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ORIGINAL ARTICLE

The Influence of Bilateral and Unilateral Flat Foot on Coronal Spinopelvic Alignment in Asymptomatic Young Healthy Males

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Background: This cross-sectional retrospective study aimed to present the influence of unilateral and bilateral flatfoot on coronal spinopelvic alignment in asymptomatic young healthy males.

Methods: It was carried out by examining the medical reports of individuals who apply to the National Health Board to work in positions requiring physical fitness between January 2018 and January 2019. Plain radiographies of the feet, pelvis, and spine were analyzed. Calcaneal pitch angle (CPA) for flatfoot, pelvic obliquity (PO), and Cobb angle (CA) for spinal asymmetry was measured. After all analyzes were completed, participants divided into 2 groups as unilateral (UniFF) or bilateral (BiFF) flatfoot, depending on the CPA measurements and compared.

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Results: There was no statistically significant difference in age *(p= .609).* The UniFF group showed higher values in terms of BMI with a statistically significant difference *(p= .01).* The curve patterns identified as single thoracal, lumbal and double. Post hoc analyses suggests that males without spinal asymmetry were more likely to have unilateral flatfoot *(p< .008).* There were statistically significant differences between groups in PO and CA *(p< .05).* The effect size was found small to medium effect for PO and medium to large for CA.

Conclusions: In conclusion, young males with bilaterally increased foot pronation demonstrate more increased pelvic obliquity and spinal curvature.

Acquired flatfoot (AFF) is very common worldwide and may be seen unilaterally or bilaterally[1,2]. It has been characterized as decreased medial arch height, talus adduction and medial rotation, calcaneal eversion, and forefoot abduction [3,4]. The causes of AFF include dysfunction of the posterior tibial tendon, arthritis, trauma, Charcot, neuromuscular disorders, or tumors of the foot [5]. It has been reported that result of the loss of the normal interplay between the bones of the foot, the alternations of the foot posture interfere with normal foot function [1,6]. As a result of this process, the pelvic and spinal alignment may be altered [7-9]. The proper alignment of the weight-bearing segments creates a good posture [10]. The pelvis and spine are identified as key segments of appropriate postural alignment. While the pelvis provides a connection with the lower extremities, the spine provides anatomical connection and force transmission between the lower and upper parts of the body [11]. If the ideal alignment and connection are disrupted, compensatory postural alternations of spinopelvic alignment occur [12].

The biomechanical process of alternation of the pelvic and spinal alignment *(via foot pronation)* was explained with a reduction in limb length. The adduction of the talus and eversion of the calcaneus results in internal rotation of the lower limb and consequently, reduction in limb length [8,9]. Bilateral calcaneal eversion may lead to lower limb internal rotation and consequently, results in pelvic anteversion and lumbal hyperlordosis [7,9]. Gurney reported that the unilateral calcaneal eversion may cause a functional limb length alternation and may produce pelvic obliquity and consequently, scoliosis may be produced [8].

Angulation of the pelvis from the transverse in the coronal plane is termed as *'pelvic obliquity'* by the Scoliosis Research Society and broadly defined as the malalignment between the spinal and pelvic structures in the coronal, sagittal, or transverse planes [13]. The leg length alternation, contractures about hip and spinal asymmetries, or a combination of all were reported as the causes of pelvic obliquity [14].

There is still a lack of evidence about the influence of increases in foot pronation on pelvic and spinal alignment. And also, the possible changes in spinopelvic alignment due to unilateral or bilateral flatfoot need to clarify. Therefore, the aim of this study was to present the influence of unilateral and bilateral flatfoot on coronal spinopelvic alignment in asymptomatic young healthy males.

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MATERIALS AND METHODS

The hypothesis of this study was that pelvic obliquity and spinal asymmetry would be influenced more in individuals with unilaterally flatfoot than in individuals with bilaterally flatfoot.

Participants

A cross-sectional retrospective study was carried out by extracting the medical reports of 360 healthy individuals who applied to the National Health Board to work in positions requiring physical fitness between January 2018 and January 2019. These medical examinations by the National Health Board have been including, in a routine, detailed physical examination and plain radiographies of both feet, pelvis, and spine.

The participants were selected from young and healthy males by means of convenience and opportunistic or emergent sampling. Inclusion criteria for all participants were a body mass index (BMI) ranging between 18.5–24.9 kg/m^2 (accepted as normal weight by World Health Organisation (WHO)), age ranging between 18-25 years, and male gender. Participants were excluded if they were/had (1) older than 25 years, (2) BMI out of normal weight according to WHO, (3) female, (4) history of spinal trauma/ surgery, (5) spinal disorders like spondylolisthesis, spondylodiscitis, etc., (6) chronic inflammatory arthritis especially spodiloarthrosis (i.e., ankylosing spondylitis, psoriatic arthritis, etc.), (7) vertebral fracture, (8) aseptic necrosis of the vertebra, and (9) radiographs with inappropriate image qualities.

Outcome Measures

Lateral spinal asymmetry and pelvic obliquity were analyzed with imaging software (RadiAnt DICOM viewer version 5.5.) using the Cobb method by a single examiner on the standing full-length posteroanterior radiograph. All the radiographs were performed following the same convensional protocol: All participants were asked to stand in a comfortable position, facing forward, without rotation of the feet, with arms resting to the side of the body during radiography. To diagnose flatfoot *(via Calcaneal pitch angle)*, weight-bearing lateral plain radiographs were analyzed on the same software and by the same examiner; an experienced orthopedic surgeon. The same conventional protocol was followed for lateral radiography of the foot: All participants were asked to stand in a comfortable and weight equally distributed to both feet.

Calcaneal pitch angle (CPA) is defined as an angle between a line drawn from the inferior of the calcaneocuboid joint to the inferior border of the calcaneus and a second line drawn from the inferior aspect of the sesamoid bones to the inferior border [15] (Figure.1). The interrater reliability of the CPA was .948 (for digital) and .955; the intrarater reliability of the

CPA was .977 to .980. CPA for both (right and left) foot was evaluated from all plain radiographs in this study and the angles equal to or less than 20 degrees were accepted as a *flatfoot.*

Pelvic obliquity (PO) was measured by transverse pelvic obliquity according to Osebold et al. from a posteroanterior radiograph [16]. The angle between the line drawn between the most proximal points on the iliac crest and the line drawn parallel to the lower end of the radiograph was recorded (Figure.1). The intra- and interrater reliability of the Osebold's PO measurement were reported as .955 and .954 in neuromuscular scoliosis.

The Cobb angle (CA) is a gold standard measurement for identifying the magnitude of spinal curves [17]. Spinal curvature was measured from the standing full-length posteroanterior radiograph. The angle of the curve is measured as an angle between the perpendiculars of the lines parallel to the upper border of the upper vertebral body and parallel to the lower border of the lowest vertebral body of the curve [18] (Figure.1). Straight or symmetrical spines in the coronal plane were accepted as a normal spine, and curves<10 degrees accepted as spinal asymmetry, and the curves ≥ 10 degrees accepted as scoliosis [19]. The intra- and interrater reliability of the Cobb angle was reported as .93 to .96. Spinal curve patterns in coronal planes were classified according to the Scoliosis Research Society classification. If the curve exists through the thorocal or lumbal spine is classified as single-thoracal or single-lumbal curve. If it exists both in the middle thoracal and lumbal spine is classified as a double-curve. While if the double-curve is accompanied by the upper thorocal spine, it is classified as a triple-curve [20].

Statistical Analysis

Statistical tests were performed using *"Statistical Processing for The Social Sciences Software (SPSS 22.0 Inc., Chicago, Illinois)"*. The Kolmogorov- Smirnov test was used to recognize a normal distribution. Descriptives were presented using means (X) and standard deviations (SD), and 95% confidence of interval (95%CI). The proportions of the spinal curve patterns in the coronal plane were presented using cross-tabulation. The Chi-Square *(X^2)* test was used to compare these proportions and was followed by the Bonferroni-corrected posthoc comparisons. The differences between the two groups were analyzed using *Student's t-test*. The effect sizes *(to emphasize the size of difference)* of the comparisons with statistically significant differences were also calculated and *Cohen's d* was cited. The effect size was considered small if *d*= .20, medium if *d*= .50, and large if *d*= .80. The level of significance for all tests was set at .05.

RESULTS

A total of 360 individuals were identified from the electronic database. The 229 of 360 healthy males, who met with inclusion criteria, were included in this study. After all analyzes were completed, participants divided into 2 groups as unilateral (UniFF, n=95, 41.48%) or bilateral (BiFF, n=134, 58.51%) flatfoot, depending on the CPA measurements (Figure.2).

The demographic characteristics of the participants are shown in Table.1. There was no statistically significant difference in age *(p= .609).* But the UniFF group showed slightly higher values in terms of BMI with a statistically significant difference *(p= .01).*

The proportions of the spinal curve patterns in the coronal plane are shown in Table.2. The curve patterns identified in this study were single thoracal, single lumbal, and double (one curve exists through thoracal and lumbal). Overall significant differences between the 4 groups were found *(p< .001).* Posthoc analyses suggests that males without spinal asymmetry were more likely to have a unilateral flatfoot (Table.3).

There were statistically significant differences between groups in PO and CA (*p*< .05). The effect size was found small to medium effect for PO and medium to large for CA (Table.1).

DISCUSSION

In this study, significant differences were found with small to medium effect size for pelvic obliquity and medium to large for the spinal asymmetry between subjects with bilateral and unilateral flatfoot. A result of this study suggests that subjects with bilateral flatfoot have increased pelvic obliquity and spinal asymmetry.

Although the alternation in foot biomechanics and their effects on whole-body mechanics have recently become a prominent topic, there is still a lack of evidence about possible changes in spinopelvic alignment due to the unilateral or bilateral flatfoot. Pinto et al.

reported that alternations in calcaneal eversion and foot arches resulted in an alternation of pelvic alignment, for example, increases of pelvic anteversion and pelvic obliquity [7]. Furthermore, it was shown that changes in pelvic alignment affected lumbal lordosis and may be led the occurence of scoliosis, via the anatomical relationship between the pelvis and lumbal spine [8,21]. And also Khamis and Yizdar reported that these alternations in the body can occur even if the foot alternations were temporary [9].

In contrast to our results, Pinto et al. reported that unilaterally-increased foot pronation generates a significant increase in pelvic obliquity [7]. In the previous studies, it was shown that the unilateral increase in foot pronation causes pelvic obliquity due to lower limb discrepancy. This limb length difference is expressed as functional but results in a pelvic obliquity in the coronal plane [8,22,23].

Raoof et al. investigated the influence of flatfoot on spinal and pelvic mechanics in young females in their study. Similar to previous studies, they found no change in pelvic obliquity. The reason for the researchers was that all included participants with a bilateral flexible second-degree flatfoot [22]. However, the inclusion of young male participants in the current study may explain the difference in results. Also the differences in lower extremities and spinopelvic alignment have been reported between men and women in the previous studies [24].

Our study also demonstrates that young males with bilateral flatfoot had more increased spinal asymmetry compared to unilaterally affected ones. Legaye et al. have attributed their results to the anatomical relationship between the pelvis and lumbal spine [21]. Indeed, this anatomical relationship can be explained by the connection between the pelvic girdle and lumbal spine at the sacroiliac joint via strong fibrous tissue [25]. Levine et al. found a strong correlation between pelvic and lumbal positions. And also it is stated that the alternations in spinal alignment have effects on the trunk area either internally or externally [22].

In contrast, in some studies not in agreement with the previous ones, Betsch et al. and Duval et al. similarly reported that although they found alternations in pelvic position due to the foot pronation and supination, no significant changes in the spinal curvature occurred [25,26]. On the other hand, these results can be derived from the inclusion of the participants with minimal changes of foot position and short follow-up.

We believe that this may have derived from bilaterally-increased foot pronation that affects the kinematic chain of the lower limb and spinopelvic alignment more than unilaterally-increased ones. In other words, bilateral foot postural alternations can produce more reactive forces and cause more changes to existing on the pelvic girdle and spine.

Limitations

The cross-sectional design of the current study limits the ability to generalize the results to other age groups and sex because of the inclusion of young male participants. Another limitation may have been the BMI difference between groups, as the different BMI scores may have caused alternation of loading response of the foot and entire alignment of lower limb and spine.

In conclusion, young males with bilaterally-increased foot pronation demonstrate more increased pelvic obliquity and spinal curvature. The results of this study suggests, more attention should be payed to evaluating the patient's whole posture, rather than focusing only on the foot posture.

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Conflict of Interest: None reported.

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Table.1. Comparison of the demographic and outcome measures of the participants among groups

	Unilateral FF (n=95) Mean (SD) *(95% CI)*	Bilateral FF (n=134) Mean (SD) *(95% CI)*	Between- group differences Mean dif. *(95%CI)*	*p*	*d*
Age (years)	18.78 (0.98) (18.58 – 18.97)	18.72 (0.92) (18.56 -18.87)	0.065 (-0.18 – 0.31)	0.609	0.063
BMI (kg/m^2)	21.90 (1.97) (21.49 – 22.30)	21.10 (1.67) (20.81 – 21.38)	0.79 (0.320 – 1.27)	0.010*	0.438
PO (degree)	7.74 (7.64) (6.18 – 9.29)	10.55 (7.58) (9.25 – 11.84)	-2.81 (-4.28 – -0.80)	0.006	0.369
CA (degree)	3.88 (3.37) (3.19 – 4.56)	6.29 (3.53) (5.68 – 6.86)	-2.40 (-3.32 – -1.48)	<0.001*	0.698

PO: Pelvic obliquity, **CA:** Cobb Angle, **FF:** Flat foot, **SD:** Standart deviation, **95% CI:** Confidence of interval, **Mean dif.:** Mean difference, **d:** Cohen's d , **p<0.05.*

Table.2. The crosstabulation of spinal curve pattern between groups

Spinal Curve Pattern	UniFF n (%)	BiFF n (%)	Total
None	40 (64.5)	22 (35.5)	62
Double	19 (35.2)	35 (64.8)	54
Single thorocal	21 (34.4)	40 (65.6)	61
Single lumbal	15 (28.8)	37 (71.2)	52
Total	95	134	229

UniFF: Participants with flat foot unilateraly, **BiFF:** Participant with flat foot bilaterally, **Spinal curve patterns- None:** without spinal asymmetry, **Single thoracal:** one curve exists in thoracal spine, **Single lumbal:** one curve exists in lumbal spine, **Double:** one curve exist through thoracal and lumbal spine.

Table.3. Post hoc analyses (Bonferroni corrected post-hoc comparisons)

	None	Double	Single thorocal	Single lumbal
None	-	0.002*	0.001*	<0.001*
Double	0.002*	-	0.932	0.485
Single thorocal	0.001*	0.932	-	0.526
Single lumbal	<0.001*	0.485	0.526	-

Spinal curve patterns- None: without spinal asymmetry, **Single thoracal:** one curve exists in thoracal spine, **Single lumbal:** one curve exists in lumbal spine, **Double:** one curve exist through thoracal and lumbal spine,
* Post hoc significant difference, Bonferroni corrected as *p <0.008*

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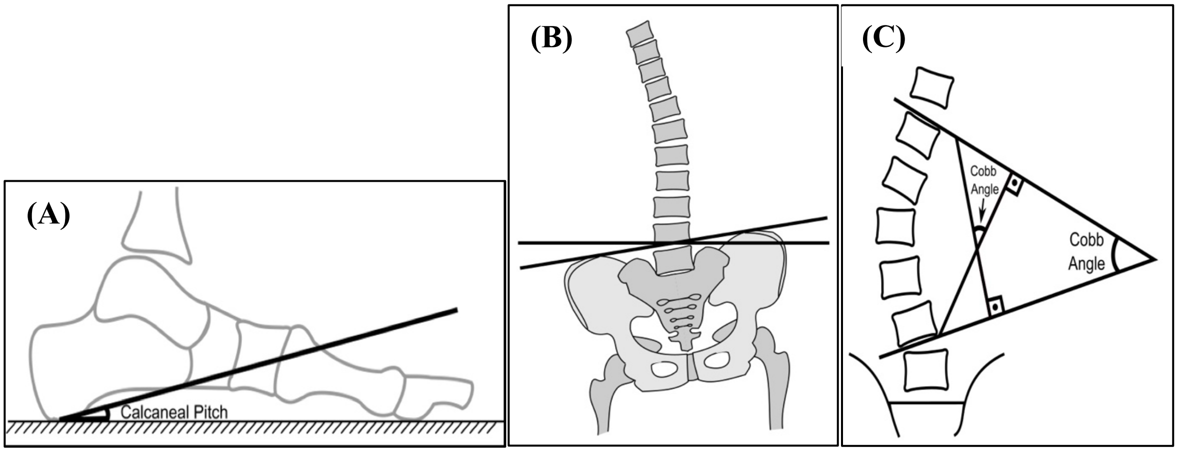

Figure.1. Outcome Measures; **(A) Calcaneal pitch angle:** *An angle between a line drawn from the inferior of the calcaneocuboid joint to the inferior border of the calcaneus and a second line drawn from the inferior aspect of the sesamoid bones to the inferior border* [15]*.* **(B) Pelvic obliquity:** *An angle between the line drawn between the most proximal points on the iliac crest and the line drawn parallel to the lower end of the radiograph* [16]*.* **(C) The Cobb angle:** *An angle of the curve is measured as an angle between the perpendiculars of the lines parallel to the upper border of the upper vertebral body and parallel to the lower border of the lowest vertebral body of the curve* [18]*.*

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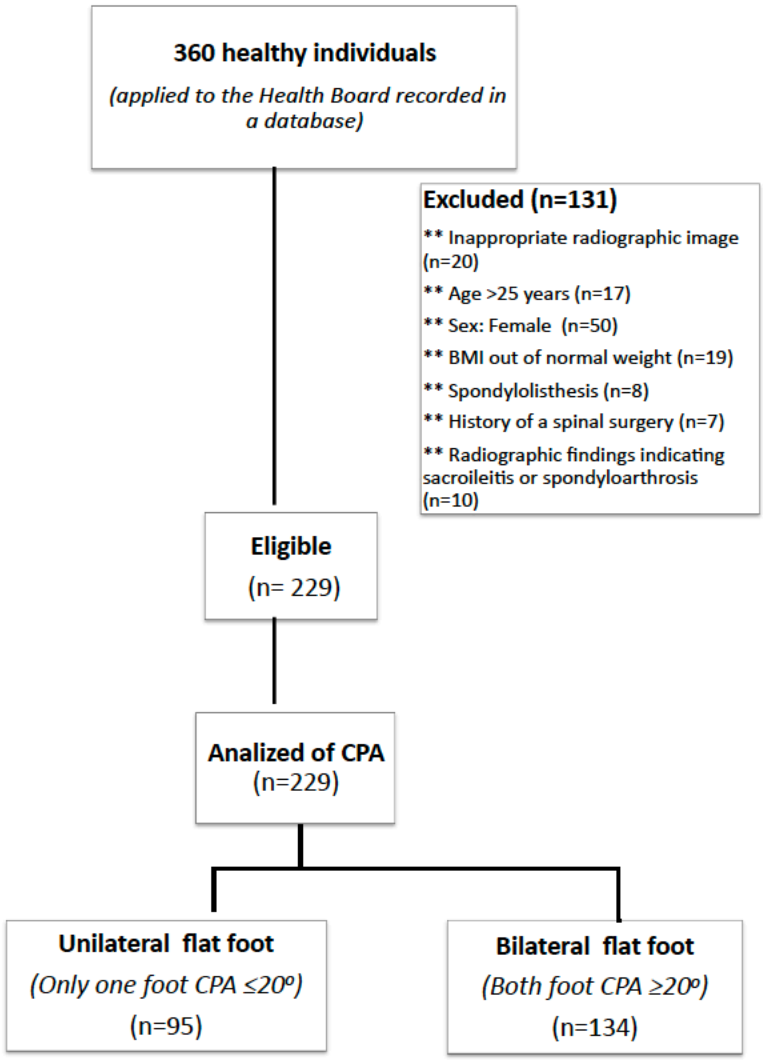

Figure.2. Flow diagram for participants of the study