

Received: 2018.08.28
Accepted: 2018.10.23
Published: 2019.02.02

Foot Morphology in Chinese Adolescents Aged Between 13 to 18 Years Varies by Gender and Age

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

CDEF 1,2 **Miaomiao Xu**
AB 3 **Jing Xian Li**
AB 4 **Youlian Hong**
ABCDG 1,2 **Lin Wang**

1 Key Laboratory of Exercise and Health Science of the Ministry of Education, Shanghai University of Sports, Shanghai, P.R. China
2 School of Kinesiology, Shanghai University of Sports, Shanghai, P.R. China
3 School of Human Kinetics, University of Ottawa, Ottawa, Ontario, Canada
4 Department of Sports Medicine, Chengdu Sports University, Chengdu, Sichuan, P.R. China

Corresponding Author: Lin Wang, e-mail: wanglin@sus.edu.cn

Source of support: This study was supported by the Natural Science Foundation of Shanghai (15ZR1439300) and the National Natural Science Fund of China (11572202)

Background: We recently reported age and gender differences in foot shape and size in Chinese school children aged between 7–12 years. This study aimed to analyze age and gender differences in foot shape and size in Chinese adolescents aged between 13–18 years.





Material/Methods: The study included 1,252 adolescent boys and 1274 adolescent girls from seven regions in China. Twelve measurements of foot shape were recorded using a video filming system. One-way analysis of variance (ANOVA) compared the changes in the measurements with age. An independent t-test was used to analyze gender-associated differences in foot size and shape.

Results: In adolescent boys, foot length and width increased significantly at 13–14 years and heel width, arch height, and fifth metatarsal head height increased until 18 years ($P < 0.05$). In adolescent girls, most foot measurements ceased to increase after 15 years, except for arch height. Adolescent boys showed significantly larger foot length, width, height, and girth compared with adolescent girls ($P < 0.05$) (Cohen's d effect size > 0.8). Adolescent boys showed a significant increase in ball width and girth, and instep length and height compared with adolescent girls, who had a longer medial foot length and higher fifth metatarsal head height compared with adolescent boys ($P < 0.05$) (Cohen's d effect size > 0.5).

Conclusions: Age and gender associated differences were found in foot measurements in Chinese adolescents, aged between 13–18 years. These differences should be considered by shoe manufacturers and when making clinical decisions about normal foot development.

MeSH Keywords: **Adolescent Development • Age Factors • Foot • Growth • Sex Factors**

Full-text PDF: <https://www.medscimonit.com/abstract/index/idArt/912947>

 2833  2  7  26



Background

The foot is a complex structure with 26 bones, 33 joints, and related muscles, tendons, and ligaments and this complex structure contributes to the overall foot shape [1,2]. The shape of the human foot is associated with some intrinsic and extrinsic factors, including age and gender [3–5], race [6], body weight [7,8] and shoe-wearing habits [9,10].

Foot shape changes with age during adolescence, or the teenage years. Anderson et al. found that the foot length increased by 7–26 mm between 13–18 years of age in American adolescents, and suggested that the end of foot growth occurred at varied ages in American teenagers, and was dependent on the time of skeletal maturation [11]. Also, Ran et al. measured foot length and foot width in Chinese adolescents and showed that foot length increased by 6–23 mm and foot width increased by between 3–6 mm from 13–17 years of age in Chinese teenagers [12]. Waseda et al. found the navicular height slowly increased from 1.4–9.9 mm from 13–18 years of age in Japanese adolescents [13].

The feet of adolescents also show gender differences in the development of foot shape. Chen et al. showed that, in Taiwan, adolescent girls at the age of 13 years had significantly narrower ball and heel widths, and smaller ball and instep circumference compared with the adolescent boys of the same age [14]. Stavlas et al. found that Greek adolescent boys had a lower arch height compared with adolescent girls aged between 13–17 years [15]. Also, Anderson et al. reported that a growth peak of foot length usually occurred at the age of 11 years in American girls and at the age of 13 years in American boys [11]. The growth rate of foot length decreased after 13 years in adolescent girls continued to increase up to the age of 16 years in adolescent boys, and the average mature foot length of adolescent boys was about 1 inch (25.4 mm) longer than that of adolescent girls [11]. Barisch-Fritz et al. showed that foot length did not increase after 15 years of age in German adolescent boys and after 13 years of age in German adolescent girls, and the average mature foot length of adolescent boys was about 22 mm longer than that of adolescent girls [10].

Also, there may be ethnic differences in the development of foot shape. Hawes et al. found that the forefoot of people from East Asia was broader than in Caucasians [16]. Kouchi found that Mongol populations had a broader foot compared to Caucasian and Australian populations and that East Asian populations had a shorter foot length compared to Southeast Asians and Africans [17]. Several studies have investigated gender and age differences in foot morphology in Greek [15], German [10], American [11], and Japanese populations [13].

There have been few studies on the three-dimensional foot measurements and characteristics of Chinese adolescents.

Therefore, this study aimed to analyze age and gender differences in foot shape and size in Chinese adolescents aged between 13–18 years.

Material and Methods

Study participants

In this study, stratified sampling was used to select study participants from seven regions in China, which included Northern China, Southern China, Eastern China, Central China, Southwest China, Northwest China, and Northeast China. In each region, at least thirty participants were chosen respectively for each age and each gender. A total of 1,252 adolescent boys and 1,274 adolescent girls, between 13–18 years of age, from Chinese middle schools and high schools were recruited for the study. Individuals with injuries of the limb or foot deformities, including toe amputation or hallux valgus, were excluded from the study. The study protocol was approved by the Regional Ethical Committee of the Shanghai University of Sports (Ref. no. 2016-016, April 15th, 2016). The parents or guardians of the study participants signed informed consent for participation in the study.

Measurement and imaging procedures

The height and weight of each study participants were measured while wearing light clothes and while barefoot. Height was determined with a Seca 213 portable stadiometer (Seca GmbH & Co. Kg, Hamburg, Germany). Body weight was measured using a digital Seca 770 electronic weighing scale (Seca GmbH & Co. Kg, Hamburg, Germany). Data on three-dimensional foot shape of the right foot were collected for each study participant using a video filming system composed of four 9800 JVC video cameras (JVC Inc., Yokohama, Japan).

The foot model used in the study was developed by the Biomechanics Institute of Valencia, Spain [18–20]. The model used had eight anatomical reference points, which were marked with a black marker pen before filming. All the reference points were marked manually by one investigator (Figure 1). While filming, the study participants were required to stand still on both feet, with their bipedal body weight distributed equally. Four digital cameras were used to synchronously record the measurements of the right foot for at least 5 s using the sample frequency set at 50 Hz. After filming, the video images were analyzed using a Motion Analysis System (Ariel Dynamics, Trabuco Canyon, CA, USA). Automatic digitization of the video image created co-ordinates using eight reference points. The three-dimensional digitized data were then smoothed using a Butterworth filter (a maximally flat magnitude filter) at 6 Hz. The ball girth (BG) and heel-instep girth (HIG) were measured

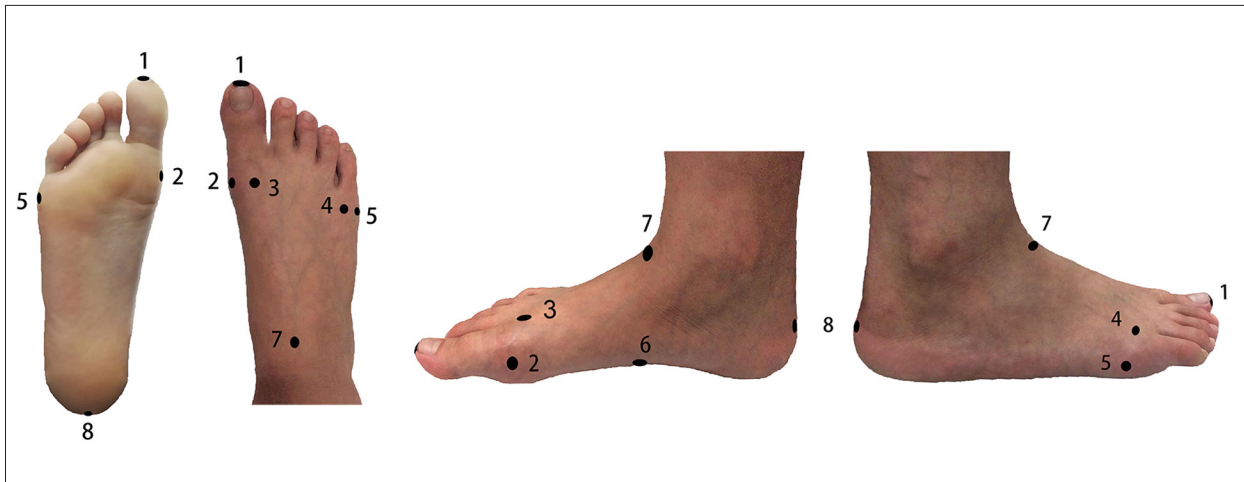


Figure 1. Reference landmarks used for foot measurements. 1) Front end of the longest toe; 2) First metatarsal head; 3) Highest point of the first metatarsal head; 4) Highest point of the fifth metatarsal head; 5) Fifth metatarsal head; 6) Lowest point of the foot arch; 7) The point where the leg meets the foot; 8) The pterion (the most prominent point of the heel).

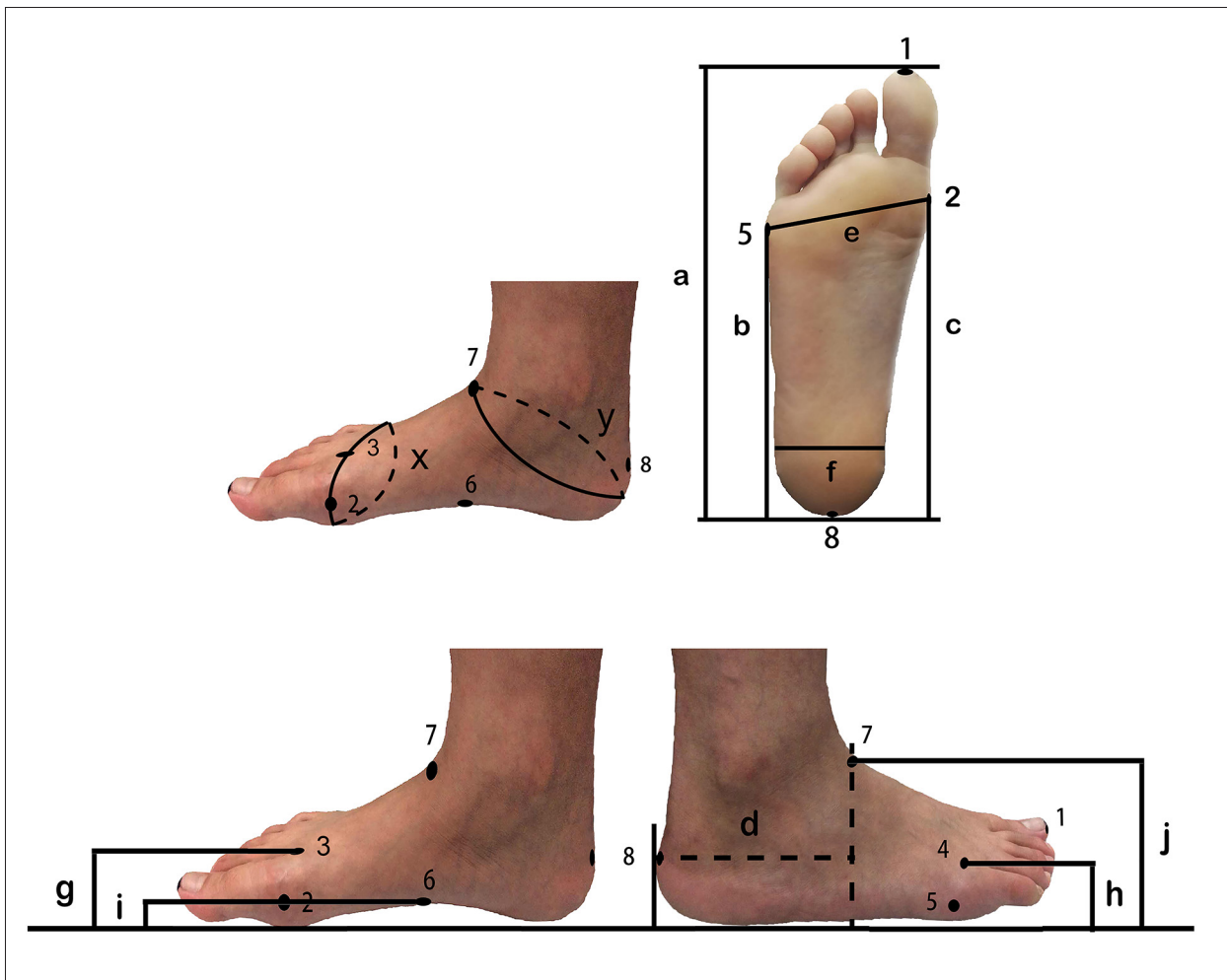


Figure 2. Foot measurements. a) Foot length; b) Lateral ball length; c) Medial ball length; d) Instep length; e) Ball width; f) Heel width; g) Height of the first metatarsal head; h) Height of the fifth metatarsal head; i) Arch height; j) Instep height; x) Ball girth; y) Heel-instep girth.

Table 1. The physical characteristics of the participants.

Age (years)	Gender	Height (cm)	Weight (kg)	Foot Length (mm)
13	Boys (n=224)	160.1 (7.9)*	51.5 (11.6)*	246.0 (12.7)*
	Girls (n=208)	156.8 (6.1)	48.8 (9.1)	230.3 (9.4)
14	Boys (n=227)	165.0 (8.5)*	56.6 (13.2)*	250.0 (13.3)*
	Girls (n=256)	160.1 (5.9)	51.7 (8.1)	232.3 (9.3)
15	Boys (n=174)	169.9 (7.3)*	61.1 (12.2)*	252.0 (11.8)*
	Girls (n=193)	162.5 (6.3)	56.5 (8.8)	236.6 (10.1)
16	Boys (n=189)	172.3 (6.3)*	63.8 (10.6)*	253.3 (10.6)*
	Girls (n=182)	160.9 (5.6)	56.1 (7.1)	232.3 (10.4)
17	Boys (n=238)	172.5 (6.9)*	64.2 (11.9)*	252.5 (11.6)*
	Girls (n=237)	161.8 (6.3)	56.9 (8.1)	233.3 (10.7)
18	Boys (n=200)	173.9 (6.2)*	64.8 (8.7)*	253.4 (10.8)*
	Girls (n=198)	162.8 (5.4)	57.1 (7.8)	232.3 (9.3)
Total	Boys (n=1252)	168.7 (8.8)*	60.1 (12.5)*	251.1 (12.2)*
	Girls (n=1274)	160.8 (6.3)	54.4 (8.8)	232.8 (10.0)

* $P < 0.05$ showed significant differences between boys and girls.

with a flexible tape to the nearest 1 mm by the investigator who had marked the measurement reference points (Figure 2).

Variables

Foot measurements (Figure 2) were obtained from the coordinates of the eight reference points. Four length variables were acquired including foot length (FL), medial ball length (MBL), lateral ball length (LBL), and instep length (IL). Two width variables were acquired, including ball width (BW) and heel width (HW). Four height variables were acquired including first metatarsal head height (M1H), fifth metatarsal head height (M5H), arch height (ArH), and instep height (IH) (Figure 2). Together with the two girth-related variables measured after filming, twelve foot-morphology variables were collected in total. This method was used in previous studies to measure three-dimensional foot variables [18,19].

Statistical analysis

Data were shown as the mean \pm standard deviation (SD). Statistical analysis was performed using the SPSS version 20.0 software package (IBM Corp., Armonk, NY, USA). Partial correlation analysis adjusted by age was conducted to determine the relationships between individual height and foot length. One-way analysis of variance (ANOVA) was used to calculate the changes in foot dimensions in each year of age and for each gender. Cohen's d effect size was calculated to determine the standardized difference between two means. Cohen's

d effect size $n \leq 0.2$ was interpreted as a minimal effect, a small effect size was 0.2–0.5, a moderate effect size was between 0.5–0.8, and a large effect size was ≥ 0.8 [20]. When a significant effect size occurred, the Bonferroni post hoc test was used. Independent t-tests were used to compare gender differences in absolute foot measurements and relative values, as the percentage FL, between adolescent boys and girls of the same age. Statistical significance was set at a P -value < 0.05 .

Results

Physical characteristics of the study participants

Adolescent boys were found to have significantly higher values in height, body weight, and foot length when compared to the values obtained in the group of adolescent girls of similar age (Table 1).

The relationship between height and foot length

The foot length was linearly correlated with height among Chinese adolescents, as shown in Figures 3 and 4 ($r = 0.683$ for adolescent boys) ($r = 0.628$ for adolescent girls) ($P < 0.001$).

Age differences in foot dimensions

The mean growth rates in foot length were 0.6% for adolescent boys and 0.18% for adolescent girls per year. Length-related

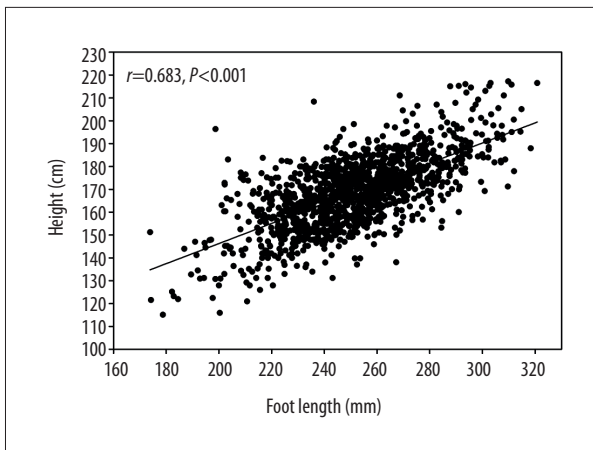


Figure 3. Correlation between height and foot length adjusted by age in adolescent boys.

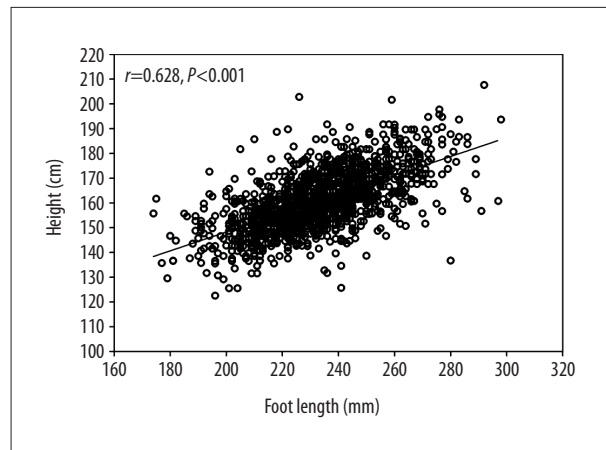


Figure 4. Correlation between height and foot length adjusted by age in adolescent girls.

Table 2. Percentage of change per year in boys and girls (%).

Variables	13–14 years		14–15 years		15–16 years		16–17 years		17–18 years		13–18 years	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
FL	1.6*	0.9	0.8	1.8*	0.5	-1.8*	-0.3	0.4	0.4	-0.4	3.0	0.9
MBL	1.4	0.5	0.7	1.8*	0.0	-1.8*	-0.1	0.5	0.7	0.2	2.8	1.1
LBL	1.3	0.3	0.5	1.9*	1.0	-1.6*	-0.3	0.5	1.4	1.4	4.0	2.4
IL	2.1*	1.3	0.5	0.7	1.3	-0.6	-0.1	0.8	0.1	-0.2	3.9	2.1
BW	2.7*	1.1	1.3	2.2*	-0.4	-1.2	-0.1	-0.3	-0.1	-0.6	3.4	1.3
HW	0.1	-1.2	-1.8	-0.3	4.5*	2.1	-1.7	-0.1	5.0*	4.4	6.0	4.9
M1H	1.3	1.1	-0.2	0.1	-0.4	-0.9	0.3	-0.1	3.2*	1.7	5.2	1.8
M5H	2.5*	0.6	1.1	1.6	-2.1	-3.3*	-1.6	-0.3	1.1	2.1	0.8	0.6
ArH	1.4	-2.2	-7.0	-6.2	9.4*	5.6	4.9	6.5	19.5*	20.9*	29.3	24.6
IH	4.9*	3.6*	1.8	2.7*	-0.4	-3.2*	0.2	0.3	-1.4	-3.6*	5.1	-0.4
BG	2.4*	0.8	1.0	1.3	-0.4	-0.8	0.3	0.0	1.4	0.9	4.7	2.1
HIG	1.9*	1.0	0.4	1.1	0.5	-1.1	-0.2	0.5	0.9	0.4	3.5	1.8

* $P<0.05$ showed significant differences between consecutive years. FL – foot length; MBL – medial ball length; LBL – lateral ball length; IL – instep length; BW – ball width; HW – heel width; M1H – height of the first metatarsal head; M5H – height of the fifth metatarsal head; ArH – arch height; IH – instep height; BG – ball girth; HIG – heel-instep girth.

and width-related foot measurements increased significantly at 13–14 years of age in adolescent boys and 14–15 years of age in adolescent girls. In adolescent girls, most foot measurements ceased to increase after 15 years of age, except for arch height. In adolescent boys, most foot measurements ceased to increase after 16 years of age, except for heel width, the height of the first metatarsal head (H1M), and arch height. Measurements indicating the greatest mean increases were arch height, instep height, heel width, ball girth, and the height of the first metatarsal head (H1M) for both genders (Table 2).

Gender-associated differences in foot dimensions

Adolescent boys showed significantly higher values in foot lengths, widths, heights, and girths compared with adolescent girls ($P<0.05$) (Cohen's d effect size >0.8) (Figure 5). Analysis of the normalized measurements by foot length of adolescents of the same age showed that adolescent boys had wider ball width and ball girth, longer instep length and higher instep height when compared with adolescent girls, and girls had significantly longer medial foot length and higher height of the

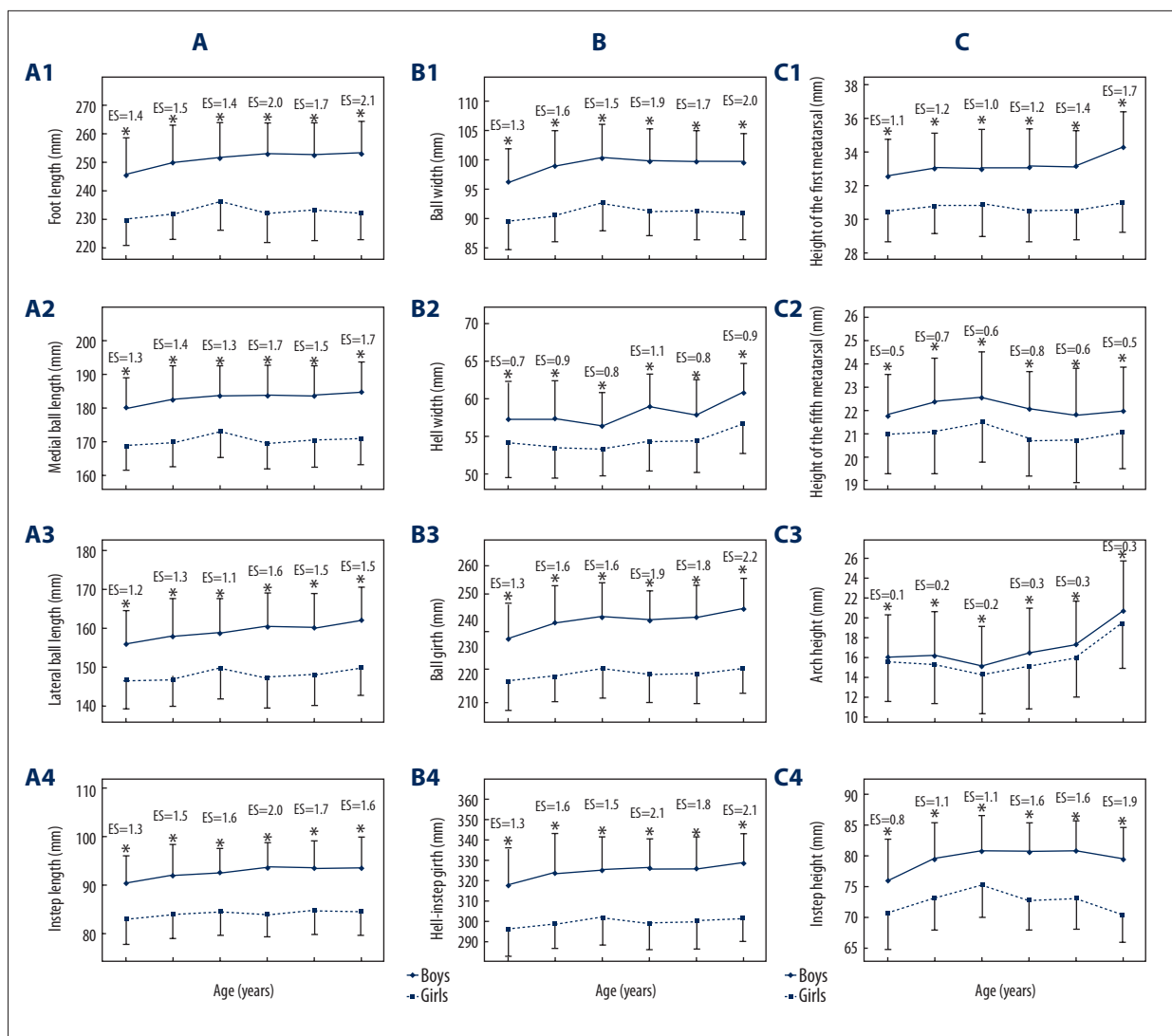


Figure 5. Differences between adolescent boys and girls in absolute foot measurements. * $P < 0.05$. (A) Differences between adolescent boys and girls in absolute length-related variables. (A1) Foot length; (A2) medial ball length; (A3) lateral ball length; (A4) instep length. (B) Differences between adolescent boys and girls in absolute width-related variables and girth-related variables. (B1) ball width; (B2) heel width; (B3) ball girth; (B4) heel-instep girth. (C) Differences between adolescent boys and girls in absolute height-related variables. (C1) height of the first metatarsal (M1H); (C2) height of the fifth metatarsal (M5H); (C3) arch height; (C4) instep height.

fifth metatarsal head (M5H) when compared with adolescent boys ($P < 0.05$) (Cohen's d effect size > 0.5) (Figure 6).

Discussion

The findings of this study showed that three-dimensional foot shapes varied according to age and gender among Chinese adolescents, aged between 13 years and 18 years. Within the age range of the participants in the study, the foot length was linearly correlated with the standing height for adolescent boys and girls. A growth peak in foot dimensions was found

to occur at the age of 13–14 years in adolescent boys and at the age of 14–15 years in adolescent girls. In adolescent girls, most foot measurements ceased to increase after 15 years of age. In adolescent boys, most foot measurements ceased to increase after 16 years of age. Adolescent girls showed significantly smaller values in absolute foot measurements compared with adolescent boys of the same age. However, when the relative foot measurements were analyzed, the gender differences decreased.

In this study, the foot length showed a linear correlation with standing height, which was greater in adolescent boys than girls.

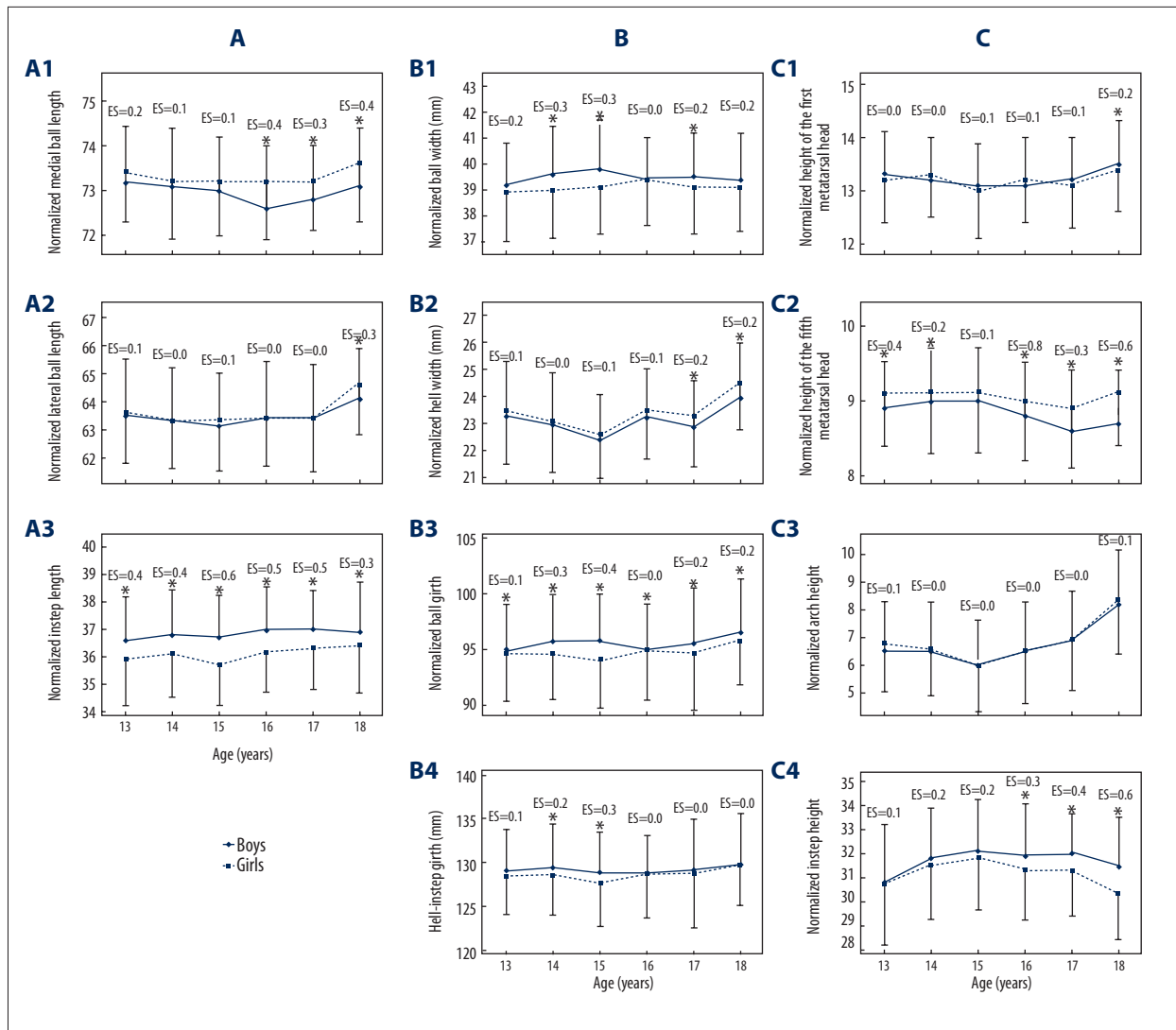


Figure 6. Differences between adolescent boys and girls in normalized foot measurements. * $P < 0.05$. (A) Differences between adolescent boys and girls in normalized length-related variables. (A1) normalized medial ball length; (A2) normalized lateral ball length; (A3) normalized instep length. (B) Differences between adolescent boys and girls in normalized width-related variables and girth-related variables. (B1) normalized ball width; (B2) normalized heel width; (B3) normalized ball girth; (B4) normalized heel-instep girth. (C) Differences between adolescent boys and girls in normalized height-related variables. (C1) normalized height of the first metatarsal (M1H); (C2) normalized height of the fifth metatarsal (M5H); (C3) normalized arch height; (C4) normalized instep height.

Krishan and Sharma, in a study in India, also reported a significant correlation between foot length and stature in Indian adolescents ($r=0.741$ for boys) ($r=0.734$ for girls), which were similar to the findings of the current study [21]. However, the correlation scores between foot length and stature among Chinese adolescents in this study were lower than those previously reported in our previous study of Chinese children's foot shape [22], and higher than those previously reported in a study of Chinese adult foot shape (Figure 7) [23]. Xu et al. found a significant correlation between foot length and stature among Chinese children aged 7–12 years of age ($r=0.792$ for

boys) and ($r=0.747$ for girls) [22]. Zhang et al. found a significant correlation between foot length and height in Chinese adults ($r=0.602$ in men) and ($r=0.565$ in women) [23]. The process of maximal growth in height, limb length, and foot length vary in time in childhood and adolescence. Anderson et al. found that the maximal growth in foot length was found to occur at 4–12 years and that foot length ceased to increase at 16 years of age, while the maximal growth in individual height was found to occur at 4–14 years of age and ceased by 18 years of age in male Americans [11]. These findings indicate that maximal foot length developed at a younger age than maximal individual height.

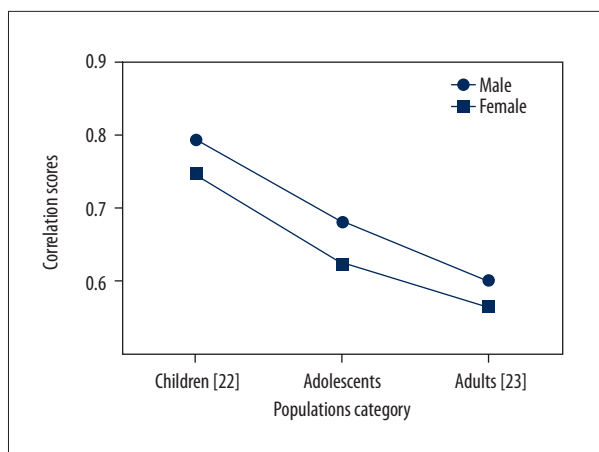


Figure 7. Comparisons of the correlation scores between foot length and stature among Chinese children [22], adolescents (the current study), and adults [23].

In the current study, the feet of adolescent girls reached maturity earlier than for adolescent boys, according to the analysis of foot measurement data. Most foot measurement variables reached ceased to increase by the age of 15 years of age in adolescent girls and by 16 years of age in adolescent boys. These findings are supported by a study of children and adolescents in Japan reported by Waseda et al., who found that the foot length ceased to increase at 13 years of age in girls and 14 years of age in boys [13]. In the present study, the most significant increase in foot measurements was found in foot lengths, foot widths, and foot girth, toes height, and instep height and at a younger age than in previous studies, in both boys and girls. At the age of 17–18 years of age, the arch height was found to significantly increase in both genders, and the heel width and M1H also were found to be significantly increased by 18 years in adolescent boys. The increase in foot arch height, heel width, and toe height at 18 years showed that the foot has a dynamic and continuously changing shape, even during adulthood.

In the present study, the increases in measured foot dimensions among Chinese adolescents, aged between 13–18 years, were less rapid than we have previously shown in Chinese children, aged between 7–12 years [22]. In the present study, the mean annual growth rates in foot length were 0.6% in adolescent boys and 0.18% in adolescent girls. While in the study by Delgado et al. on foot growth, Spanish children between the age of 6–12 years had an annual increase in foot length of 4.2% for boys and 3.8% for girls [5], which is larger than the findings in the current study. Previous studies have indicated that there is an optimum time for human foot development, which occurs between the age of 6–12 years, and that after 12 years of age, foot measurements were unlikely to increase [24,25].

The findings of this study showed that Chinese adolescent boys had greater absolute variables for foot measurements when compared with adolescent girls of the same age. Several previously published studies have reported similar results for gender differences in foot measurements and morphology among children and adults. Delgado et al. reported that Spanish boys had longer foot lengths, wider foot widths, and a higher instep when compared with girls [5]. Mickle et al. showed that the foot lengths of preschool boys were significantly greater when compared with girls of the same age [26]. Chen et al. found that foot measurements of boys were significantly greater compared with those of girls of the same age for 11 out of the 15 variables studied including foot length, breadth, height, and girths [14].

Also, gender differences in foot measurements and morphology have been studied in adult populations. Hong et al. reported that Chinese men had wider foot breadth, greater ball girth and instep girth, higher arch height compared with adult Chinese women of a similar age [18]. Saghazadeh et al. reported that the feet of men and women between 20–25 years of age were significantly different in foot length, width, height, and girth, which are findings that support those of the present study [4]. Previous studies have also shown that several gender differences were no longer present when normalized foot measurements were compared [5,17,26], and that the remaining differences in foot measurements may be caused by differences in foot proportions between the genders rather than foot size [26]. In the present study, comparison of the relative foot measurements, or percentage increase in foot length, between adolescent boys and girls, were supported by several previous studies. Adolescent girls showed a longer medial foot length, wider heel measurements, and an increase in height of the fifth metatarsal head (M5H), which are findings that have rarely been reported in previous studies. These findings may indicate that adolescent girls had a more pointed forefoot shape [18] and a wider heel than adolescent boys with the same foot length. The results of this study, including the findings of differences in foot shape might be considered in the future design of working shoes for adolescent girls and women.

This study had several limitations. The body mass index (BMI) and physical activity of the study participants, which may influence foot shape, were not considered in the current study. Also, an important measurement of foot morphology is arch height, which is typically measured as the navicular or talonavicular joint line, but this landmark was not digitally imaged and measured in this study. This study did not distinguish between individuals with flat-foot from individuals without flat-foot in the study population, and flat-foot is a factor that was likely to influence the findings. These limitations should be considered in the design of future studies.

Conclusions

Chinese adolescents, aged between 13–18 years, had a foot growth rate that was comparable with adolescents in other countries. In adolescent girls, most foot measurements ceased to increase after 15 years of age. In adolescent boys, most foot measurements ceased to increase after 16 years of age. Adolescent boys had greater values in total foot length, width, girth, and height compared with adolescent girls of the same

age. However, from the analysis of the normalized foot measurements, adolescent girls had a longer medial foot length and an increased fifth metatarsal head (M5H) height when compared with adolescent boys, and adolescent boys had a greater heel width, instep girth, and instep length when compared with adolescent girls. The results of the current study might be used to distinguish between physiologic and pathologic foot changes in adolescents and might be used to design and manufacture better shoes for Chinese adolescents.

References:

1. McKeon PO, Hertel J, Bramble D, Davis I: The foot core system: A new paradigm for understanding intrinsic foot muscle function. *Br J Sports Med*, 2015; 49: 290
2. Mauch M, Grau S, Krauss I et al: A new approach to children's footwear based on foot type classification. *Ergonomics*, 2009; 52: 999–1008
3. Ansuategui Echeita J, Hijmans JM, Smits S et al: Age-related differences in women's foot shape. *Maturitas*, 2016; 94: 64–69
4. Saghazadeh M, Kitano N, Okura T: Gender differences of foot characteristics in older Japanese adults using a 3D foot scanner. *J Foot Ankle Res*, 2015; 8: 29
5. Delgado-Abellan L, Aguado X, Jimenez-Ormeno E et al: Foot morphology in Spanish schoolchildren according to sex and age. *Ergonomics*, 2014; 57: 787–97
6. Sacco IC, Onodera AN, Bosch K, Rosenbaum D: Comparisons of foot anthropometry and plantar arch indices between German and Brazilian children. *BMC Pediatr*, 2015; 15: 4
7. Price C, Nester C: Foot dimensions and morphology in healthy weight, overweight and obese males. *Clin Biomech*, 2016; 37: 125–30
8. Zhao X, Tsujimoto T, Kim B et al: Does weight reduction affect foot structure and the strength of the muscles that move the ankle in obese Japanese adults? *J Foot Ankle Surg*, 2018; 57: 281–84
9. Branthwaite H, Chockalingam N, Greenhalgh A: The effect of shoe toe box shape and volume on forefoot interdigital and plantar pressures in healthy females. *J Foot Ankle Res*, 2013; 6: 28
10. Barisch-Fritz B, Plank C, Grau S: Evaluation of the rule-of-thumb: Calculation of the toe allowance for developing feet. *Footwear Science*, 2016; 8: 119–27
11. Anderson M, Blais M, Green WT: Growth of the normal foot during childhood and adolescence; length of the foot and interrelations of foot, stature, and lower extremity as seen in serial records of children between 1–18 years of age. *Am J Phys Anthropol*, 1956; 14: 287–308
12. Ran L, Zhang X, Chao C, Liu T: Anthropometric measurement of the feet of Chinese children. In: Duffy VG (eds.), *Third International Conference of Digital Human Modeling*, 2011 Jul 30–36; Orlando, Florida, USA
13. Waseda A, Suda Y, Inokuchi S et al: Standard growth of the foot arch in childhood and adolescence – derived from the measurement results of 10,155 children. *Foot Ankle Surg*, 2014; 20: 208–14
14. Chen JP, Chung MJ, Wang MJ: Flatfoot prevalence and foot dimensions of 5- to 13-year-old children in Taiwan. *Foot Ankle Int*, 2009; 30: 326–32
15. Stavlas P, Grivas TB, Michas C et al: The evolution of foot morphology in children between 6 and 17 years of age: A cross-sectional study based on footprints in a Mediterranean population. *J Foot Ankle Surg*, 2005; 44: 424–28
16. Hawes MR, Sovak D, Miyashita M et al: Ethnic differences in forefoot shape and the determination of shoe comfort. *Ergonomics*, 1994; 37: 187–96
17. Kouchi M: Foot dimensions and foot shape. Differences due to growth, generation and ethnic origin. *Anthropol Sci*, 1998; 106: 161–88
18. Hong Y, Wang L, Xu DQ, Li JX: Gender differences in foot shape: A study of Chinese young adults. *Sports Biomech*, 2011; 10: 85–97
19. Li JX, Xu DQ, Wang A, Shao K: Analysis of foot shape measures from Chinese male and female adults. In: Hamill J, Hardin E, Williams K (eds.), *Proceedings of the 7th Symposium on Footwear Biomechanics*; 2005 Jul 27–29; Brentwood, CA, USA
20. Cohen J: *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale (NJ). Lawrence Erlbaum Associates, 1988
21. Krishan K, Sharma A: Estimation of stature from dimensions of hands and feet in a North Indian population. *J Forensic Leg Med*, 2007; 14: 327–32
22. Xu M, Hong Y, Li JX, Wang L: Foot morphology in Chinese school children varies by sex and age. *Med Sci Monit*, 2018; 24: 4536–46
23. Zhang X, Wei Y, Zheng L et al: Estimation of stature by using the dimensions of the right hand and right foot in Han Chinese adults. *Sci China Life Sci*, 2017; 60: 81–90
24. El O, Akcali O, Kosay C et al: Flexible flatfoot and related factors in primary school children: A report of a screening study. *Rheumatol Int*, 2006; 26: 1050–53
25. Garcia-Rodriguez A, Martin-Jimenez F, Carnero-Varo M et al: Flexible flat feet in children: A real problem? *Pediatrics*, 1999; 103: e84
26. Mickle KJ, Steele JR, Munro BJ: Is the foot structure of preschool children moderated by gender? *J Pediatr Orthop*, 2008; 28: 593–96