Age, Sex, Body Mass Index, and Laterality in the Foot Posture of Adolescents: A Cross Sectional Study

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ABSTRACT

Objective: To investigate the relationship between the right and left foot posture in terms of body mass index (BMI), sex, and age in adolescents aged 10 to 14.

Methods: A total of 1400 adolescents were included. For assessment, the Foot Posture Index (FPI-6) was used. Each foot was assessed and ranked as supinated, normal, or pronated by the sum of the FPI-6 criteria. Each criterion was scored on a scale of −2 to +2, with negative for supinated and positive for pronated posture. A linear mixed model with repeated measures was used for statistical analysis.

Results: Sex, BMI, and right and left foot are associated with FPI-6. The total score attributed for male sex ($\beta = 0.29$, $P = .04$) and the left foot ($\beta = 0.73$, $P < .001$) was higher (male right foot: mean ± standard deviation [SD], 3.09 ± 2.84, male left foot: 3.76 ± 2.80; female right foot: mean ± SD, 2.28 ± 2.61, female left foot: 3.45 ± 2.66; laterality for left foot: mean ± SD, 3.55 ± 2.71, laterality for right foot: mean ± SD, 2.82 ± 2.7). On the other hand, the correlation coefficient for the BMI was negative ($\beta = -0.08$, $P = < .001$), which means that the higher the BMI the lower the score attributed to the FPI-6.

Conclusions: The FPI-6 is positively related to the male sex and the left foot—that is, the predicted score is higher, so the feet tend to present with a tendency to pronation. Although BMI is associated with FPI-6, it was not possible to establish a relationship between high BMI and pronation of the feet. (J Manipulative Physiol Ther 2020;00;1-9)

Key Indexing Terms: *Posture; Foot; Adolescent; Body Mass Index*

INTRODUCTION

The human foot reaches its full development in adolescence. Specifically, it can be said that it grows rapidly up to 3 years of age and, after this phase, maintains a pattern of continuous growth in both sexes. Around 12, the feet of girls stop growing, but boys exhibit a pattern of development to 15 years of age.[1]

The evaluation of foot posture can be affected by extrinsic and intrinsic factors. Extrinsic factors correspond to the place of residence (urban or rural), level of physical activity, types of footwear, and age at which the use of footwear begins. Intrinsic factors are categorized as biological (sex, age, ligamentous laxity, family history) or anthropometric (body composition).[2-5]

Among the intrinsic factors, the most controversial in the literature is still the body mass index (BMI). Some studies in children and adolescents have shown that overweight and obese subjects have distinct morphology[6] and more pronated feet,[7] that is, with larger feet and greater circumference. However, other studies in adolescents and adults do not establish this relationship.[8-10] One of the hypotheses for the discrepancy in results is the methodology and target population characteristics being studied, for example, age.[11]

The shape of the foot is influenced by age and the most frequent postural change is the pronated or flat foot, which corresponds to a reduction in the height of the medial longitudinal arch (MLA) and calcaneal valgus.[2] Studies have

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Paper submitted February 10, 2018; in revised form June 25, 2018; accepted November 2, 2018.
0161-4754

https://doi.org/10.1016/j.jmpt.2018.11.035

shown that the prevalence of pronated feet in children under 3 years of age is quite high, and its prevalence decreases with advancing age because the arch develops in the first decade of life, more specifically from 2 to 6 years of age.[1,12] In this sense, it has been observed that young people (3-17 years) and elderly people (60 and over) have more pronated feet than adults (18-59 years).[9]

In addition to age, it is important to emphasize the influence of sex on foot posture because it has been observed that boys present more cases of pronated feet than girls.[3,13,14] Mickle et al[14] corroborated this finding by comparing children from 3 to 5 years of age. The authors found that boys showed a thicker fat pad along the MLA, which suggests a later development because, in girls, the fat pad has been resorbed by this age. Other studies have also shown that boys more often have pronated feet and that considerable changes occur from childhood to adolescence.[3]

There are several methodologies for assessment and postural foot classification. Among them, we highlight the Foot Posture Index (FPI-6)[15] for being valid and reliable[16] and for allowing a multidimensional assessment in all planes of movement, opposite the footprints, which has as its focus the analysis of the midfoot region.[17,18] The advantages of FPI-6 include the low cost, the reproducibility of the data, and the clinical access of the anatomical measurements to be palpated. Unlike an X-ray examination, this does not require expensive technology involving radiation.[15]

Although some studies have already investigated the anthropometric and biological determinants of foot posture, this study differs as to the research methodology used and the target population (adolescents), providing greater clarity regarding these variables in this period of life marked by intense body modifications.[19] Despite the growing number of studies in this line of reasoning, it seems there is still no consensus on the influence of sex, BMI, age, and laterality (right and left side) in foot posture in adolescents, so it is important to better elucidate the effect of these factors.

It is important to note that, in a study using the same methodology as this research in the adult population, no significant differences were found between the position of both feet (right and left)[20]; however, it is essential to perform this observation in adolescence, as a phase of life marked by development and physiological and anatomical adaptations,[19] so that other findings can most likely be verified.

Identifying the parameters that affect the normal development of the foot during adolescence facilitates the development of an understanding of important risk factors related to any misalignment of the foot and of other dysfunctions (eg, musculoskeletal disorders such as sprains or patellofemoral pains) or foot injuries. The posture of the foot can be altered by anthropometric factors, among them excess body mass. A study by Smith et al[21] identified evidence that obese children and adolescents presented greater prevalence of fractures, self-reported ankle and foot problems, valgus and hyperextension of the knees, and pain symptoms in particular segments of the lumbar spine, knees, ankles, and feet. This had a direct impact on the level of physical activity (exercises and sports) of the child or adolescent and quality of life in general. These changes affect body balance and performance for dynamic motor coordination.[22] Understanding foot posture in adolescents according to FPI-6 criteria may yield reference values for assessing the anthropometric characteristics of the feet. Knowledge of these parameters will support more accurate therapeutic treatments for the rehabilitation of anthropometric foot changes, such as pronation and supination, and will help in health surveillance.

Thus, the primary objective of this study was to characterize foot posture in school children aged 10 to 14 years and the secondary was to verify that there is a relationship between foot posture classified by the FPI-6 with BMI, sex, age, and right and left laterality. Our main hypotheses are that there will be a positive relationship with the male sex, age, and high BMI; that is, in all conditions, the foot will present as more pronated. It is believed that there will be no postural differences between the feet, taking into consideration what has been presented in the literature in adults.

Materials and Methods

Location and Population Study

This is a cross-sectional study with a convenience sample. Data from this research were collected in conjunction with a doctoral project titled "Prevalence of idiopathic scoliosis in adolescents in cities in the state of São Paulo."[23,24] Data were collected between 2013 and 2014 in public schools, administered by the School Board of Mogi Mirim—Amparo and Pedreira—in São Paulo, Brazil. The study was approved by the Ethics Committee of the Medical School of the University of São Paulo (protocol number 254/12)[25] and should be considered a complement to another study already published by the same authors, thus the methodology is the same.[25] The informed consent forms signed by adolescents or responsible parents (children) were collected for all adolescents included.[21]

The group was homogeneous, and the adolescents had similar ethnicity and environmental cultural uniformity, with the same traditions, knowledge, skills, language, and behavior. In addition, the 2 cities had the same socio-economic conditions.

The inclusion criterion was that the adolescents were from 10 to 14 years of age. Exclusion criteria included the presence of congenital or acquired deformities of the foot, neurological diseases, diabetic neuropathy, foot or ankle injury (such as fracture, sprains, and dislocations), collagen disorders (such as Marfan's syndrome and benign joint

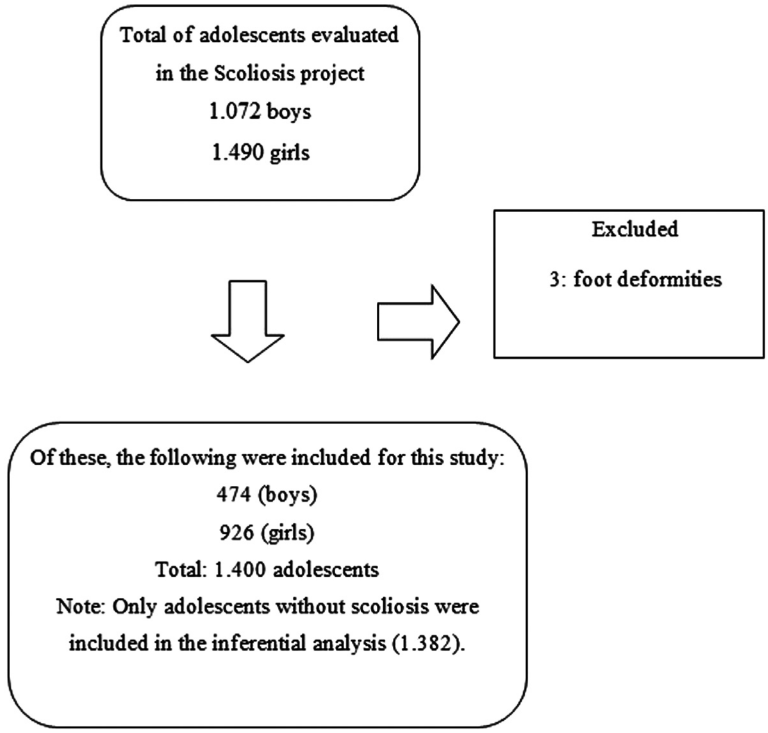

Fig 1. *Fluxogram.*

hypermobility), subjects with only one limb, and discrepancies in the length of the lower limbs ≥1.5 cm.

The sample size calculation (Fig 1) was based on the estimated mean value of the FPI-6 score, which was carried out using G*Power 3.0 software, considering a moderate effect size ($F = 0.25$), a statistical power of 95%, and a significance level of 5%. Linear regression was assumed, and factorial design based on age, sex, and BMI was used as a reference for the information presented in Neter et al,[26] which aimed to detect a mean difference of 1 in the mean scores of the subpopulations.

The possibilities of 2 types of error were controlled for type I (rejecting that the population means that these groups are the same) and type II (accepting that the average populations of these groups are the same). The type II error probability was defined as power. A number of combinations were used to obtain the following sample size: 95% power with a type I error probability of 5%, resulting in 1364 subjects.

FPI-6 Measurements

A total of 1400 subjects from 10 to 14 years of age participated voluntarily in the study (926 girls and 474 boys) with a total of 2800 feet. We evaluated more adolescents considering possible sample loss.[25]

Each adolescent was instructed to stand barefoot on a wooden base 19 cm high, 37 cm wide, and 44 cm long. The base had a line 10 cm from its rear edge for positioning the calcaneus, and another line that divided it into 2 equal parts and intersected with a third line, forming an angle of 45 degrees. A rectangle of ethyl vinyl acetate 7.5 cm × 20 cm was positioned in the middle of the central line to allow standardization of the distance between the feet.[25]

All subjects were instructed to position their upper limbs along the trunk with eyes directed forward without any movement, such as inclinations and rotations, which could interfere with the measurement. FPI-6 criteria were used to quantify foot posture. This form of evaluation has 6 anatomical criteria, each of which are graded from 0 (neutral), to +1 or +2 (pronated) and −1 or −2 (supinated)[27]:

(1) Talar head palpation, in which the head of the talus is palpated in the front of the ankle in medial and lateral aspects. Negative values indicate that the talar head is more prominent in the lateral region, whereas positive values show that it is more prominent in the medial region.[27]
(2) Supra and infra lateral malleolar curvature, which are seen at the back of the ankle region. Negative values indicate that the curve below the lateral malleolus is straighter or convex to the top, whereas positive values mean that this curve is more concave.[27]
(3) Calcaneal frontal plane position, where the orientation of the calcaneal tendon on the supporting surface is the reference. Negative values indicate that the

calcaneus is in an inverted position, whereas positive values show that it is in an everted position.[27]

(4) Bulging in the region of the talonavicular joint. Negative values indicate that this region has a concave appearance, with positive values indicating a convex appearance.[27]

(5) Height and congruence of the medial longitudinal arch. Negative values indicate that the arch is high and more acute at the posterior end. Positive values indicate that the foot is flattened at the center of the arch or in contact with the ground.[27]

(6) Abduction or adduction of the forefoot on the rearfoot. Here, the foot should be viewed in line with the longitudinal axis of the calcaneus (too many toes sign). Negative values indicate the visibility of the medial toes, with positive values showing the lateral toes.[27]

Scores for each item are added up. A total score of 0 to +5 ranks as normal, +6 to +9 as pronated, 10+ as highly pronated, −1 to −4 as supinated, and −5 to −12 as highly supinated. The final score is a number between −12 and +12 (highly supinated and highly pronated, respectively).[27]

The FPI-6 assessment was conducted by 2 previously trained physical therapists. Intra-rater reliability was tested in 248 adolescents with a 7-day interval and was classified as substantial (Kappa = 0.62). Inter-rater reliability was tested in 280 subjects on different days owing to the logistics of the research, and was classified as moderate (Kappa = 0.52).[28]

Anthropometric Variables

Anthropometric data such as height, weight, and BMI were collected. For BMI classification the Cole index was used.[29,30]

Statistical Analysis

In order to study possible relationships of sex, age, and BMI with the FPI-6 total score in the evaluation of the position of the right and left feet, we used a linear mixed model with repeated measures.[31] Opting for this type of model is due to the fact that it considers measures (ratings) carried out on the same individual; thus, it considers the variations among adolescents and incorporates possible correlations of the ratings of feet of the same individual.

At first, a model was set, called the initial model, with all the variables described earlier and the interactions between age and sex, age and BMI, sex and BMI, and among age, BMI, and sex. To create a more concise model, it was decided to adopt the following variables selection strategy. Multiple variables that had no significance were removed from the established model, that is, those variables with a *P* value greater than 5% were removed from the model, resulting in the final model adjusted only for variables age, BMI, sex, and foot. According to estimates by this model, it was observed that the variable age was not significant at a level of 5%. As the age variable had the highest *P* value (.35), it was decided to fit a model without it. Estimates of the final model parameters are shown in Table 1. To check the quality of the final adjustment, a graphical analysis was made based on conditional residuals.[32]

Table 1. *Final Model Parameters Estimates*

Effect	Estimated coefficient	Standard error	t	*P* value
Intercept (α_0)	4.30	0.37	11.68	< .001
Male (β_2)	0.29	0.15	2.04	.04
BMI (β_3)	-0.08	0.02	-4.33	< .001
Left foot (β_{10})	0.73	0.04	18.04	< .001
Random effects				
Intercept (τ^2)	6.07			
Residue (σ^2)	1.16			

BMI, body mass index; *t,* multiple linear regression analysis considering statistical differences, $P > .05$.

The classifications described by Mukaka[33] were used for the correlations. The value of r is always between +1 and −1. To interpret this value, the correlation classification was 0.90 to 1.0 very high positive (negative), 0.70 to 0.90 high positive (negative), 0.50 to 0.70 moderate positive (negative), 0.30 to 0.50 (low positive (negative), and 0.0 to 0.30 negligible correlation.

The ethnicity of the subjects evaluated is a variable that could influence the results, and this was considered. We were careful to control for this in the model with the subjects analyzed having environmental cultural uniformity, with the same traditions, knowledge, skills, language, and behavior. In addition, the 2 cities had the same socio-economic conditions.

Results

In Table 2, it can be observed that the distribution of adolescents by age and sex is not homogeneous. The lowest percentage for adolescent age groups corresponds to 10-year-olds (8%) and the highest corresponds to 12-year-olds (26%). Moreover, the proportion of girls was greater than the boys, representing 66% of the total sample.

It can also be observed in Table 3 that, for all BMI ranges, the proportions of adolescents evaluated with pronated or highly pronated feet are larger for the left foot when compared with the right foot; in addition, the frequency of nonobese individuals with highly supinated feet is very small.

Table 4 shows that the mean score for the assessment of the left foot (3.55) was greater than that for the right foot

Table 2. *Distribution of Adolescents by Sex and Age*

Age (y)	Sex				Total	
	Female		Male			
10	72	(63%)	43	(37%)	115	(8%)
11	208	(67%)	104	(33%)	312	(22%)
12	234	(64%)	130	(36%)	364	(26%)
13	230	(67%)	113	(33%)	343	(25%)
14	182	(68%)	84	(32%)	266	(19%)
Total	926	(66%)	474	(34%)	1400	(100%)

(2.82). Moreover, Table 1 indicates that the coefficient related to the effect of the left foot was high and positive ($\beta = 0.73$); therefore, it was expected that the values of FPI-6 scores assigned for the left foot of the evaluation would be higher than those of the right foot; that is, the left foot was more pronated.

In Table 1, it can also be noted that the coefficient related to the effect of the male sex was low and positive ($\beta = 0.29$); thus, higher FPI-6 scores can be expected to be attained for boys. Corroborating this fact, as can be seen in Fig 2, the predicted score in the evaluation of the feet of boys was higher than that of girls.

On the other hand, the coefficient related to the effect of BMI was negligible and negative ($\beta = -0.08$). This indicates that the higher the FPI-6 score is the lower will be the BMI (Table 1 and Fig 2).

Discussion

The hypotheses of this study have not been fully confirmed because the foot posture was shown to be related only to the male and, interestingly, to the left foot. As for BMI and age, it is not possible to say from our findings that these are crucial determinants in foot posture.

It can be seen through our data and other studies that adolescent males have more cases of pronated feet, as the predicted score in the evaluation of boys is higher than in girls.[3,13,14] This finding is due to the fact that boys' feet reach maturity later than girls, as was seen in the study of Stavlas et al,[13] who found significant differences in the positions of the feet between the sexes in ages 7, 9, 11, 14, and 15 years.

It is possible that the score assigned to the left foot assessment was higher than for the right foot. Although Rokkedal-Lausch et al[20] did not find significant differences between the feet, it is known that there is an asymmetry in the human body, and the left foot is more related to the bearing function,[34-36] whereas the right is more related to the propulsion of the body during locomotion.[36] In this sense, because postural assessment is performed in a static posture, the foot of support probably takes a more pronated feature as a result of increased weight bearing.

Table 3. *Distribution of Adolescents by Postural Classification of the Right and Left Foot, According to BMI Classifications*

Right foot												
BMI classification	Highly supinated		Supinated		Normal		Pronated		Highly pronated		Total	
Thinner	0	(0%)	7	(6%)	82	(75%)	17	(16%)	3	(3%)	109	(100%)
Normal	1	(<1%)	39	(5%)	671	(78%)	134	(16%)	11	(1%)	856	(100%)
Overweight	1	(<1%)	19	(6%)	248	(79%)	44	(14%)	0	(0%)	312	(100%)
Obesity	4	(4%)	8	(8%)	80	(76%)	13	(12%)	0	(0%)	105	(100%)
Total	6	(<1%)	73	(5%)	1081	(78%)	208	(15%)	14	(1%)	1382	(100%)

Left foot												
BMI classification*	Highly supinated		Supinated		Normal		Pronated		Highly pronated		Total	
Thinner	0	(0%)	5	(5%)	82	(75%)	19	(17%)	3	(3%)	109	(100%)
Normal	0	(0%)	27	(3%)	618	(72%)	193	(23%)	18	(2%)	856	(100%)
Overweight	0	(0%)	15	(5%)	231	(74%)	64	(21%)	2	(1%)	312	(100%)
Obesity	2	(2%)	8	(8%)	80	(76%)	14	(13%)	1	(1%)	105	(100%)
Total	2	(<1%)	55	(4%)	1011	(73%)	290	(21%)	24	(2%)	1382	(100%)

* Based on Cole index [29,30] *BMI,* body mass index.

Table 4. *Descriptive Measures of the Values of the FPI-6 Total Score of Adolescents for Each Foot*

Foot	Mean	Standard Deviation	Minimum	Q1	Median	Q3	Maximum
Right	2.82	2.7	−7	1	2	4	12
Left	3.55	2.71	−6	2	3	5	12

Q1, interquartile interval; *Q3,* interquartile interval.

Furthermore, it is important to point out that adolescence is a period of transition when there are intense musculoskeletal changes.[19] In this context, it is plausible to consider the issue of flexibility or body hypermobility, and although it was not determined in this study, previous research has shown that subjects with greater flexibility present the most pronated feet,[37] either bilaterally or unilaterally,[38] and that perhaps even in adolescence this pattern of postural adaptation has remained.

Age was not a determining factor in foot posture in this sample. Although some studies show that there are differences between the age groups, especially in the extremes, that is, children and the elderly,[3,9,13,39,40] it was not possible to confirm the relationship between age and the foot posture in adolescents. Perhaps this was because the age groups included were very close (10 to 14 years), and thus adolescents exhibit a very similar posture. This finding is corroborated by another study that used the same methodology as ours and also found no relationship between age and posture of the foot.[37]

It is important to emphasize the results regarding the relationship between high BMI and pronation. It should be noted that this finding is not fully consistent in the literature[6,7,8,11] because some studies have found that subjects who are overweight and suffer from obesity have more pronated feet than others, but we did not find such a relationship. Corroborating this finding, Evans and Karimi[8] examined the foot posture and BMI of 728 subjects from 3 to 15 years of age and found no association between increased BMI and pronation. Another study also evaluated the same variables in 140 volunteers who were closer in age, 7 to 10 years, and noted that the heavier children had less flat feet.[11]

On the other hand, some authors claim that overweight and obese individuals have pronated and larger feet (width, length), and in addition, it has been shown that excess body mass interferes with development, making it more gradual at puberty.[6] Riddiford-Harland et al[41] conducted a study to see whether the feet of subjects with higher BMI were flat or pronated, or whether they had thicker fat pads along the MLA, giving the appearance of a flat foot due to

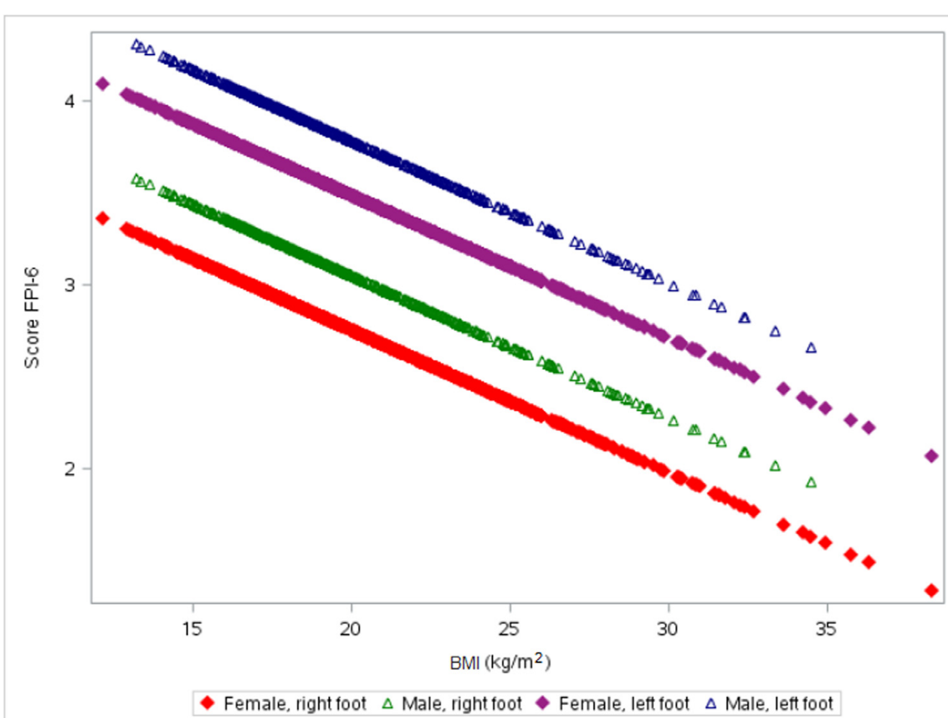

Fig 2. *Predicted values of FPI-6 total score for BMI (kg/m^2). BMI, body mass index; FPI-6, foot posture index.*

greater ground contact. These authors concluded that, despite the fat pad being thicker, the more obese children also displayed a lowered MLA height. However, this finding further strengthens the doubt about the influence of adipose tissue on the arch indirect measures because it is likely that an excess of it can mask the precise location of the navicular and lead to misinterpretations.

Another hypothesis for this finding is that, owing to excess body weight, these adolescents have adopted an adaptive postural mechanism for improving or maintaining balance, as it has been shown in the literature that high BMI and poor posture of the feet are associated with deficits of the same.[42-44]

In summary, this study raises some interesting and intriguing hypotheses. Although male sex is a variable that influences foot posture, as has been shown by other studies,[12,14,45] we find that the left foot is more pronated. However, our results cannot display a variable to explain this finding, although one can make hypotheses about the questions concerning laterality and muscle flexibility. Moreover, it should be noted that high BMI and age did not have an influence on foot posture, unlike other studies that confirm the opposite. Although Pfeiffer et al[12] and Chen et al[38] demonstrated the relationship between these variables, it is important to consider the target population being studied. Both studies were conducted in children (3-6 years of age), and at that stage of development, a more pronated foot posture is expected because the child has not reached full growth nor maturity. Thus, this is a finding that cannot be universalized to other populations in addition to adolescents.

In this sense, this study has great clinical and scientific importance, as it adds knowledge and raises hypotheses about anthropometric determinants in foot posture of adolescents aged 10 to 14 years. Thus, the data can be used as a benchmark for a health surveillance process assisting in clinical decision-making mainly in boys with left foot issues. Understanding foot posture in adolescents according to FPI-6 criteria is important because children with flat feet, for example, are more likely to have knee or hip and back symptoms and reduction in vertical ground reaction force.[46]

Limitations

Some limitations should be identified, such as the discrepancy in sample size in sex and BMI classifications (926 girls and 474 boys in total, 871 adolescents with normal BMI and 312 with overweight), so the groups were not homogeneous in relation to the number of subjects for statistical analysis. However, we believe that the data can be extrapolated to populations with similar characteristics; that is, adolescents in urban areas and public schools with similar levels of physical development. As a future consideration, it is suggested that longitudinal studies be conducted to track changes in the feet of adolescents, as it has been shown that after 11.8 months, follow-up in children show postural changes that previously were not expected.[45]

Conclusion

The FPI-6 in adolescents aged 10 to 14 years is related to the male sex and the left foot—that is, in both conditions, the predicted score is higher so the feet tend to present with a tendency to pronation. In relation to BMI, however, a negative relation is observed—that is, the score attributed to the FPI-6 in the adolescents who are classified as overweight and obese is lower. However, regardless of the sex and BMI of the adolescent and the foot on which the evaluation is performed, the foot posture is expected to be classified as normal.

Acknowledgments

The authors are grateful to the CEA USP- Centro de Estatística Aplicada da Universidade de São Paulo for the statistical analysis.

Funding Sources and Potential Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): B.K.G.C., P.J.P., S.M.A.J.
Design (planned the methods to generate the results): B.K.G.C., P.J.P., S.M.A.J.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): B.K.G.C., S.M.A.J.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): B.K.G.C., P.J.P., N.L.J.P.R., R.M.A.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): A.P.R.
Literature search (performed the literature search): B.K.G.C.
Writing (responsible for writing a substantive part of the manuscript): B.K.G.C.

Practical Applications

- The FPI-6 is related to the male sex and the left foot; that is, the feet tend to present with a tendency to pronation.
- It was not possible to establish a relationship between high BMI and pronation of the feet.
- This study can be used as a benchmark for health surveillance, assisting in clinical decision making.

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