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The effects of low arched feet on lower limb joints moment asymmetry during gait in children: A cross sectional study

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ABSTRACT

Background: The prevalence of flexible flat feet in children was reported to be up to 20% in previous studies. However, the role of foot type in the development of musculoskeletal injuries is less clear, particularly in children. The purpose of this study was to investigate the differences in the joint moment asymmetry in children with flexible flat feet and healthy matched control subjects.
Methods: Fourteen male children with flexible flat feet and 15 healthy control subjects served as the sample of the study. Three dimensional kinematics and kinetic data were collected using a Vicon camera system and two Kistler force platforms during walking. Then between-limb asymmetry was examined for each joint moment.
Results: Normal individuals experienced higher asymmetry in the ankle eversion and the external rotation moments than the flat feet group. Asymmetry indices in the knee abduction, adduction, and the internal rotation moments in the flat feet group were higher than that in the normal group by 15%, 24% and 13%, respectively. Furthermore, in comparison of the two groups, individuals with flat feet had higher asymmetry in the hip flexion moment as well as the hip abduction moment.
Conclusions: In order to provide appropriate protocols or footwear design for male children with flat feet, clinicians need to understand that flat feet children do not have higher levels of joint moment asymmetry as compared to normal children in all joints and all planes; consequently, they must differentiate their treatments for each specific joint. However, further larger study is warranted.

1. Introduction

Flexible flat foot is defined as a disorder which is associated with reduced medial longitudinal arch height and increased hindfoot eversion during weight bearing [1,2]. While flexible flat foot is common, affecting around 20–78% in the group of 3- to 15-year-old children [3–6] there is ambiguity in terms of its definition and diagnosis strategies. The prevalence of flat foot decreases significantly with age: in the group of 3-year-old children 54% showed a flat foot, whereas in the group of 6-year-old children only 24% had a flat foot [3]. The role of foot type in the development of musculoskeletal injuries is less clear, particularly in children.

Previous studies have principally focused on three techniques for evaluating lower extremity biomechanics and assessment of relationship between foot posture and injury. These three techniques include: kinetics, electromyography (EMG), and kinematics. With regard to kinetics or plantar pressures, it has been found that those with flat feet display significantly lower second peak of vertical ground reaction force [7], lower peak pressure and maximum force in the lateral forefoot, higher maximum force in the medial midfoot [8], higher anterior posterior impulse [9], and higher invertor moment compared to individuals with normal feet during gait [10]. Additionally, the literature shows that a low arch height is normally associated with a reduced peak hip extension moment, second peak knee varus moment and peak knee internal rotation moment [7], as well as reduced peak plantarflexor moment [10]. With regard to EMG, there is evidence that flat feet subjects demonstrate increased activity of some leg muscles (tibialis posterior, tibialis anterior, toe flexors, calf) and decreased activation of evertor musculature compared to those with normal feet [10–12]. With regard to kinematics, the review literature provides some evidence of a relationship between flat feet and altered rear foot and forefoot kinematics [13–15], external hip rotation [16], pelvic external rotation

Abbreviations: EMG, electromyography; GA, gait asymmetry; BMI, body mass index; AHI, arch height index; ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine; BW, body weight; PAT, Polygon Authoring Tool

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(retraction) and knee valgus [7], as well as decreased peak forefoot adduction [13], total transverse plane range of motion [10], midfoot frontal plane range of motion during gait [17]. In spite of fact that, the proposed link between foot posture and injury appears to be biomechanically and physiologically plausible [18–20], the precise etiology of the symptoms remains unclear and further studies are necessary in order to conclude a causal relationship between them. Furthermore, it seems that the gait asymmetry (GA) is a useful index that can provide an important role in clinical treatment.

According to medical sciences, the rationale for the importance of GA may be associated with a number of negative consequences. These include: challenges to postural control [21], and healthy limb overuses and loss of bone mass density in other limbs [22,23]. The human gait is generally considered symmetric in healthy individuals [24]. However, previous studies on healthy subjects have investigated joint moment symmetry with conflicting results [25–29]. There remains a need to further investigate symmetry in joint moments during gait in healthy and other pathological gait conditions such as flat foot (especially in children), while there is a paucity of information regarding to the comparison between flexible flat foot and healthy subjects for GA. An accurate and precise understanding of lower limb joint moment asymmetry values during walking in children with flexible flat foot is an important step towards developing enhanced rehabilitation protocols for their pathological gait.

Therefore, to clarify the aspects of gait disorder in flat feet children, the aim of the present study was to determine the differences in the GA in children with flexible flat feet and healthy subjects. The authors expected to observe more symmetrical gait patterns in healthy controls than individuals with flexible flat feet.

2. Materials and methods

2.1. Subjects

This study is a cross sectional study. Fourteen male children with flexible flat feet (age: with mean (SD) of 10.2 (1.4) years, height: 150.6 (10.2) cm, mass: 42.6 (7.5) kg, body mass index (BMI): 19.1 (3.5) kg/m^2) and 15 healthy matched control subjects (age: 10.2 (1.3) years, height: 151.4 (10.3) cm, mass: 43.1 (6.9) kg, BMI: 18.9 (3.3) kg/m^2) served as subjects of the study (Table 1). A prior statistical power analysis program (G*power) revealed that for a statistical power of 0.80 with an effect size of 0.70 and an alpha level of 0.05 a sample size of at least 11 subjects was required.

Inclusion criteria were either a neutral (Arch height index (AHI) between 0.31–0.37 indicative of normal arch dimension [30,31]) or asymptomatic flat feet posture (navicular drop greater than 10 mm, and AHI lesser than 0.31 indicative of flat arch dimension [30,31]) and no concurrent use of in-shoe orthotics. Also, to qualify for the flat-arched group, participants had an AHI or navicular height measurement greater than two standard deviations from mean values obtained for the normal-arched group [32]. The measure of AHI is unitless and was defined as the ratio of dorsal height at 50% of total foot length, divided by the truncated foot length, defined as the foot length from the back of the heel to the head of the first metatarsal [32]. Exclusion criteria were any history of surgery, trauma, limb length discrepancies of greater than 5 mm, orthopaedic disease and neuromuscular problems, and also heavy physical tasks or exercise during the past two days. The subjects were all right foot dominant determined by the kicking ball test [33,34]. Ethics approval was obtained from the Medical Sciences University of Mohaghegh Ardabili Research Ethics Board and all participants' parents provided written informed consent prior to participation.

Table 1
Participants' demographic and feet characteristics (mean ± SD).

Variable	Normal group (N = 14)	Flat feet group (N = 15)	Sig.
Demographic measurement			
Age (year)	11.27 ± 0.8	10.89 ± 1.19	0.32
Height (cm)	152.9 ± 12.0	149.0 ± 11.9	0.37
Body mass (kg)	43.78 ± 6.50	42.30 ± 7.26	0.57
BMI (kg/m^2)	19.56 ± 5.26	18.94 ± 3.69	0.71
Feet characteristics			
Left-navicular drop	5.53 ± 0.40	11.73 ± 1.36	0.00*
Right-navicular drop	5.54 ± 0.42	11.71 ± 0.84	0.00*
Left-AHI	0.33 ± 0.01	0.26 ± 0.03	0.00*
Right-AHI	0.33 ± 0.01	0.27 ± 0.01	0.00*
Spatio-temporal parameters			
Gait velocity (m/s)	1.25 ± 0.15	1.22 ± 0.12	0.56
Stride length (cm)	98.31 ± 4.98	101.6 ± 6.5	0.12
Cadence (step/min)	113.6 ± 8.1	113.8 ± 7.3	0.94

SD stands for standard deviation.
* Significant difference at $P < 0.05$.

2.2. Apparatus

3-Dimensional kinematics and kinetic data were collected using a Vicon 370 six camera system (Vicon system, Oxford Metrics, Oxford, UK) at a sampling rate of 100 Hz and two force platforms (Kistler, type 9281, Kistler Instruent AG, Winterthur, Switzerland) at a sampling rate of 1000 Hz [35]. A preliminary calibration procedure was performed (Vicon Motion Capture System, 2014. http://www.vicon.com) before the experiments. All data were analyzed using the models implemented in Vicon Clinical Manager, employing the Plug in Gait marker set, an estimation of joint centers based on Davis' anthropometric model and an inverse dynamics solution of joint kinetics.

2.3. Kinematic and kinetic data collection and analysis

On the test day, 16 reflective spherical markers (diameter 7 mm) were attached bilaterally to the subjects on the following landmarks: anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), lateral mid-thigh, lateral femoral epicondyle, mid shank, lateral malleoli, heel and second metatarsal heads (mounted on the vamp of the shoe) (Fig. 1).

All kinetics data were filtered using a fourth-order low-pass Butterworth filter with a 20 Hz cutoff frequency [36,37] and all were normalized to child's body weight (BW). The Kinematics data were low-passed using a digital zero-lag fourth-order Butterworth filter with cut-off frequency of 6 Hz [38]. Each stride was time normalized to 100 points representing equal intervals from 0% to 100% using Polygon Authoring Tool (PAT) (Oxford Metrics Ltd., Oxford, England). Then, data points were exported from PAT to a spreadsheet in order to calculate the joint moment asymmetry in lower limbs.

The GA index for each variable and for each subject was computed using the following equation [29]:

$$GA(\%) = 100 \times \left(1 - \frac{\text{lesser moment}}{\text{greater moment}}\right) \quad (1)$$

Based on this formula, the asymmetry will be zero once the higher and lower moment are equal [29].

2.4. Task and procedure

Prior to each experimental condition, a static trial was captured to identify the relation between the marker coordinate systems and the anatomical coordinate systems and then to determine marker to anatomical matrixes. During the tracking trials, subjects walked at a self-selected speed (1.23 (0.13) m/s) through the middle of a walkway with a calibrated field approximately 4 m in length. The force plates were located at the center of the calibrated space in middle part of walk way. Six walking trials were captured for each subject, whereby the left and