3D FOOT MORPHOLOGY AND GENDER DIFFERENCES IN CHINESE YOUTH AGED 17–25

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ABSTRACT. Accurate understanding of foot morphology is essential for ergonomic footwear design, particularly for young adults whose foot structure may differ from older generations due to lifestyle and nutritional changes. This study aimed to investigate three-dimensional foot morphology and gender differences among Chinese youth aged 17–25. A total of 943 university students (664 males, 279 females) were recruited, and their feet were scanned using a 3D foot scanner. Fifteen key foot dimensions were extracted for analysis. Independent t-tests revealed significant gender-based differences: males tended to have longer and narrower feet, whereas females exhibited higher arches and relatively broader forefeet. Principal component analysis (PCA) identified three main morphological dimensions—length, girth, and height structure. Cluster analysis based on PCA scores classified both male and female feet into three types: slender, standard, and wide. Compared with historical data, modern Chinese youth show increased foot length and girth, suggesting a secular trend. These findings provide updated foot anthropometry data and highlight the necessity for gender- and foot type-specific shoe lasts. This study contributes valuable insights for footwear design, improving product fit, comfort, and reducing the risk of foot-related issues in young adult populations.

KEY WORDS: foot morphology, 3D foot scanning, gender differences, foot shape classification, footwear design

MORFOLOGIA 3D A PICIORULUI ȘI DIFERENȚELE DE GEN LA TINERII CHINEZI CU VÂRSTE CUPRINSE ÎNTRE 17 ȘI 25 DE ANI

REZUMAT. Înțelegerea exactă a morfologiei piciorului este esențială pentru proiectarea ergonomică a încălțămintei, în special pentru tinerii adulți a căror structură a piciorului poate diferi de cea a generațiilor mai în vârstă datorită stilului de viață și a schimbărilor nutriționale. Acest studiu a avut ca scop investigarea morfologiei tridimensionale a piciorului și a diferențelor de gen în rândul tinerilor chinezi cu vârste cuprinse între 17 și 25 de ani. S-au recrutat în total 943 de studenți universitari (664 de bărbați, 279 de femei), iar picioarele acestora au fost scanate folosind un scaner 3D pentru picioare. Cincisprezece dimensiuni cheie ale piciorului au fost extrase pentru analiză. Testele t pentru eșantioane independente au relevat diferențe semnificative în funcție de gen: la bărbații s-a constatat tendința de a avea picioare mai lungi și mai înguste, în timp ce femeile au prezentat arcade plantare mai înalte și zonele anterioare ale piciorului relativ mai late. Analiza componentelor principale (PCA) a identificat trei dimensiuni morfologice principale – lungimea, circumferința și înălțimea. Analiza cluster bazată pe scorurile PCA a clasificat atât picioarele masculine, cât și cele feminine în trei tipuri: subțiri, standard și late. Comparativ cu datele istorice, tinerii chinezi moderni prezintă o lungime și o circumferință ale piciorului crescute, sugerând o tendință seculară. Aceste descoperiri oferă date actualizate despre antropometria piciorului și evidențiază necesitatea unor calapoade specifice sexului și tipului de picior. Acest studiu aduce informații valoroase pentru designul încălțămintei, îmbunătățind potrivirea produsului, confortul și reducând riscul de probleme ale piciorului la populațiile de tineri adulți.

CUVINTE CHEIE: morfologia piciorului, scanare 3D a piciorului, diferențe de gen, clasificarea formei piciorului, designul încălțămintei

LA MORPHOLOGIE 3D DU PIED ET LES DIFFÉRENCES DE GENRE CHEZ LES JEUNES CHINOIS ÂGÉS DE 17 À 25 ANS

RÉSUMÉ. Une compréhension précise de la morphologie du pied est essentielle à la conception de chaussures ergonomiques, en particulier pour les jeunes adultes dont la structure du pied peut différer de celle des générations plus âgées en raison de changements de mode de vie et d'alimentation. Cette étude visait à examiner la morphologie tridimensionnelle du pied et les différences entre les sexes chez les jeunes Chinois âgés de 17 à 25 ans. Au total, 943 étudiants universitaires (664 hommes, 279 femmes) ont été recrutés et leurs pieds ont été scannés à l'aide d'un scanner 3D. Quinze dimensions clés du pied ont été extraites pour analyse. Des tests t indépendants ont révélé des différences significatives selon le sexe : les hommes avaient tendance à avoir des pieds plus longs et plus étroits, tandis que les femmes présentaient des voûtes plantaires plus hautes et des avant-pieds relativement plus larges. L'analyse en composantes principales (ACP) a identifié trois dimensions morphologiques principales : la longueur, la circonférence et la hauteur. L'analyse de cluster basée sur les scores de l'ACP a classé les pieds masculins et féminins en trois types : fins, standard et larges. Comparés aux données historiques, les jeunes Chinois modernes présentent une longueur et une circonférence de pied accrues, suggérant une tendance séculaire. Ces résultats fournissent des données anthropométriques actualisées sur le pied et soulignent la nécessité de formes de chaussures spécifiques au genre et au type de pied. Cette étude apporte des informations précieuses pour la conception de chaussures, améliorant l'ajustement et le confort des produits, et réduisant le risque de problèmes de pieds chez les jeunes adultes.

MOTS CLÉS : morphologie du pied, scan 3D du pied, différences entre les sexes, classification des formes de pied, conception de chaussures

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INTRODUCTION

Ill-fitting shoes affect up to 70% of people worldwide, contributing to discomfort, fatigue, and long-term foot health issues [1]. Accurate foot morphology data are vital for crafting ergonomic footwear that ensures comfort and supports the needs of young adults, whose feet continue to develop into their early twenties [2, 3]. Chinese youth aged 17-25, a significant and expanding segment of the footwear market, may exhibit distinct foot shapes influenced by modern lifestyle changes—such as reduced physical activity [4] and improved nutrition [5]. These factors may differentiate their foot morphology from that of older generations and other populations. However, comprehensive data on this demographic remain scarce, restricting the footwear industry's capacity to design shoes that optimize fit and minimize health risks.

Previous studies highlight that foot morphology varies by gender and ethnicity, with direct implications for shoe design. Results showed that females often have narrower feet and higher arches than males [6, 7], while East Asians, including Chinese populations, tend to have wider forefeet compared to Caucasians of similar lengths [8, 9]. However, previous Chinese foot surveys lack the resolution to reflect the nuanced profiles of today's youth [10], and traditional manual measurement techniques offer limited precision and consistency [11, 12]. These gaps highlight an urgent need for updated, detailed data to meet contemporary design demands. The emergence of 3D scanning technology provides a powerful tool to overcome these limitations [13], delivering precise measurements that can transform how foot morphology is understood and applied in footwear innovation [14].

While prior studies offer valuable insights, they often focus on broader adult populations [8] or use manual measurement techniques [11], leaving the specific foot shape characteristics of Chinese youth underexplored. This study aims to address this gap by investigating foot morphology in Chinese individuals aged 17-25 using 3D scanning technology. By doing so, it seeks to provide foundational data to inform footwear design tailored to this key demographic, enhancing comfort and supporting foot health in a rapidly evolving market.

MATERIALS AND METHODS

Participants

A total of 943 healthy Chinese university students (664 males, 279 females), aged between 17 and 25 years, were recruited from Shaanxi University of Science and Technology, located in Xi'an, Shaanxi Province, China. The university's student body comprises individuals from various provinces across the country, enabling the recruitment of a demographically diverse cohort representative of Chinese youth.

Participants were recruited between March and June 2024 through university-wide announcements and voluntary sign-up campaigns. A convenience sampling method was employed, considering the logistical practicality of accessing a large student population within a controlled academic environment. Inclusion criteria for participation included the absence of any diagnosed foot deformities (e.g., severe *pes planus*, *hallux valgus*), lower limb injuries within the previous six months, and neurological or musculoskeletal disorders that could potentially affect posture, gait, or foot morphology [15]. All participants were screened through self-reported medical histories and a brief physical examination conducted by trained research personnel [16]. Written informed consent was obtained from each participant prior to data collection.

Basic anthropometric data were recorded, including age, body height, body mass, and body mass index (BMI). These characteristics are summarized in Table 1 and are expressed as mean ± standard deviation.

Table 1: Demographic characteristics of study participants by Gender

Variables	Male (n = 664)	Female (n = 279)
Age(years)	19.7 ± 1.7	20.9 ± 1.6
Body height (cm)	176.1 ± 5.8	163.3 ± 17.3
Body mass (kg)	68.2 ± 8.1	55.9 ± 10.4
BMI (kg/m^2)	22.0 ± 2.1	21.2 ± 4.2

Note: Data are presented as mean ± standard deviation. BMI = Body Mass Index.

Foot Scanning Procedure

Foot morphology data were collected using the Upod-S 3D foot scanner (Guangzhou Kangyou Technology Co., Ltd., Guangzhou, China), a non-contact laser scanner with a measurement accuracy of ± 0.5 mm and a resolution of 0.1 mm [17, 18]. The scanner was calibrated before each session per manufacturer guidelines to ensure measurement consistency. Scans were conducted in a laboratory maintained at 20–25°C to minimize thermal effects on foot dimensions.

Participants stood barefoot on a rigid platform in a standardized anatomical posture: upright, feet shoulder-width apart, weight evenly distributed, eyes facing forward, and arms relaxed at their sides [12, 19]. This posture replicated natural standing conditions and ensured uniformity across measurements. Both feet were scanned simultaneously under static, full weight-bearing conditions (Figure 1). Each participant was scanned once under static, full weight-bearing conditions [17]. Based on preliminary tests in a 30-subject subsample, intra-device measurement reliability (ICC) exceeded 0.90 for all dimensions.

Based on prior research and subsample analysis indicating no significant differences between left and right foot measurements ($p > 0.05$) [20], only right foot data were analyzed to simplify processing and reduce redundancy. This choice aligns with standard practices in foot morphology studies where bilateral symmetry is typically observed in healthy populations.

Foot Measurements

The Upod-S system automatically extracted fifteen key foot dimensions, which encompassed length, width, girth, and height parameters [21]. These included: foot length (heel to the most anterior point of the toes), first and fifth metatarsal lengths, ball width (across the metatarsal heads), metatarsal width, heel width, ball girth, instep girth, heel girth, instep height, hallux height, fifth metatarsal height, navicular height, lateral malleolus height, and medial malleolus height. Each anatomical landmark and corresponding measurement location are depicted in Figure 2.

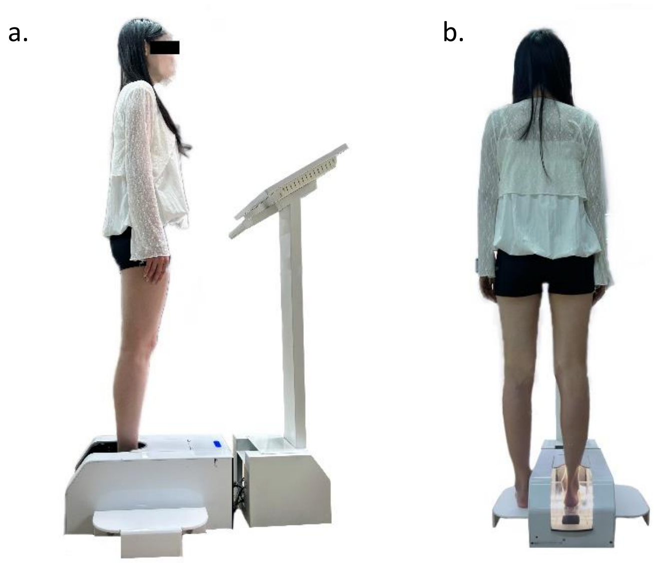

Figure 1. Foot scanning posture

Note: (a) Side view and (b) rear view of the standardized posture using the Upod-S 3D scanner. Participants stood barefoot with feet shoulder-width apart, weight evenly distributed, and maintained an upright posture with eyes forward.

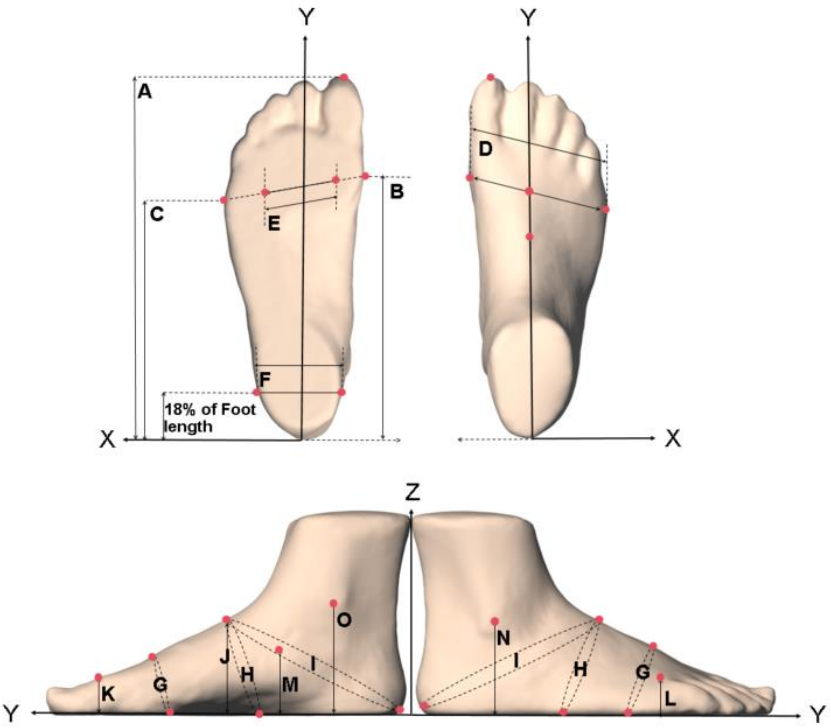

Figure 2. Major indicators of foot structure

Note: The figure depicts foot measurements, including foot length (A), first metatarsal length (B), fifth metatarsal length (C), ball width (D), metatarsal width (E), heel width (F), ball girth (G), instep girth (H), heel girth (I), instep height (J), hallux height (K), fifth metatarsal height (L), navicular height (M), lateral malleolus height (N), and medial malleolus height (O).

Data Processing

Raw data were first examined using Microsoft Excel (version 16.0) to identify and remove entries with missing values or extreme outliers, based on standardized z-scores ($|z| > 3$). To ensure consistency and facilitate inter-individual comparisons, all 15 foot dimensions were standardized using z-transformation before multivariate analysis [22].

In addition to the z-score normalization, relative dimension standardization was applied to account for individual variations in foot size. Specifically:

Length- and height-related variables (e.g., foot length, instep height, navicular height, hallux height) were normalized using Foot Length (FL) as the base unit [21]:

$$Relative\ Value\ (\%FL) = \left(\frac{Dimension}{Foot\ Length}\right) \times 100 \qquad (1)$$

Width- and girth-related variables (e.g., ball width, heel width, ball girth, instep girth, heel girth) were normalized using Ball Girth (BG) as the reference:

$$Relative\ Value\ (\%BG) = \left(\frac{Dimension}{Ball\ Girth}\right) \times 100 \qquad (2)$$

These procedures enabled proportional comparisons between participants, allowing gender differences to be interpreted independent of overall foot size.

Statistical Analysis

Statistical analyses were performed using SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (means and standard deviations) were calculated separately for male and female participants for both absolute and normalized foot dimensions.

Data normality was assessed using the Shapiro–Wilk test ($\alpha = 0.05$), and homogeneity of variances was evaluated with Levene's test [23]. Two-tailed independent samples t-tests compared gender differences in absolute and normalized dimensions, with a significance threshold of $p < 0.05$.

To examine the distributional characteristics of Foot Length and Ball Girth by gender, participants were grouped into 5 mm intervals. For each interval, the number of participants within that range was divided by the total number of participants of the same gender to calculate the relative frequency (percentage) [8]. This allowed for visualization of the distribution patterns of foot size characteristics across genders. The resulting distributions were illustrated in histograms to compare male and female trends and to highlight clustering in typical size ranges.

Principal Component Analysis (PCA) was conducted separately for males and females using correlation matrices of standardized variables to explore the underlying structure of foot morphology and reduce dimensionality [24]. Varimax orthogonal rotation enhanced the interpretability of the factor structure. Principal components with eigenvalues greater than 1.0 were retained. PCA scores were used as input for a two-step cluster analysis. First, Ward's hierarchical clustering method determined the optimal number of clusters. Then, the K-means algorithm refined cluster membership, classifying participants into three foot shape categories (slender, standard, and wide) based on width and thickness indices [25].

RESULTS

Descriptive Statistics of Foot Dimensions

Table 2 showed pronounced and consistent differences in foot morphology between male and female participants across all measured dimensions. Overall, males exhibited significantly larger foot measurements, not only in linear dimensions such as foot length and metatarsal lengths but also in girth and height-related variables. These differences were statistically significant with all p-values below 0.0001.

Table 2: Mean foot dimensions of male and female participants

Dimensions (mm)	Male (n = 664)	Female (n = 279)	t	*p* value
Foot length	256.1±11.1	237.7±9.5	24.21	<0.0001
First metatarsal length	184.4±7.9	169.0±6.9	28.33	<0.0001
Fifth metatarsal length	161.3±7.0	147.9±6.0	27.95	<0.0001
Ball width	100.2±4.4	91.1±4.6	28.60	<0.0001
Heel width	60.9±3.3	55.2±3.0	24.86	<0.0001
Metatarsal width	67.1±3.0	61.1±3.1	27.76	<0.0001
Ball girth	242.7±9.9	221.8±10.2	29.32	<0.0001
Instep girth	246.0±10.5	220.6±9.9	34.48	<0.0001
Heel girth	343.4±13.3	313.2±11.9	32.81	<0.0001
Instep height	68.3 ±4.2	61.7±4.2	22.03	<0.0001
Hallux height	24.5±2.3	23.2±2.3	7.92	<0.0001
Fifth metatarsal height	20.8±2.3	19.9±2.2	5.56	<0.0001
Navicular height	40.7±3.2	37.1±3.0	16.06	<0.0001
Lateral malleolus height	73.7±5.8	67.4±6.2	14.91	<0.0001
Medial malleolus height	84.9±4.8	76.4±5.6	23.59	<0.0001

The distribution of foot length (Figure 3) showed that males generally had longer feet, with a peak frequency around 255–260 mm (approximately 20% of males), while females peaked around 235–240 mm (approximately 25% of females), indicating a clear shift toward smaller foot lengths in females. Similarly, the distribution of ball girth (Figure 4) revealed that males had larger girths, peaking at 240–245 mm (around 20% of males), whereas females peaked at 220–225 mm (around 20% of females).

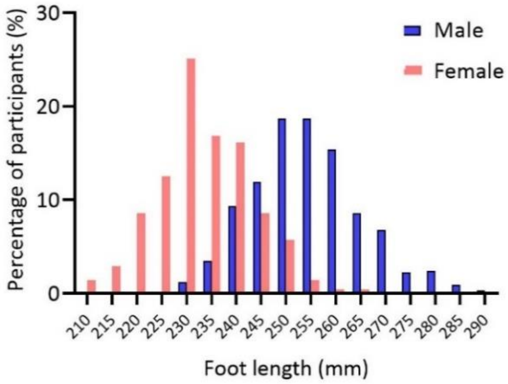

Figure 3. Distribution of foot length among male and female participants

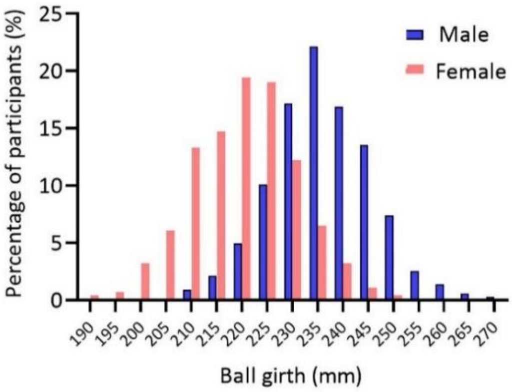

Figure 4. Distribution of ball girth among male and female participants

Gender Differences in Foot Morphology

To explore proportional differences, foot dimensions were normalized to foot length (FL) or ball girth (BG). While absolute dimensions were consistently larger in males, females exhibited relatively higher arches and wider forefeet. Statistically significant differences were found in nearly all proportional measurements, as shown in Table 3.

Table 3: Gender Differences in Relative Foot Proportions

Dimensions	Male (n = 664)	Female (n = 279)	MD
First metatarsal length (% FL)	72.01±0.13	72.02±0.14	-0.01***
Fifth metatarsal length (% FL)	63.00±0.13	63.02±0.14	-0.02***
Instep height (% FL)	26.72±1.82	26.33±1.87	0.39*
Hallux height (% FL)	9.61±0.96	9.89±1.04	-0.28***
Fifth metatarsal height (% FL)	8.14±0.93	8.47±0.93	-0.33***
Navicular height (% FL)	15.93±1.38	15.80±1.33	0.13*
Lateral malleolus height (% FL)	28.80±2.41	28.72±2.64	0.08*
Medial malleolus height (% FL)	33.21±1.99	32.59±2.42	0.62***
Foot width (%BG)	41.27±0.49	41.06±0.65	0.21***
Heel width (%BG)	25.10±1.12	24.92±1.08	0.18*
Metatarsal width (%BG)	27.64±0.44	27.55±0.54	0.09*
Ball girth (%BG)	94.87±3.91	94.55±4.19	0.32
Instep girth (%BG)	101.35±2.17	99.48±2.23	1.87***
Heel girth (%BG)	141.55±4.47	141.33±4.73	0.22

Note. Data are presented as mean ± standard deviation. %FL = percentage of Foot Length; %BG = percentage of Ball Girth. MD = Mean difference between male and female values. Significance levels: *p < 0.05, **p < 0.01, ***p < 0.001.

Principal Component Analysis of Foot Dimensions

To reduce dimensionality and explore latent structure, PCA was conducted separately for male and female datasets. Three principal components were extracted, cumulatively explaining over 79% of the variance in both groups. The components were interpreted as follows:

- PC1: Overall length and longitudinal proportions;
- PC2: Girth and width-related metrics (foot volume);
- PC3: Vertical structure (arch and dorsal height).

Table 4: Results of PCA for male's and female's foot dimensions relative to foot length

Dimensions	Male			Female		
	PC1	PC2	PC3	PC1	PC2	PC3
First metatarsal length	0.973	-	-	-	0.962	-
Fifth metatarsal length	0.972	-	-	-	0.962	-
Foot length	0.973	-	-	-	0.962	-
Foot width	-	0.797	-	0.873	-	-
Heel width	-	0.598	-	0.625	-	-
Metatarsal width	-	0.760	-	0.844	-	-
Ball girth	-	0.833	-	0.881	-	-
Instep girth	-	0.755	-	0.787	-	-
Heel girth	-	0.851	-	0.507	-	-
Instep height	-	-	0.082	-	-	0.867
Hallux height	-	-	0.535	-	-	0.618
Fifth metatarsal height	-	-	0.577	-	-	0.798
Navicular height	-	-	0.805	-	-	0.823
Lateral malleolus height	-	-	0.860	-	-	0.812
Medial malleolus height	-	-	0.831	-	-	0.785
Eigenvalue	7.606	2.708	1.598	7.757	2.702	1.506
Variance explained (%)	33.093	24.983	21.340	28.282	28.134	23.349
Cumulative (%)	33.093	58.075	79.415	28.282	56.416	79.765

Cluster-Based Foot Shape Classification

Based on the PCA-derived scores, foot shapes were classified into three morphological categories: Slender, Standard, and Wide. Among both male and female participants, the Standard type was the most common, followed by Wide and Slender types.

Foot thickness was further divided into Thin, Normal, and Thick categories within each foot shape. In males, Thin feet were relatively uncommon, with Normal and Thick types predominating across all foot shape categories. In females, Thin feet appeared mainly in the Slender and Standard groups, while Wide feet were mostly characterized by Normal and Thick types.

Representative 3D foot shapes classified by width and thickness for young male and female participants are illustrated in Figures 5 and 6, respectively.

Table 5: Distribution of foot thickness types across foot shape clusters by gender

Sex	Type	Thin (%)	Normal (%)	Thick (%)
Male (n = 664)	Slender	88(13.2%)	94(14.2%)	19(2.9%)
	Standard	70(10.5%)	147(22.1%)	71(10.7%)
	Wide	12(1.8%)	69(10.4%)	94(14.2%)
Female (n = 279)	Slender	27(9.7%)	32(11.5%)	6(2.1%)
	Standard	37(13.3%)	68(24.4%)	29(10.4%)
	Wide	9(3.2%)	43(15.4%)	28(10.0%)

Note: Values represent the number of participants and the corresponding percentages in each thickness category (thin, normal, and thick) within each foot shape cluster. Percentages are calculated based on the total number of participants.

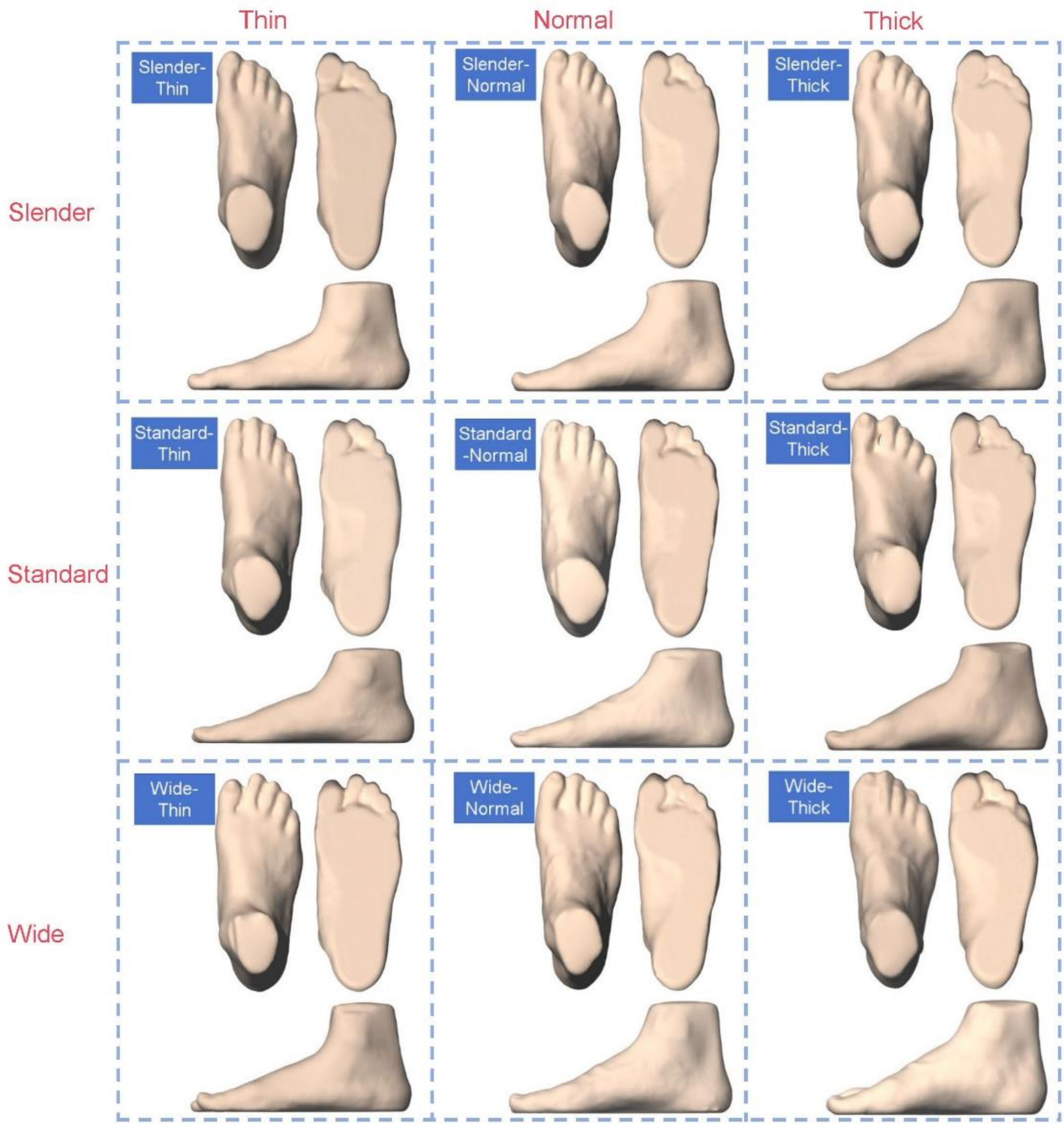

Figure 5. Representative foot shapes classified by width and thickness among young male participants

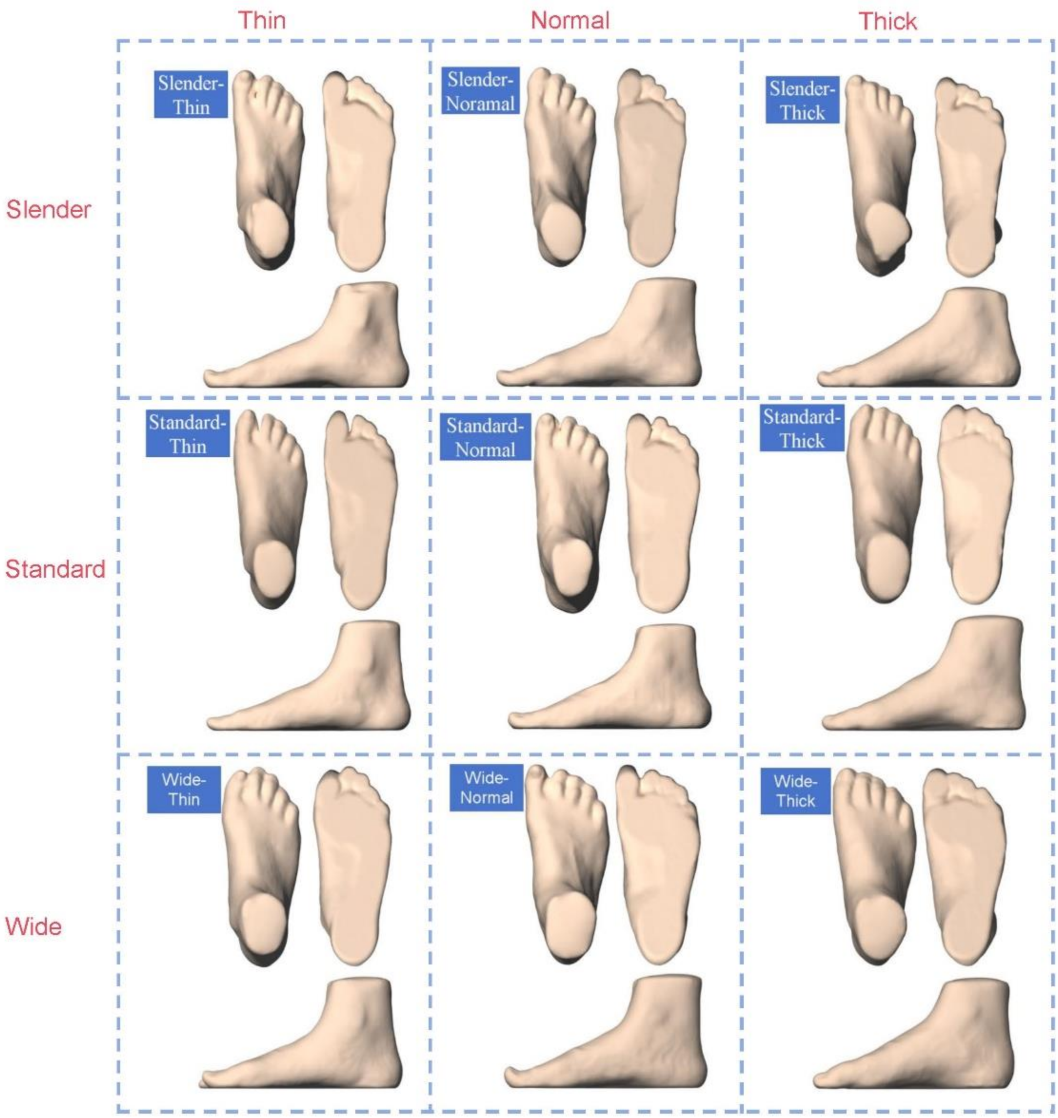

Figure 6. Representative foot shapes classified by width and thickness among young female participants

Comparison with Historical Data

Compared with historical foot dimension data from the 2005 Chinese foot census [10], the current youth cohort exhibited generally larger foot sizes. In both males and females, increases were observed in overall foot length and ball girth measurements. The most notable differences appeared in foot length, with youth participants showing longer feet than the adult reference population. Increases in ball girth were also present, though to a lesser extent.

Table 6: Comparison with historical Chinese foot census

Sex	Dimension	Current study (mm)	Foot census (mm)	Mean difference (mm)
Male	Foot Length	256.1±11.1	248.9±10.9	7.2
(n = 664)	Ball Girth	242.7±9.9	241.7±11.3	1.0
Female	Foot Length	234.7±9.6	228.8±10.9	5.9
(n = 279)	Ball Girth	221.8±10.3	219.3±11.7	2.5

DISCUSSION

This study provides a detailed analysis of foot morphology in Chinese youth aged 17–25 using 3D scanning technology, offering insights into gender differences, foot shape classifications, and secular trends. The findings have significant implications for footwear design and foot health management, addressing a critical gap in high-resolution data for this demographic.

Secular Changes in Foot Morphology

The observed increases in foot length (7.2 mm for males, 5.9 mm for females) and ball girth (1.0 mm for males, 2.5 mm for females) compared to historical Chinese data [10] reflect secular trends likely driven by environmental and lifestyle changes. Improved nutrition, particularly increased protein intake, and reduced manual labor due to urbanization are key factors contributing to larger body and foot sizes in modern youth [5, 26]. For instance, studies have linked higher caloric and nutrient availability to increased anthropometric measurements in Chinese adolescents over recent decades [26]. These changes parallel global trends observed in populations with similar socioeconomic shifts, such as in Japan and South Korea [27, 28]. The larger foot dimensions in this cohort suggest that footwear manufacturers must update sizing standards to accommodate contemporary Chinese youth, ensuring comfort and reducing the risk of foot-related disorders caused by ill-fitting shoes.

Regional and Ethnic Comparisons

Within the East Asian context, the foot morphology of Chinese youth appears distinct from that of Japanese and Korean populations, which tend to have shorter and narrower feet [27, 28]. Compared to historical data from Hong Kong, Mainland Chinese youth in this study exhibited more elongated foot profiles [6], possibly due to regional dietary and lifestyle differences. These variations underscore the importance of localized footwear standards, as a one-size-fits-all approach based on broader East Asian data may not adequately serve the Chinese market. While comparisons with Western populations were not a focus of this study, prior research suggests that East Asian feet, including Chinese, are generally shorter but broader with thicker midfoot profiles than Caucasian feet [8, 29, 30]. Future studies could quantify these differences using 3D scanning to inform global footwear design strategies.

Gender Differences and Design Implications

The study highlights distinct gender differences in foot morphology, with females exhibiting relatively higher arches and wider forefeet compared to males. These findings align with prior research indicating that women's feet differ structurally from men's, not merely in size [6, 7]. The higher arches in females suggest a need for shoe lasts with enhanced instep support to prevent discomfort and arch-related issues, such as plantar fasciitis. Similarly, the relatively broader forefeet in females indicate that women's shoes should incorporate wider toe boxes to accommodate forefoot spread during weight-bearing activities.

These gender-specific characteristics challenge the traditional practice of scaling down men's shoe designs for women. Instead, manufacturers should develop distinct lasts that account for proportional differences, particularly in the midfoot and forefoot regions. Such adaptations could reduce the prevalence of foot discomfort, which affects up to 70% of individuals wearing ill-fitting shoes [1], and enhance consumer satisfaction in the growing Chinese footwear market.

Classification of Foot Shape Types

The classification of foot shapes into slender, standard, and wide types, with further subdivision by thickness (thin, normal, and thick), provides a practical framework for footwear design. The predominance of the standard type suggests that most Chinese youth can be accommodated by conventional sizing, but the significant proportions of slender and wide feet highlight the need for diverse size offerings. Notably, the higher prevalence of thick feet in males, particularly in the wide category, indicates a demand for shoes with increased volume in the instep and midfoot areas.

This classification system can optimize inventory management by aligning production with the distribution of foot types, reducing mismatches in retail settings. Additionally, it supports the development of online sizing algorithms, where consumers can select shoes based on their foot shape and thickness profiles. By integrating these classifications into design workflows, manufacturers can enhance fit precision, improving comfort and reducing returns in e-commerce platforms.

Limitations

Several limitations of this study should be acknowledged. Although the sample was sizable and geographically diverse, all participants were university students from a single institution, which may limit the generalizability of the findings to the broader Chinese youth population. Furthermore, the cross-sectional design offers only a temporal snapshot, preventing analysis of developmental changes in foot morphology over time. Additionally, key lifestyle factors—such as physical activity levels, footwear habits, and occupational demands—were not assessed, despite their potential influence on foot structure. To address these gaps, future research should adopt longitudinal designs, include more demographically diverse cohorts, and incorporate relevant lifestyle and environmental variables to achieve a more comprehensive understanding of youth foot morphology.

CONCLUSIONS

This study provides a comprehensive analysis of foot morphology among Chinese youth aged 17–25 using 3D scanning and multivariate statistical methods. The findings reveal significant gender differences and a general increase in foot dimensions compared to historical data, reflecting ongoing secular trends. By classifying foot shapes into slender, standard, and wide types, this research offers practical insights for the development of more anatomically appropriate and comfortable footwear. The results highlight the importance of gender-specific and type-specific shoe lasts to accommodate morphological diversity and improve fit. Moreover, the application of PCA and cluster analysis demonstrates a robust framework for understanding complex foot shape patterns. Although the study is limited by its cross-sectional design and sample source, it establishes a strong foundation for future work. Continued research with broader populations and longitudinal approaches will be critical to optimizing footwear design and promoting foot health in evolving demographics.

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