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Correlation of Foot Dimensions with Body Mass Index: A Study in Young Population of Central India

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Abstract

Background and Objectives: Identifying a human individual through scientific means is a key component of forensic investigation. Anatomists, forensic scientists, anthropologists, physicians, podiatrists, and numerous other groups all over the world have studied human foot in different ways. In developing countries like India, people tend to walk barefooted for various reasons like spiritual thoughts, religious reasons, during socio-cultural events, climatic condition, in rural areas and due to socio-economic reasons. This increases the importance of foot impression for forensic investigation. Human foot morphology is greatly influenced by the combined effects of heredity and living style. The present study was proposed to correlate the foot dimensions with body mass index of an individual.

Methodology: This cross-sectional study was conducted amongst 1000 participants (500 male and 500 female) of ESIC Institute Gulbarga over a period of 14 months. Foot length, foot breadth along with stature and weight was measured.

Results: Mean stature was 161.88. Mean weight (male) was 58.21 kg and female was 50.14 kg. No statistically significant correlation was observed between BMI and Foot length of both sides; whereas BMI and foot breadth on both sides had significant correlation. Linear regression equation was calculated.

Interpretation and Conclusion: Statistically significant correlation wasn't observed between BMI and Foot length of both sides; whereas BMI and foot breadth on both sides observed statistically significant correlation, $r = 0.124$ (right), $r = 0.125$ (left). This data would be useful for forensic investigations for the purpose of inclusion, exclusion of a suspect.

Keywords: Correlation; Foot length; Foot breadth; Body mass index; Linear regression Coefficient; Crime; Bare foot.

Introduction

Identifying a human individual through scientific means is a key component of forensic investigation. Every human body part is unique in itself. There is a relationship between each part of the body and the whole body.[1] Anatomists, forensic scientists, anthropologists, physicians, podiatrists, and numerous other groups all over the world have studied human foot in various ways.[2] Foot-impression is one of the commonest physical evidence foundin crime scenes that can help to link the crime and criminal.

In developing countries like India, people tend to walk barefooted for various reasons like spiritual thoughts, religious reasons, during socio-cultural events, climatic condition, in rural areas

and due to socio-economic reasons. This increases the importance of foot impression for forensic investigations. Human foot morphology is greatly influenced by the combined effects of heredity and living style determinants that make the size and shape data of the feet/footprints unique to establish a human identity.[1] Foot-outline is defined as the line tracing around the outer margins of the fleshed foot. Both footprints and foot-outlines can provide promising information to establish the identity of suspect or perpetrator.[3]

Human height and weight has also been studied in many forensic and medical domains. Foot-impression is likely to correlate with weight as feet bear body weight. The utility of foot-impression as an indicator of body mass has been less explored.[4] In forensic perspective, the researchers have conducted population standard body weight determination from footprint for use in crime scene investigation.[5–8] But unfortunately, the literature review shows feeble number of studies recorded correlating foot-outline with living human body mass index.[9,10] The present study, aims to correlate the body mass index and foot-outline measurements in young population of Central India.

Aim

To study the relationship between foot dimensions with Body Mass Index.

Materials and Methods

Study design: Descriptive cross sectional study.

Setting: Anthropometric section of Department of Anatomy, ESIC Medical College and Hospital, Gulbarga, Karnataka.

Duration of study: 14 months; From 31 October 2017 to 31 December 2018.

Sample size: 1000 participants which includes Medical, Dental and Nursing students aged between 18 and 21 years of age in ESIC Institute, Gulbarga.

Sampling technique

Inclusion criteria

Medical, Dental and Nursing students aged between 18 and 21 years in ESIC Medical College, Gulbarga.

Exclusion criteria

Students of NRI quota and students those with poorly defined wrist creases, deformities of vertebral column and limbs, contractures, missing limbs, history of trauma to hand and foot, with features suggestive of dysmorphic syndromes, chronic illness, hormonal therapy were excluded from the study.[11,12]

Sample selection

Simple random sampling method[13] as we selected 1000 participants out of total 3000 Medical, Dental and Nursing students in our institute satisfying the inclusion criteria. As subjects belonged to 1st to 3rd year, they were easily accessible and also represented the young adult age group.

Data collection procedure

Foot Length

Each subject will stand on a Calibrated Foot Board with his/her back against the wall in such a manner that the posterior most point of the heel will gently touch the wall. A vertical stop was placed against the anterior most point of the foot. The distance between the posterior most point of the heel and the anterior most point of the foot was measured as the foot length[14] (Fig 3).

Foot Breadth

It will be measured as distance between Metatarsal tibiale (point projecting most medially on the head of the 1st metatarsal bone) and Metatarsal Fibulare (point projecting most laterally on the head of the 5th metatarsal bone)[15] (Fig 2).

Height

Standing height will be measured to the nearest centimeters (cm) using a Stadiometer with subject standing erect on a horizontal resting plane bare footed having the palms of the hands turned in ward and the finger pointing downwards. The height will be measured from the sole of the feet to the vertex of the head as recommended by International Biological Program[16] (Fig 1).

Body weight

It will be taken using the Mechanical Weighing Balance to the nearest kg according to the standard

procedures A. Ibegbu, David et al.[16] (2013).[16]

Body Mass Index

It will be calculated by dividing weight by height squared (weight/height squared (kg/mt^2)) AIbegbu, David et al.[16] (2013).

Data collection tools

Vernier slide calipers, calibrated foot board, stadiometer, regular weight machine, questionnaire for collection of personal details, academic scores, lead pencils, stationary etc.

Data collected were tabulated, graphically represented and statistically analyzed.

Results

Table 1: Correlation of Foot length and Body Mass Index and its graphical representation as shown in Fig 4. There was no statistically significant

Fig. 1: Measurement of stature

Fig. 2: Measurement of foot breadth

Fig. 3: Measurement of foot length

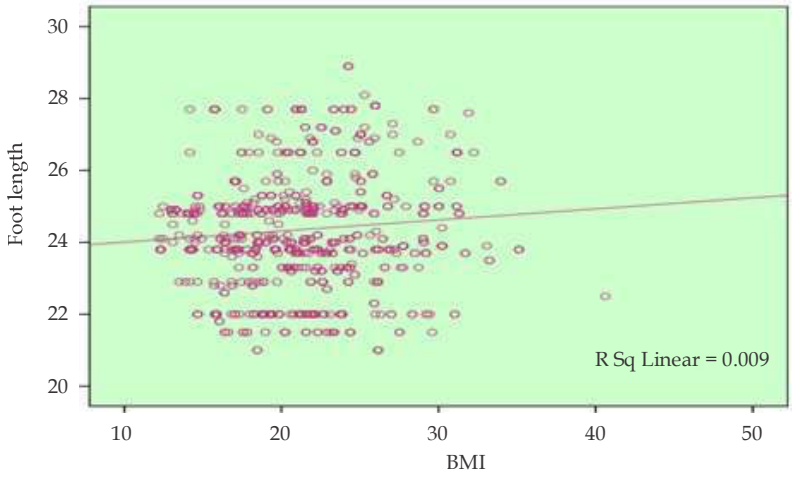

Fig. 4: Graphical representation of foot length and body mass index

correlation between BMI and Foot length of right and left ($p > 0.05$), so, linear regression equation couldn't be derived.

Table 2: Correlation of Foot breadth and Body Mass Index and its graphical representation as shown in Fig 5. There was a statistically significant correlation between BMI and Foot breadth of right and left ($p < 0.01$). Study reveals that, foot breadth of both sides was significantly more in those who had higher body mass index.

Table 3: Gender wise comparison of parameters and its graphical representation as shown in Fig 6. There was statistically very highly significant difference in Foot length on right and left, Foot breadth right and left, Height and weight among males and females ($p < 0.001$). The Foot length right and left, Foot breadth right and left, Height and weight were significantly more in males as

Table 1: Correlation of Foot length and Body Mass Index

Variables	Minimum	Maximum	Range	Mean	SD	n	Correlation r	*p* - value
Body Mass Index	12.22	40.61	28.39	20.97	4.66	1000	—	—
Foot length right	21.0	28.9	7.9	24.34	1.54	1000	r = 0.073	$p > 0.05$ NS
Foot length left	21.5	29.0	7.5	24.32	1.50	1000	r = 0.024	$p > 0.05$ NS

Table 2: Correlation of Foot breadth and Body Mass Index

Variables	Minimum	Maximum	Range	Mean	SD	n	Correlation r	*p* - value
Body Mass Index	12.22	40.61	28.39	20.97	4.66	1000	—	—
Foot breadth right	7.5	10.9	3.4	8.95	0.78	1000	r = 0.124	$p < 0.05$ S
Foot breadth left	7.7	11.5	3.8	8.96	0.68	1000	r = 0.115	$p < 0.05$ S
Linear Regression Equation	BMI = 19.306 + 0.168 (Foot breadth right)							
Linear Regression Equation	BMI = 17.214 + 0382 (Foot breadth left)							

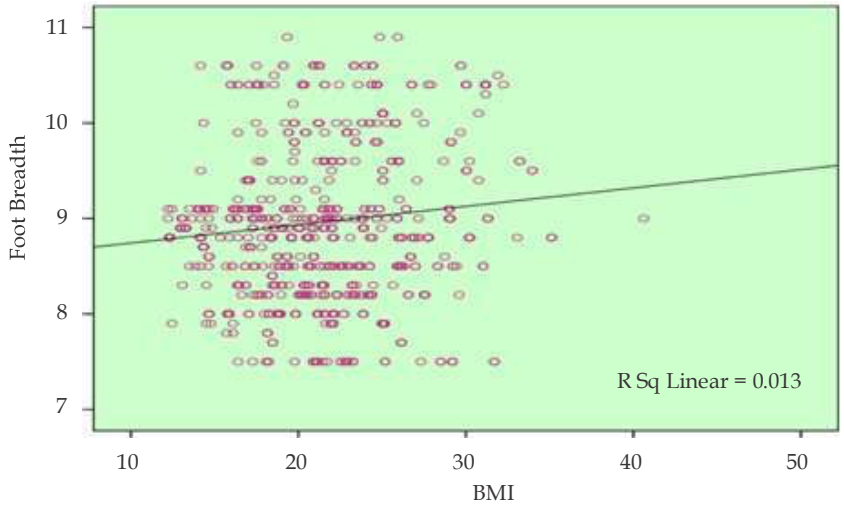

Fig. 5: Graphical representation of foot breadth and body mass index

Table 3: Gender wise comparison of parameters

Variables	Male (n = 500) Mean ± SD	Female (n = 500) Mean ± SD	Z test value	*p* - value and significance
Foot length right	25.18 ± 1.32	23.39 ± 1.19	Z = 30.07	p<0.001, VHS
Foot length left	25.31 ± 1.16	23.19 ± 0.96	Z = 31.19	p<0.001, VHS
Foot breadth right	9.39 ± 0.71	8.45 ± 0.52	Z = 22.97	p<0.001, VHS
Foot breadth left	9.35 ± 0.59	8.52 ± 0.47	Z = 23.21	p<0.001, VHS
Height	169.28 ± 11.75	153.42 ± 9.75	Z = 22.26	p<0.001, VHS
Weight	58.21 ± 11.91	50.14 ± 9.85	Z = 11.21	p<0.001, VHS
BMI	20.58 ± 4.94	21.41 ± 4.27	Z = 2.53	p<0.05, S

NS= not significant, S=significant, HS=highly significant, VHS=very highly significant

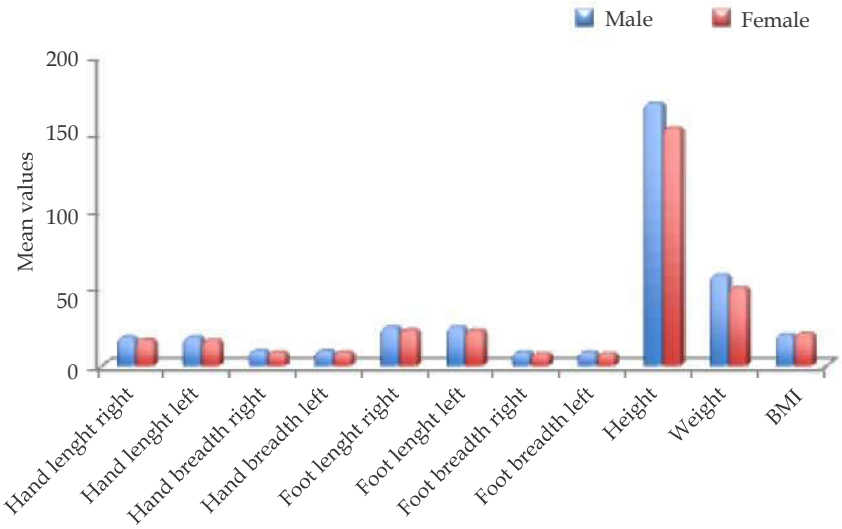

Fig. 6: Graphical representation of gender wise comparison of parameters

Table 4: Comparison of present study with previous studies

Sl No	Study/Author/Year	Sample size	Parameters studied	Observations				
				Mean height M/F	Mean foot length		Mean foot breadth	
					Right M/F	Left M/F	Right M/F	Left M/F
1	Anitha Oommen et al.[14](2005)	100	HL, FL	NA	26.21/23.75	26.0/23.68	NM	NM
2	B Danborno, AElukpo et al.[25] (2007)	400	H, HL, HB, FL, FB	173.7/160.0	28.39/24.52	26.42/24.70	9.02/8.23	9.09/8.11
3	Patel SM, Shah GV et al.[24] 2007	502	H, FL	170.9/156.14	Male- 24.44	Female- 2.34	NM	NM
4	Chikhalkar BG et al.[23] (2008)	300	H, W, FAL, HL, HB, FL, FB	167.26	24.008 with SD 1.420		8.895 with SD 0.703	
5	Krishna K, Kanchan T et al.[28] (2011)	246	HL, HB, FL, FB	NA	NA	NA	NA	NA
6	Patel PN, Tanna JA et al.[21] (2012)	273	H, FL, FB, HL, HB, AS	164.59	24.178 with SD 1.809		9.28 with SD 0.865	
7	A. Ibegbu, David et al.[16] (2013)	600 children	H, HL	NC	NC	NC	NC	NC
8	Prakash M Mohite et al.[22] (2015)	230	H, HL, HB, FL	165.02	Male- 25.86, Female- 22.67		NM	NM
9	Uhrova P, Benus R et al.[29] (2015) -Slovakadults	250	H, HL, HB, FL, FB	NA	NA	NA	NA	NA
10	Rati Tandon et al.[15](2016)	497	H, HL, HB, FL, FB, DL	172.7/157.1	Male - 26.22, Female - 23.35		Male- 9.95, Female - 8.89	
11	Kim W, Kim YM et al.[30] (2018)	5195	H, HL, HB, FL, FB	NM	NA	NA	NA	NA
12	Present study (2018–19)	1000	H, FL, FB	161.88	25.18/23.39	25.31/23.19	9.39/8.45	9.35/8.52

H= Height, HL = Hand length, HB = Hand breadth, FL = Foot length, FB = Foot breadth, PL = Palm length, DL = Digit/finger length, AS-Arm span, FAL = Forearm length, NM = Not measured NC = Not comparable, NA = Not available.

compare females, whereas BMI was significantly more in females as compare to males.

Table 4: Comparison of present study with previous studies

Fig. 1: Measurement of Height (cm) from the sole of the feet to the vertex of the head using Stadiometer

Fig. 2: Measured as distance between Metatarsal

tibiale (point projecting most medially on the head of the 1st metatarsal bone) and Metatarsal Fibulare (point projecting most laterally on the head of the 5th metatarsal bone).

Fig. 3: Foot length measured as the distance between the posterior most point of the heel and the anterior most point of the foot was measured as the foot length.

Fig. 4: Graphical representation of correlation between Foot length and BMI

Fig. 5: Graphical representation of correlation between Foot breadth and BMI

Fig. 6: Multiple bar diagram represents gender wise comparison of variables

Discussion

The study participants were of age group between 18 and 21 years, as the participants were students from 1st to 3rd medical, dental, nursing and ayurvedic streams of ESIC Institute. The age of 18 years has been accepted as adult and foot grows to adult size by age of 16 years.[17–20]

In present study, human stature ranged from 135.2 cm to 195.2 cm mean stature was 161.88 cm with SD of 13.45. These findings correspond closely with studies done on Indian population like that of Patel et al.[21](164.59 cm) and Mohite et al.[22] (165.02 cm) and Chikhalkar et al.[23] (167.2 cm), shown in (Table 4). Mean human weight was observed as 58.21 kg in male and 50.14 kg in females. Mean foot length on right side was 25.18 cm in male, 23.39 cm in female. Mean foot length on left side was 25.31 cm in male, 23.19 cm in female, (Table 3) and Fig 6. These findings correspond with studies of Anitha Oommen et al.[14], Rati Tandon et al.[15], Patel SM, Shah GV et al.[24] 2007, Prakash M Mohite et al.[22] (2015), shown in (Table 4). Foot breadth on right side was 9.39 cm in male, 8.45 cm in female. Foot breadth on left side was 9.35 cm in male, 8.52 cm in female, (Table 3) and Fig 6. These findings correspond with studies of B Danborno, AElukpo et al.[25] (2007), Rati Tandon et al.[15], Patel PN, Tanna JA et al.[21] (2012), Chikhalkar BG et al.[23] (2008), shown in (Table 4). Gender wise correlation revealed statistically highly significant difference between males and females ($p < 0.001$) in foot dimensions on both sides and also in height, (Table 3, Fig. 6) and were higher in males as compared to females. These findings matched with studies of Chikhalkar BG, Mangaonkar AA et al.[23] (2008), Kavyashree AN et al.[26] (2015) and Prakash M Mohite et al.[22] (2015), shown in (Table 4).

Body mass index was calculated from stature and weight as weight (kg)/height (mt^2) as 20.58 in male and 21.41 in female. BMI was observed significantly more in female as compared to male,(Table 3 and Fig 6). Based on foot dimensions and living body weight measurements, regression equations have been developed. Regression is a statistical tool, with the help of which we can estimate the unknown values of one variable from known values of another variable.[27] In present study, linear regression coefficient couldn't be calculated between BMI and foot length, but regression coefficient equation was successfully calculated between BMI and foot breadth as BMI = 19.306 + 0.168 *Foot breadth right and BMI = 17.214 + 0382 *Foot breadth left.

There was a statistically significant correlation between BMI and Foot breadth of right side, r = 0.124 and left side, r = 0.115. Whereas, statistically significant correlation between BMI and foot length couldn't be observed neither on right side, $r = 0.073$, nor on left side, $r = 0.024$. That proved that, foot breadth of both sides was significantly more in those who had higher body mass index.

Conclusion

1. Highly statistically significant difference was observed in mean foot length and breadth on both sides in both sexes.
2. Body mass index was observed significantly higher in females as compared to males.
3. Statistically significant correlation was observed between body mass index and foot breadth.
4. Statistically non-significant correlation was observed between body mass index and foot length.
5. The linear regression formula derived can be used for population between 17 and 20 years but it might be of limited use for children and older people.
6. Equation derived from present study can be used to estimate body mass index from foot width and *vice versa* among the Central Indian population.
7. It would be unwise to use the same equations for body mass index estimation for different Indian populations.
8. The data collected should be useful for forensic investigations in cases of crime in Kalaburagiregion.

Limitations

1. In the present study, age range of only 17 to 20 years was considered.
2. Only healthy individuals were included in the study. Hence, the data may not be applicable students those with deformities of foot, vertebral column and limbs, contractures, those with h/o of trauma to foot, those with features suggestive of dysmorphic disorder, pregnant females.
3. Applicability of anthropometric measurements in living and deceased individuals may practically differ.
4. The present study is a preliminary one and would be followed up by other studies to address the above limitations.

Compliance with ethical standards

1. *Conflict of interest*: All authors hereby disclose that there is no financial and personal relationships with other people or organizations that could inappropriately influence (bias) this work. A document declaring this has been attached.
2. *Animal subjects research:* The present study had no involvementof animal subjects in any form or manner.
3. *Human subjects research*:
   a. The present study was conducted on human subjects. The present studyhas received the approval of Institutional Ethical Committee of ESIC Medical College, Gulbarga. IEC comes under the Rajiv Gandhi University of Health Sciences, Bangalore.
   b. The present study, being approved by the Institutional Ethics Committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and all subsequent revisions.
   c. Informed consent was taken from each and every human participant and the records have been kept with Anthropometry section of Department of Anatomy of ESIC MC, Gulbarga.
   d. The scan copy of Ethical Committee Approval letter has been attached along with the manuscript.

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