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Morphometric evaluation of the relationship between foot arch types and lower-limb alignment: A cross-sectional study

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Abstract

Objective: This study investigated the relationship between medial longitudinal foot arch morphology and lower limb alignment in asymptomatic young adults.

Methods: A cross-sectional study of 204 healthy adults aged 18-30 years was used to conduct the study. The Type of arch was categorized by the Arch Index and confirmed by the ChippauxSmirak Index, Staheli Index, Foot Posture Index-6 (FPI-6) and Navicular Drop Test. The alignment of the lower limbs was evaluated using standardized goniometric measures of the quadriceps (Q) angle, the tibiofemoral and the rearfoot angle. One-way ANOVA with Bonferroni post-hoc testing was used to compare differences between the groups of flat, normal and high arch. **Findings:** 54.9% of the participants had normal arches, 29.9% had flat feet, and 15.2% had high arches. The individuals having flat feet had much higher Q-angle ($16.9 \pm 2.6^\circ$), tibiofemoral angle ($8.7 \pm 2.2^\circ$), navicular drop (12.6 ± 2.4 mm), and rearfoot angle ($9.1 \pm 2.5^\circ$) compared to those with normal or high arches ($p < 0.001$). The moderate positive correlation of navicular drop with Q-angle was $r = 0.51$ and Arch Index ($r = 0.44$) and FPI-6 ($r = 0.47$) were also positively associated. **Conclusion:** The medial longitudinal arches below were linked to a higher degree of lower limb malalignment, which validated foot arch measurement as a valuable screening method to determine people who may experience biomechanical impairments and possible musculoskeletal trauma.

Keywords: *Pes planus, Pes cavus, Foot posture index, Q-angle, Lower-limb alignment*

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1. Introduction

The foot is the last weight-bearing part of the lower limb's kinetic chain. The medial longitudinal arch plays a key role in shock absorption, load distribution, and energy storage and release during movement. Feet are generally sorted into three categories based on arch height: low-arched (*pes planus*), neutral, and high-arched (*pes cavus*) (Xu *et al.*, 2026; Araújo *et al.*, 2020). The morphological phenotypes are characterized by plantar-loading and rearfoot kinematic strategies. Low-arched feet show greater hindfoot eversion and excessive

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pronation during stance; high-arched feet present a more rigid, supinated posture with increased hindfoot inversion (Tong and Kong, 2013). Although the effect size varies between studies, both low and high arched feet are associated with an increased risk of lower limb overuse injuries in comparison with neutral feet (Ye *et al.*, 2026).

The prevalence of the different foot arch types varies greatly between populations and the way they are measured. Low-arched foot phenotypes have been reported to be from approximately 2% to 23% and high-arched feet around 10% in adult samples (Cavanagh and Rodgers, 1987). Such a large discrepancy mainly indicates that there is no widely accepted evaluation method. Commonly used metrics for foot arch morphology comprise clinical and footprint-based methods such as the Arch Index, Chippaux-Smirak Index, Staheli Index, clinical Foot Posture Index (FPI-6) and the navicular drop test. These methods, however, evaluate different aspects of the foot anatomy, leading to only moderate agreement between them (Paecharoen *et al.*, 2023; Redmond *et al.*, 2006).

Mechanistically, arch morphology is hypothesised to influence proximal alignment through the closed kinetic chain. Excessive subtalar pronation and rearfoot eversion, characteristic of the low arch, are coupled with obligatory internal rotation of the tibia; this internal rotation is transmitted to the knee, where it is associated with increased dynamic knee valgus and an increased quadriceps (Q) angle (Cömert and Gruber, 2025; Tabrizi *et al.*, 2025). Conversely, the rigid, supinated cavus foot attenuates shock less effectively and may shift load laterally. Excessive pronation has therefore been implicated in patellofemoral pain, medial tibiofemoral loading, Achilles and plantar-fascia pathology, and anterior cruciate ligament injury risk (Peng *et al.*, 2020; Mahmoudiyan *et al.*, 2026).

Although there is a solid biochemical background to static arch types and frontal plane alignment of the knees, there is no clear relationship known yet. There have been several studies that have indicated that an increased foot pronation and navicular drop were linked to increased Q-angle and genu valgum tendencies (Chandan *et al.*, 2023). On the other hand, some researchers suggested that navicular drop was a poor determinant of Q-angle considering proximal variables like femoral anteversion and tibiofemoral angle (Gül *et al.*, 2025). Studies on patients with knee osteoarthritis have also suggested that lower and stiffer medial longitudinal arch may be linked to abnormality in lower limbs and symptoms experienced by the patient (Karatas and Utkan Karasu, 2024). However, the majority of current evidence is related to clinical or athletic subgroups, uses one method of measuring foot arches and analyzes one aspect of lower limb alignment.

This is a critical understanding for a healthy young adult since it gives an idea about biomechanical adaptation before the development of any degenerative condition. These observations may lead to an improvement in clinical evaluation, shoe selection and orthotics prescription as well as preventing any injuries. Hence, the current study was intended to (i) categorize foot arch type with the use of various morphometric measures; and (ii) assess the correlation between foot arch type and lower extremity alignment.

2. Materials and methods

2.1. Study design and setting

This single-centre observational cross-sectional study was performed. The study was approved by the Institutional Ethics Committee and were carried out in accordance with the principles of the Declaration of Helsinki. Informed consents were obtained from all the participants.

2.2. Participants and eligibility

Subjects aged 18-30 years with a healthy lifestyle were recruited among the university students using the convenience sampling method. Individuals included in the study were able to stand and walk independently and had a Body Mass Index (BMI) of 18.5-29.9 kg/m². Exclusion criteria included the presence of any lower limb pain or injuries, any recent or previous surgeries of the lower limbs or spine, fractures, or congenital deformities of the musculoskeletal system. Excluded from the study were participants with neurological, rheumatological, or vestibular diseases, leg length discrepancy, pregnancy, or those who used foot orthoses. The dominant limb was determined by asking subjects to kick a ball.

2.3. Sample size

The sample size was determined for a one-way ANOVA comparing three arch-type groups. With an assumed medium effect size ($f = 0.25$), alpha level of 0.05 and power level of 0.8, a sample size of 159 was required. Allowing for uneven distribution and 10% of missing data, 204 participants were recruited.

2.4. Foot arch assessment and classification

Static footprints were obtained in bipedal stance using an ink-based pedograph with the participant looking straight ahead and weight evenly distributed. The Arch Index (AI) was calculated as the ratio of the midfoot area to the total footprint area, excluding the toes, following Cavanagh and Rodgers ([Basgün et al., 2025](#)). The Chippaux-Smirak Index (CSI) and Staheli Index (SI) were derived from the same footprints ([Yang et al., 2022](#)). Foot posture was also classified using a six-item Foot Posture Index (FPI-6) ([Aquino et al., 2018](#)) and measured using the navicular drop test (difference between the height of the navicular tuberosity in subtalar-neutral sitting position and relaxed standing position) with a rigid ruler. All assessments were made by a single assessor to ensure consistency, and test-retest reliability was found to be good to excellent (intra-class correlation from 0.85 to 0.96) in a sample of 20 participants at one-week follow-up.

Table 1: Morphometric methods and thresholds used to classify foot arch type

Method	Parameter	High arch	Normal	Low arch
AI	Midfoot/total print area	< 0.21	0.21–0.26	> 0.26
CSI	Min. midfoot/max. forefoot width	< 30%	30–45%	> 45%
SI	Min. midfoot/max. heel width	< 0.44	0.44–0.70	> 0.70
FPI-6	Composite 6-item posture score	≤ -1	0 to +5	$\geq +6$
ND	Navicular height change (mm)	< 5	5–9	> 9

2.5. Lower-limb alignment assessment

The quadriceps (Q) angle was measured with a long-arm universal goniometer in relaxed supine lying, as the angle formed by a line from the anterior superior iliac spine to the mid-patella and a line from the mid-patella to the tibial tuberosity. The tibiofemoral angle (frontal-plane femur-to-tibia angle; positive values denote valgus) was measured in relaxed standing. The rearfoot (calcaneal) angle was measured in bilateral stance as the angle between the bisection of the posterior lower leg and the bisection of the calcaneus, with eversion recorded as positive. Each measure was recorded three times and the mean used for analysis. Analyses were performed on the dominant limb.

2.6. Statistical analysis

Data were analyzed using IBM SPSS Statistics version 26. Descriptive statistics were expressed by mean $\pm$ standard deviation and frequencies. To compare lower limb alignment parameters between the three groups, a one-way analysis of variance (ANOVA) was performed. For categorical variables, the chi-square test was used. The strength of the association between continuous variables was evaluated using Pearson's correlation coefficient.

3. Results

There were 204 subjects (112 females and 92 males) included in the study. The subjects' mean age was 22.6 ± 3.1 years, while their mean BMI was $23.4 \pm 2.6 \text{ kg/m}^2$. In regard to the Arch Index, 112 (54.9%) participants had a normal foot arch, 61 (29.9%) subjects presented with pes planus, and 31 (15.2%) had pes cavus. Subject attributes were similar among the three categories, except for the fact that subjects with pes planus had a somewhat higher BMI than other subjects (Table 2).

3.1. Differences in lower-limb alignment across arch types

A one-way ANOVA demonstrated that all of the alignment parameters were different between the groups at p

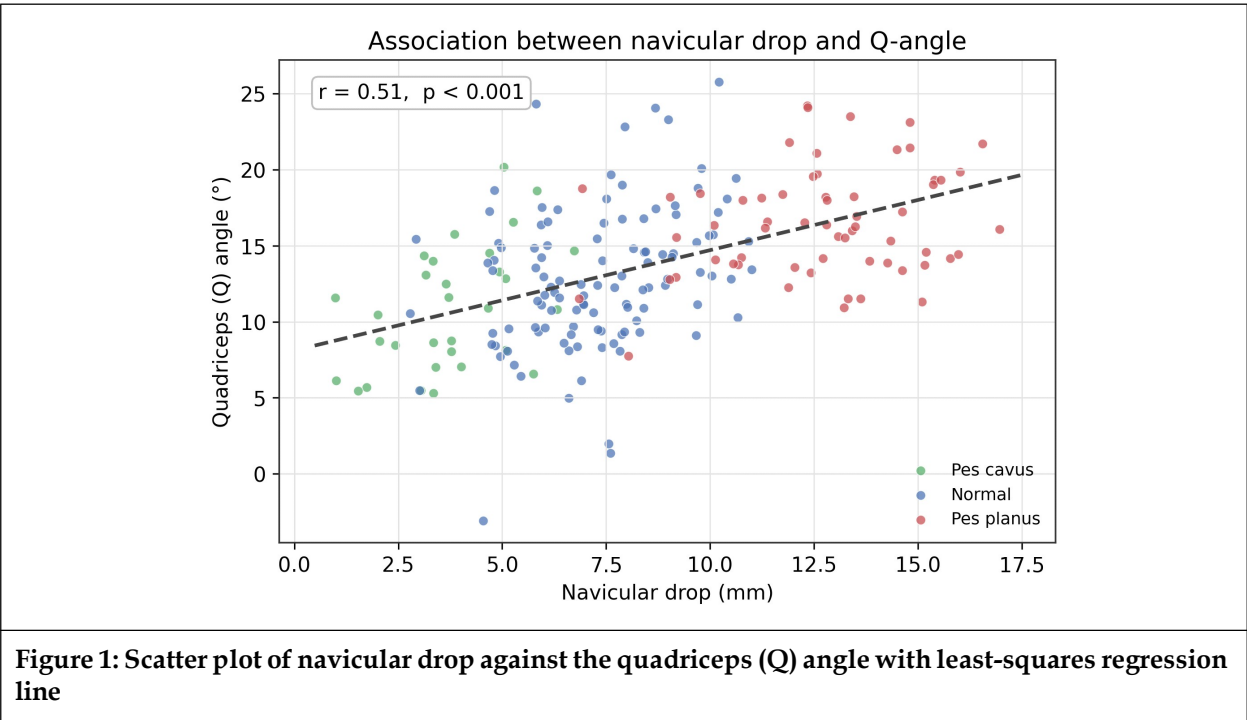
Table 2: Demographic and anthropometric characteristics by foot arch type				
Variable	Normal (n = 112)	Pes planus (n = 61)	Pes cavus (n = 31)	p-value
Age (years)	22.4 ± 3.0	23.1 ± 3.2	22.5 ± 3.1	0.42
Sex (women/men)	62/50	34/27	16/15	0.88
Height (cm)	168.9 ± 8.6	167.4 ± 9.1	169.7 ± 8.2	0.47
Weight (kg)	66.7 ± 10.8	70.1 ± 11.9	64.9 ± 9.7	0.06
BMI (kg/m²)	23.0 ± 2.4	24.6 ± 2.9	22.5 ± 2.2	<0.01
Dominant limb (R/L)	101/11	55/6	28/3	0.97

<0.001 (Table 3). When performing Bonferroni post-hoc comparisons, it was found that the pes planus group had significantly higher Q-angle, tibiofemoral (valgus) angle, navicular drop and rearfoot eversion angle compared to the normal and pes cavus groups, whereas the pes cavus group had the lowest values in all parameters. Effect sizes were large for navicular drop and rearfoot angle and moderate-to-large for the knee measures.

Table 3: Comparison of lower-limb alignment parameters across foot arch types						
Parameter	Normal	Pes planus	Pes cavus	F	p	η² _p
Q-angle (°)	13.4 ± 2.1	16.9 ± 2.6 a,b	12.0 ± 2.3 a	63.5	<0.001	0.39
Tibiofemoral angle (°)	6.1 ± 1.8	8.7 ± 2.2 a,b	4.6 ± 1.9 a	55.7	<0.001	0.36
Navicular drop (mm)	7.2 ± 1.9	12.6 ± 2.4 a,b	4.1 ± 1.6 a	221.0	<0.001	0.69
Rearfoot angle (°)	5.0 ± 2.0	9.1 ± 2.5 a,b	2.3 ± 1.8 a	122.4	<0.001	0.55
FPI-6 (score)	2.8 ± 1.7	7.9 ± 2.1 a,b	-1.6 ± 1.9 a	295.1	<0.001	0.75

3.2. Correlations between arch morphology and alignment

Across the whole sample, continuous measures of arch morphology were positively associated with knee



alignment. Navicular drop showed the strongest relationship with the Q-angle ($r = 0.51$, $p < 0.001$; Figure 1), followed by the FPI-6 ($r = 0.47$) and the Arch Index ($r = 0.44$). A similar pattern of weaker but significant positive correlations was observed with the tibiofemoral angle. Thus, flatter, more pronated feet were consistently associated with a larger Q-angle and greater genu valgum.

4. Discussion

This cross-sectional study investigated the association between the morphometry of the foot arch and the lower limb alignment in young adults who did not report any musculoskeletal symptoms. The main results were mostly consistent with the a priori hypothesis: pes planus was associated with increased knee valgus compared to normal and pes cavus, while continuous decreases in the foot arch were correlated with increases in the knee valgus. The high-arched cavus group sat at the opposite end of every measure, supporting a graded, arch-dependent pattern of proximal alignment (Ikuta *et al.*, 2022; Zhang *et al.*, 2022).

These observations are congruent with the closed-chain biomechanical model in which excessive rearfoot eversion and midfoot collapse compel internal rotation of the tibia, which is in turn coupled with knee valgus and a widened Q-angle. The same coupling has been invoked to explain why flatfoot posture elevates patellofemoral joint contact force and is associated with a greater risk of knee and lower-limb pain, and why medially posted orthoses that resist pronation reduce patellofemoral and ankle joint loading. Systematic-review evidence likewise identifies distal foot pronation as a contributor to frontal-plane knee valgus within the kinetic chain. Our correlational pattern, navicular drop showing the strongest single association with the Q-angle, accords with reports linking increased navicular drop and dynamic knee valgus, including in the context of anterior cruciate ligament injury-prevention programmes (Akaltun and Koçyigit, 2021).

Multivariable analyses have found navicular drop to be a weak or non-independent predictor of the Q-angle once proximal alignment variables such as femoral anteversion and the tibiofemoral angle are entered. The moderate magnitude of the associations observed here, and the acknowledged low-to-moderate strength of the arch-type-injury relationship reported in meta-analysis, both caution against over-interpreting static arch morphology as a dominant determinant of knee alignment. Arch morphology is best viewed as one contributor within a multifactorial chain that also includes hip and pelvic mechanics, muscular control and dynamic loading. The population based investigations have also demonstrated that the higher flatfoot severity is associated with more pronounced lower extremity symptoms, reinforcing the clinical relevance of identifying variations in foot arch morphology (Alsancak *et al.*, 2021).

Clinically, the results support the pragmatic inclusion of simple morphometric arch screening-footprint indices, FPI-6 and navicular drop, which require minimal equipment-within lower-limb assessment, particularly for individuals with, or at risk of, patellofemoral or overuse complaints. Identifying a low, mobile arch associated with increased valgus alignment may help target conservative measures such as foot-orthoses, arch-support footwear and intrinsic-foot and hip-abductor strengthening, several of which have been shown to modify frontal-plane foot and knee posture. Simple footprint based evaluation showed good applicability for identifying flatfoot in both adolescents and young adults, making them suitable for routine clinical and screening settings (Shen *et al.*, 2025; Ramos *et al.*, 2021).

5. Conclusion

This cross-sectional morphometric study established the significant association between foot arch morphology and lower limb alignment among young adults. The subjects with pes planus (low-arched) feet had a higher Q-angle and also had a greater tibiofemoral valgus and rearfoot eversion while those with pes cavus (high-arched) feet had a lower Q-angle and also less tibiofemoral valgus and rearfoot eversion. Moreover, continuous arch measurements were positively correlated with the lower limbs parameters. The above mentioned findings are in line with the biomechanical theory where the excessive foot pronation can lead to tibial internal rotation and knee valgus via the closed kinetic chain. However, the moderate magnitude of the effect sizes obtained implies that the foot arch morphology is one of many factors determining the lower limbs alignment. The results of the study imply that the simple morphometric evaluation of the medial longitudinal arch can be used as a reliable adjunct to the conventional lower limb alignment evaluation.

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