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Anthropometric Parameters of the Right and Left Foot among Indian Adults: A Pilot Study

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Abstract: *Background:* Anthropometric foot data is important in designing and manufacturing shoes. Wearing inappropriate shoes increases the likelihood of problems like ankle injuries, corns, chronic pain, and foot blisters. As yet there is no accurate database on Indian feet till today for the Indian Footwear Industry to develop more comfortable footwear. *Objectives:* This study aimed to measure the dimensions of the feet of Indian adults to analyze the anthropometric variations between the Right and Left feet within and between genders. *Method:* This cross-sectional study was carried out with 117 participants (69 male and 48 female) aged 18 to 50 years. Different anthropometric foot parameters were measured by using a 3D foot scanner. *Result:* Results showed significant gender differences in most parameters but no significant differences between the left and right foot of each gender. *Conclusion:* This investigation emphasizes the importance of using size data for designing comfortable and well-fitting footwear. The obtained foot anthropometric data can serve as a reference for designing footwear 'Last' for Indian adults, ensuring better comfort and fit. The findings are intended to assist the Indian footwear industry fill the current data gap for the Indian population during the 'Last' preparation. This could lead to the prevention of foot problems caused by ill-fitting footwear, as well as improved general foot health.

Keywords: Foot anthropometry, Indian adults, Male and Female, Footwear last, Footwear Design.

Introduction

Anthropometry is a method in anthropology that involves measuring and evaluating the human body, including the relationship between measurements of different body parts. Foot anthropometry specifically focuses on measuring the foot's size and dimensions. The human foot is a complex structure due to its many bones and joints [1]. The first anthropometric measures were taken in England before The Hundred Years' War (1337-1453). In Romania, mass anthropometry began in 1968 and was repeated in 1981-82 and 1994-95, although with significantly smaller sample sizes [2].

Anthropometric data of foot plays an important role in designing and manufacturing footwear. In the past, shoe design started with determining its durability using a wooden or metal replica of a human foot. However, in addition to genetic factors, foot shape variations also depend on locality, race, and culture [3]. A population's anthropological structure, as well as its dimensional and conformational variability, is governed by genetic and ecological factors. When examining a population's anthropological structure, numerous elements influence this structure and distinguish it from other populations or within these groups. Thus, each country creates its anthropometric database to define dimensions criteria for footwear, clothing, modifying environmental objects in the workplace, private life, medicine, and so on [4]. When measuring a human foot, multiple factors including kinetic properties of the human foot (Eversion, Inversion, Dorsiflexion, plantar flexion) are taken into consideration and these affect the

overall data obtained [5]. Static measurements of the feet have proven valuable as basic design criteria for footwear [6]. Today, foot anthropometry can be used not only to aid in individual identification, health status assessment, comfort, and safety, but also it is extremely important in epidemiology, evolutionary research, and ergonomics. In many cases, footwear deforms feet, causing numerous troubles, mostly due to improper fit or bad design [7]. Footwear designers and manufacturers should use anthropometric data from feet to avoid ill-fitting footwear that can cause pain, injury, or deformities. Previous studies show that New Zealand army troop's foot anthropometric data was utilized to improve shoe designs and manufacturing processes thus reducing the risk of getting injured or hurting oneself [8].

It has been noted that there was a link between incorrect footwear and repeated usage of inappropriate footwear with foot deformities and foot pain [9]. The left foot and the right foot together contain about a quarter of the body's bones, making them a significant part of the whole body. Many approaches to designing footwear for different manufacturing processes do not always consider the structural and functional needs of the feet, as well as current fashion trends [10-11]. Consequently, footwear affects muscles, bones, and joints that gradually become overstretched leading to changes in the feet's morphological and structural attributes. This may involve pain, discomfort, or disfigurement like hallux valgus, hallux rigidus, flat foot, hollow foot, hammer toes, etc. Improperly made or ill-fitting footwear can cause several mentioned foot problems which may change their structure over time [12-13].

Recent literature results have shown that male foot dimensions are significantly larger than those of females, regardless of the condition. However, it's important to note that the shape of the female foot is not simply a scaled-down version of the male foot. The average angle of female feet is greater than that of males, which indicates a higher prevalence of hallux valgus in females. Additionally, both males and females show significant correlations in foot dimensions between their left and right feet, with minimal differences [14]. The use of anthropometry in the design of footwear can improve its fitness and that of the foot. For a long time, gender has been researched concerning Foot dimensions. These research findings imply that footwear for each gender should be designed utilizing their respective foot anthropometric data. Footwear is worn by people who are involved in different activities to protect their feet from harm [15]. As yet there is no accurate foot anthropometric database on the Indian population till today for the footwear industry to develop optimized 'Last'. Therefore, this study measures the dimensions of the feet of Indian adults to analyze the anthropometric variations between the right and left feet within and between genders and will gather foot dimension data for the Indian footwear industry.

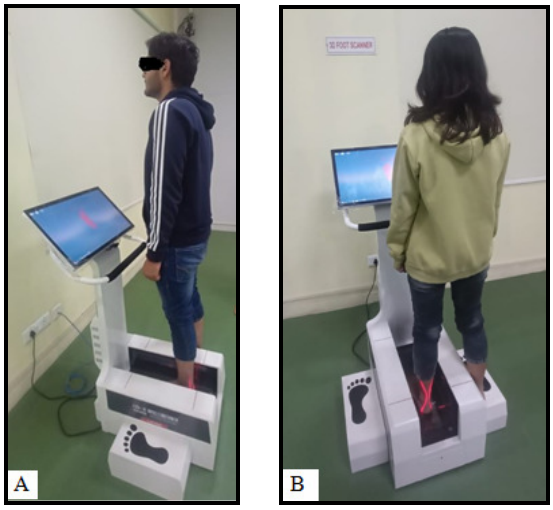
Material and Methods

Participants of the Study: The cross-sectional study was aimed to collect Foot anthropometric data of Indian adults (N = 117), including both males and females. This study was conducted at the Footwear Design and Development Institute (FDDI) in India. The male (n=69) and female (n=48) participants' dimensions of both feet were scanned using the 3D scanner. The mean age, height, and weight of the male participants were 31.16±12.50 years, 170.95±6.288 cm, 72.96±12.604 kg, and female participants were 22.46±6.451 years, 159.07±4.436 cm, and 54.85±13.64 kg respectively. Selected participants in this study were healthy; they had no foot deformities or musculoskeletal abnormalities in the lower limbs.

Measurement procedure: Before beginning the study, the participants were informed about all the necessary information and the study protocol, and also, completed an informed permission form. The subjects had the freedom to withdraw their participation at any point during the experiment. They then removed their shoes and socks and had their height and weight measured using an Anthropometric rod (R.S. Scientific Works, India) and a standard weighing machine. Next, they underwent a foot-scanning process using a 3D foot Scanner instrument, during which a machine scanned their feet and generated a report detailing the

condition of the feet along with several foot anthropometric parameters.

Fig-1: A and B - 3D Foot scanning of the participants.



In this study, 11 Foot anthropometric parameters were considered as the most essential parameters for the 'Last' design. All the parameters were tabulated in Table no 1.

Table-1: Details of 11-foot anthropometric parameters

Parameters	Definition
Arch Height	Distance between the ground and the highest point of the arch.
Arch length	Distance between the heel to the ball of the foot along the inner border of the foot where the arch is located.
Foot length	Distance between pterion and the tip of the longest toe, measured along the foot axis.
Heel heart width:	It measured from the lateral to the medial aspect of the heel.
Thumb height	The height or position of the big toe.
Toe width	Distance between the medial (inner) and lateral (outer) borders of the toes or the widest part of the forefoot.
Ball girth	Measurement of the curve that passes from the first to the fifth metatarsal head on the dorsum foot.
Heel girth	It refers to the circumference or measurement around the heel area of the foot.
Instep girth	Measurement of the curve of the vertical section of the dorsum foot in the most prominent region of the navicular bone.
Waist girth	Distance between the ball and the heel but the measurement was taken at the narrowest part of the foot.
Heel piece pump height	Measured from the bottom of the heel to the highest point of the heel.

Instrumentation: In this study, all foot anthropometric parameters were captured by LSF-350-A (Shenzhen 3DOE Technology Co., Ltd., China) 3D foot scanners with high measuring precision and standard error up to <0.5mm. The laboratory environment was maintained at an optimal temperature and humidity of 25°C - 27°C and 50% - 55%, respectively at the Footwear Design and Development Institute (FDDI) in India.

Ethical clearance: The present study protocol on human use as an experimental subject and the entire principles of the experiment outlined by the Declaration of Helsinki Protocol, 1964, and as per approved ethical clearance No HMC/ IEC/ FDDI/ 01, dated 18.04.2024.

Statistical analysis: Statistical analysis was conducted using the Statistical Product and Service Solutions (SPSS) Statistics software package (Version 26, SPSS Inc., Chicago). Normal distribution of data was assessed by the Shapiro-Wilk normality test, along with visual histograms, and Q-Q plots. The data was presented as mean ± SD. Two-way-ANOVA was performed to evaluate differences in gender (male and female) and between the left and right feet of studied parameters. When considering the left and right feet for both genders together, resulting in a total of four groups, ANOVA with Tukey's post hoc analysis was conducted. The significance level was set as 0.05.

Results

This study included Indian adults with an average age of male 22.46±6.451 years and female 22.46±6.451 years. The foot anthropometric parameters were measured including arch height, arch length, foot length, heel height width, toe width; thumb height,

heel piece pump height, ball girth, heel girth, waist girth, and instep girth were tabulated in Tables 2 & 3.

Table-2: Mean ± SD of Foot anthropometric parameters

Parameters (mm)	Mean ± SD
Arch Height	14.87 ± 7.782
Foot Length	249.47 ± 16.965
Arch length	110.50 ± 25.472
Hell Heart Width	62.19 ± 5.742
Toe Width	91.71 ± 7.396
Thumb Height	20.82 ± 2.354
Heelpiece Pump Height	19.97 ± 3.526
Ball Girth	232.59 ± 16.178
Heel Girth	310.87 ± 25.751
Waist Girth	234.05 ± 19.371
Instep Girth	230.38 ± 17.469

Table-3: Two-way ANOVA of Foot anthropometric parameters based on gender and foot

Parameters (mm)	Gender		Foot (left and right)	
	F score	P value	F score	P value
Arch Height	4.33	**0.04 (p<0.05)**	0.32	0.57(p>0.05)
Foot Length	318.09	**0.00 (p<0.05)**	0.16	0.69(p>0.05)
Arch length	12.18	**0.00 (p<0.05)**	0.02	0.88(p>0.05)
Heel Heart Width	167.43	**0.00 (p<0.05)**	3.35	0.07(p>0.05)
Toe Width	97.58	**0.00 (p<0.05)**	0.17	0.68(p>0.05)
Thumb Height	75.14	**0.00 (p<0.05)**	0.29	0.59(p>0.05)
Heelpiece Pump Height	33.00	**0.00 (p<0.05)**	0.45	0.50(p>0.05)
Ball Girth	220.07	**0.00 (p<0.05)**	0.00	0.96(p>0.05)
Heel Girth	174.94	**0.00 (p<0.05)**	0.03	0.87(p>0.05)
Waist Girth	151.22	**0.00 (p<0.05)**	2.21	0.14(p>0.05)
Instep Girth	264.08	**0.00 (p<0.05)**	0.10	0.75(p>0.05)
(p<0.05) Significant				

Two-way ANOVA was conducted to compare the differences among genders and both feet (left and right) of studied foot anthropometric parameters. The analyzed data showed significant differences in all studied 11-foot anthropometric parameters (Arch height, Foot length, Arch length, Heel heart width, Toe width, Thumb height, Heel piece pump height, Ball girth, Heel girth, waist girth, and Instep girth) between the two genders at p< 0.05 level, df = 1, 232, but no significant differences were found between left and right foot in all parameters for both male and female subjects.

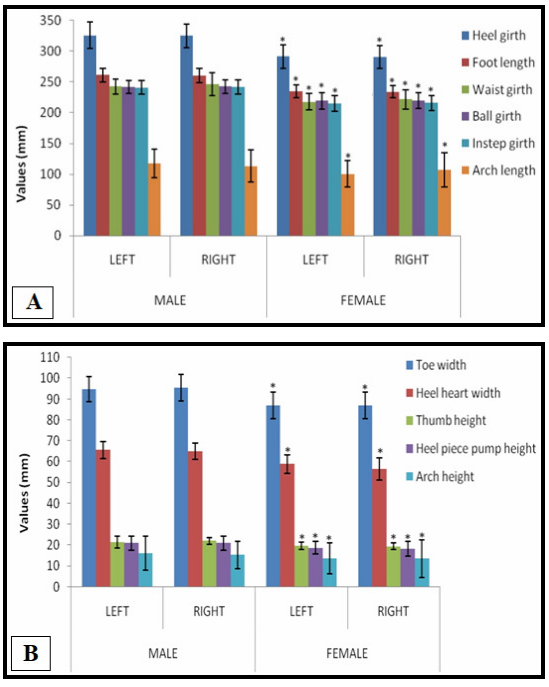


Fig-2: (A & B) Variation of foot anthropometric parameters of left and right foot among male and female participants. Male feet were significantly different from female feet. In the bar diagram, the "*" sign indicates that the parameters are significant at the 0.05 level.

Table-4: Tukey Simultaneous Test to identify differences among the foot anthropometric parameters (post hoc ANOVA)

Parameters			Mean Difference	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Arch height	Male left	Male right	2.7203	1.3188	0.169(p>0.05)	-0.693	6.133
		Female left	1.9387	1.4559	0.544(p>0.05)	-1.829	5.707
		Female right	2.7408	1.4559	0.238(p>0.05)	-1.027	6.509
	Male right	Male left	-2.7203	1.3188	0.169(p>0.05)	-6.133	0.693
		Female left	-0.7816	1.4559	0.950(p>0.05)	-4.549	2.986
		Female right	0.0205	1.4559	1.000(p>0.05)	-3.747	3.788
	Female left	Male left	-1.9387	1.4559	0.544(p>0.05)	-5.707	1.829
		Male right	0.7816	1.4559	0.950(p>0.05)	-2.986	4.549
		Female right	0.8021	1.5812	0.957(p>0.05)	-3.290	4.894
	Female right	Male left	-2.7408	1.4559	0.238(p>0.05)	-6.509	1.027
		Male right	-0.0205	1.4559	1.000(p>0.05)	-3.788	3.747
		Female left	-0.8021	1.5812	0.957(p>0.05)	-4.894	3.290
Foot Length	Male left	Male right	0.8899	1.8869	0.965(p>0.05)	-3.993	5.773
		Female left	26.4467*	2.0831	**0.000(p<0.05)**	21.056	31.838
		Female right	26.7842*	2.0831	**0.000(p<0.05)**	21.393	32.175
	Male right	Male left	-0.8899	1.8869	0.965(p>0.05)	-5.773	3.993
		Female left	25.5569*	2.0831	**0.000(p<0.05)**	20.166	30.948
		Female right	25.8944*	2.0831	**0.000(p<0.05)**	20.504	31.285
	Female left	Male left	-26.4467*	2.0831	**0.000(p<0.05)**	-31.838	-21.056
		Male right	-25.5569*	2.0831	**0.000(p<0.05)**	-30.948	-20.166
		Female right	0.3375	2.2623	0.999(p>0.05)	-5.517	6.192
	Female right	Male left	-26.7842*	2.0831	**0.000(p<0.05)**	-32.175	-21.393
		Male right	-25.8944*	2.0831	**0.000(p<0.05)**	-31.285	-20.504
		Female left	-0.3375	2.2623	0.999(p>0.05)	-6.192	5.517
Arch length	Male left	Male right	11.9290*	4.2793	**0.029(p<0.05)**	0.855	23.003
		Female left	1.3271	4.7242	0.992(p>0.05)	-10.899	13.553
		Female right	7.0375	4.7242	0.445(p>0.05)	-5.188	19.263
	Male right	Male left	-11.9290*	4.2793	**0.029(p<0.05)**	-23.003	-0.855
		Female left	-10.6019	4.7242	0.115(p>0.05)	-22.828	1.624
		Female right	-4.8915	4.7242	0.729(p>0.05)	-17.117	7.334
	Female left	Male left	-1.3271	4.7242	0.992(p>0.05)	-13.553	10.899
		Male right	10.6019	4.7242	0.115(p>0.05)	-1.624	22.828
		Female right	5.7104	5.1307	0.682(p>0.05)	-7.567	18.988
	Female right	Male left	-7.0375	4.7242	0.445(p>0.05)	-19.263	5.188
		Male right	4.8915	4.7242	0.729(p>0.05)	-7.334	17.117
		Female left	-5.7104	5.1307	0.682(p>0.05)	-18.988	7.567
Heel heart width	Male left	Male right	6.7130*	0.8196	**0.000(p<0.05)**	4.592	8.834
		Female left	-0.1201	0.9048	0.999(p>0.05)	-2.462	2.221
		Female right	5.5611*	0.9048	**0.000(p<0.05)**	3.220	7.903
	Male right	Male left	-6.7130*	0.8196	**0.000(p<0.05)**	-8.834	-4.592
		Female left	-6.8332*	0.9048	**0.000(p<0.05)**	-9.175	-4.492
		Female right	-1.1519	0.9048	0.581(p>0.05)	-3.493	1.190

Parameters			Mean Difference	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Heel heart width	Female left	Male left	0.1201	0.9048	0.999(p>0.05)	-2.221	2.462
		Male right	6.8332*	0.9048	**0.000(p<0.05)**	4.492	9.175
		Female right	5.6813*	0.9827	**0.000(p<0.05)**	3.138	8.224
	Female right	Male left	-5.5611*	0.9048	**0.000(p<0.05)**	-7.903	-3.220
		Male right	1.1519	0.9048	0.581(p>0.05)	-1.190	3.493
		Female left	-5.6813*	0.9827	**0.000(p<0.05)**	-8.224	-3.138
Toe width	Male left	Male right	7.1290*	1.1161	**0.000(p<0.05)**	4.241	10.017
		Female left	0.9539	1.2321	0.866(p>0.05)	-2.235	4.142
		Female right	7.6518*	1.2321	**0.000(p<0.05)**	4.463	10.840
	Male right	Male left	-7.1290*	1.1161	**0.000(p<0.05)**	-10.017	-4.241
		Female left	-6.1751*	1.2321	**0.000(p<0.05)**	-9.364	-2.987
		Female right	0.5228	1.2321	0.974(p>0.05)	-2.666	3.711
	Female left	Male left	-0.9539	1.2321	0.866(p>0.05)	-4.142	2.235
		Male right	6.1751*	1.2321	**0.000(p<0.05)**	2.987	9.364
		Female right	6.6979*	1.3381	**0.000(p<0.05)**	3.235	10.161
	Female right	Male left	-7.6518*	1.2321	**0.000(p<0.05)**	-10.840	-4.463
		Male right	-0.5228	1.2321	0.974(p>0.05)	-3.711	2.666
		Female left	-6.6979*	1.3381	**0.000(p<0.05)**	-10.161	-3.235
Thumb height	Male left	Male right	1.9986*	0.3662	**0.000(p<0.05)**	1.051	2.946
		Female left	0.2142	0.4043	0.952(p>0.05)	-0.832	1.261
		Female right	2.1246*	0.4043	**0.000(p<0.05)**	1.078	3.171
	Male right	Male left	-1.9986*	0.3662	**0.000(p<0.05)**	-2.946	-1.051
		Female left	-1.7843*	0.4043	**0.000(p<0.05)**	-2.831	-0.738
		Female right	0.1261	0.4043	0.989(p>0.05)	-0.920	1.172
	Female left	Male left	-0.2142	0.4043	0.952(p>0.05)	-1.261	0.832
		Male right	1.7843*	0.4043	**0.000(p<0.05)**	0.738	2.831
		Female right	1.9104*	0.4391	**0.000(p<0.05)**	0.774	3.047
	Female right	Male left	-2.1246*	0.4043	**0.000(p<0.05)**	-3.171	-1.078
		Male right	-0.1261	0.4043	0.989(p>0.05)	-1.172	0.920
		Female left	-1.9104*	0.4391	**0.000(p<0.05)**	-3.047	-0.774
Heel piece pump height	Male left	Male right	1.9058*	0.5836	**0.007(p<0.05)**	0.396	3.416
		Female left	0.0534	0.6443	1.000(p>0.05)	-1.614	1.721
		Female right	1.7429*	0.6443	**0.037(p<0.05)**	0.076	3.410
	Male right	Male left	-1.9058*	0.5836	**0.007(p<0.05)**	-3.416	-0.396
		Female left	-1.8524*	0.6443	**0.023(p<0.05)**	-3.520	-0.185
		Female right	-0.1629	0.6443	0.994(p>0.05)	-1.830	1.504
	Female left	Male left	-0.0534	0.6443	1.000(p>0.05)	-1.721	1.614
		Male right	1.8524*	0.6443	**0.023(p<0.05)**	0.185	3.520
		Female right	1.6896	0.6997	0.077(p>0.05)	-0.121	3.500
	Female right	Male left	-1.7429*	0.6443	**0.037(p<0.05)**	-3.410	-0.076
		Male right	0.1629	0.6443	0.994(p>0.05)	-1.504	1.830
		Female left	-1.6896	0.6997	0.077(p>0.05)	-3.500	0.121
Ball Girth	Male left	Male right	18.4420*	2.2207	**0.000(p<0.05)**	12.695	24.189
		Female left	0.2981	2.4515	0.999(p>0.05)	-6.046	6.642
		Female right	20.7335*	2.4515	**0.000(p<0.05)**	14.389	27.078
	Male right	Male left	-18.4420*	2.2207	**0.000(p<0.05)**	-24.189	-12.695
		Female left	-18.1439*	2.4515	**0.000(p<0.05)**	-24.488	-11.800
		Female right	2.2915	2.4515	0.786(p>0.05)	-4.053	8.636

Parameters			Mean Difference	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Ball Girth	Female left	Male left	-0.2981	2.4515	0.999(p>0.05)	-6.642	6.046
		Male right	18.1439*	2.4515	**0.000(p<0.05)**	11.800	24.488
		Female right	20.4354*	2.6625	**0.000(p<0.05)**	13.545	27.326
	Female right	Male left	-20.7335*	2.4515	**0.000(p<0.05)**	-27.078	-14.389
		Male right	-2.2915	2.4515	0.786(p>0.05)	-8.636	4.053
		Female left	-20.4354*	2.6625	**0.000(p<0.05)**	-27.326	-13.545
Heel girth	Male left	Male right	24.7667*	3.7500	**0.000(p<0.05)**	15.062	34.471
		Female left	-3.1370	4.1399	0.873(p>0.05)	-13.851	7.577
		Female right	26.9588*	4.1399	**0.000(p<0.05)**	16.245	37.673
	Male right	Male left	-24.7667*	3.7500	**0.000(p<0.05)**	-34.471	-15.062
		Female left	-27.9037*	4.1399	**0.000(p<0.05)**	-38.617	-17.190
		Female right	2.1921	4.1399	0.952(p>0.05)	-8.522	12.906
	Female left	Male left	3.1370	4.1399	0.873(p>0.05)	-7.577	13.851
		Male right	27.9037*	4.1399	**0.000(p<0.05)**	17.190	38.617
		Female right	30.0958*	4.4961	**0.000(p<0.05)**	18.460	41.731
	Female right	Male left	-26.9588*	4.1399	**0.000(p<0.05)**	-37.673	-16.245
		Male right	-2.1921	4.1399	0.952(p>0.05)	-12.906	8.522
		Female left	-30.0958*	4.4961	**0.000(p<0.05)**	-41.731	-18.460
Waist Girth	Male left	Male right	19.1710*	2.8479	**0.000(p<0.05)**	11.801	26.541
		Female left	2.2802	3.1440	0.887(p>0.05)	-5.856	10.417
		Female right	22.6197*	3.1440	**0.000(p<0.05)**	14.483	30.756
	Male right	Male left	-19.1710*	2.8479	**0.000(p<0.05)**	-26.541	-11.801
		Female left	-16.8909*	3.1440	**0.000(p<0.05)**	-25.027	-8.755
		Female right	3.4487	3.1440	0.692(p>0.05)	-4.688	11.585
	Female left	Male left	-2.2802	3.1440	0.887(p>0.05)	-10.417	5.856
		Male right	16.8909*	3.1440	**0.000(p<0.05)**	8.755	25.027
		Female right	20.3396*	3.4145	**0.000(p<0.05)**	11.503	29.176
	Female right	Male left	-22.6197*	3.1440	**0.000(p<0.05)**	-30.756	-14.483
		Male right	-3.4487	3.1440	0.692(p>0.05)	-11.585	4.688
		Female left	-20.3396*	3.4145	**0.000(p<0.05)**	-29.176	-11.503
Instep girth	Male left	Male right	20.5957*	2.3372	**0.000(p<0.05)**	14.547	26.644
		Female left	0.2130	2.5802	1.000(p>0.05)	-6.464	6.890
		Female right	23.4755*	2.5802	**0.000(p<0.05)**	16.798	30.153
	Male right	Male left	-20.5957*	2.3372	**0.000(p<0.05)**	-26.644	-14.547
		Female left	-20.3826*	2.5802	**0.000(p<0.05)**	-27.060	-13.705
		Female right	2.8799	2.5802	0.680(p>0.05)	-3.797	9.557
	Female left	Male left	-0.2130	2.5802	1.000(p>0.05)	-6.890	6.464
		Male right	20.3826*	2.5802	**0.000(p<0.05)**	13.705	27.060
		Female right	23.2625*	2.8022	**0.000(p<0.05)**	16.011	30.514
	Female right	Male left	-23.4755*	2.5802	**0.000(p<0.05)**	-30.153	-16.798
		Male right	-2.8799	2.5802	0.680(p>0.05)	-9.557	3.797
		Female left	-23.2625*	2.8022	**0.000(p<0.05)**	-30.514	-16.011
(p<0.05) Significant							

Tukey's post hoc ANOVA was utilized to examine the impact of anthropometric parameters on gender (male and female) and side (left and right). In Arch height, there was no significant difference between male left vs male right, female left vs female right, male left vs female left, or male right vs female right. In terms of foot length, the male left and right foot differs significantly from the female left and right foot. However, no significant differences were identified between individual left and right feet in the case of both male and female subjects. There were no significant differences in arch length between the male and female

feet on both sides and the individual group's left and right feet. The present study shows a significant difference between male left and right arch length. But no such difference was observed between male and female arch length. Similarly, no significant difference in gender (male left vs female left, male right vs female right) arch length was observed.

In terms of heel piece pump height, the male left foot significantly differs from the male and female right foot. The measurements revealed that there was no significant difference between the left feet of males and females. However, the right foot of males showed significant differences when compared to both the left foot of males and females. On the other hand, there was no significant difference observed between the right feet of males and females. Specifically, the left foot of males differed significantly from the right foot of both males and females in terms of heel width, toe width, arch height, ball width, heel circumference, instep circumference, and waist circumference.

Discussion

The present study measured 11-foot anthropometric parameters among 117 male and female participants and aimed to measure the dimensions of the feet of Indian adults to analyze the anthropometric variations between the right and left feet within and between genders. In this study, no significant difference was observed between the left and right feet of male participants. Males have larger left foot dimensions (arch height, foot length, arch length, heel heart width, heel piece pump height, and heel girth) than right feet except for ball girth, instep girth, waist girth, toe width, and thumb height. Several previous literatures on gender differences in anthropometric foot parameters support this study's findings as a study on young Nigerian adults found that there was no significant variation in foot length between the right and left of males [16].

A study on the foot length of adult Bangladeshi males found no significant difference in foot length between both feet [17]. A study of foot anthropometric measurements in Arizona, United States of America, to predict dynamic plantar surface contact area found no significant variations between left and right foot length in males [18]. Research on the Melanau people in Sarawak, Malaysia, showed that adult men don't have noticeably different-sized feet on both sides [19]. A comparable investigation on the footprint length dimension among individuals from the Iban ethnic group in Sarawak, East Malaysia, found no significant bilateral foot asymmetry in males. In this study, it was found that there is no significant difference between the left and right feet of female participants, except for ball girth, waist girth, instep girth, waist, and toe width. It was also observed that females' left feet are often larger than their right feet in terms of arch height, foot length, heel width, heel height, thumb height, and heel circumference. A comparison study on the length of footprints among the Iban ethnic group in Sarawak, East Malaysia, similarly found no significant difference in foot size between the left and right feet in females [20]. However, another study on the Western Australian population found no significant difference in right and left foot length in females [21].

Another study on the young adult Nigerian population revealed a substantial difference in foot length between the right and left female foot [22]. According to this study, men have larger feet than women. Men's and women's feet differ significantly in size and shape. Another study discovered that men's feet are around 24 millimeters longer and 10 millimeters wider than women's. In Africa, the difference in foot length between men and women is 30 millimeters, and in width, it's 10 millimeters [23]. Previous studies showed that Indian females had significantly smaller values than males in all six measured foot dimensions [24]. Some measurements of the foot were discovered to be bigger in women than in men. For instance, in the U.S. Army, all 26-foot anthropometric measurements were larger in men than in women, when adjusted for foot length, 10 of these measurements were larger in women than in men [25].

However, the Tukey post hoc ANOVA test showed that there was no significant difference in arch height between males and females. This study found that women have a significantly lower arch height than men.

Earlier research has indicated that analyzing foot X-ray images showed a larger degree of angular change in the medial longitudinal arch in females compared to males, both when standing and moving, unlike when not bearing weight. This suggests that higher arch flexibility, which is more common in women, may raise the risk of soft-tissue injuries to the foot and ankle. Women may be more susceptible to these types of accidents than men [26]. Furthermore, it is well known that many ladies often wear high-heeled shoes. Using high heels has been linked to the formation of feet that turn inward and have low arches because of changes in how the legs and feet work. This might be the reason why women usually have lower arch heights than men [27]. Anthropometric data is useful when designing a product for a certain demographic. Foot anthropometric measurements are very important for footwear design and manufacture. Foot measurement can help determine the optimized size and fit of footwear, improving the final product's comfort and lifetime [3].

Differences in foot characteristics between men and women can affect the available footwear fit in young and elderly women. A recent survey demonstrated that nearly 59% of female consumers reported difficulty in finding “correctly” fitting footwear, which can lead to foot pain, deformity, and increased susceptibility to falls [28]. As of now, India does not have any specific foot anthropometric data that can be used by Indian footwear manufacturers to design shoes ‘Last’ for better comfort and fit. Hence, there is a need for a study to gather the foot dimensions of Indians of different ethnicities. The obtained foot anthropometric data can serve as a reference for designing footwear 'Last' for Indian adults, ensuring better comfort and fit.

Conclusion

The study provides information about the foot dimensions of Indian adults, revealing considerable gender variations but significant variance found between left and right feet on specific anthropometric foot parameters. Males have larger left foot dimensions in arch height, foot length, arch length, heel heart width, heel piece pump height, and heel girth than right feet. However, female subjects had a significant difference between the left and right feet on ball girth, waist girth, instep girth, waist, and toe width. Furthermore, it was observed that females often have larger left feet in various dimensions including arch height, foot length, heel width, heel height, thumb height, and heel circumference compared to their right feet.

The findings underline the need for gender-specific footwear design to improve comfort and prevent foot-related disorders. This research explores the importance of precise anthropometric data for better fitting footwear, to prevent discomfort and injury, and to inform the design of footwear products and accessories. The study found differences in arch length and heel pump height between male and female feet, highlighting the need for more comfortable and well-fitting shoes in the Indian footwear industry. However, the study was limited by a small sample size and recommends larger sample sizes for future research on footwear design.

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