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Foot types of young Indian adolescents analyzed by anthropometric measurements of foot and FPI-6: A correlational study

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Abstract
Background and objectives: The variation in the foot may lead to gait and postural defects in all age groups. The Foot Posture Index (FPI) is a validated method for quantifying standing foot posture, and is being used in a variety of clinical settings. The use of foot anthropometric measurements have found a salient role in the analysis of the foot types by using Navicular height (NH) and Relaxed Calcaneal Stance Position (RCSP) measurements. The aim of this research work was to determine various foot types amongst a heterogenous group of young Indian children aged between 11 to 16 years and to find the relationship between the results of FPI-6 and Anthropometric measurements.
Methods: The study was conducted in schools of South Bangalore and children were recruited as per the inclusion/ exclusion criteria. Permission was obtained from the school authorities and an informed consent was taken from parents and the children were evaluated by the researcher using FPI-6 and anthropometric measures using standardized techniques. The data obtained was recorded and analyzed.
Results and Conclusion: Pearson's correlation coefficient (r) showed a large correlation both in adolescent girls and boys between FPI-6 and Anthropometric measurements which was statistically significant at $p<0.001$. Hence, like Anthropometric measurements, Foot Posture Index (FPI-6) may be used as an appropriate, accurate clinical tool in assessing and classifying foot types in young Indian adolescents.

Keywords: Foot types, young Indian adolescents, foot posture index- 6 (FPI-6), Navicular height (NH), relaxed calcaneal stance position (RCSP)

Introduction

The human foot is a complex anatomical marvel, the very structure and dynamics of which establishes base for static stance and locomotor abilities. It is divided into 3 anatomic regions- the hind foot/ rear-foot (talus and calcaneus) the mid-foot (navicular, cuboid, and 3 cuneiforms) and fore-foot (metatarsals and phalanges). The longitudinal arch of the foot is not present at birth and slowly develops during childhood, usually about age 5-6 [1].

Since the first description of flat foot by the ancient Greek physician Galen, the height of the medial longitudinal arch has been the focus of considerable attention in the biomedical literature. A range of factors, including age, gender, ethnicity, and the wearing of footwear are thought to influence the structure of the arch. Arch height is also thought to have considerable functional significance, as several studies have reported that a range of arch height measurements influence the motion of the lower limb, affect balance ability and affect predisposition to overuse injuries [2].

The children start showing evidence of development of foot arch and alignment once they start walking independently [3]. The foot grows faster than the rest of the body and achieves three quarters of its mature length by the time the child is 7 years old although some may take until 10 or 11 years to complete development [4, 5]. So it is an accepted fact that the foot complex generally develops the arches by adolescence which is an age between 10-19 years as defined by the UN (United Nations).

The ankle and foot complex play a critical role in maintaining erect posture, as also in adaptation to supporting surfaces, in correcting postural sway in single limb stance, in shock absorption and in transition of ground reaction force (GRF) in order to aid the push off during normal gait [6].

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Variations and deviation from normal foot types in children always deems attention and calls for conservative or surgical management strategies to be employed. A rigid flat foot apparently requires prompt medical intervention while flexible flatfoot in children almost never causes any problems although if it persists into adolescence some may experience aching along the medial arch at the bottom of the foot. Symptoms begin to develop as the contracted achilles tendon limits full ankle dorsiflexion thus transferring forces to mid foot leading to breakdown of tarsal bones and resulting in a flat or rocker bottom foot with calcaneus valgus and navicular drop which is apparent when standing [1, 7].

Some variations in foot morphology, such as flat or high arched foot type, also have long been recognised to cause tissue stress that result in injury [8]. Although there are many variations of flat- or high-arched feet that may or may not be functionally abnormal, some prospective studies provide evidence that flat or high-arched feet increase the risk of lower limb injury [9]. Determining the influence of static foot posture on dynamic function is therefore an important component of physical therapy practice.

A vast array of techniques have been used including visual observation, various footprint parameters, measurement of frontal plane heel position, and assessment of the position of the navicular tuberosity. Although the reliability of clinical measures of static foot posture used have been debated, only recently has the validity of clinical measurement been addressed [2].

Therefore there is a need to identify an accurate and convenient clinical assessment tool to assess and understand the various foot types and foot postures in young adolescents on clinical examination. Thus, this study aims at drawing a normative data for foot types via standardized objective foot anthropometric measurements like the Navicular height (NH) and Relaxed Calcaneal Stance Position (RCSP) in young Indian adolescents. Further, the Foot Posture Index (FPI-6) is a clinical tool aimed at assessment of foot types and posture and quantifying the degree to which a foot can be considered to be in pronated, supinated or neutral positions. Concern about the variations in foot posture is a common reason for frequent clinical consultations with medical professionals but there is limited research published in the Indian set up on adolescents. Therefore the current study intended to draw a normative data and to classify the various foot types in a heterogenous group of young Indian adolescents and correlate the results of foot anthropometric measures and FPI-6 in young Indian adolescents.

Materials and Methods
The schools in Bangalore were selected randomly for the study. Permission from the school authorities to carry out the study was obtained. Children of both genders from the age group of 11 to 16 years were recruited from the schools as per the inclusion and the exclusion criteria. The informed consent form and subject assessment form were sent home with every child for parents' consent to include the child in the study.

Inclusion Criteria: Apparently healthy children of both genders in the age group between 11 to 16 years were included in the study.

Exclusion Criteria: Children with any history of congenital malformation of lower extremities, musculoskeletal/ neurological deformities or any previous surgery of the lower extremities were excluded. Also children with any other condition that affected their performance of unsupported standing were not considered for the study.

Materials Used: The following materials were used for the study- Examination table, elevated platform on which the subject can safely stand, digital weighing machine, measuring tape, standard 360° goniometer with 1° increments, ruler in millimeter increments, hypoallergenic non-permanent Pen/marker and The Foot Posture Index-6 (FPI-6) scale.
The testing place was arranged prior to the test. Children were measured for physical parameters like height, weight and Body Mass Index (BMI) and the data was recorded. The child was then taken on an examination table in prone lying position with the feet positioned outside of the surface and the calcaneal bisection was done on the skin surface using a pen or marker. To carry out the foot anthropometric measurements and the FPI-6 scale evaluation the subject was then positioned on an elevated platform where they can comfortably stand for about 3-4 minutes while the examiner assess and records the scores and parameters. The test procedure was carried out as under:

Foot Anthropometric Measurements
Navicular Height (NH): The NH is a direct measurement of the medial longitudinal arch. NH is the distance between the navicular tuberosity and the supporting surface. It enables the classification of the foot arch structure.

Test: Prior to the NH assessment, the child was positioned on the platform so he becomes familiar with the testing position. The child stood on the platform in a static relaxed stance position. The child was instructed that he/she will have to stay upright during the assessment and that no stepping was allowed. The foot was in a relaxed calcaneal stance. The most prominent point of the navicular tubercle was marked with a fine line on the skin. NH is obtained by measuring, to the nearest millimeter, the distance between the supporting surfaces at a 90° angle to a line drawn on the navicular tubercle. The measurements were then recorded.

Relaxed Calcaneal Stance Position (RCSP)
The Relaxed Calcaneal Stance Position (RCSP) indicates the position of the calcaneus in the frontal plane after all compensatory pronation has taken place at the subtalar joint. The calcaneus is considered to be in varus when it is inverted to the transverse plane. The calcaneus is considered to be in valgus when it is everted to the transverse plane. RCSP is the angle formed by the posterior aspect of the calcaneus to the supporting surface in stance position, measured with a standard goniometer.

Test: Two testers were used – One tester to stabilize the ankle and foot in neutral position while the other marks the skin with the pen. The subject was positioned in prone lying with the feet extending out of the examination table. Prior to the RCSP assessment, the child was positioned on the platform so he becomes familiar with the testing position. The child was instructed to march in place, stop and remain in a relaxed stance position. No stepping was allowed. The RCSP angle was then measured using the goniometer and the results were recorded.

Foot Posture Index-6 (FPI-6)
The Foot posture Index-6 (FPI) is a 6 item revised clinical tool aimed at quantifying the degree to which a foot can be considered to be in a pronated, supinated or neutral position.

Test: The subject was instructed to stand still in a relaxed stance position with double limb support. The subject was instructed to march in place, stop and remain in a relaxed stance position. The subject will need to stand still approximately 2 minutes for the assessment to be conducted. It was ensured that the assessor will have uninterrupted access to the posterior aspect of the leg and foot to be able to assess and score the subject. Using the FPI-6 recording sheet the subjects was individually evaluated and the scores were then recorded.

Results

Statistical Methods: Descriptive and correlational statistical analysis has been carried out in the present study [20-23] Results on continuous measurements are presented on Mean ± SD (Min-Max) and results on categorical measurements are presented in Number (%). Significance is assessed at 5% level of significance.

Statistical software: The Statistical software namely SAS 9.2, SPSS 15.0, Stata 10.1, MedCalc 9.0.1, Systat 12.0 and R environment ver.2.11.1 were used for the analysis of the data and Microsoft word and Excel have been used to generate graphs, tables etc.

Chi-square test was used to analyze the BMI distribution and the total score of FPI-6 and anthropometric measurements namely the NH and RCSP. Pearson's correlation coefficient was used to find association between anthropometric measurements and FPI-6 scale scores.

Demographic data of BMI (kg/m2) distribution in girls and boys included in the study is shown in Table No 1. The girls were in the BMI range of <18.5 which accounted for 47.8% and BMI 18.5-25 which accounts for 42.2% while 62.1% of boys were in the BMI range of <18.5and 30.7% were in the range 18.5-25.

Table 1: BMI (kg/m^2) distribution in girls and boys studied

| BMI (kg/m^2)	Girls	Boys	Total
<18.5	120(47.8%)	87(62.1%)	207(52.9%)
18.5-25	106(42.2%)	43(30.7%)	149(38.1%)
25-30	20(8%)	9(6.4%)	29(7.4%)
>30	5(2%)	1(0.7%)	6(1.5%)
Total	251(100%)	140(100%)	391(100%)

P=0.049*, Significant, Chi-Square test
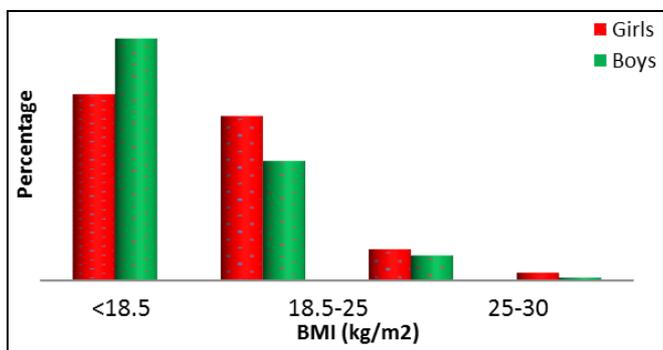
The foot type distribution according to FPI-6 scale is listed in Table No 2. Overall 78.1% of girls and 80.4% of boys showed neutral foot. 17.5% and 14.3% of girls and boys respectively demonstrated slight foot pronation while 1.6% of girls and 3.6% of boys showed slight supinated feet.

Table 2: Total FPI score distribution in girls and boys studied

FPI-Total score	Girls	Boys	Total
1. Neutral foot (0 to +5)	392(78.1%)	225(80.4%)	617(78.9%)
2. Slight foot Pronation(+6 to +9)	88(17.5%)	40(14.3%)	128(16.4%)
3. Increased foot Pronation(+10 to +12)	10(2%)	4(1.4%)	14(1.8%)
4. Slight foot Supination(-1 to -4)	8(1.6%)	10(3.6%)	18(2.3%)
5. Increased foot Supination(-5 to -12)	4(0.8%)	1(0.4%)	5(0.6%)
Total	502(100%)	280(100%)	782(100%)

P=0.268, Not Significant, Chi-Square test
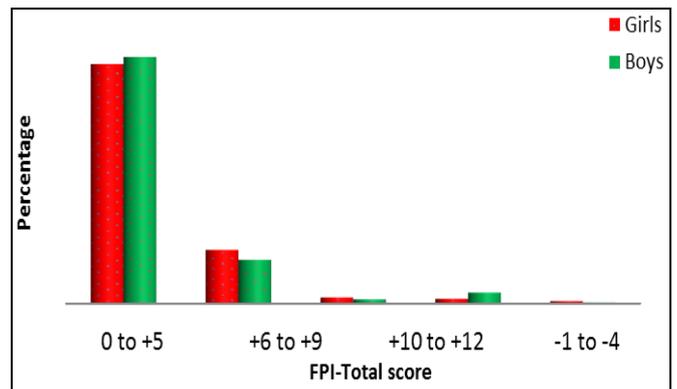
Normative data of types of foot postures using FPI-6 on Left and Right sides is compiled in Table No 3. 18.5% boys showed pronated foot on the Left and 9.2% on the Right side while 20.3% girls demonstrated pronated foot on Left and 14.7% on the Right side. Similarly 4.2% of boys showed supinated foot on the left and 2.8% on the right while in girls foot supination was noted 2% on the left and 1.2% on the right side.

Table 3: Normative data of types of foot postures using FPI-6

| Gender	Foot Types	Left	Percentage	Right	Percentage
Boys	N	105	75%	120	85.70%
	P	26	18.50%	13	9.20%
	HP	3	2.10%	2	1.40%
	S	6	4.20%	4	2.80%
	HS	0	0%	1	0.70%
Total		140		140	
Girls	N	187	74.50%	205	81.60%
	P	51	20.30%	37	14.70%
	HP	7	2.70%	3	1.20%
	S	5	2%	3	1.20%
	HS	1	0.40%	3	1.20%
Total		251		251	

HS- Highly supinated, S- Supinated, N- Normal, HP- Highly pronated, P- Pronated,
M- Male, F- Female, R- Right, L- Left

Anthropometric measurement of Navicular Height is shown in Table No 4. It shows 73.3% of girls and 50.7% of boys NH measurements was between 20 to 40mm whereas 26.3% of girls and 45.7% of boys were between 40 to 50mm and only 0.4% of girls and 3.6% of boys NH measurements were over 50mm.

Table 4: Anthropometric Measurement: Normative data of NH scores in Millimeters (mm)

Anthropometric Measurements: Navicular Height (mm)	Girls	Boys	Total
20-40	368(73.3%)	142(50.7%)	510(65.2%)
40-50	132(26.3%)	128(45.7%)	260(33.2%)
>50	2(0.4%)	10(3.6%)	12(1.5%)
Total	502(100%)	280(100%)	782(100%)

*P*<0.001**, Significant, Chi-Square test
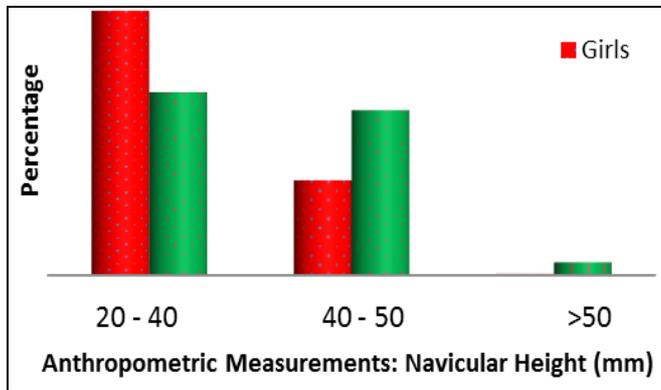
Anthropometric measurement of Relaxed Calcaneal Stance Position is listed in Table No 5.

It shows 52.8% of girls and 62.5% of boys had neutral calcaneal stance and 30.7% of girls and 28.2% of boys had up to +2°calcaneal valgus.

Table 5: Anthropometric Measurements: Normative data of Relaxed Calcaneal Stance Position (RCSP) scores (Degrees)

Anthropometric Measurements: Relaxed Calcaneal Stance Position (Degrees)	Girls	Boys	Total
<-2	4(0.8%)	0(0%)	4(0.5%)
-2 to 0	4(0.8%)	4(1.4%)	8(1%)
0	265(52.8%)	175(62.5%)	440(56.3%)
0-2	154(30.7%)	79(28.2%)	233(29.8%)
>2	75(14.9%)	22(7.9%)	97(12.4%)
Total	502(100%)	280(100%)	782(100%)

P=0.009**, Significant, Chi-Square test
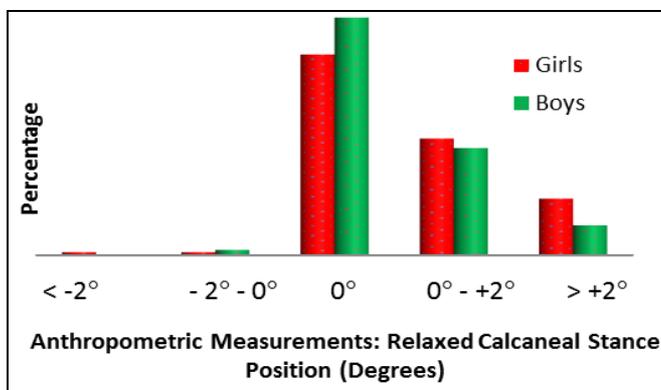
Pearson's Correlation coefficient (r) between Anthropometric measurements and Anthropometric measurements with FPI-6 scores is demonstrated in Table No 6.

The Pearson's Correlation coefficient (r) between Navicular height (NH) and Foot Posture Index (FPI-6) both in girls (-0.672) and boys (-0.542) showed large inverse correlation with $p<0.001$ suggestive of strong statistical significance

The r value between Relaxed Calcaneal Stance Position (RCSP) and Foot Posture (FPI-6) both in girls (0.712) and boys (0.725) showed very large direct correlation with $p<0.001$ suggestive of strong statistical significance.

Table 6: Correlation between Anthropometric measurements and Anthropometric measurements with FPI-6

Pair	Girls		Boys	
	r value	P value	r value	P value
Navicular Height (mm) vs Foot Posture Index-6	-0.674	<0.001**	-0.542	<0.001**
Relaxed Calcaneal Stance Position (Degrees) vs Foot Posture Index-6	0.712	<0.001**	0.725	<0.001**

Discussion

Understanding foot posture in developing children helps to detect any persistence of deviations beyond a certain stage of development, and also to provide scope for timely intervention to prevent any possible deformities and dysfunctions. Even though there are several methods available one of the major limitations pertaining to static foot posture measurements is that generally only one clinical technique is evaluated in each investigation. Due to differences in sample characteristics and measurement procedures, it is difficult to compare the findings across different studies to make an informed decision as to which is the more appropriate technique. Considering that the foot complex is almost developed by the adolescent years necessitates a normative baseline data in this population which may help in comparing the deviations seen in children with impaired foot posture. These values can also be used to monitor the outcome of the rehabilitation process in foot impairments.

The data as obtained in the present study indicates greater percentage of the adolescents having Neutral feet. Pronated foot posture was found to be more commonly observed deviation from normal foot in both girls and boys with girls exhibiting pronation posture more than boys. The present findings of higher occurrence in females may be due to increased incidence of ligamentous laxity in females, as reported earlier by Jansson *et al*. [24]. We also noted that there was a difference in the foot postures of the same individual on the left and the right sides in all categories as measured on FPI-6 scale.

In our study we recorded the BMI values of children as a part of the screening. Though we did not intend to draw any relations between the BMI values and the foot posture the previous studies done by Riddiford- Harland *et al*. [25], Dowling *et al*. [26], Gilmour & Burns [17] have shown that obese children typically display flatter feet relative to their leaner counterparts the cause of their flatter feet is unknown. It has been postulated that the flatter feet of obese children may be caused by the existence of a plantar fat pad under the midfoot region. It is known that a fat pad is present underneath the medial longitudinal arch of the infant foot while the arch develops Hefti& Brunner [27] mentioned in their literature that this fat pad resolves by the age of 5-8 years as the arch of the foot is formed. Riddiford-Harland *et al*. [25]. speculated that this midfoot plantar fat pad might remain in the feet of obese children as a protective adaptation to cushion the loads associated with their excess mass, in turn, causing their characteristic flatter feet relative to their leaner counterparts. Alternatively, it has been suggested that the flatter feet of obese children may be caused by a collapse of

the medial longitudinal arch due to excessive loading of the feet as a result of continually bearing additional body mass.

Foot Posture Index is a diagnostic clinical tool aimed at quantifying the degree to which a foot can be considered to be in pronated supinated or neutral position. FPI-6 is a revised, validated 6 item version and a simple method of scoring various features of foot posture into a single quantifiable result. It is a descriptive scale with specific explanation on various foot postures. In the present study a good correlation found between the traditional objective anthropometric measurements and FPI-6 score establishes the scale as a convenient and appropriate clinical tool that may be used to evaluate the foot posture in Indian adolescents.

Limitations and Recommendations

The present study has following limitations and recommendations-

1) Normative data of FPI-6 in adolescents obtained in the present study was carried out on a sample in south Bangalore and may not be generalized to include all Indian adolescents.

2) Though we calculated the BMI while screening the presence of fat pads and soft tissue dispersion which may contribute to lower score in the medial longitudinal arch height in children's feet during double-limb supported stance, was not taken into consideration during the scoring procedure.

3) Relationship between leg dominance and foot posture was not addressed.

Also further studies can be carried out in order to comparing the foot posture between obese and non-obese children and in pathological conditions using FPI-6. We suggest the study may be carried out on larger sample size in larger and varied geographical regions.

Conclusion

As per the objectives proposed for the present study the normative data of Foot Posture Index-6 for children from 11 to16 years of age was established.

The measurements obtained by Anthropometric measurement using Navicular Height (NH) and Relaxed calcaneal Stance Position (RCSP) to classify foot types had a significant correlation with measurements obtained from Foot Posture Index (FPI-6) scale.

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