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RESEARCH ARTICLE

IMPACT OF ASYMMETRICAL FOOTON NAVICULAR DROP HEIGHT, BODY MASS INDEX, GENDERAS RISK FACTOR FOR LOWER LIMB INJURY AMONG AMATEUR ATHLETE AND NON-ATHLETE MEDICOS -VALIDATION USING STAHELI INDEX

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ABSTRACT

Background: The medial longitudinal arch plays a crucial role in foot biomechanics, shock absorption, and energy transfer during locomotion, and variations in foot posture may influence lower limb injury risk and athletic performance.[1,3,5] Foot asymmetry has also been linked to altered functional performance and muscle fatigue, emphasizing its clinical relevance. [4,7] The Navicular Drop Test (NDT) and Staheli Arch Index (SAI) are practical, reliable, and cost-effective methods for assessing foot posture asymmetry and arch characteristics.[2,6,9] **Aim and Objectives:** To evaluate foot posture asymmetry and arch characteristics in amateur athletes and non-athletes using NDT and SAI, and to examine their association with BMI, gender, and injury occurrence. **Materials and Methods:** A cross-sectional observational study was conducted among 48 MBBS students aged 17–25 years, equally divided into sports (n=24) and non-sports (n=24) groups, with equal representation of males and females. Demographic details, BMI, physical activity status, and injury history were recorded using a structured questionnaire. Foot posture was assessed bilaterally using the NDT (card test method) and SAI (India ink footprint method), with measurements obtained using a digital vernier calliper. Data were analyzed using IBM SPSS Statistics with chi-square and Fisher–Freeman–Halton exact tests to determine associations. **Results:** BMI showed a significant association with physical activity status ($\chi^2 = 6.76$, $p = 0.034$), with sports participants demonstrating healthier BMI profiles. However, no significant associations were found between injury occurrence and physical activity, NDT, or SAI classifications. **Conclusion:** Static foot posture measures alone may have limited value in predicting injury risk. These findings support existing evidence that lower limb injuries are multifactorial and should be evaluated using broader functional and biomechanical screening approaches.

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INTRODUCTION

The human foot is a specialized biomechanical structure designed to provide stability, mobility, and effective shock absorption during locomotion. It acts as the first component of the lower limb kinetic chain, helping to distribute body weight and absorb ground reaction forces generated during walking, running, and jumping. This function is mainly supported by the foot arches—transverse, lateral longitudinal, and medial longitudinal arches—with the medial longitudinal arch (MLA) being the most important for maintaining biomechanical efficiency and transferring energy during movement. The integrity of the MLA depends on the shape of the foot, bony alignment, ligament stability, muscle strength, and plantar fascia support, while external factors such as age, gender, footwear, race, body mass index (BMI), and physical activity may influence its structure and function.[1,2] Based on the structure and height of the MLA, feet are commonly classified into three types: pes cavus (high arch), neutral foot, and pes planus (flat foot). These variations can alter weight distribution and foot biomechanics, potentially increasing susceptibility to lower limb injuries.

Previous studies have reported that both flat feet and high arches are associated with a greater risk of lower extremity injuries, although the strength of this relationship remains variable.[3] The Navicular Drop Test (NDT), first described by Brody, is a simple clinical method used to assess the functional integrity of the MLA by measuring the displacement of the navicular tuberosity from sitting to standing. Studies suggest that NDT values <5 mm indicate pes cavus, 5–9 mm indicate a neutral arch, and >10 mm indicate pes planus, with higher values reflecting excessive pronation.[2,6] Similarly, the Staheli Arch Index (SAI) is a footprint-based method used to quantitatively assess arch morphology by calculating the ratio of the midfoot width to heel width. Based on established cut-off values, SAI <0.50 indicates pes cavus, 0.50–0.70 indicates normal arch, and >0.70 indicates pes planus, with values >1.15 suggestive of pathological flatfoot.[8,11]

Recent evidence indicates that foot asymmetry, rather than arch type alone, may be a stronger determinant of injury risk and athletic performance. Studies by Domaradzki *et al*. and Helme *et al*. have shown that inter-foot asymmetry may contribute to increased injury susceptibility, while asymmetrical arch patterns have also been linked to greater muscle fatigue and reduced biomechanical efficiency.[1,5,7] However, literature assessing these relationships in South Indian young adults remains scarce. Therefore, this study aims to compare NDT and SAI as simple, reliable, and cost-effective tools for foot arch assessment and to examine their relationship with foot asymmetry, BMI, gender, physical activity, and injury occurrence.

Aim

To investigate foot posture asymmetry and arch characteristics among amateur athletes and non-athletes using the Navicular Drop Test and Staheli Arch Index, and to determine their association with BMI, gender, and lower limb injury occurrence.

Objectives

- To assess foot asymmetry in sports-playing and non-sports-playing individuals using the Navicular Drop Test and correlate findings with BMI and gender.
- To compare arch assessment using the Navicular Drop Test with the Staheli Arch Index.
- To explore the relationship between foot type and lower limb injury occurrence.

MATERIALS AND METHODS

Study Design and Setting: This cross-sectional observational study was conducted in the Department of Anatomy, MVJ Medical College and Research Hospital, Bengaluru, after obtaining approval from the Institutional Ethics Committee. The study aimed to evaluate foot arch morphology and asymmetry among young adults and examine its relationship with body mass index (BMI), gender, physical activity, and lower limb injury occurrence.

Study Population and Sampling: A total of 48 MBBS students aged between 17 and 25 years were recruited from MVJ Medical College. Participants were equally divided into two groups based on physical activity status: sports-playing (n=24) and non-sports-playing (n=24). Equal representation of males (n=24) and females (n=24) was ensured to reduce gender bias and facilitate comparison of arch characteristics between sexes. Participants were selected using convenience sampling from the undergraduate student population. Before recruitment, all participants were informed about the purpose and procedure of the study, and written informed consent was taken.

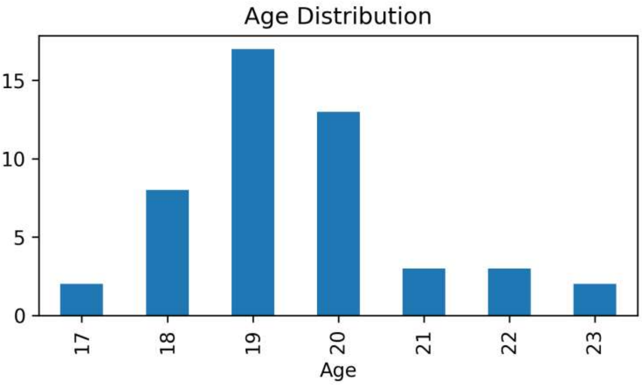

Chart 1. Study subjects - age distribution.

Inclusion Criteria

- MBBS students aged 17–25 years.
- Individuals actively participating in outdoor sports for 1–2 hours/day, at least 4 days/week (sports category).
- Individuals not regularly participating in sports activities (non-sports category).
- Participants willing to provide informed consent.

Exclusion Criteria

- Presence of congenital or acquired foot deformities.
- Previous lower limb surgery.
- History of lower limb injury within the last 2 months.
- Pain or musculoskeletal discomfort affecting standing posture or NDT performance.

Data Collection

Data collection was carried out using a structured questionnaire that recorded demographic details such as age, gender, physical activity status, and history of lower limb injuries. Anthropometric measurements including height and weight were obtained using a measuring scale and weighing balance, and BMI was calculated using the standard formula: weight in kilograms divided by height in meters squared.

Foot Arch Assessment

Foot arch assessment was performed bilaterally using two methods: the NDT and the SAI.

Navicular Drop Test (NDT): the participant was first seated comfortably with both feet resting on the floor in a relaxed position. The navicular tuberosity was identified by palpation on the medial aspect of the foot, and its height from the floor was marked using the card test method. The participant was then asked to stand in a relaxed, weight-bearing position, and the navicular height was marked again. The difference between the sitting and standing measurements was recorded in millimeters using a ruler and verified using a digital vernier calliper with an accuracy of ± 0.02 mm. This value represented the navicular drop height. Based on established cut-off values, measurements below 5 mm were classified as pes cavus, values between 5–9 mm as neutral foot, and values above 10 mm as pes planus.

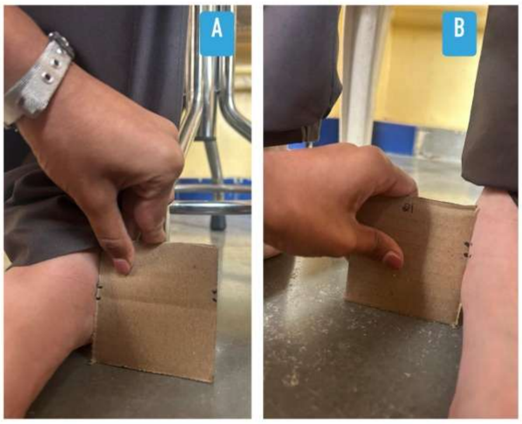

Figure 1- A. Navicular tuberosity in neutral foot position (sitting); B - Navicular tuberosity in loaded position (standing)

Staheli Arch Index (SAI): Assessed using the India ink footprint method. The plantar surface of the participant's foot was evenly coated with stamp ink using a roller, and the participant was instructed to stand naturally on graph paper placed on a flat platform. A footprint was obtained for both feet. The maximum width of the midfoot region (A) and the maximum width of the heel region (B) were measured using the digital vernier caliper. The Staheli Arch Index was then calculated as the ratio of A to B. Based on established cut-off values, an SAI below 0.50 was classified as pes cavus, values between 0.50–0.70 as neutral foot, and values above 0.70 as pes planus. To ensure accuracy and reliability, all measurements were repeated and cross-verified.

SAI = A / B

The primary outcome variables assessed were foot arch type, inter-foot asymmetry, Navicular Drop Test values for the right and left foot, and Staheli Index values for the right and left foot. Secondary variables included BMI, gender, physical activity status, and previous injury occurrence. The values obtained from both methods were compared and correlated with BMI, gender, physical activity, and injury occurrence.

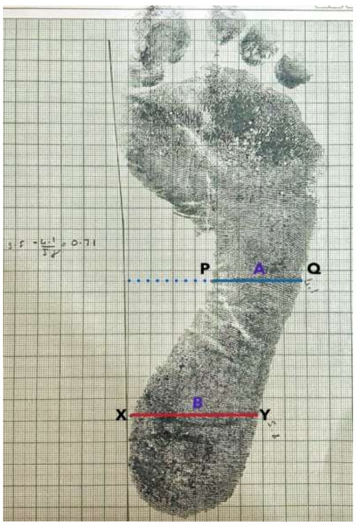

Figure 2 - Foot print obtained using India-ink method, A: Maximum mid-foot width; B: Maximum heel region width; Staheli-Arch Index calculated as SAI = A/B.

Statistical Analysis: All collected data were entered and analyzed using IBM SPSS Statistics version 31 data analytical software. Descriptive statistics including means, standard deviations, frequencies, and percentages were used to summarize the data. Associations between categorical variables were analyzed using the chi-square test, while Fisher–Freeman–Halton exact tests were used where expected cell frequencies were small. Effect size for significant associations was determined using Cramer's V. A p-value of less than 0.05 was considered statistically significant. This methodological approach enabled comparison between NDT and SAI, assessment of foot asymmetry, and evaluation of their relationship with BMI, gender, physical activity, and injury occurrence.

OBSERVATION AND RESULTS

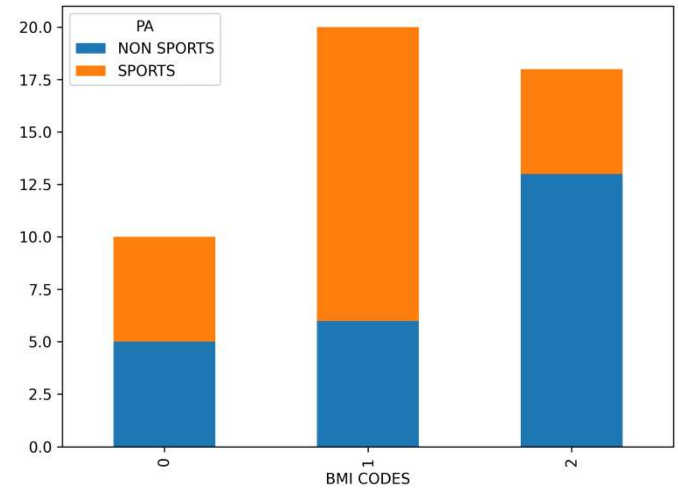

Chart 2. BMI category distribution according to physical activity (PA) status.

A significant association was observed between BMI category and physical activity status (χ^2=6.76, p=0.034, Cramer's V=0.375). Non-sports participants demonstrated a higher prevalence of overweight/obesity, whereas sports participants were predominantly within the normal BMI category.

Table 1. Association of Physical Activity (PA) and BMI with Injury Status

Variable	Category	No Injury (n)	Injury (n)	p-value
PA	Sports	18	6	1.000
PA	Non-sports	17	7	
BMI	Normal (higher in sports)	-	-	0.034*

Physical activity alone did not show a significant association with injury occurrence, but sports participants demonstrated healthier BMI profiles, suggesting better musculoskeletal health. Navicular Drop Test is useful for identifying foot arch type, but navicular asymmetry alone may not be enough to explain lower limb injuries. Staheli Arch Index proved to be a simple and reliable footprint-based method for arch classification, but similar to NDT, it showed limited value as an independent predictor of injury. The consolidated analysis showed that none of the foot posture variables (NDT and SAI) or physical activity status had a statistically significant association with injury occurrence (p > 0.05). Although the Navicular Drop Test and Staheli Index remain useful tools for

Table 2. Association of Navicular Drop Test (NDT) Classification with Injury Status

Variable	Category	No Injury (n)	Injury (n)	Chi-square (p-value)	Fisher Exact test (p-value)
NDT - Right	Normal	25	8	0.094 (0.759)	0.509
	Pes Planus	10	5		
NDT - Left	Normal	21	7	1.160 (0.560)	0.625
	Pes Cavus	2	2		
	Pes Planus	12	4		

Table 3. Association of Staheli Arch Index (SAI) Classification with Injury Status

Variable	Category	No Injury (n)	Injury (n)	Chi-square (p-value)	Fisher Exact test (p-value)
SAI - Right	Normal	22	11	2.580 (0.275)	0.385
	Pes Cavus	9	2		
	Pes Planus	4	0		
SAI - Left	Normal	18	7	0.387 (0.824)	1.000
	Pes Cavus	12	5		
	Pes Planus	5	1		

Table 4. Consolidated Chi-square and Fisher Exact Test Results

Variable	Categories	No Injury (n)	Injury (n)	Chi-square (p-value)	Fisher Exact test (p-value)
PA	Non-sports	17	7	$\chi^2 = 0.000$ (1.000)	1.000
	Sports	18	6		
NDT - Right	Normal	25	8	$\chi^2 = 0.094$ (0.759)	0.509
	Pes Planus	10	5		
NDT - Left	Normal	21	7	$\chi^2 = 1.160$ (0.560)	0.625
	Pes Cavus	2	2		
	Pes Planus	12	4		
SAI - Right	Normal	22	11	$\chi^2 = 2.580$ (0.275)	0.385
	Pes Cavus	9	2		
	Pes Planus	4	0		
SAI - Left	Normal	18	7	$\chi^2 = 0.387$ (0.824)	1.000
	Pes Cavus	12	5		
	Pes Planus	5	1		

foot arch classification, they may have limited ability to independently predict lower limb injury risk.

DISCUSSION

The present study looked at the relationship between foot asymmetry, foot arch type, physical activity, BMI, and injury occurrence in young adults using the NDT and the SAI. The results showed that there was no significant relationship between injury occurrence and foot type based on either NDT or SAI. However, BMI showed a significant relationship with physical activity, with sports participants having healthier BMI values. This suggests that while NDT and SAI are useful for identifying foot arch types, they may not be enough on their own to predict lower limb injuries. A study by Domaradzki *et al.* (2024)[12] on 45 male recreational athletes found that athletes with unequal foot posture (where one foot was normal and the other was flat or high-arched) had higher injury rates compared to athletes with similar foot types on both sides. This partly supports the idea that foot asymmetry can increase injury risk. However, in the present study, such a significant relationship was not found. This difference may be because the present study had fewer participants and included both sports and non-sports individuals. Similarly, Tong and Kong (2013)[13] conducted a systematic review and meta-analysis and found that both flat feet and high arches were linked to a higher risk of lower limb injuries. However, the association was weak. Their study involved a much larger number of participants and multiple methods of assessment. While their results show the importance of foot arch type, the present study did not find the same strong relationship, possibly because of the smaller sample size and younger participants who may adapt better to structural differences. The findings are also comparable to Fox *et al.* (2023)[14], who studied the effect of lower limb asymmetry on athletic performance. They found that asymmetry did not significantly affect vertical jump performance but had a weak negative effect on sprinting and change-of-direction performance. Although the present study focused on injury rather than performance, both studies suggest that asymmetry may affect body function in ways that are not always visible through static measurements. In Helme *et al.* (2021)[15], a systematic review showed low to moderate evidence that lower limb asymmetry may increase injury risk in athletes. Their study mainly focused on dynamic and functional asymmetry tests such as movement and strength-based assessments. This is different from the present study, which used static methods like NDT and SAI. This difference suggests that dynamic tests may be better at identifying injury risk than static foot measurements. A study by Woźniacka *et al.* (2022)[16] found that people with asymmetrical high-arched feet had greater muscle fatigue, especially in the lower limb and trunk muscles. Although muscle fatigue was not measured in the present study, their findings support the idea that foot asymmetry can create biomechanical stress. This stress may indirectly increase the risk of injuries over time. The findings of the present study also support earlier studies on the reliability of the Staheli Arch Index. Hernandez *et al.* (2007)[17] established normal SAI values and showed that it is a useful method for assessing flat feet in children. Singrolay and Kushwah (2015)[18] showed that the India ink footprint method was as reliable as radiological methods for diagnosing flat feet. Shariff *et al.* (2017)[19] also showed that footprint-based measurements can effectively identify different foot arch types in adults. Similarly, Vangara *et al*. (2019)[20] used SAI to classify normal, flat, and high arches in tribal children. The present study supports these findings and shows that SAI is also useful as a simple and low-cost screening tool in South Indian young adults. An important finding in the present study was the significant relationship between BMI and physical activity. Sports participants had healthier BMI profiles than non-sports participants. This agrees with other Indian studies showing that regular physical activity helps maintain healthy body weight and may improve musculoskeletal health. This suggests that lifestyle factors like physical activity and BMI may play a bigger role in injury prevention than foot shape alone. The absence of a significant relationship between foot posture and injury in this study may be due to several reasons. First, the small sample size (48 participants) may have reduced the ability to detect significant differences. Second, injuries are caused by many factors such as training load, footwear, strength, recovery, and flexibility. Third, the participants were young adults who may have better strength and motor control to compensate for foot differences. Lastly, NDT and SAI are static tests and may not fully reflect how the foot behaves during movement. Overall, the present study adds to the growing evidence that static foot posture tests are useful for classifying and screening foot types, but they should not be used alone to predict injury risk. A more complete assessment, including movement analysis, strength testing, and biomechanical evaluation, may be more helpful in identifying individuals at risk for lower limb injuries.

CONCLUSION

The present study showed that both **NDT** and **SAI** are easy, reliable, and useful methods for evaluating foot arch type and asymmetry. However, since neither method showed a significant link with injury occurrence, static foot posture alone may not be enough to predict lower limb injuries. Although physically active individuals had healthier BMI profiles, injury risk seems to depend on several factors other than foot structure, emphasizing the importance of a broader functional and biomechanical evaluation.

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Conflict of interest: The authors declare no conflict of interest in relation to this study. The study was conducted at MVJ Medical College & Research Hospital, Bengaluru, following approval from the Institutional Research Board, including both the Scientific Committee and the Institutional Ethics Committee. All participants were recruited from MVJ Medical College & Research Hospital after obtaining written informed consent. The instruments and materials used for the study, including the weighing scale, measuring tape, vernier caliper, ink pad, roller, graph paper, and other miscellaneous items, were provided by the corresponding author, Dr. Athul Antony Simon.

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