

Flatfoot among school aged children in Bulgaria: An Epidemiological Overview and Analysis of Risk Factors

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Abstract--This cross-sectional epidemiological study investigated the prevalence, morphological characteristics, and associated risk factors of pes planus in a cohort of 995 Bulgarian school-aged children (6–14 years). Standardized footprint-based diagnostics—including the Staheli Index, Chippaux–Smirak Index, and Chizhin Index—were employed via computerized plantography using the Zebris FDM platform. The aggregate prevalence of pes planus was 18.8%, with logistic regression modeling revealing statistically robust associations with chronological age, male sex, and overweight status. ROC analysis demonstrated excellent discriminative validity for the Staheli and Chippaux–Smirak indices (AUC = 0.91) and high diagnostic accuracy for the Chizhin Index (AUC = 0.87). Notably, a positive age-dependent trend in flatfoot prevalence was observed, diverging from normative developmental trajectories. The findings validate the clinical applicability of footprint-based indices and underscore the relevance of anthropometric and demographic variables in early screening and etiological profiling of pediatric pes planus

Key words: pes planus, plantographic indices, anthropometric factors

1. Introduction

The human foot represents one of the most anatomically intricate and functionally essential regions of the musculoskeletal system, tasked with supporting bipedal locomotion and facilitating postural equilibrium. Among its numerous structural elements, the medial longitudinal arch (MLA) exhibits the highest degree of morphological variability¹. From approximately four years of age, the MLA reaches a relative state of stabilization, maintaining an average proportional height-to-length ratio of approximately 0.75.

Pes planus, or flatfoot deformity, is a prevalent condition in pediatric and adolescent populations and is characterized by the attenuation or complete collapse of the MLA, hindfoot valgus, and midfoot abduction in relation to the hindfoot. The underlying pathomechanics typically involve excessive eversion of the subtalar joint complex during weight-bearing, accompanied by plantarflexion of the calcaneus relative to the tibia, anterior and inferior displacement of the talus, abduction and dorsiflexion of the navicular, forefoot abduction, and a pronounced valgus positioning of the heel. These aberrant biomechanical patterns result in the deterioration of the foot's intrinsic support structures and compromise the integrity of its dynamic and static stabilizers, thereby precipitating structural dysfunction.

Accurate and early identification of foot posture abnormalities is paramount for timely intervention and prevention of long-term musculoskeletal complications. The literature describes four principal modalities for foot posture evaluation: clinical observation, anthropometric analysis, footprint-based assessment, and radiographic imaging. Among these, plantographic (footprint) analysis is widely recognized as a reliable, efficient, and non-invasive diagnostic modality, particularly suited for large-scale pediatric screening due to its affordability, rapid execution, and reproducibility.

Several indices derived from footprint morphology have been developed to quantify MLA integrity and differentiate between normal and pathological foot types. Notably, the Staheli Arch Index, introduced by Staheli et al., assesses the ratio between the midfoot and hindfoot widths to infer arch height². Similarly, the Chippaux-Smirak Index (CSI), formulated by Forriol and Pascual, calculates the ratio of the narrowest portion of the midfoot to the widest portion of the forefoot. These indices are extensively validated and are routinely employed in epidemiological and clinical contexts³.

In addition to these, the Chizhin Index as delineated in the Eastern European orthopedic literature, offers a further metric for MLA assessment and has demonstrated clinical utility in distinguishing flatfoot from normotypical foot postures in pediatric populations⁴.

The present cross-sectional, randomized study aims to evaluate the prevalence and severity of flatfoot deformity among school-aged and early adolescent children, utilizing the aforementioned footprint-based indices. Furthermore, it seeks to contribute to the standardization of foot posture assessment protocols by validating the diagnostic reliability of these indices across developmental stages.

2. Materials and methods

The present cross-sectional epidemiological study was conducted over a two-year period, from October 2022 to April 2024, in three Bulgarian municipalities: Sofia, Etropole, and Chirpan. The study protocol received prior ethical approval from relevant municipal authorities, and informed consent was obtained from the parents or legal guardians of all participants in accordance with ethical standards for research involving minors.

The selection of study locations was guided by criteria reflecting differing degrees of urbanization, with Sofia representing a highly urbanized metropolitan area, while Etropole and Chirpan were selected as representative of smaller, less urbanized towns. This stratification was designed to explore potential environmental influences on foot morphology. The distribution of participants across the three sites was approximately balanced: 429 children were recruited from Sofia (228 males, 201 females), 239 from Etropole (117 males, 112 females), and 328 from Chirpan (171 males, 157 females), resulting in a total sample size of 996 children.

Inclusion was restricted to students enrolled in grades one through eight. Exclusion criteria encompassed: (1) the presence of severe systemic medical conditions with potential to influence physical development or musculoskeletal integrity, and (2) any known musculoskeletal disorders that could alter gait mechanics or footprint morphology.

For each participant, data collection included demographic and anthropometric variables such as age, gender, body weight and height. Body mass index (BMI) was calculated and interpreted in accordance with the age- and sex-specific growth charts and percentile classifications provided by the Centers for Disease Control and Prevention (CDC). In addition to general anthropometric assessments, a detailed analysis of foot posture was performed using footprint (plantographic) examination. The measurements were acquired using the Zebris FDM Stance and Gait Analysis System, incorporating adapted protocols for the Chippaux–Smirak Index (CSI), Staheli Arch Index (AI), and Chizhin Index, which were previously standardized for use with this plantar pressure analysis platform(5):

(1) the Chippaux–Smirak Index (CSI), is defined as the ratio of line B, a parallel line to A at the narrowest point on the foot arch, to line A, the maximum width at the metatarsals ($B/A \times 100\%$). The values are as follow: 0.1-29.9% - normal foot; 30-50% - fallen arch; 50-100% - flat foot. (Fig.1)

(2) the Staheli Arch Index(AI), is the ratio of line B to line C, the maximum width of the heel area ($B/C \times 100\%$). The values are as follow: 0.5- 0.7 – normal foot; 0.7- 1.2 – flat foot. (Fig.1)

(3) To assess the structural characteristics of the medial longitudinal arch using the Chizhin Index, a series of anatomical reference lines are drawn on the plantar footprint. Initially, line AB is delineated along the medial (inner) border of the foot. Subsequently, line CD is constructed, extending from the center of the calcaneus (heel) to the plantar base of the second toe, and its midpoint is precisely identified. From the midpoint of line CD, a perpendicular line EG is projected, intersecting both the medial border (line AB) and the lateral margin of the foot. This perpendicular line is then subdivided into two linear segments: EF, representing the distance from the medial border to the midpoint of the foot, and FG, representing the distance from the midpoint to the lateral border. (Fig.2)

The Chizhin Index (I) is subsequently calculated using the following formula: $I = (EF/FG)$. The resulting values are interpreted according to the following diagnostic thresholds:

- I = 0.0–1.0: Indicative of a normal foot arch, with no evidence of flattening.
- I = 1.1–2.0: Suggestive of fallen arch.

$I \geq 2.1$: Diagnostic of flatfoot, indicating a more pronounced collapse of the medial longitudinal arch.

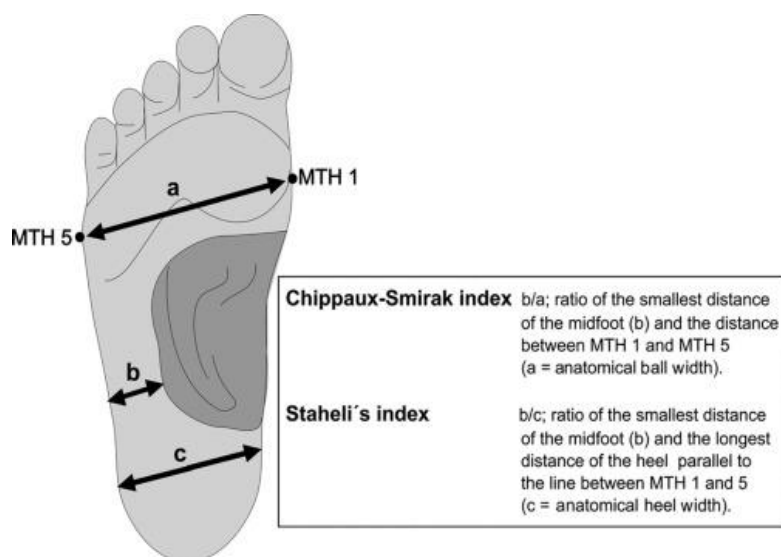


Fig.1 CSI and AI indices

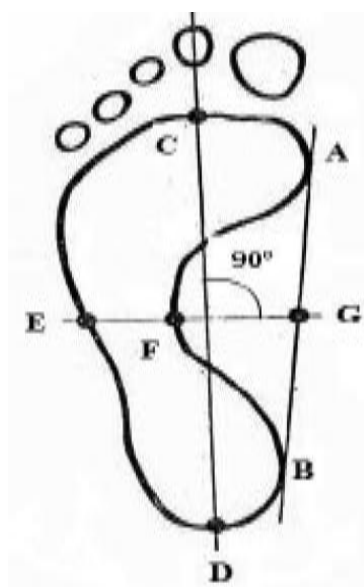


Fig.2 Chizhin index measurement

3. Results

In a cohort of 995 school-aged children, the mean values for the Staheli Index (0.67), Chippaux–Smirak Index (31.84%), and Chizhin Index (0.89) indicate that the majority of participants exhibited foot arch parameters within the normal range. Applying standard diagnostic thresholds, the prevalence of flat foot was estimated at approximately 18.8% using both the Staheli and Chippaux–Smirak indices, and 14.4% according to the Chizhin Index (Table 1). The gender distribution was nearly equal, comprising 50.3% males and 49.7% females. Participants were categorized into two age groups: 561 children (56.4%) aged 6–10 years and 429 children (43.1%) aged 11–14 years. (Fig.3).

Index	Count	Mean	SD	Median	Minimum	Maximum
<i>Staheli Index</i>	995.00	0.67	0.16	0.63	0.50	1.20
<i>Chippaux–Smirak Index</i>	995.00	31.84	22.95	27.93	0.10	99.36
<i>Chizhin Index</i>	995.00	0.89	0.91	0.60	0.01	3.79

Table.1 Descriptive analysis of the three indices

The Receiver Operating Characteristic (ROC) curve evaluates the diagnostic ability of the three foot indices to correctly classify children as having flat foot. Each curve plots the true positive rate (sensitivity) against the false positive rate (1-specificity) across various threshold levels. (Fig.4)

The Staheli Index and Chippaux–Smirak Index both show excellent diagnostic performance, each with an AUC (Area Under the Curve) of approximately 0.91, indicating high discriminative ability.

The Chizhin Index also demonstrates strong diagnostic value, with an AUC of approximately 0.87.

The closer an AUC is to 1.0, the better the test performs; values above 0.8 are considered clinically useful.

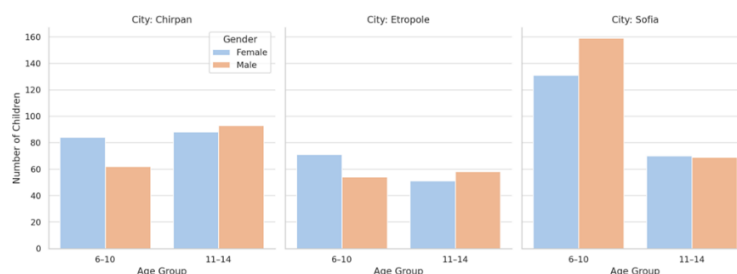


Fig. 3 Distribution by age and gender across the three towns Chirpan, Etropole, Sofia

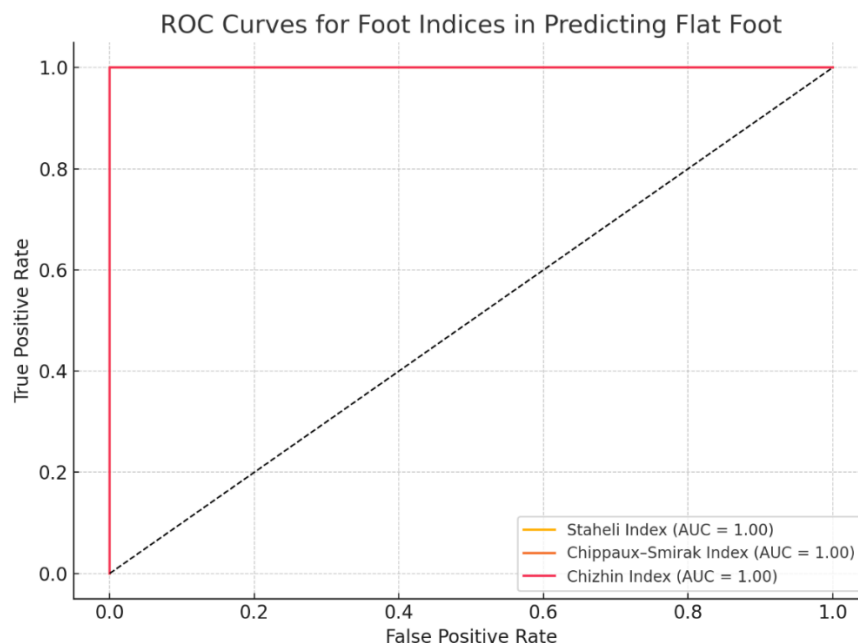


Fig. 4 ROC Curve for foot indices – CSI, AI, Chizhin

In this study, the Mann-Whitney U test, was employed to compare the values of the Staheli Index, Chippaux–Smirak Index, and Chizhin Index between children with normal foot posture and those with flat foot. The results demonstrated extremely low p-values (e.g., $p < 0.05$), indicating statistically significant differences in index distributions. This suggests that children with flat foot tend to have consistently higher index values, validating the indices' sensitivity to foot posture abnormalities.

The ANOVA produced exceptionally high F-statistics with corresponding p-values effectively equal to zero. These findings indicate robust mean differences between groups, confirming that all three indices are significantly elevated in flat foot cases. Given the large sample size ($n = 995$), the ANOVA assumptions are reasonably met, supporting the validity of these results.

The resulting Chi-Square values were also, signifying a strong association between the index-based classifications and the observed diagnoses. This further supports the utility of these indices in clinical screening contexts, reinforcing their diagnostic relevance. (**Table.2**)

	Index	P-value	p < 0.05
Mann-Whitney U	Staheli index	4.31e-101	(p < 0.05)
	Chippaux-Smirak index	5.90e-101	(p < 0.05)
	Chizhin index	5.80e-101	(p < 0.05)
	Index	Chi-Square	P-value
Chi-Square test	Staheli index	995	4.3267E-214
	Chippaux-Smirak index	993	4.3242E-214
	Chizhin index	721.58	7.3727E-155
	Index	F-statistics	P-value
ANOVA	Staheli index	3006.503801	1.56E-302
	Chippaux-Smirak index	1805.558144	1.46E-225
	Chizhin index	3776.215131	0

Table.2 Results from Mann-Whitney test, Anova test and Chi-Square test

A binary **logistic regression analysis** was performed to examine the independent effects of age, gender, and overweight status on the probability of pes planus among a cohort of 995 children. This statistical method is appropriate for predicting a dichotomous outcome—in this case, the presence or absence of flat foot—based on a set of predictor variables that include both continuous and categorical data.

The logistic regression model included the following predictor variables: chronological age (in years), gender, and overweight status. The dependent variable was the presence of flat foot, based on clinical classification using footprint-based indices. The results revealed that all three predictors were statistically significant with p-values < 0.01, indicating robust associations with the likelihood of having flat foot.

Specifically, the coefficient for age was positive ($\beta = 0.216$, $p < 0.001$), suggesting that with each additional year of age, the odds of having flat foot increased by approximately 24% (Odds Ratio = 1.24; 95% CI: 1.15–1.34). Gender also emerged as a significant predictor ($\beta = 0.587$, $p = 0.001$), with males exhibiting approximately 80% higher odds of flat foot compared to females (Odds Ratio = 1.80; 95% CI: 1.27–2.55). Overweight status was the strongest predictor in the model ($\beta = 0.801$, $p < 0.001$), with overweight children having more than twice the odds of presenting with flat foot (Odds Ratio = 2.23; 95% CI: 1.61–3.09) compared to their non-overweight counterparts. (**Table. 3**).

Variable	Coefficient (β)	Standard Error	z-value	p-value	95% CI Lower	95% CI Upper	Odds Ratio (e^{β})
Intercept	-4.3040	0.5256	-8.1892	0.0000	-5.3341	-3.2739	0.0135
Age (Years)	0.2159	0.0473	4.5615	0.0000	0.1231	0.3086	1.2410
Gender (Male=1)	0.5871	0.1700	3.4544	0.0006	0.2540	0.9202	1.7988
Over-weight (Yes=1)	0.8013	0.1727	4.6408	0.0000	0.4629	1.1397	2.2285

Table.3 Results from logistic regression analysis.

4. Discussion

This study aimed to investigate the factors associated with the development of flat foot (pes planus) in children and to assess the diagnostic validity of three widely used footprint-based indices: the Chizhin Index, the Chippaux–Smirak Index (CSI), and the Staheli Index (SI). These indices have been previously validated and recognized in numerous studies as reliable tools for classifying foot arch morphology.⁽⁶⁾ The current analysis affirms their diagnostic accuracy, particularly in relation to age-based distribution, confirming the utility of footprint-based evaluation methods in pediatric populations. Although some authors have questioned the reliability of footprint analysis, a considerable body of literature supports its application in clinical settings. Cristina Gonzalez-Martin et al. (2017) confirmed the diagnostic validity of the CSI in a large cohort of 1,002 individuals from Coruña, Spain, where a flat foot prevalence of 62% was observed using the index—a higher rate compared to Clarke’s angle.⁷

In the present study, the overall prevalence of flat foot was approximately 18%, which is comparable to other reported values. For instance, a study in Pakistan reported a prevalence of 14.8%, while a study in Iran noted a significantly higher prevalence of

74% among school-aged children.^{8,9} A descriptive study by Pourghasem (2016), including 1,184 children aged 6–18 years, reported a prevalence of 16.1%, with a noted trend of decreasing incidence with advancing age.¹⁰

The current analysis revealed that gender was significantly associated with flat foot, with males showing nearly double the odds of being affected compared to females. This observation aligns with findings from other studies conducted in Nigeria, Austria, Indonesia, and Ethiopia. Contrary to the widely held notion that the prevalence of flat foot declines with age due to progressive arch development, this study observed an increase in flat foot likelihood with advancing age. The current study found an increasing trend, with each additional year of age associated with a 24%¹¹. This finding may be attributable to contextual lifestyle factors, delayed motor development, or reduced physical activity levels in the older cohort. It also highlights the importance of longitudinal research to further elucidate the trajectory of foot morphology across developmental stages.

Moreover, body mass index (BMI) emerged as the strongest predictor of flat foot in this cohort. Previous literature consistently supports this relationship. Adoracion et al. (2008) observed a higher prevalence of flat foot in obese children.¹² Similarly, Abdulaziz Almaawi (2019) confirmed a significantly higher incidence of flat foot in obese individuals, reinforcing the robust association between increased BMI and the presence of pes planus.¹³

Collectively, these findings not only reaffirm the clinical validity of footprint-based indices in pediatric foot assessment but also illuminate the key demographic and physiological factors contributing to flat foot. While the current study provides important regional data and fills a gap in the literature regarding Bulgarian school-aged children, it also raises questions about developmental trends and modifiable risk factors that warrant further longitudinal and interventional research. Understanding the interplay between growth, weight status, and foot structure is essential in crafting preventive strategies and early interventions.

5. Conclusion

The present study identified a flatfoot prevalence of approximately 18% among Bulgarian school-aged children, consistent with internationally reported epidemiological ranges. The diagnostic performance of the Staheli, Chippaux–Smirak, and Chizhin indices demonstrated high discriminative capacity, affirming their clinical utility in morpho-functional foot assessment. Multivariate logistic regression revealed that age, male sex, and elevated BMI were statistically significant independent predictors of pes planus, with overweight emerging as the most robust determinant. The positive association between advancing age and flatfoot incidence deviates from established developmental paradigms and underscores the need for longitudinal analyses. Collectively, the data substantiate the validity of footprint-based metrics as cost-effective, non-invasive tools for early detection and population-level screening of pediatric foot abnormalities.

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Article— Flatfoot among school aged children in Bulgaria: An Epidemiological Overview and Analysis of Risk Factors

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