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Research Article

Estimation of Stature using footprints in an adult student population in Nigeria

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Abstract

Background: Footprints reveal that the human foot, its bones and its impressions can successfully be used in estimation of stature for forensic and legal examinations. The aim of the study was to find the relationship between stature and footprint dimensions, and to generate a population-specific equation.

Materials and Method: In the present study, stature and bilateral footprint measurements of 200 Igbo adults (100 males and 100 females) of ages 18 to 30 years were measured. Participants' bio-data were noted and their footprints collected using endorsing ink. The obtained values were statistically analyzed using SPSS Version 16.0.

Results: The mean height and footprints of males were greater than that of females. There were significant and positive correlations between stature and various left and right footprints (T-1 to T-5) in males and females ($p<0.001$). However, in male subjects the relationship between stature and breadth at ball was insignificant at both feet ($r=0.145$ [left]; $r=0.032$ [right]; $p>0.05$); the relationship between stature and breadth at heel was equally insignificant ($r=0.152$ [left]; $r=0.184$ [right]; $p>0.05$). While in females, the relationship between stature and left and right breadth at ball was very significant ($r=0.474$ [left]; $r=0.450$ [right]; $p<0.001$); there was also a significant association between stature and the left ($r=0.353$; $p<0.001$) and right ($r=0.262$; $p<0.01$) breadth at heel.

Conclusion: The study revealed that footprint dimensions are strongly correlated with stature and can be used for predicting stature in forensic examinations.

Keywords: Footprint, Forensic science, Stature estimation.

1. Introduction

To estimate stature in forensic sciences is quite important during the identity defining stage.[1] For better accuracy, stature estimation may be attempted only after the attainment of maturity.[2] Accurate estimation from known parameters is a fundamental aspect of science and is evident as emerging approach in the area of footprints and stature estimation;[3] because foot length displays a biological correlation with stature that suggests the latter might be estimated from foot or shoe prints.[4] Morphology of human feet is greatly influenced by combined effects of heredity and living style of man that determines the size and shape of feet and footprints.[5] Therefore, careful examination of foot impressions in forensic examination can provide useful clues to establish personal identity whenever complete or partial foot prints are recovered at the crime scene and it can help in including and excluding possible presence of individuals at the crime scene.[6]

Various studies have been conducted on estimation of stature from the measurements of foot prints. Krishan[7] derived regression formula to estimate stature from various dimensions of footprints and foot outline in an endogamous group of North India. Fawzy and Kamal[8] estimated stature from various foot print measurement among 50 male Egyptian medical students. Reel *et al*[4] sought to estimate stature from static and dynamic footprints among 61 adult males and females in the United Kingdom.

Little is known concerning the relationship between foot print dimensions and stature among the Igbo ethnic group, hence the study seeks to explore their relationship and to develop a regression model for stature estimation.

2. Materials and Methods

2.1 Sample

The study sample comprises of 200 subjects (100 males and 100 females) aged between 18-30 years. The study was carried out in Nnewi, Anambra State. Subjects were screened; any with deformities or fractures of the feet or lower limbs were excluded from the study.

2.2 Methodology

Ethical approval was obtained from the Ethical Committee, Faculty of Basic Medical Sciences, College of Health Sciences, Nnewi. A total of 400 footprints were obtained from left and right feet of 200 male and female students residing in Nnewi, Anambra state. Precautions were taken by cleaning their soles with soap and water. Informed consent was obtained prior to taking the footprints. With an endorsing ink poured in a plastic slab, the subjects were asked to stand on the plastic slab and then on the clean duplicating papers which were attached to a flat board lying on a ground surface. With the feet still on the paper, the following anatomical landmarks of the foot were carefully noted and marked on the paper close to the foot prints using a sharp pointed pencil.

a. Mid-rear heel point (pternion)
b. Medial Metatarsal point (mt.m)
c. Lateral metatarsal point (mt.l)
d. Calcaneal concavity medial (cc.m) and
e. Calcaneal tubercle lateral (ctu.l)

A total of seven (7) measurements were taken on left and right footprints. Firstly, following Krishan,[7] the designated longitudinal axis (DLA) and baseline (BL) were drawn on the foot prints in an attempt to establish a definite axial orientation for length measurement. The DLA is from the pternion (Pte.) landmark at the most posterior point of the rear heel margin to the lateral side of the toe 1 margin. The DLA enables one to take foot length measurement from a specific landmark along the foot to the rear of the foot while keeping the line of measurement parallel to the DLA. The baseline (BL) is drawn at the rear edge of the foot and perpendicular to the DLA. The BL extends from the landmark pternion at the rear of the heel in both the medial and lateral directions while maintaining its perpendicular alignment with the DLA.

The measurement taken on the footprints include:

- Footprint length measurements (T-1 length, T-2 length, T-3 length, T-4 length and T-5 length): these measurements were taken from the pternion (Pte.) to the most anterior point of each toe i.e. d1.t, d2.t, d3.t, d4.t, and d5.t.
- Foot print breadth at ball: foot breadth was measured from metatarsal lateral (mt.l), the most lateral point on the metatarso-phalangeal joint to toe 5, and metatarsal medial (mt.m), the most medial point on the metatarso-phalangeal joint of toe 1.
- Foot print breadth at heel: foot breadth at heel was measured from calcaneal concavity medial (cc.m) to calcaneal tubercle lateral (Ctu.l)

The different footprint measurements are shown in Figure 1 and Figure 2.

Figure 1: Left footprint showing the different footprint measurements

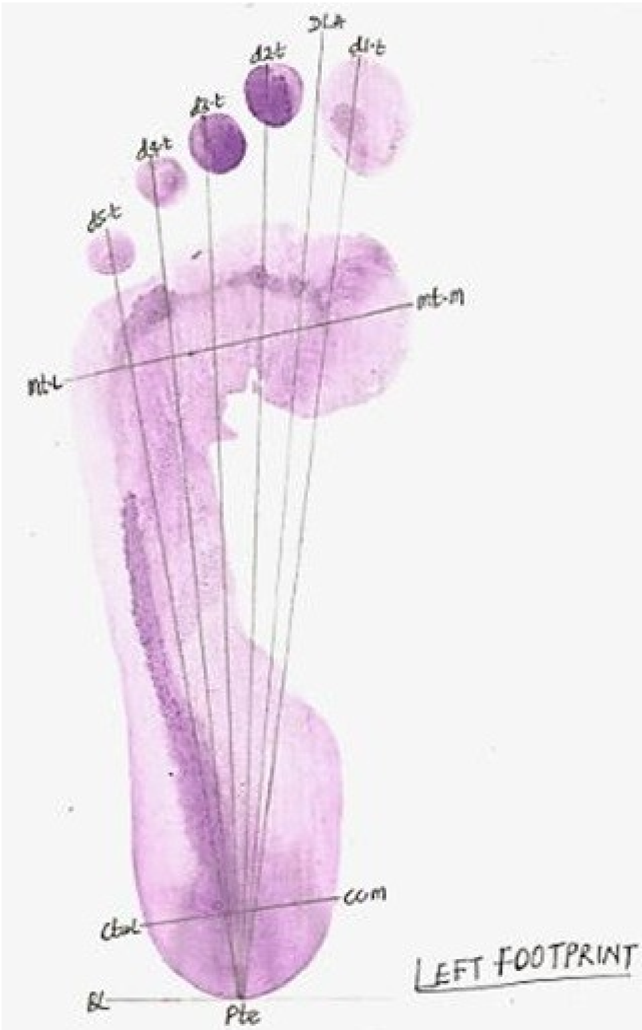
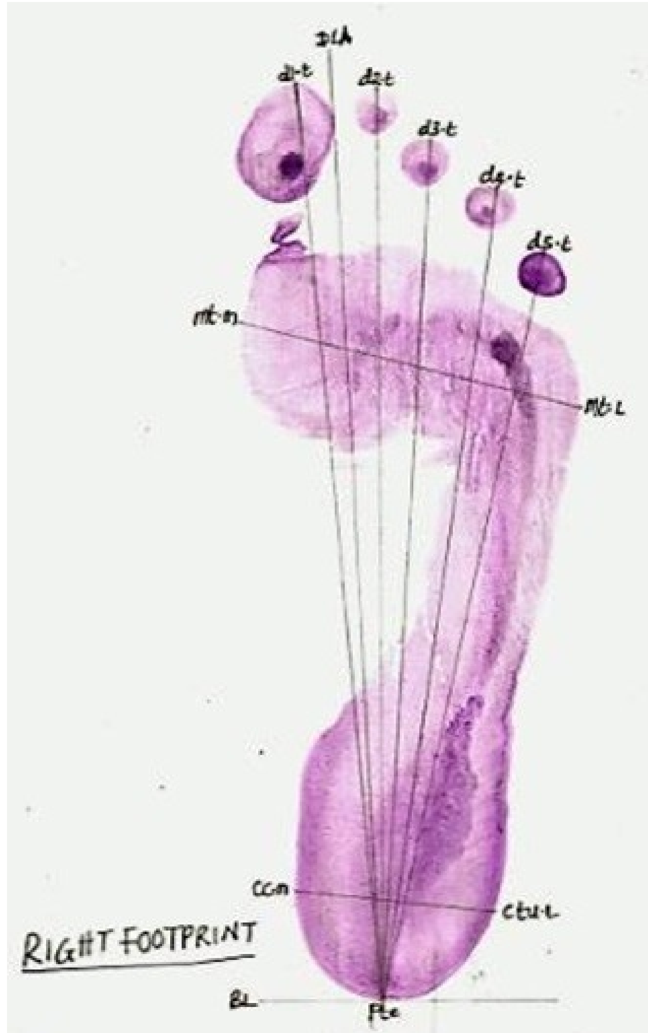


Figure 2: Right footprint showing the different footprint measurements



2.3 Measurement of Stature

Stature was measured as the vertical distance between the point vertex and the floor. The subject was made to stand bare foot in an anatomical position on the base board. Both feet were in contact with each other and head oriented in Frankfurt's plane. The height was then recorded in centimeter from the standing surface to the vertex using a height meter.

2.4 Data Analysis

The data was collected, analyzed and subjected to statistical analysis using Statistical Package for Social Sciences (SPSS) version 16.0. The mean, standard deviation and correlation coefficient between stature and footprint dimension were determined for both male and female subjects. A simple linear regression formula was derived from the individual footprints dimensions to serve as a model for stature estimation. The reliability of estimation of stature from the footprint dimension was determined from the standard error of estimation (SEE). Every care was taken while measuring the subjects for stature and while taking measurements on footprints. To avoid inter-observer error, all the measurements were taken by the author himself.

3. Result

Table 1: Mean, standard deviation and range of stature and footprints of male subjects (N=100).

Measurement (cm)	Mean		Standard Deviation		Minimum		Maximum	
	Right	Left	Right	Left	Right	Left	Right	Left
T-1 length (d1.t)	26.19	26.29	1.09	1.04	24.10	23.90	29.50	28.80
T-2 length (d2.t)	25.72	25.86	1.11	1.09	23.60	23.90	29.10	28.70
T-3 length (d3.t)	24.72	24.92	1.17	1.07	20.20	22.80	28.20	28.10
T-4 length (d4.t)	23.49	23.61	0.98	0.95	21.30	21.75	26.80	26.40
T-5 length (d5.t)	21.96	22.07	0.88	0.90	19.70	19.90	24.40	24.70
Breadth at ball (mt.m-mt.l)	9.83	9.91	0.59	0.60	8.30	8.10	11.20	11.50
Breadth at heel (cc.m-ctu.l)	5.93	5.96	0.53	0.53	4.50	4.70	7.10	7.00
Stature	175.70		5.87		161.00		189.00	

Table 1 gives the range of variation in the measurement of variables which can be observed by examining the minimum and maximum columns of the tables. Variables that show greater or lesser changes in size between their footprint measurements can be observed.

Table 2: Mean, standard deviation and range of stature and footprints of female subjects (N=100).

Measurement (cm)	Mean		Standard Deviation		Minimum		Maximum	
	Right	Left	Right	Left	Right	Left	Right	Left
T-1 length (d1.t)	24.12	24.06	1.09	1.11	21.60	21.50	26.90	27.00
T-2 length (d2.t)	23.91	23.82	1.03	1.17	21.40	20.20	26.30	26.60
T-3 length (d3.t)	23.02	22.93	1.07	1.13	20.40	20.00	25.40	25.70
T-4 length (d4.t)	21.98	21.87	1.01	1.04	19.50	19.40	24.30	25.00
T-5 length (d5.t)	20.61	20.51	0.91	0.96	17.90	18.00	23.00	23.30
Breadth at ball (mt.m-mt.l)	9.18	9.21	0.51	0.53	8.10	8.10	10.60	10.50
Breadth at heel (cc.m-ctu.l)	5.41	5.29	0.39	0.42	4.50	4.30	6.50	6.20
Stature	165.10		6.41		146.00		182.00	

Table 2 presents the range of variation in the measurement of variables which can be observed by examining the minimum and maximum columns of the tables. Variables that show greater or lesser changes in size between their footprint measurements can be observed.

Table 3: Gender differences in foot measurements and stature.

Measurement (cm)	t-STAT	
	Right	Left
T-1 length (d1.t)	13.386*	14.667*
T-2 length (d2.t)	11.965*	12.760*
T-3 length (d3.t)	10.746*	12.739*
T-4 length (d4.t)	10.662*	12.363*
T-5 length (d5.t)	10.648*	11.897*
Breadth at ball (mt.m-mt.l)	8.327*	8.675*
Breadth at heel (cc.m-ctu.l)	7.895*	9.963*
Stature	12.19*	

* $p < 0.001$

Independent sample t-test indicated significant gender differences in foot measurements and stature. The male subjects had significantly greater left and right foot measurements (P<0.001) and stature (P<0.001) when compared to the females.

Table 4: Correlation between stature and left and right footprints of male subjects.

MEASUREMENTS	Right		Left	
	Coefficient (r)	P-Value	Coefficient (r)	P-Value
T-1 length (d1.t)	0.572	0.000	0.584	0.000
T-2 length (d2.t)	0.560	0.000	0.580	0.000
T-3 length (d3.t)	0.510	0.000	0.605	0.000
T-4 length (d4.t)	0.541	0.000	0.604	0.000
T-5 length (d5.t)	0.494	0.000	0.547	0.000
Breadth at ball (mt.m-mt.l)	0.032	0.750	0.145	0.149
Breadth at heel (cc.m-ctu.l)	0.184	0.067	0.152	0.131

Table 4 presents the correlation between stature and left and right footprints of male subjects. Pearson's correlation test indicated very significant association between stature and left and right footprint (T1-T5) of the male subjects ($p<0.001$). However, the relationship between stature and breadth at ball was insignificant at both feet ($p>0.05$), also the association between stature and breadth at heel ($p>0.05$).

Table 5: Correlation between stature and left and right footprints of female subjects.

MEASUREMENTS	Right		Left	
	Coefficient (r)	P-Value	Coefficient (r)	P-Value
T-1 length (d1.t)	0.607	0.000	0.608	0.000
T-2 length (d2.t)	0.570	0.000	0.607	0.000
T-3 length (d3.t)	0.520	0.000	0.607	0.000
T-4 length (d4.t)	0.594	0.000	0.607	0.000
T-5 length (d5.t)	0.549	0.000	0.602	0.000
Breadth at ball (mt.m-mt.l)	0.450	0.000	0.474	0.000
Breadth at heel (cc.m-ctu.l)	0.262	0.008	0.353	0.000

Table 5 also presents the correlation between stature and left and right footprints of female subjects. Pearson's correlation test (table 5) indicated very significant association between stature and left and right foot prints (T1-T5) in females ($p<0.001$). The relationship between stature and left and right breadth at ball is also very significant ($p<0.001$). There is also significant association between stature and left ($p<0.001$) and right ($p<0.01$) breadth at heel.

Table 6: Regression equations for estimating stature from right and left footprints of male subjects.

MEASUREMENTS (cm)	REGRESSION EQUATION		± SEE	
	Right	Left	Right	Left
Breadth at ball (mt.m-mt.l)	172.562 + 0.319BAB	161.585 + 1.425BAB	9.850	9.731
Breadth at heel (cc.m-ctu.l)	163.535 + 2.053BAH	165.660 + 1.683BAH	6.602	6.612
T-1 length (d1.t)	95.042 + 3.080[d1.t]	89.180 + 3.291[d1.t]	4.842	4.794
T-2 length (d2.t)	99.356 + 2.968[d2.t]	94.463 + 3.141[d2.t]	4.893	4.809
T-3 length (d3.t)	112.134 + 2.571[d3.t]	93.141 + 3.313[d3.t]	5.079	4.702
T-4 length (d4.t)	99.870 + 3.229[d4.t]	87.166 + 3.750[d4.t]	4.966	4.707
T-5 length (d5.t)	103.534 + 3.287[d5.t]	96.742 + 3.577[d5.t]	5.134	4.942

Table 6 illustrates the regression equations for stature estimation from footprint measurement calculated by linear regression analysis. Stature = a + bx, where 'a' is the regression coefficient of the dependent variable, i.e. stature, and 'b' regression coefficient of the independent variable, and 'x' is any footprint measurement. The table also depicts the standard error of estimate (SEE).

Table 7: Regression equations for estimating stature from right and left footprints of female subjects.

MEASUREMENTS (cm)	REGRESSION EQUATION		± SEE	
	Right	Left	Right	Left
Breadth at ball (mt.m-mt.l)	113.243 + 5.648BAB	112.008 + 5.762BAB	5.749	5.669
Breadth at heel (cc.m-ctu.l)	142.112 + 4.252BAH	136.286 + 5.445BAH	6.214	6.023
T-1 length (d1.t)	78.925 + 3.573[d1.t]	80.628 + 3.511[d1.t]	5.115	5.113
T-2 length (d2.t)	80.773 + 3.528[d2.t]	86.181 + 3.313[d2.t]	5.291	5.118
T-3 length (d3.t)	93.401 + 3.114[d3.t]	86.513 + 3.427[d3.t]	5.499	5.119
T-4 length (d4.t)	82.038 + 3.779[d4.t]	83.636 + 3.726[d4.t]	5.180	5.119
T-5 length (d5.t)	85.152 + 3.879 [d5.t]	82.733 + 4.017[d5.t]	5.383	5.142

Table 7 illustrates the regression equations for stature estimation from foot print measurement calculated by linear regression analysis. Stature = a + bx, where 'a' is the regression coefficient of the dependent variable, i.e. stature, and 'b' regression coefficient of the independent variable, i.e. any footprint measurement, 'x' is any footprint measurement. The table also depicts the standard error of estimate (SEE).

4. Discussion

The results indicate that one can successfully estimate stature from different parts of the footprints with a standard error of estimate using regression analysis.The reason for taking the adult sample ranging from 18 to 30 years (average being 24.47) may be due to the fact that generally stature at 18 years is accepted as adult although there are small increments in stature after this.[9] Stature estimates are estimates, they are not exact and should always be expressed with range of error.

All measurement of the footprints can be compared with those of Krishan.[7] The footprint dimensions of the present Igbos indicate large values than that of Krishan who presented data for only males ranging from 18-30 years in an endogamous group of North India. In this study, it was observed that in most of the samples of footprints, there were bilateral differences in the footprint measurements. This is supported by Krishan,[7] suggesting that the difference between the left and right footprints in the same individual is not a coincidence but may be explained on the basis of the dominant foot. Oberoi *et al*[10] selected footprints from right foot for the study. This study showed statistically significant differences between sexes for all footprints ($p < 0.001$) in Table 3. These findings are in concordance with several previous studies.[1,9,10] Oberoi *et al*[10] reported that the mean height and footprints measurements of males were greater than that of females which corresponds with the present study. Krishan[7] used only male subjects with the same measurements and so did not encounter the bilateral differences in sexes.

The standard error of estimate for the correlation between stature and left and right toe length measurements (4.702 - 5.499) are small compared to the breadth at ball/heel (5.669 - 9.850). Krishan[7] makes it apparent that the estimation of stature from toe length measurements in footprints has more reliability of prediction than from the other measurements. Fawzy and Kamal[8] reported that the regression equations presented smaller standard errors of estimate (3.52 - 4.09) in determination of stature for only 50 Egyptian males.

Reel *et al*[3] reported that the highest correlations with stature were shown to be the heel-to-fourth print for the static group of footprints ($r = 0.786$, $p < 0.01$) and the heel-to-fifth toe print in dynamic footprints ($r = 0.858$, $p < 0.01$). In the present study, the highest correlations with stature for males were shown to be the T-1 length ($r = 0.572$, $p < 0.001$) for right and T-3 length ($r = 0.605$, $p < 0.001$) for left. For females the highest correlation with stature were shown to be the T-1 length for both feet ($r = 0.607$, $p < 0.001$) for right and ($r = 0.608$, $p < 0.001$) for left. The correlations of stature with various length measurements from toes in both left and right footprints are quite high with the average of the left and right being (0.52, 0.58) for males and (0.57, 0.60) respectively for females suggesting a close relationship with them. One can therefore estimate stature from either left or right side measurements of footprints.

5. Conclusion

The study revealed that footprint dimensions are strongly correlated with stature and can be used for predicting stature in forensic examinations. However, in view of the statistically significant differences between sexes for all footprints measurements and bilateral asymmetry occuring in most of the footprint measurements in adult Nigerian population, one has to be careful because these results and regression equations in particular can only be applied to the population from which the data has been obtained. It is therefore suggested that similar studies should be conducted in other groups of the world so that the effect of genetics and environment can be investigated and appraised in medical forensic terms.

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