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# Footprint analysis and prevalence of flatfoot: a study among the children of South 24 Parganas, West Bengal, India

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Abstract: The present study envisages the morphological differences in anthropometric measurements on footprints among the preschool children and analyzes its manifestation in the different weight category. This study also focuses on the diagnosis of flatfoot among the studied population. Data has been collected from 160 participants (80 boys and 80 girls) from Bengali Hindu caste population aged 3 to 6 years. Anthropometric measurements included height, weight and body mass index. Other measurements on foot morphology included foot length, foot breadth diagonal, foot breadth horizontal, ball of the foot length, outside ball of the boot length, heel breadth, and toe lengths T1, T2, T3.T4, T5. Staheli's Plantar Arch Index, Chippaux-Smirak Index and foot angle were calculated. Various statistical tests like t-test, Pearson's correlation and ANOVA were performed. Among all the variables, foot breadth horizontal showed statistically significant difference between boys and girls ($p<0.05$). All the footprint dimensions showed a significant ($p<0.05$) positive correlation with height and weight in both the boys and the girls. However, the Staheli's Plantar Arch Index showed a significant ($p<0.05$) negative correlation with height and weight and Chippaux-Smirak Index showed a significant ($p<0.05$) negative correlation with height only among both the boys and the girls. Significant differences (ANOVA) were found between the foot morphology of children in three different weight categories (underweight, healthy and overweight) except the foot angle, and both indices. The present study evinces that weight affects the foot structure of the children. The prevalence of flatfoot was found to be 57.5% among the children with no significant difference ($p<0.05$) between the boys and the girls. The results thus provide a podium for intricate studies in the future. Timely prognosis of flatfoot in children can instigate early rectification of flat-footedness.

Key words: Footprint, flatfoot, children, Staheli's Plantar Arch Index, Chippaux-Smirak Index, Body Mass Index (BMI)

## Introduction

Anthropometric data are important for product design and development in global markets. Appropriate use of anthropometric measures may improve wellbeing, health, comfort and safety,

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especially for footwear design. In normal human growth, foot shape and proportions change progressively due to several aspects, however a key factor for foot development are mechanical stresses during bipedal locomotion. Foot dimension measurements are important for footwear design, fit evaluation and clinical application (Witana 2004).Therefore, the lasts used in children's footwear industry should fit the foot morphology according to user's foot dimensions to produce comfortable shoes, avoiding subsequent foot deformities for the rest of their lives (Delgado-Abellán et al. 2014; Mauch et al.2008). The morphology and functional development of the foot are influenced by internal factors (sex, genetics, and age) and external factors (footwear habits, loading, and physical activity (Echaari and Forriol 2003). Because the foot structure of children is not fully developed, the influence of ill-fitting shoes can prevent the normal development of the foot and result in problems and pathologies in both childhood and adulthood (Riddiford Harland et al. 2011) Therefore, footwear should be designed to satisfy the foot dimensions of children, according to the characteristics of the population (Jiménez-Ormeño et al. 2013).

The foot plays an important role in maintaining a static position and providing a stable base when performing functional activities (Chang et al.2012). While walking, it has responsibility for the absorption of ground reaction forces (GRF), adaptation to the floor and forward movement (Hillstorm et al. 2013). It plays a role in load support and shock absorption as well as providing balance and stabilization of the body during gait (Tsung et al. 2003; Deepashini et al. 2014). The foot arches are very important in terms of foot structure and biomechanics (Özdinc and Turanz 2016). Medial Longitudinal Arch and other foot arches appear when a child starts to walk, and the age up to six years is critical. It has been claimed that foot structuring continues up to 14 and even 16 years even though it might be slower (Chang et al. 2010). The morphology of human foot varies considerably due to the combined effects of heredity, lifestyle, and climatic factors (Ukoha et al. 2013). In addition, natural biological variance, age, population group, BMI, parity and sex have significant influences on the morphology of an individual's foot (Krauss et al. 2008).

Excess weight affects the foot structure of children. Childhood obesity is associated with long-term consequences for the musculoskeletal system, including misalignment of the lower limbs (Wearing et al. 2006). Children almost universally are "flat-footed" when they start walking(Nemeth 2011). Initial treatment options include activity modification, proper shoe and orthoses, exercises and medication (Halabchi et al. 2013). In the neonates and toddlers, it is known that a fat pad is present underneath the medial longitudinal arch of the infant foot while the arch develops; although this fat pad is thought to resolve between the ages of 2 and 5 years as the arch of the foot is formed (Mickle et al. 2006).

Different studies (Cheng et al. 1997; Hernandez et al 2007; Morrison et al. 2007; Chen et al. 2009) on measurements of foot have been conducted in worldwide scenario among the children and adult population. Studies conducted by Mauch et al. (2008) on children aged 2–14 years and found significant difference in foot types and Body Mass Index (BMI). Villaroya et al. (2009) conducted studies on obese children/adolescents aged 9 to 16.5 years in Zaragoza where they found that obese children have lower footprint angle and higher Chippaux-Smirak Index. Studies has been conducted by Bari et al. (2010) examined foot anthropometry data of Malaysian preschool children of 5 and 6 years old and found that there were significant relationships among all the foot anthropometric measurements. The study also found that there was a significant difference between the length and width of the right and left foot. Jiménez Ormeno et al. (2013) compared the foot morphology of Spanish school children of 6 to 12 years old based on their Body Mass Index and found that significant differences were found between normal weight and overweight children for all variables, except for the arch height. Studies conducted by Sacco et al. (2015) showed a higher Chippaux-Smirak index of Brazilian children compared to German children. Abledu et al. (2015) obtained bilateral foot prints from Ghanainan students aged between 18–30 years and found footprint dimensions (i.e. T1, T2, T3, T4, T5, Breadth at ball, Breadth at heel and Heel Ball Index) showed no statistically significant differences between left and right footprints in females but in males all dimensions except BAB, BAH and HB index showed statistically significant difference between left and right footprints. Sexual differences were observed between male and female footprints for all dimensions. Studies has been conducted by Hazzaa et al. (2015) on Egyptian children ranged in age from 8 to 14 years found that flatfoot was not affected by age in both sexes but flatfoot was more in boys than girls. Studies conducted by Ozdinc and Turan (2016) found that the difference between age, height, weight and body mass index between the two groups of Turkish girls was insignificant. Positive correlations were found between body mass index and foot length, metatarsal width, heel width, and medial longitudinal arch contact width and halluxvalgus angle; between ballet starting age and metatarsal width, heel width; between duration of training and foot length, metatarsal width and halluxvalgus angle.

Studies on foot morphology and its association with height, weight and BMI are scanty among the pre-school children of Bengali Hindu ethnic population. Therefore this study is an endeavour to assess the morphological differences in anthropometric measurements on footprints among the preschool children and examine its association with height, weight and BMI. The present study also accentuates on the sexual differences in footprint measurements among the studied population and identifies the prevalence of flatfoot among the studied population

## Materials and Methods

The study was carried out among 160 pre-school children (80 boys and 80 girls), aged 3 to 6 years of two schools located at Raspunjee and Bakhrahat, under South 24 Parganas, West Bengal. Each age-group comprises of 40 children (20 boys and 20 girls). The study participants were healthy and free from any apparent symptomatic deformity of the foot. Participants with major medical diseases such as diabetes mellitus, diseases in heart, liver and kidney and cerebral palsy that could affect physical fitness were not included. Participants with musculo-skeletal disorders (such as clubfoot, limb deficiency and leg length discrepancy) and recent lower limb injuries or disorders in the foot bones which affect footprint measurements were excluded from the study. Participation in the study was voluntary and entirely based on written informed consents. School authorities and respective parents were previously informed of the study and written informed consent were obtained to confirm the participation of their children. Informed consent from the school authorities and respective guardians were obtained.

Three hundred and twenty bilateral foot prints were obtained from the study participants using ink stamp pad. After cleansing their feet, the participants were requested to step their soles on the ink-pad with minimal pressure and then the inked foot was transferred onto a plain white A4 size paper kept aside on a flat surface. A total of 11 measurements comprising of eight length dimensions and three breadth dimensions were obtained from left and right foot prints of each participants (Abledu et al, 2015; Jimenez-Ormeno et al, 2013). The contour has been drawn on the footprints accordingly. Weight and height has been measured following standard technique (Mukerji et al. 2007) using portable weighing machine and Martin's Anthropometer with rod compass.

The following measurements were taken on each footprint (Fig. 1a, Fig. 1b). The foot morphology measurements conducted on the foot prints were:

a) Foot length – The direct distance from the *pternion* point to the most anteri-

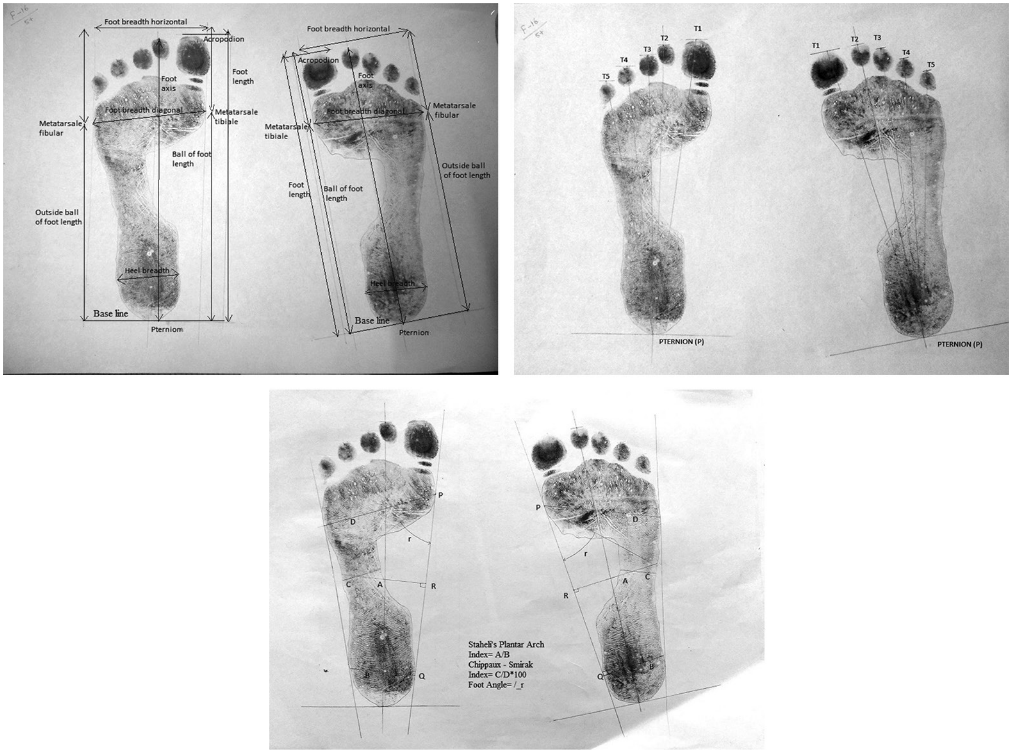


Fig. 1. Diagram of foot showing the landmarks and measurements

or point of the longest toe (first or second) measured parallel to the foot axis

b) Ball of foot length – The distance from the end of the heel to *the metatarsal tibiale* measured parallel to the foot axis
c) Outside ball of foot length – The distance from the end of the heel to the *metatarsal fibular*e measured parallel to the foot axis,
d) Foot breadth diagonal – The distance between the *metatarsal tibiale* and *metatarsal fibulare* of the ball cross section projected to the standing surface,
e) Foot breadth horizontal – The horizontal distance between *metatarsal tibiale* to *metatarsal fibular*e
f) Heel breadth – The breadth of position at 16% foot length straight from the *pternion* point to toe
g) T1 – Length measurement taken from the *pternion* to the most anterior point of toe 1
h) T2 – Length measurement taken from the *pternion* to the most anterior point of toe 2
i) T3 – Length measurement taken from the *pternion* to the most anterior point of toe 3
j) T4 – Length measurement taken from the *pternion* to the most anterior point of toe 4
k) T5 – Length measurement taken from the *pternion* to the most anterior point of toe 5

The foot axis has been considered as the line passing from *the pternion* to the tip of the second toe and the base line has been drawn extending from the *pternion* in both medial and lateral directions. Foot axis is perpendicular to the base line (Fig. 1).

The Staheli's Plantar Arch Index and Chippaux-Smirak Index (Sacco et al. 2015) were calculated (Fig. 1).

a) Staheli's Plantar Arch Index (SPAI) – Calculated as the ratio of the support width of the central region to the foot and of the heel region of the foot.
b) Chippaux-Smirak Index (CSI) – Calculated as the ratio between the smallest length of midfoot and the largest length of the metatarsal head region

Angular measurement include foot angle (Nikolaidu and Boudolos, 2006).

a) Foot angle – Obtained by calculating the angle of the first medial tangential line that connects the medial edges of the first metatarsal head and the heel and the second line that connects the first metatarsal head and innermost point of longitudinal arch region on the footprint (Fig. 1).

## Statistical Analysis

The data obtained were computed and analyzed using Statistical Package for Social Science (SPSS, version 18) computer software. Footprint measurements were compared for bilateral and sex differences using paired and unpaired t tests respectively. Since there were no significant differences between the measures of the left foot and right foot, subsequent analysis and results obtained were made with mean values between both feet (Jimenez-Ormeno et al. 2013). This was followed by descriptive statistical analysis for all the variables studied, grouping the children in different weight category (Underweight, healthy, Overweight) according to Body Mass Index (BMI) and comparing the children development of the morphology of the foot as for the weight category. A one way ANOVA (three weight levels) was utilized to compare the foot in the three weight groups. Karl Pearson's correlation coefficient was derived to find correlation between height, weight and foot dimensions. A *p* value of <0.05 was considered to be statistically significant, while $p \geq 0.05$ was considered to be statistically not significant.

Cut off BMI Values used for the classification of weight status were as followed:

- Underweight when BMI was less than 5th percentile.
- Healthy weight when BMI was from 5th percentile but less than 85th percentile.
- Overweight when BMI was from 85th percentile but less than 95th percentile.
- Obese then BMI was equal to or greater than 95th perecentile.

Classification of foot according to foot angle (Nikolaidu and Boudolas 2006) were as followed:

- Flatfoot – From 0 degree to 29.9 degree.
- Low flat foot – From 30.0 degree to 34.9 degree.
- Borderline – From 35.0 degree to 41.9 degree.
- No flat foot – Greater than equal to 42.0 degree.

## Results

Descriptive statistics for the foot measurements, foot angle and plantar arch indices of left and right feet of both boys and girls are presented in Table 1. An independent t-test was performed but no significant difference was observed between the measures of the left foot and right foot. Thus bilateral asymmetry is not present and subsequent analyses were made with mean values between both the feet as representative of each child's foot measures.

Table 2 shows the difference between male and female footprint dimensions.

Table 1. Mean and standard deviations of footprint measurements stratified by sex

| Foot print measurements | Boys (n-80) | | | Girls (n-80) | | |
|---|---|---|---|---|---|---|
| | Mean (SD) | | | Mean (SD) | | |
| | Left | Right | *p*-value | Left | Right | *p*-value |
| Foot Length (cm) | 16.29 (1.35) | 16.20 (1.46) | NS | 16.15 (1.32) | 16.13 (1.32) | NS |
| Foot Breadth diagonal (cm) | 6.62 (0.54) | 6.57 (0.53) | NS | 6.41 (0.50) | 6.43 (0.52) | NS |
| Foot Breadth horizontal (cm) | 6.47 (0.54) | 6.44 (0.54) | NS | 6.27 (0.46) | 6.27 (0.47) | NS |
| Ball of Foot Length (cm) | 12.06 (1.13) | 12.03 (1.09) | NS | 11.82 (0.96) | 11.86 (1.04) | NS |
| Outside ball of Foot Length (cm) | 10.62 (0.96) | 10.73 (1.02) | NS | 10.56 (0.91) | 10.61 (0.90) | NS |
| Heel breadth (cm) | 3.55 (0.39) | 3.52 (0.34) | NS | 3.47 (0.32) | 3.49 (0.37) | NS |
| T1 (cm) | 16.35 (1.33) | 16.32 (1.37) | NS | 16.17 (1.27) | 16.12 (1.32) | NS |
| T2 (cm) | 16.18 (1.40) | 16.14 (1.40) | NS | 16.00 (1.33) | 16.02 (1.30) | NS |
| T3 (cm) | 15.68 (1.34) | 15.66 (1.35) | NS | 15.47 (1.25) | 15.52 (1.23) | NS |
| T4 (cm) | 14.93 (1.24) | 14.92 (1.28) | NS | 14.68 (1.16) | 14.74 (1.12) | NS |
| T5 (cm) | 13.94 (1.16) | 13.94 (1.17) | NS | 13.71 (1.07) | 13.77 (1.06) | NS |
| Foot Angle (Degree) | 26.01 (11.03) | 28.30 (12.49) | NS | 28.31 (11.81) | 29.40 (11.88) | NS |
| SPAI | 0.85 (0.27) | 0.82 (0.24) | NS | 0.84 (0.23) | 0.81 (0.21) | NS |
| CSI | 41.39 (13.17) | 40.15 (13.17) | NS | 39.75 (12.26) | 40.31 (11.12) | NS |

Table 2. Sexual differences in footprint measurements

| Footprint measurement | Boys (n-80) mean (SD) | Girls (n-80) mean (SD) |
|---|---|---|
| Foot Length (cm) | 16.24 (1.38) | 16.14 (1.32) |
| Foot Breadth diagonal (cm) | 6.55 (0.64) | 6.42 (0.49) |
| Foot Breadth horizontal (cm) | 6.46 (0.53)* | 6.27 (0.45)* |
| Ball of Foot Length (cm) | 12.05 (1.09) | 11.85 (0.97) |
| Outside ball of Foot Length (cm) | 10.67 (0.94) | 10.58 (0.86) |
| Heel breadth (cm) | 3.53 (0.35) | 3.48 (0.32) |
| T1 (cm) | 16.34 (1.34) | 16.15 (1.28) |
| T2 (cm) | 16.15 (1.39) | 16.01 (1.31) |
| T3 (cm) | 15.67 (1.34) | 15.50 (1.23) |
| T4 (cm) | 14.92 (1.25) | 14.71 (1.13) |
| T5 (cm) | 13.94 (1.16) | 13.73 (1.04) |
| Foot Angle (Degree) | 27.10 (10.65) | 29.10 (10.52) |
| SPAI | 0.83 (0.23) | 0.82 (0.20) |
| CSI | 40.76 (12.54) | 40.12 (10.91) |

*$p<0.05$.

Apart from foot breadth horizontal ($p<0.05$), all the footprint dimensions, foot angle, plantar arch indices (SPAI and CSI) showed no statistically significant differences between the boys and girls.

The results of the correlation between height, weight and all footprint measurements, foot angle, SPAI and CSI are presented in Table 3. In boys, all the footprint measurements showed significant positive correlation with both height and weight ($p<0.05$) and SPAI showed significant negative correlation with both height and weight ($p<0.05$). CSI showed statistically significant negative correlation with height ($p<0.05$) and negative correlation (not statistically significant) with weight.Similar results were also observed among the girl participants.

Figure 2 shows the percentage distribution of weight status among the studied children stratified by sex. The prevalence (overall age and sex combined) of underweight children was 31.9%,

Table 3. Pearson's correlation (r) between height weight foot measurements, foot angle and Plantar Arch Indices stratified by sex

| Variables | Foot Length (cm) | Foot Breadth Diagonal (cm) | Foot Breadth Horizontal (cm) | Ball of Foot Length (cm) | Outside Ball of Foot Length (cm) | Heel Breadth (cm) | T1 (cm) | T2 (cm) | T3 (cm) | T4 (cm) | T5 (cm) | Foot Angle (degree) | SPAI | CSI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Boys | | | | | | | | | | | | | | |
| Height | 0.90* | 0.65* | 0.77* | 0.88* | 0.81* | 0.76* | 0.91* | 0.89* | 0.88* | 0.88* | 0.88* | 0.43* | –0.41* | –0.40* |
| Weight | 0.75* | 0.64* | 0.78* | 0.72* | 0.68* | 0.73* | 0.75* | 0.74* | 0.73* | 0.74* | 0.76* | 0.25* | –0.23* | –0.21 |
| Girls | | | | | | | | | | | | | | |
| Height | 0.86* | 0.69* | 0.70* | 0.83* | 0.79* | 0.61* | 0.86* | 0.87* | 0.84* | 0.84* | 0.84* | 0.33* | –0.39* | –0.33* |
| Weight | 0.74* | 0.68* | 0.72* | 0.71* | 0.68* | 0.70* | 0.74* | 0.75* | 0.74* | 0.76* | 0.74* | 0.22* | –0.23* | –0.18 |

SPAI – Staheli's Plantar Arch Index; CSI- Chippaux-Smirak Index; *$p<0.05$.

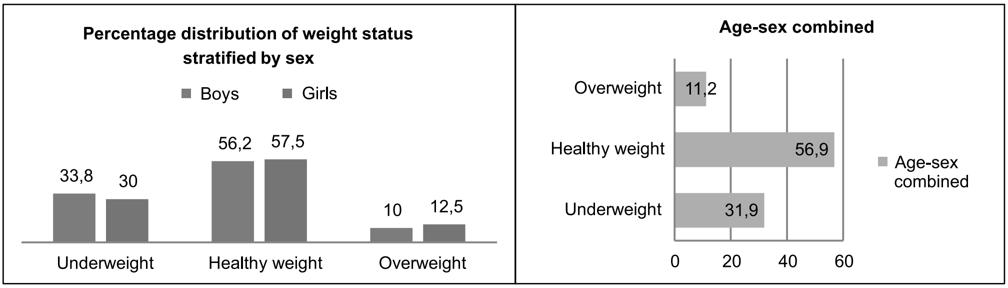


Fig. 2. Percentage distribution of weight status in the study sample

Healthy weight 56.9% and Overweight 11.2% is also reflected in the figure.

A morphological difference in the foot according to the weight status is presented in Table 4. The overweight weight category represents both the overweight and obese children. Morphological measurements of the foot increase differently depending on weight category i.e. overweight children have larger feet than healthy weight children and healthy weight children have greater foot dimensions than their underweight counterparts.

Comparison by weight category with foot measures shows significant differences between the underweight, healthy weight and overweight children in all variables ($p<0.05$) except foot angle, SPAI and CSI. Moreover CSI was greater in overweight children, SPAI in underweight children and foot angle in healthy weight children.

The prevalence of flat footedness stratified by sex is presented in Figure 3. The prevalence of flatfoot was higher among the boys (62.5%) than the girls

Table 4. Association of footprint measurement with weight status (results of ANOVA)

| Footprint measurements | Weight status (n-160) | | |
|---|---|---|---|
| | Underweight Mean (SD) | Healthy Weight Mean (SD) | Overweight Mean (SD) |
| Foot Length (cm) | 15.71 (1.21)* | 16.25 (1.32)* | 17.23 (1.23)* |
| Foot Breadth diagonal (cm) | 6.30 (0.43)* | 6.50 (0.60)* | 6.93 (0.55)* |
| Foot Breadth horizontal (cm) | 6.14 (0.40)* | 6.40 (0.48)* | 6.80 (0.55)* |
| Ball of Foot Length (cm) | 11.61 (0.92)* | 12.00 (1.04)* | 12.68 (0.95)* |
| Outside ball of Foot Length (cm) | 10.32 (0.79)* | 10.68 (0.90)* | 11.25 (0.88)* |
| Heel breadth (cm) | 3.37 (0.30)* | 3.52 (0.31)* | 3.82 (0.36)* |
| T1 (cm) | 15.79 (1.15)* | 16.30 (1.32)* | 17.21 (1.31)* |
| T2 (cm) | 15.60 (1.19)* | 16.14 (1.32)* | 17.13 (1.30)* |
| T3 (cm) | 15.13 (1.15)* | 15.65 (1.26)* | 16.58 (1.21)* |
| T4 (cm) | 14.37 (1.05)* | 14.88 (1.19)* | 15.77 (1.03)* |
| T5 (cm) | 13.44 (0.98)* | 13.88 (1.10)* | 14.71 (0.93)* |
| Foot Angle (Degree) | 26.92 (11.02) | 28.71 (10.40) | 27.97 (10.65) |
| SPAI | 0.84 (0.22) | 0.82 (0.22) | 0.82 (0.19) |
| CSI | 40.27 (11.19) | 40.52 (12.50) | 40.56 (9.41) |

*$p<0.05$.

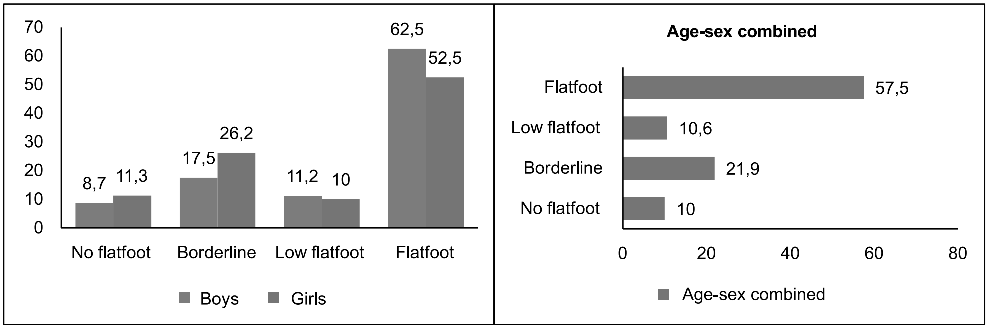


Fig. 3. Prevalence of flatfoot among the studied population

(52.5%). However Figure 3 reveals that overall (age & sex combined) 57.5% of the children were flatfoot, 10.6% were low flatfoot, 21.9% were in the borderline and 10% were with no flatfoot.

## Discussions

The results of the present study indicated that there were no significant differences between the measures of the left foot and right foot. This finding is in accordance with the studies conducted by Jimenez-Ormeno et al. 2013; Mauch et al.2008a, 2008b;Hemy et al. 2013. Conversely, various studies have reported the existence of asymmetry in different footprint dimensions (Ukoha 2013; Krishan 2008; Moorthy 2014; Abledu et al. 2015), suggesting that left and right feet of the same individual may not make identical footprints.

Descriptive statistical analysis for all the variables studied showed that except foot breadth horizontal, there was no statistically significant difference between the boys and the girls. The present finding is in contrast with Abledu et al.(2015), Krauss et al.(2008),Wunderlich et al.(2001), Krishan and Sharma (2007), Krishan et al.(2012), Fessler et al.(2005), Kanchan et al.(2008), Agnihotri et al.(2007a, 2007b) where all the footprint dimensions were significantly greater in boys than girls. However, this study is in consistent with Hernandez et al 2006 where SPAI showed no significant difference in terms of gender.

The height and weight of the children showed a positive correlation with all the footprint measurements in both the males and females. Ozdinc and Turan (2016) showed similar results among the girls taking ballet classes in Turkey.

From the results obtained in the analysis of the morphology of the foot according to weight category, it is found that the feet of underweight children are different from those of healthy weight children. Nonetheless, the feet of healthy weight children differ from those of the overweight children. Thus, the dimensions of the feet were greater in overweight children and were also higher in healthy weight than underweight children, when comparing all the variables of foot measures in three different weight categories, statistically significant results were obtained. This finding is consistent with the general agreement that with increase in BMI, the foot measures also increases (Jimenez-Ormeno et al. 2013; Chen et al

2009; Mauch et al. 2008; Morrison et al. 2007; Riddiford et al. 2000).

The present study shows the prevalence of flat footedness in the studied population. The percentage distribution of flatfeet was higher in boys than girls. Our results confirms the findings of Chen et al (2009); Chang et al (2010); (2014); El et al (2006); Gracia et al (1999).

## Conclusions

Based on the results of this study, it can be concluded that bilateral asymmetry is not present among the studied participants. Boys and girls foot significantly differ for foot breadth horizontal ($p<0.05$). Morphological measurements of the foot are higher among the boys than girls and it increases with each age-group (except heel breadth in girls) and weight category. Significant difference exists between the foot dimensions of underweight, healthy and overweight participants ($p<0.05$). Thus morphological differences in the foot according to the weight category highlights that overweight children have larger feet than their healthy weight and underweight counterparts. Height and weight has been found to be positively correlated ($p<0.05$) with all the variables except SPAI andCSI (negative correlation at $p<0.05$). Prevalence of flatfoot was observed among the studied population with no statistical difference between the boys and girls.

The results thus provide a podium for intricate studies in the future. With the identification of flatfoot, prognosis can be provided to families and societies for the rectification of flatfoot among the children at an early age.

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### Authors' contributions

NB carried out the data acquisition, dataset tabulation, statistical analysis and drafted the manuscript. MG conceived and designed the study, analyzed the data and helped to draft the manuscript.

### Conflict of interest

The authors declare that they have no conflict of interest.

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