortening of the ipsilateral lower limb that led to functional limb length difference between the two lower limbs and resulted in pelvic obliquity in frontal plane [1], [3], [23].

Because of the anatomical relationship between the pelvis and lumbar spine, the lumbar spine posture depends on the pelvic alignment especially in standing position [9]. Changes in the inclination of the pelvis affected the degree of lumbar lordosis [20], [33] and thus, anteversion and lateral tilt of the pelvis may lead to the presence of hyperlordosis and scoliosis respectively [3], [9], [20], [34].

Lumbar hyperlordosis resulted in an increase of the loads placed on different spinal structures and it has been associated to the occurrence of low back pain [35], [36]. In addition, lumbar scoliosis leads to asymmetric loads on different spinal structures including intervertebral discs, which contributes to the degeneration of these structures [21]. Thus, the changes in pelvic alignment as observed in the present study as a result of bilateral or unilateral flatfeet, and the possible changes occurred in lumbar posture, may contribute to the development of low back pain. Therefore, flatfeet either bilateral or unilateral may play an important role in low back pain etiology.

Our studies helped to attract the attention to evaluate the patient's whole posture and not to focus on the symptomatic area as foot posture alterations can produce and maintain long term effects both in pelvis and spine. When these changes are overlooked, symptoms referred to other parts of the body continue because their cause, being in the feet, has failed to be properly diagnosed and removed. Further studies are required to investigate the effect of bilateral and unilateral flatfeet on spinal mechanics and to investigate the relationship between flatfeet and low back pain.

VI. Conclusion

Bilateral and unilateral flatfeet led to significant changes in pelvic alignment. The bilateral and unilateral flatfeet caused increases of pelvic anteversion and the unilateral flatfeet caused lateral pelvic tilt in the direction of the affected feet. This study provided evidence about that bilateral and unilateral flexible second degree flatfeet may be considered as a contributing factor for the production of pelvic misalignments in standing position. Thus, foot posture should be considered when assessing patients with lumbopelvic misalignment and disorders.

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