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Effect of Axial Loading on the Arches of the Foot in Varying Age Groups

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ABSTRACT

Background: The arches of the foot, particularly the Medial longitudinal arch is crucial for supporting body weight and absorbing shock. Axial loading, or vertical weight-bearing, impacts foot arch structure differently across age groups. This study investigates the effect of axial loading on foot arches across different age groups using the Arch Index (AI) and the Feiss Line assessment.

Methods: This observational study included 84 participants (49 Female and 35 Male) categorized into four age groups (10-16, 17-30, 31-45, and >45 years). Arch structure was analyzed using ink-based footprint methods and the Feiss Line test under weight-bearing conditions. Arch Index values were calculated, and Feiss line grading was recorded for both feet. Data analysis involved applying ANOVA and Chi-square tests to compare group outcomes.

Results: Notable variations in Arch Index values were observed between age groups in both right ($p=0.023$) and left foot ($p=0.014$). Older adults (>45 years) exhibited the flattest arches. Age-related differences in Feiss Line grading were statistically significant in the right foot ($p=0.038$), but not in the left ($p>0.05$).

Conclusion: Aging is associated with progressive flattening of the arch under axial loading. Routine foot screening and early interventions are recommended to maintain foot biomechanics across the lifespan.

Keywords: Axial Loading, Arch Index, Age-related changes, Foot Morphology, Feiss Line, Medial Longitudinal Arch.

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INTRODUCTION

The foot is essential for bearing the body's weight, maintaining posture, and facilitating locomotion. Its structural design includes three primary arches—medial longitudinal, lateral longitudinal, and transverse—that distribute forces during weight-bearing activities such as walking, running, and jumping [1]. Among these three arches, the medial longitudinal arch (MLA) is most biomechanically important, as it functions in shock absorption and load transmission [2].

Foot arch morphology varies considerably across populations and is shaped by variables such as age, sex, body structure, movement patterns, and shoe choices [3,4]. In children, the MLA is typically underdeveloped due to immature ligamentous and muscular structures, often resulting in a flexible flatfoot presentation that usually resolves with growth [5, 6]. Conversely, older adults frequently experience a progressive decline in arch integrity due to degenerative changes, decreased muscle strength, and ligament laxity [7, 8].

Axial loading, defined as the vertical force transmitted through the lower limb during standing and ambulation, can affect the MLA's structural configuration [9]. Repeated or prolonged axial stress has been shown to influence foot posture and can potentially lead to musculoskeletal issues affecting the foot and lower extremities [10]. Hence, the MLA's response to axial loading is a crucial factor in clinical assessments and biomechanical research.

Various methods are used to assess foot arch structure. The Arch Index (AI) is a quantitative technique based on footprint analysis that classifies foot arches as high, normal, or flat [11]. It has demonstrated good reliability and correlation with radiographic measures. The Feiss Line Test is a simple clinical method for evaluating the position of the navicular bone relative to key anatomical landmarks during weight-bearing [12]. These tools are particularly valuable in understanding arch behaviour across different age groups under load.

Previous studies have shown that age-related variations significantly influence arch morphology. Mickle et al. (2009) observed that with increasing age, a reduction in arch height is commonly observed, which may contribute to balance issues in elderly individuals [2]. Similarly, Wozniacka emphasized that body mass and arch mobility affect foot structure in paediatric populations [14]. However, there remains limited evidence comparing arch response to axial loading across distinct age groups using both the Arch Index and the Feiss Line.

This research aims to investigate and contrast how axial load affects the MLA across age categories, using both the Arch Index and Feiss Line methods.

METHOD

Study design

This study adopted an observational design to assess the effect of axial loading on the MLA of the foot across varied age groups. The analysis was conducted using two standard

assessment tools: the Arch index (AI) and the Feiss Line test. A total of 84 participants were enrolled and equally categorized into four age groups: Children (10-16 years) (10 Female and 11 Male), Young adults (17-30 years) (12 Female and 9 Male), Middle-aged (31-45 years), and Older adults (>45 years) (13 Female and 8 Male).

Participants were selected using convenience sampling and evaluated in a single session using standardized procedures; no interventions were administered. The study was conducted in an outpatient physiotherapy department, and assessments were made bilaterally on both right and left feet. The study included individuals within the specified age ranges who were independent, able to maintain a standing posture, and willing to participate. Exclusion criteria included subjects with congenital foot deformities (e.g., clubfoot) [15], recent fractures or surgeries involving the lower limbs [16], systemic conditions such as rheumatoid arthritis or diabetic neuropathy, neurological disorders, pregnancy, or significant ankle instability or musculoskeletal dysfunctions interfering with normal foot loading.

PROCEDURE

To collect static weight-bearing footprints for Arch Index (AI) analysis, the study used a soft brush, blue ink, and A4-sized white sheets. The Feiss Line test was also used to assess the alignment of the medial longitudinal arch under axial loading. Before data collection, the Institutional Ethics Committee of Krupanidhi College of Physiotherapy.

Participants were clearly informed of the study's objectives and process, and informed consent was secured from each participant, including parental consent for minors, before participation. Participants were selected as per the defined inclusion and exclusion criteria.

Each participant was evaluated in a relaxed bipedal standing position to simulate axial loading. The assessment involved two standard clinical methods: the Arch Index (AI) and the Feiss Line test, both performed on the right and left feet independently.

Arch index Assessment

Each participant's sole was coated with blue ink using a soft brush, and they were instructed to stand evenly on a white A4 sheet to produce a full weight-bearing footprint. The footprint was divided into three zones: Forefoot (A), Midfoot (B), and Rearfoot (C).

Feiss Line Assessment

During the Feiss Line assessment, three key anatomical points—medial malleolus, navicular tuberosity, and the first metatarsophalangeal joint—were identified and marked on each foot.

The medial malleolus and the first MTP joint were connected using a straight reference line for assessment. The position of the navicular tuberosity relative to this line was observed. This test provides a visual and anatomical assessment of arch alignment. A single examiner conducted all assessments to ensure consistency, and the data were recorded for both feet for each participant.

Outcome Measures

To assess the influence of axial loading on the MLA of the foot across age groups, two standardized outcome measures were used: the Arch Index (AI) and the Feiss Line Test. Both assessments were conducted in a static standing position to simulate natural weight-bearing conditions.

1. Arch Index (AI) [11, 17]

The AI calculated the percentage of the footprint area covered by the central one-third of the foot, excluding the toes.

Participants were asked to stand barefoot on a clean A4 sheet of paper after the plantar surface of each foot was coated evenly with ink using a soft brush. Full body weight was distributed equally between both legs. The resulting footprints were recorded for both Right and Left feet.

To establish the foot's longitudinal axis, a straight reference line was marked from the heel centre to the tip of the second toe. Excluding the toes, the footprint was segmented into three equal zones: A (forefoot), B (midfoot), and C (rearfoot/heel), with L denoting the entire footprint length. Based on Arch Index scores, feet were categorized as follows: normal arch (0.21-0.26), flatfoot (>0.26), and high arch (<0.21).



Picture 1: Plantar impressions taken for Arch Index Measurement

2. Feiss Line Test [17, 18]

The Feiss Line Test was used to evaluate the position of the navicular bone in both loaded and unloaded conditions, to determine the type of medial longitudinal arch.

The participant was seated with legs over the table, in the NWB condition. The following anatomical landmarks were identified and marked: Apex of the medial malleolus, Navicular tuberosity, and Medial aspect of the first metatarsal head. A straight line was drawn connecting the apex of the medial malleolus and the first metatarsal head. The position of the navicular tuberosity in relation to this line was observed. And the participant was then asked to stand barefoot in a relaxed bipedal stance (full weight-bearing). The examiner re-evaluated the navicular position relative to the drawn line. Based on this line, the navicular on the line – normal arch, navicular below the line indicates pes planus (flat foot), and navicular above the line indicates pes cavus (high foot).



Picture 2: Foot Marking for Feiss Line Evaluation

RESULTS

All statistical analyses were carried out using SPSS version 20.0 software. Descriptive data included frequencies, percentages, means, and standard deviations. One-way ANOVA was used to compare numerical variables across groups. The Chi-square test was employed to examine associations among categorical variables. An unpaired t-test was used to compare quantitative variables between groups. A p-value less than 0.05 was regarded as statistically significant in this study.

Table 1: Showing the distribution of Gender among various Age groups

	Group				Total
	0-16 years	17-30 years	31-45 years	>45 years	
Female	10	12	14	13	49
	47.6%	57.1%	66.7%	61.9%	58.3%
Male	11	9	7	8	35
	52.4%	42.9%	33.3%	38.1%	41.7%
Total	21	21	21	21	84
	100.0%	100.0%	100.0%	100.0%	100.0%

Table 1: data show that in the 0–16 years group, males are 52.4% and females 47.6%. In the 17–30-year-old group, females are 57.1% and males 42.9%. In the 31–45 years group, females account for 66.7% and males for 33.3%. In the >45 years group, females are 61.9%, and males are 38.1%. Overall, females account for 58.3% and males for 41.7% of the total sample.

Table 2: Showing mean and standard deviation of age in years among various Age groups

	Group	N	Mean	Std. Deviation
Age	0-16 years	21	12.190	1.401
	17-30 years	21	24.095	3.145
	31-45years	21	37.095	4.182
	>45 years	21	52.571	4.342

Table 2: data presents the average age and variability across four equal-sized age groups (N = 21 each). The 0–16 years group has an average age of 12.19 ± 1.40 years, the 17–30 years group shows an average of 24.10 ± 3.15 years, the 31–45 years group has an average age of 37.10 ± 4.18 years,

while the >45 years group records the highest average of 52.57 ± 4.34 years.

Table 3: Comparison of ARCH INDEX RIGHT based on age group

ARCH INDEX RIGHT		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0-16 years	17-30 years	.00952	.00960	1.000	-.0165	.0355
	31-45 years	.01238	.00960	1.000	-.0136	.0384
	>45 years	-.01524	.00960	.699	-.0412	.0107
17-30 years	31-45 years	.00286	.00960	1.000	-.0231	.0288
	>45 years	-.02476	.00960	.070	-.0507	.0012
31-45 years	>45 years	-.02762*	.00960	.031	-.0536	-.0016

Table 3: post hoc evaluation of the right Arch Index showed a statistically significant difference between participants aged 31-45 years and those over 45 years ($p=0.031$), with the younger group exhibiting a lower arch index (mean difference = -0.02762 ; 95% CI: -0.0536 to -0.0016). While the 17-30 age group also showed a lower arch index than the >45 group, this difference did not reach statistical significance ($p=0.070$). No significant differences were observed among the other age group comparisons ($p > 0.05$ for all).

Table 4: Comparison of ARCH INDEX LEFT based on age group

ARCH INDEX LEFT		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0-16	17-30	.00843	.00832	1.000	-.0141	.0310
	31-45 years	.01081	.00832	1.000	-.0117	.0333
	>45 years	-.01443	.00832	.521	-.0370	.0081
17-30 years	31-45 years	.00238	.00832	1.000	-.0201	.0249
	>45 years	-.02286*	.00832	.045	-.0454	-.0003
31-45 years	>45 years	-.02524*	.00832	.020	-.0478	-.0027

Table 4: The comparison of Arch Index (left foot) across age groups revealed statistically significant differences between some age groups. Specifically, individuals aged 31-45 years had a significantly lower arch index than those >45 years (mean difference = -0.02524 , $p = 0.020$), and the 17-30 years group also showed a significantly lower arch index compared to the >45 years group (mean difference = -0.02286 , $p = 0.045$). However, no significant differences were observed between other age groups (all $p > 0.05$).

Table 5: Showing the distribution of FEISS LINE RIGHT between various Age groups

		Group				Total	Chi-Square	p value
		0-16 years	17-30 years	31-45 years	>45 years			
FEISS LINE RIGHT	Flat Foot	9	5	6	13	33	13.370	0.038
		42.9%	23.8%	28.6%	61.9%	39.3%		
	High Arch	0	0	2	0	2		
		0.0%	0.0%	9.5%	0.0%	2.4%		
	Normal	12	16	13	8	49		
		57.1%	76.2%	61.9%	38.1%	58.3%		
Total	21	21	21	21	84			
	100.0%	100.0%	100.0%	100.0%	100.0%			

Table 5: data shows the distribution of foot arch types based on the Feiss Line test for the right foot across four age groups. In the 0-16 years group, 42.9% had flat feet, 0% had high arches, and 57.1% had normal arches. The 17-30 years group had 23.8% flat feet, no high arches, and 76.2% normal arches. In the 31-45 years group, 28.6% had flat feet, 9.5% had high arches, and 61.9% had normal arches. The >45 years group showed the highest percentage of flat feet (61.9%), 0% high arches, and 38.1% normal arches. Overall, 39.3% had flat feet, 2.4% had high arches, and 58.3% had normal arches. The Chi-Square value is 13.370 with a p-value of 0.038, showing a statistically significant association between age group and foot arch type on the right side.

Table 6: Showing the distribution of FEISS LINE LEFT between various Age groups

		Group				Total	Chi-Square	p value
		0-16 years	17-30 years	31-45 years	>45 years			
FEISS LINE LEFT	Flat Foot	11	4	6	11	32	10.475	0.106
		52.4%	19.0%	28.6%	52.4%	38.1%		
	High Arch	0	0	1	0	1		
		0.0%	0.0%	4.8%	0.0%	1.2%		
	Normal	10	17	14	10	51		
		47.6%	81.0%	66.7%	47.6%	60.7%		
Total	21	21	21	21	84			
	100.0%	100.0%	100.0%	100.0%	100.0%			

Table 6: data presents the distribution of left foot arch types based on the Feiss Line test across four age groups. In both the 0-16 years and >45 years groups, 52.4% had flat feet and 47.6% had normal arches, with no high arches reported. The 17-30 years group showed the lowest percentage of flat feet at 19.0%, with 81.0% having normal arches. In the 31-45 years group, 28.6% had flat feet, 4.8% had high arches, and 66.7% had normal arches. Overall, 38.1% of participants had flat feet, 1.2% had high arches, and 60.7% had normal arches. The Chi-Square value is 10.475 with a p-value of 0.106, indicating that the association between age group and left foot arch type is not statistically significant.

Arch Index (AI): A significant increase in Arch Index (Right & Left) values was observed in Older Adults and

Children, indicating arch flattening. Right Foot: $p = 0.023$, Left Foot: $p = 0.014$. Older Adults and Children showed higher Arch Index values, indicating flattened arches, while Young Adults maintained lower values within the normal range.

Axial loading caused a greater drop in the medial longitudinal arch in Older Adults and Children, while Young Adults demonstrated better arch stability.

Feiss line (FL): Statistically significant difference was found in navicular position among the groups after axial loading, Right Foot ($p = 0.038$), with more cases of navicular drop in Older Adults (61.9%) and Children (47.6%). Although similar trends were seen in the left foot, the results were not statistically significant ($p = 0.106$). Young Adults retained normal navicular alignment in most cases.

DISCUSSION

This study investigated the influence of axial loading on the structure of the medial longitudinal arch across four age groups using the Arch Index (AI) and Feiss Line test. Significant changes in foot posture were observed with advancing age, demonstrating that foot arch behaviour under load is dynamically affected by musculoskeletal maturity and degeneration.

In the Children group (10–16 years), a greater prevalence of flat feet was observed under weight-bearing conditions. These results are consistent with Pfeiffer et al. (2006) [3], who reported that flat foot is common in early childhood due to ligamentous laxity and ongoing musculoskeletal development. Similarly, Rao and Joseph et al. (1992) [5] concluded that arch formation is influenced by both maturation and external factors, such as footwear, with closed shoes contributing to higher flatfoot rates. The present study supports these findings, indicating that the paediatric foot remains structurally flexible and more prone to collapse under axial loading.

The Young Adult group (17–30 years) exhibited predominantly normal arch structure as measured by both AI and Feiss Line. This agrees with Cavanagh and Rodgers (1987) [11], who stated that the arch stabilizes by early adulthood, facilitating efficient load transmission and shock absorption. Murley et al. (2009) [19] further emphasized that a well-formed arch improves limb alignment and muscular efficiency during load-bearing tasks, aligning with the stable results observed in this age group.

In the Middle-aged Adult group (31–45 years), a slight decline in arch height was found in some individuals. Although most maintained a normal arch, a subset had borderline flat feet, suggesting early degenerative or fatigue-related changes. Banwell et al. (2018) [20] reported similar age-related trends, particularly among individuals with prolonged standing occupations, reinforcing the notion that foot posture may gradually change over time even in the absence of pathology.

The Older Adult group (above 45 years) exhibited the most pronounced flattening of the arch. This group demonstrated

increased AI values and a significant downward shift of the navicular bone, as detected through Feiss Line testing. These outcomes reflect age-related deterioration of soft tissues supporting the arch, as previously noted by Ledoux et al. (2005) [7]. Furthermore, Scott et al. (2007) [13] highlighted an increased risk of foot deformities in older adults due to reduced collagen elasticity and increased load stress, supporting the current findings.

Both the Arch Index and Feiss Line tests proved effective in capturing age-related changes in arch structure under axial load. Plantar surface distribution was objectively measured using the Arch Index, whereas the Feiss Line test visually assessed the location of the Navicular bone and arch alignment. Dual use of these tools enhanced diagnostic sensitivity and reliability for age-related arch assessment.

Statistical analysis showed significant differences in Arch Index values between age groups for both the right foot ($p = 0.023$) and the left foot ($p = 0.014$), with the >45 age group having the highest mean values, indicating flatter arches. Post-hoc comparisons revealed that older adults had significantly higher AI values than younger cohorts, suggesting decreased arch integrity with age. The Feiss Line assessment also showed a significant association with age on the right foot ($p = 0.038$), with flatfoot most prevalent among older participants. While the left foot showed a similar trend, it did not reach statistical significance, possibly due to leg dominance or habitual postures.

Overall, flat foot prevalence was notable across the sample—39.3% on the right and 38.1% on the left—with the greatest incidence found in children and older adults. This confirms two vulnerable periods in the lifespan: early development and aging. Conversely, the young and middle-aged adult groups demonstrated greater structural resilience. Gender was not significantly associated with arch variation, reinforcing age as the primary factor influencing arch variation in this study.

The findings underline the clinical importance of routine arch assessment in age-specific populations. They further support the role of axial loading as a key biomechanical factor affecting arch morphology, especially during growth and aging. Preventive measures and early interventions tailored to high-risk groups could help maintain foot health and prevent complications arising from altered arch dynamics.

CONCLUSION

The present study highlights significant age-related variations in foot arch structure under axial loading, assessed using both the Arch index and Feiss line methods. Findings suggest that children and older adults exhibit a greater tendency toward flatfoot postures, likely due to ongoing developmental changes in younger individuals and degenerative changes in older adults. In contrast, young and middle-aged adults demonstrated more stable arch morphology under load-bearing conditions. The combined use of the Arch Index and Feiss Line provided a comprehensive understanding of medial longitudinal arch behaviour across age groups. These results underscore the

importance of early screening and age-specific interventions to prevent potential biomechanical dysfunctions associated with altered foot posture.

Limitations

A small sample size may limit generalizability
Absence of dynamic gait analysis limits functional interpretation
Randomization was not applied due to the observational design

Recommendations

The sample size can be increased
Dynamic Assessment Integration
RCT's can be done

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