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Exploring the Relationship Between Foot Arch and Lower Extremity Gait Kinematics in Healthy Adults: A Comprehensive Analysis

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ABSTRACT

Background: Flat Feet condition also known as pes planus, manifests as a prevalent postural anomaly characterized by the medial rotation and plantar flexion of the talus, along with the eversion of the calcaneus, collapse of the medial arch, and abduction of the forefoot.
Aim and Objectives: Correlation of foot arch with lower extremity gait kinematics in healthy adults.
Methods: 17 healthy adult females (82 feet, n = 82) with flexible flat feet who were between the ages of 18 and 25 were included in the study. Baseline recording of the outcome measures was done using the Foot Posture Index (FPI-6) and Navicular Drop Test which assessed individuals with flat arch and normal arch foot followed by 3D gait Analysis.
Results: A statistically significant positive connection has been observed between FPI and the maximum ankle dorsiflexion ($p = 0.02$) at mid-stance, terminal stance ($p = 0.033$), starting swing ($p = 0.027$), and maximum dorsiflexion in the mid-swing ($p = 0.002$) phase. FPI and FPA. have a negative connection, with a statistically significant p-value of less than 0.001.
Conclusion: This study strengthens the current understanding of how flat feet can influence gait patterns. The observed differences in gait mechanics among individuals with flat feet highlight the potential benefits of interventions aimed at improving foot arch support and function.

Keywords: Foot arch types, Lower extremity biomechanics, Gait analysis, Healthy gait patterns, Gait kinematics, Foot posture Index

INTRODUCTION

Flat Feet condition also known as pes planus, manifests as a prevalent postural anomaly characterized by the medial rotation and plantar flexion of the talus, along with the eversion of the calcaneus, collapse of the medial arch, and abduction of the forefoot. (1) In the stance of the bipedal form, the area defining the base of support extends posteriorly from the tips of the heels to the anterior boundary marked by a line connecting the tips of the toes. In pes planus, the medial longitudinal arch experiences flattening, causing the entire sole to make near-complete or complete contact with the ground. Studies have indicated a prevalence of flat feet among adults ranging from 13.6% to 26.62%. (2) The associated deformities often lead to discomfort, instability, irregular distribution of plantar pressure, ambulatory issues, and foot weariness, which can significantly impede daily activities. These alterations may manifest as diminished walking velocity, reduced stride length and frequency, and prolonged stance phases, compromising functional capacity and overall quality of life. (3,4)

A study by Fayez A., Saad A., and Mohammed A. revealed that individuals demonstrating asymptomatic pronation of the foot and those devoid of such pronation exhibited analogous patterns of hip kinematics across all three planes of motion. This discovery underscores the importance for clinicians to consider foot alignment during evaluations of patients presenting with asymptomatic pronation or non-pronation of the foot. (5) A separate study by Simone G., Sara K., and Jeremy D. examined the correlation between foot arch measurements and walking parameters in children. The study found that arch height indices were positively associated with navicular height. These findings suggest that employing multiple measures of the arch may be necessary to fully understand the relationship between arch height and gait. (6) Andrew B., George, et al. researched a wide range of foot postures, concluding that clinical measures of foot posture or foot mobility could only account for a small portion of the variability in dynamic kinematic behavior of the foot during walking. However, among various measures, the Foot Posture Index (FPI) emerged as a significant predictor across numerous kinematic variables. This implies that the FPI, which encompasses multiple observations in all three planes of motion, may offer a more comprehensive understanding of foot kinematics compared to measures focused on a single plane of motion. (7)

This study aims to comprehensively assess the gait kinematics of flatfooted women aged between 17 to 25 years, aiming to provide valuable insights into the biomechanical patterns and characteristics of their walking motion. By conducting a detailed analysis, the study seeks to elucidate any distinctive gait parameters, deviations, or compensatory mechanisms exhibited by this demographic group. The goal is to enhance understanding of the biomechanical implications of flatfoot in young adult women, thereby informing tailored intervention strategies and rehabilitation approaches aimed at improving gait mechanics and mitigating potential musculoskeletal issues associated with flatfoot conditions in this age range.

MATERIALS & METHODS

Subjects

An observational study using gait analysis was conducted at St. Xavier's Gait Lab in Mumbai. The study comprised 17 healthy adult females (82 feet, n = 82) with flexible flat feet who were between the ages of 18 and 25. Any lower limb soft tissue injuries or musculoskeletal trauma, as well as neurological problems that may have affected the patient's normal gait pattern within the previous six months, were excluded from consideration. The study enrolled 17 healthy adult females, aged 18 to 25 years as the inclusion criteria. The study was ethically approved and informed consent was obtained from the parents/guardians of the children included in the study. A consent form was obtained from each participant involved.

Foot posture Index (FPI-6)

The participants were told to remain motionless, keep their arms at their sides, and face front. The individuals positioned themselves so that the assessor could easily move about them and get unhindered access to the anterior, posterior, and lateral aspects of their legs and feet. Talar head palpation, supra and infra lateral malleoli curvature, calcaneal frontal plane position, prominence in the talonavicular joint region, congruence of the medial longitudinal arch, and abduction/adduction of the forefoot on the rearfoot are the six criteria of the FPI. Attributes indicative of a nearly neutral foot posture receive a grading of zero, whereas pronated postures are assigned positive values, with higher values indicating greater pronation. Conversely, supinated features are allocated negative values, with more negative values indicating increased supination. In the case of a neutral foot, the cumulative FPI score should hover around zero. (8,9)

Navicular drop test (NDT)

The participants sat with their foot flat on the floor, their knee bent 90 degrees, and their ankle in a neutral posture. The tubercle of the foot is marked on an index card that is positioned vertically from the ground on the inner side of the hindfoot, passing across the navicular bone. The individual was then allowed to stand without shifting their weight and balance equally on both feet before taking another measurement. Lastly, the difference between the navicular bone during sitting and standing (mm) was used to compute the ND in millimeters. Less than 10 mm of ND is seen as normal, whereas more than 10 mm is regarded as flat. (10,11)

Gait Analysis

A 3D gait analysis was performed on flat-foot females to assess movement characteristics such as joint angular kinematics, kinetics, and spatiotemporal gait parameters. A 12-camera Qualisys® 3D Motion Capture System (Qualisys AB, Götebor, Sweden) was used to collect data. Therefore, all children were instructed to walk barefoot at a self-selected and comfortable pace across a 10-meter walkway, which allowed them to reproduce their daily gait. The recorded data was initially processed using the Qualisys Track Manager v2.15 (Qualisys AB, Götebor, Sweden) software. A 3D model was created to analyse the relative angles of the ankle, knee, and hip joints. Finally, Visual 3D (C-Motion, Germantown, MD, USA) software commands were computed and identically replicated for each subject to identify measures, namely joint angular kinematics (ankle, knee, and hip angle), kinetics and gait spatiotemporal parameters.

STATISTICAL ANALYSIS

The data analysis was done using the Statistical Package for Social Sciences (SPSS-29). Bivariate correlation was done between the FPI and gait parameters that showed appreciable difference in their average value which was analyzed using a pivot table in Microsoft Excel. A scatter chart was plotted to show a linear trendline between the pairs of values. To compare the flat feet group and healthy group, an independent *t*-test was used with a *p*-value significance threshold of less than 0.001.

RESULT

The mean age of those with healthy feet was 24 years (± 0.68) and those with flat feet were 24 years (± 1.14). The respondents with flat feet had a mean body mass index of 25.56 (± 4.10), whereas those with healthy feet had a mean BMI of 22.40 (± 4.17). This indicates that the overweight subjects had flat feet relative to their healthy-weight counterparts with normal foot arches. The flat feet group's mean NDT score was 11.29 ± 1.12, while the healthy group's score was 5.97 ± 1.36 and was statistically significant. Individuals with flat feet averaged 1.14 (± 0.32) m/s while those with healthy feet averaged 1.27 (± 0.13) m/s when walking. The mean stride length for patients with flat feet was 1.31 (± 0.18) cm, while for subjects with healthy feet, it was 1.15 (± 0.31) cm. The mean stride width for subjects with flat feet was 0.05 (± 0.05) cm, while for subjects with healthy feet, it was 0.10 (± 0.13) cm. Thigh foot angle was statistically significant (p = <.001*) and indicated increased external rotation upon clinical assessment.

Regarding kinematic characteristics, the mean ankle mid-stance degree in the sagittal plane was 6.73 (± 6.53) degrees for those with flat feet and 0.82 (± 5.14) degrees for people with normal feet. Ankle terminal stance mean values were 2.14 ± (6.56) degrees for people with flat feet and -1.83 ± (8.82) degrees for people with normal foot lengths. Ankle initial swing mean values were -13.68 ± (9.25) degrees for flat feet and -19.93 ± (5.20) degrees for normal feet. Ankle mid-swing mean values were 7.57 ± (5.75) degrees for people with flat feet and -2.76 ± (9.76) degrees for people with normal foot lengths. A statistically significant positive connection has been observed between FPI and the maximum ankle dorsiflexion (p = 0.02) at mid-stance, (Fig 1) terminal stance (p = 0.033), (Fig 1) initial swing phase (p = 0.027), (Fig 1) and maximum dorsiflexion in the mid-swing (p = 0.002) phase. (Fig 1) (Table 2). FPI and FPA have a negative connection, with a statistically significant p-value of less than 0.001. (Table 2) (Fig 1)

Table 1: Comparison between Flat feet group and Healthy group

Parameters	Flat feet Group Mean ± SD	Healthy group Mean ± SD	P value
NDT score	11.29 ± 1.12	5.97 ±1.36	p = <.001*
Hip supine ER	57.20 ± 6.66	54.85 ± 5.62	.129
Hip supine IR	42.20 ± 8.41	40 ± 9.23	.304
Hip prone ER	52.64 ± 6.99	51.32 ± 6.89	.421
Hip Prone IR	54.85 ± 8.44	51.61 ± 7.24	.076
TFA	-16.3 ± 4.07	-6.94 ± 1.79	p = <.001*

Statistical significance (p < 0.01) * is presented.

NDT score: Navicular drop test score; ER: external rotation; IR: internal rotation; n: number of feet. TFA: Thigh foot angle

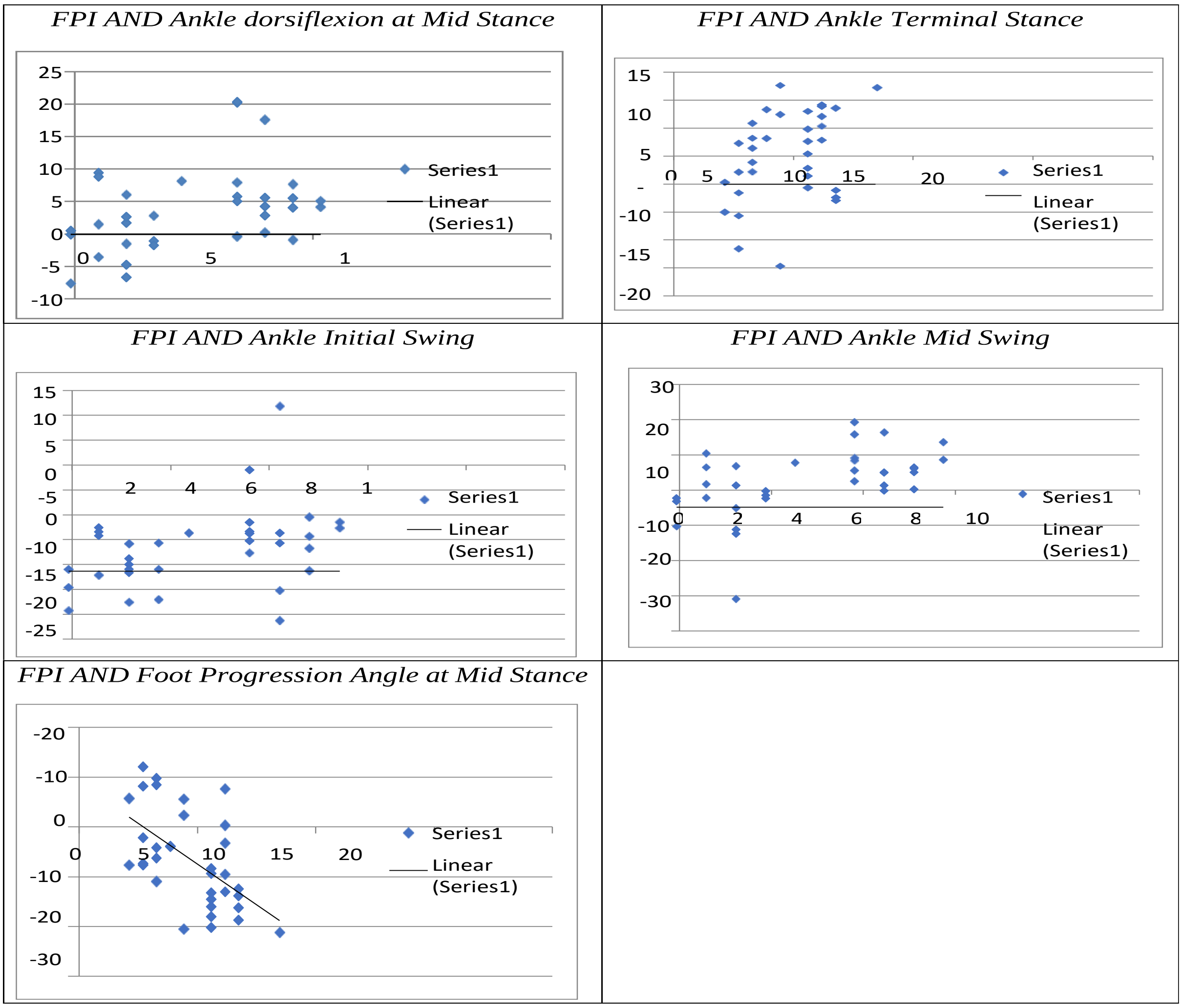

Figure 1: Scatter plot describing relation between FPI and Gait Kinematics

Table 2: Correlation between FPI, NDT with Ankle joint kinematics parameters

		FRI	Ankle DF at mid-stance	Ankle DF at terminal stance	Ankle DF at Initial swing	Ankle DF Mid-swing	FPA at midstance
FPI	**Pearson Correlation**	1	.398*	.366*	.379*	.514**	
	Sig. (2- tailed)		0.02	0.033	0.027	0.002	
NDT	**Pearson Correlation**						-.567**
	Sig. (2- tailed)						<.001

NDT score: Navicular drop test score; FPI: Foot posture Index; FPA: Foot progression angle; DF: Dorsiflexion

DISCUSSION

Flat feet, also known as pes planus, is a condition in which the arches of the feet collapse, causing the entire sole to make complete or nearly complete contact with the ground. Foot mechanics modifications in female adults include overpronation, which occurs when the foot rolls inward excessively when walking. This disrupts the natural alignment and mechanics of the foot, resulting in a less effective gait. Foot posture in flat feet causes the feet to point outward more than usual, a condition known as foot splaying. This can result in an imbalance and need extra muscular work to maintain equilibrium while walking. The goal of this study was to determine whether there is a link between different foot positions and associated gait metrics in healthy young individuals.

In a study by Daekyoo Kim et al. that looked at the impact of obesity on flat feet, the obese group had a mean navicular drop of 1.59 cm and a gait speed of 1.04m/s, whereas we had a large mean navicular drop of 11.29 cm and a speed of 1.27m/s. (12) Flat feet have an increased navicular drop because the medial arch is already lowered or collapsed, resulting in a higher displacement of the navicular bone during the transition from non-weight-bearing to weight-bearing positions. Women often have a greater range of joint mobility compared to men, which can exacerbate the extent of the navicular drop. (13) According to the temporospatial characteristics, the average step length was 0.46m and the step width was 0.23m. (12) In our study, ladies with flat feet had an average stride length of 1.31 and a mean stride width of 0.05. The slower walking speed observed in individuals with flat feet suggests a less efficient gait cycle. This could be attributed to the altered foot strike patterns and potentially increased energy expenditure during walking. Interestingly, the finding of a longer stride length with a narrower width in the flat feet group warrants further investigation. While a longer stride might seem advantageous, it could be a compensatory mechanism for the reduced dorsiflexion, leading to a less stable gait pattern. Thigh foot angle was statistically significant (p = <.001*) and indicated increased external rotation upon clinical assessment. The increased external rotation in the thigh-foot angle observed in the flat feet group suggests a potential misalignment in the lower limb. This misalignment could be a consequence of the body's attempt to compensate for the altered mechanics at the foot and ankle. Foot progression angle showed external rotation in the flat feet group which was also observed in the Daekypp Kim et al. study with a mean of 0.73 (4.85) .(12) The lack of arch support might lead to a collapse of the medial arch during gait, causing the foot to roll inwards (overpronation). In response, the leg and hip may externally rotate to compensate for this inward rolling, resulting in the observed outward rotation of the foot (external FPA).

In our study, gait kinematics, the ankle joint exhibits decreased dorsiflexion of 5 to 6 degrees during the initial contact phase, and persons with flat feet frequently have a reduced heel strike due to a lack of arch support. The foot may land more squarely, resulting in unequal pressure distribution and reduced shock absorption. In the midstance phase, mean decreased dorsiflexion with mean 6 to 8-degree flat feet might lead the arch to collapse completely, putting more strain on the medial (inside) side of the foot. This can result in a lengthy midstance period as the foot attempts to balance the body. In the terminal stance phase, there is plantar flexion of approximately 2 to 5 degrees. There is a toe-off, which may be compromised due to the absence of a stiff lever (the arch). This can lead to a weaker push-off, shorter steps, and possibly decreased walking pace. Marouvo et al. found a similar result in the FF group, which is characterized by decreased ankle peak dorsiflexion ($p = 0.029$). (14) In a study published in 2010, Levinger et al. examined how the kinematics of the foot and ankle, as well as the gait task, differed between adult FF subjects and neutral ones. A considerably higher peak forefoot plantarflexion was discovered ($p = 0.004$). (15)

The study's limitations include the lack of information on the severity of flat feet in the participants. Categorizing the flat feet based on severity (mild, moderate, or severe) could provide a clearer picture of how the degree of arch collapse influences gait mechanics. Additionally, investigating pain or discomfort associated with flat feet would be valuable, as some individuals with flat feet may not experience any gait deviations or pain, while others might. Future studies could benefit from incorporating larger sample sizes and employing advanced gait analysis techniques to capture more nuanced aspects of gait, such as joint moments and muscle activation patterns. Additionally, exploring the effectiveness of different interventions, such as orthotics, specific exercises, or footwear modifications, in improving gait efficiency in women with flat feet would be a valuable next step.

CONCLUSION

Flat feet can negatively impact gait mechanics in young women. Individuals with flat feet may walk slower, exhibit altered foot strike patterns (due to reduced dorsiflexion), and have a less efficient gait cycle compared to those with healthy foot arches. The findings suggest that flat feet are associated with overpronation, foot splaying, decreased ankle dorsiflexion, altered foot strike patterns, and potentially compromised toe-off during walking. These gait abnormalities can lead to imbalances, reduced shock absorption, and potentially slower walking speed.

Declaration by Authors

Ethical Approval: Approved

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