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Sex estimation using foot measurements, stature and body mass index (BMI) in a Nigerian population

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Abstract:
Identification of dismembered bodies recovered in disasters or crime scene is very important in forensic. This study was carried out to ascertain if foot size, body weight, height, stature and BMI can be used to predict sex using tape rule and Stadiometer scale. 150 subjects between 18 - 25yrs were recruited. Independent T-test, Pearson Correlation, Linear and Multiple Regression Analysis were determined using SPSS version 23. All measurements were higher in male than female and there was significant ($p \leq 0.05$) difference in the sex. The average foot length of 257.39mm was used to determine sex of the subjects. All foot lengths ≤ 257.39mm were presumed to belong to females while all values > 257.39mm was presumed males. Foot size and weight had the highest correlation values. Foot length gave better estimation of sex than foot breadth, BMI and weight. Results of Multiple regression equation was better than linear regression equation. In forensic anthropology, foot size has been used to predict sex. Limitation of this study is the formulae generated can only be applied to Nigerians aged 18-25 yrs. Studies should be carried out on diverse population for future inferences

Keywords: **Foot measurements, body mass index, sex prediction, forensic anthropology, human identification**

Introduction

Precise identification is the most important step in forensic and medicolegal practices. Measurement of foot, footprints [1-3] and/or other recovered [4] body parts of forensic interest are important when a body is incomplete or unavailable in estimating body height and sex in forensic investigations. [5-7] In disasters, recovery of foot is possible as they are safeguarded in shoes. [8-10] Body mass index (BMI) is an important forensic parameter. [11, 12] Human stature can be estimated using femoral length, other long bone's length [13] foot length and width. [14-16]
This study develops formulae to estimate sex using foot measurements, weight, height and BMI in Nigerians aged 18-25years.

Results and Discussion

Tables 1 shows the bilateral differences in all the subjects. Generally, the mean value of foot length is higher in the left foot whereas mean value of foot width is higher in the right foot. However, there are no statistically significant differences in the measurement of foot length and foot width. These findings are in agreement with some published data. [4, 5, 7]

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Table 1: Bilateral differences in foot measurement

SN	Foot Measurement	Mean Right foot ± SEM	Mean Left foot ± SEM	T-test (P)
1	Male Foot Length	267.23 ± 1.35	269.04 ±1.41	0.354
2	Female Foot Length	246.11 ± 1.58	246.68 ±1.62	0.800
3	Male Foot Width	87.83 ± 0.65	87.36 ±0.67	0.619
4	Female Foot Width	78.20 ± 0.82	77.59 ±0.86	0.605

(n=75)

Comparative statistics with the mean value, standard error and p-value for each measurement in sex (male and female) can be seen in Table 2 and Table 3 respectively. All measurements (including BMI, weight and height) are higher in male than female. There was no significant difference ($p \leq 0.05$) in the BMI values of the male and female as shown in table 3. Statistically significant bilateral differences in foot length and foot width have been reported in a number of studies. [5,15,17,18]

Table 2: Bilateral measurement in male and female average foot measurement

Average Foot Measurement	Male (Mean ± SEM)	Female (Mean ± SEM)	T-test (P)
Foot Length	268.13 ± 1.31	246.40 ±1.56	0.000
Foot Width	87.59 ± 0.63	77.89 ±0.82	0.000

All measurements (including BMI, weight and height) are higher in male than female. The sex differences are not significant. Males are generally taller than females due to about two years' delay that occur in males at puberty age. This delay allows them to have extra time for body growth. [5] Males are taller with increased length of the heterochromatic band Yq12 in the chromosome Y and chromosome Y is closely linked to stature. [17] The fact that females wear high heel shoes shows that females are generally shorter than males. [4]

Table 3: Differences in male and female body measurements

Measurement	Male (Mean ± SEM)	Female (Mean ± SEM)	T-test (P)
BMI	22.32 ±0.47	21.93 ±0.42	0.538
Weight	69.67 ±1.22	59.72 ±1.22	0.000
Height	1.78 ±0.01	1.65 ±0.01	0.000

Correlation between BMI, stature, height, weight and foot measurements in both sexes was evaluated and shown in Table 4 and the highest correlation values were found in left foot length (LFL), left foot width (LFW), right foot length (RFL), right foot width (RFW), and weight (W). These findings are in agreement with some other published findings. [18-20]

Table 4: Correlation between BMI, all foot measurements, stature and weight in male and female

Measurement	**RFL**		**RFW**		**LFL**		**LFW**		**Stature**		**Weight**	
	M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
BMI	0.11	0.17	0.5[a]	0.52[a]	0.18[a]	-	0.49[a]	0.49[a]	0.01	0.02	0.68[a]	0.87[a]
Rp	0.351	0.149	0.0	0.0	0.124	-	0.0	0.0	0.936	0.905	0.0	0.0
RFL	-	-	0.37[a]	0.38[a]	0.82[a]	0.90[a]	0.35[a]	0.42[a]	0.64[a]	0.66[a]	0.44[a]	0.48[a]

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Rp	-	-	0.0	0.0	0.0	0.0	0.002	0.0	0.0	0.0	0.0	0.0
RFW	0.37[a]	0.38[a]	-	-	0.43[a]	0.33[a]	0.8[a]	0.9[a]	0.23[b]	0.25[b]	0.54[a]	0.58[a]
Rp	0.001	0.001	-	-	0.0	0.004	0.0	0.0	0.05	0.03	0.0	0.0
LFL	0.82[a]	0.9[a]	0.43[a]	0.33[a]	-	-	0.31[a]	0.35[a]	0.65[a]	0.68[a]	0.51[a]	0.46[a]
Rp	0.0	0.0	0.0	0.0	-	-	0.001	0.002	0.0	0.0	0.0	0.0
LFW	0.35[a]	0.42[a]	0.8[a]	0.9[a]	0.37[a]	0.35[a]	-	-	0.12	0.26[b]	0.56[a]	0.57[a]
Rp	0.002	0.0	0.0	0.0	0.0	0.002	-	-	0.32	0.0	0.0	0.0
Stature	0.64[a]	0.66[a]	0.23[b]	0.25[b]	0.65[a]	0.68[a]	0.12	0.26[b]	-	-	0.46[a]	0.47[a]
Rp	0.0	0.0	0.0	0.0	0.0	0.0	0.32	0.0	-	-	0.0	0.0
Height	0.64[a]	0.66[a]	0.23[b]	0.25[b]	0.65[a]	0.68[a]	-0.12	0.26[b]	1.0[a]	1.0[a]	0.46[a]	0.47[a]
Rp	0.0	0.0	0.0	0.0	0.0	0.0	0.32	0.0	0.0	0.0	0.0	0.0
Weight	0.44[a]	0.48[a]	0.54[a]	0.58[a]	0.51[a]	0.46[a]	0.56[a]	0.57[a]	0.49[a]	0.47[a]	-	-
Rp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-

[a] = Correlation is significant at the 0.01 level (2-tailed)

[b] = Correlation is significant at the 0.05 level (2-tailed)

Key: RFL = Right foot length RFW = Right foot width

LFL = Left foot length LFW = Left foot width

Right foot length (RFL), right foot width (RFW), left foot length (LFL), left foot width (LFW), stature and weight were evaluated to develop formulae in BMI estimation using linear regression analysis. Multiple regression analysis was used to develop formulae from the combination of average foot length and average foot width. Table 5 shows the regression equations for estimation of BMI from foot measurements, stature and weight for general use in both sexes. Weight in all groups show higher correlation coefficient (R), with BMI other than stature and foot measurements. Linear regression equations are the best parameter for BMI estimation. [6, 9] Multiple regression equations give better results than linear regression equations [21] as the correlation coefficient (R) value was highest in the combination of average foot length and average foot width in all the formulae.

The Standard Average Foot Length as obtained from the respective formula is equal to 257.39 mm. An attempt was made to determine the sex of the subjects using this value. All the foot print lengths less than or equal to this value were presumed to belong to females while all the values greater than this were presumed to belong to males. [22]

Table 5: Specific formulae for BMI estimation in sex

Sex	Measurement	Formulae	R	R^2
Male	**RFL**	BMI=12.139+(0.038xRFL) ± 4.07	0.109	0.012
(n=75)	**RFW**	BMI=-8.847+(0.355xRFW) ± 3.559	0.495	0.245
	LFL	BMI=6.272+(0.06xLFL) ± 4.028	0.179	0.032
	LFW	BMI=-7.705+(3.566xLFW) ± 3.566	0.491	0.000
	S	BMI=21.395+(0.001xS) ± 4.094	0.009	0.453
	W	BMI=4.301+ (0.259xW) ± 3.028	0.673	0.453
Female	**RFL**	BMI=11.018+(0.44xRFL) ± 3.579	0.168	0.028
(n=75)	**RFW**	BMI=1.433+(0.262xRFW) ± 3.113	0.515	0.265
	LFL	BMI=13.336+(0.035xLFL) ± 3.597	0.135	0.018
	LFW	BMI=3.336+(0.24xLFW) ± 3.159	0.493	0.243
	S	BMI=23.064+(0.001xS) ± 3.63	0.014	0.000
	W	BMI=4.265+ (0.296xW) ± 1.822	0.633	0.468
AFL+AFW		BMI=4.827+(-0.51xAFL)+(0.209xAFW) ± 3.469	0.865	0.748

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Researcher have undertaken some studies to ascertain the variations in the measurements obtained from living body and cadaver because of its importance in forensic anthropology. [24-26] In a study by Clarys *et al*., to investigate body composition and the extent to which anthropometry can be justifiably used to predict whole-body adiposity, an extensive dissection study was undertaken on 34 cadavers. In addition, to pre-empt questions on the applicability of cadaver data to living subjects, 40 elderlies *in vivo* subjects of the same age range were compared with the cadaver population. No significant macro-morphological differences were found between males or females in the morbid and *in vivo* groups. [24] In an experiment by Petrovecki, *et al*., to predict the stature based on radiographic measurements of cadaver long bones using Croatian population, they stated that "Regression equations specific to the Croatian population were computed separately for each long bone in males and females and proven to be reliable in predicting the living stature of the individual".[25] In a study by Ferorelli *et al.*, they stated that "The findings here observed, even considering the limitation exposed in the study, do not support the theory that there is a great difference in cadaver stature postmortem". [26]

Conclusion

Conclusively, foot measurements can provide splendid reliability in prediction of stature and sex in forensic investigations. Foot length gives better estimation of stature and sex than foot breath, BMI and weight. Multiple regression equations provide better results than linear regression equations as shown by the significant difference in their R. significant impacts have be documented in forensic anthropology in stature and sex prediction using foot measurements such as foot length and foot breadth. However, the limitation in this study is that the formulae generated in this study was that they could be applied for Nigerians from aged 18-25 years old. Further studies should be carried out on more diverse population for future implications.

MATERIALS AND METHODS

Subjects:

This study was conducted among students in Faculty of Science, University of Lagos, Lagos. A total of 150 Nigerians (75 males and 75 females) ranging from 18 to 25 years old were recruited for the study.

Materials:

Stature, height, foot length and foot width were measured using anthropometric instruments such as Seca 760 Colorata mechanical bathroom scale, Stadiometer scale, tape rules, and a weighing scale.

Methods:

Values for the body mass index were deduced thereafter using appropriate parameters (weight and height). All the subjects were asked to bare their feet during the measurements. All the subjects were measured in the afternoon at 14:00-16:00 hours due to diurnal variations. [4,19,27]

Stature and all foot measurements were taken in the unit of milimeter (mm). Height and weight measurements were taken in the units of metre (m) and kilogramme (kg) respectively. Stature was taken from the point vertex to the floor in which the subject is in a standing posture using a meter. They stood up against the wall with both feet in close contact with each other and the trunk braced up to the wall. The head is positioned in Frankfurt plane (ear-eye plane) by keeping the lateral palpebral commissure and the tip of auricle of the pinna in a horizontal plane parallel to the feet in obedience to anatomical position. Right foot length (RFL) and left foot length (LFL) of the subjects were measured from the most anterior and posterior points of the foot. Right foot width (RFW) and left foot width (LFW) were measured from the surfaces of first metatarsal bone head to fifth metatarsal bone head. [19] The weight of all the subjects were taken using a Seca 760 Colorata mechanical bathroom scale and recorded. The procedures followed were in accordance with the ethical standards of the Health Research ethical committee of College of Medicine of the University of Lagos.

Statistical analysis:

All the numerical data were subjected to statistical analysis using SPSS 23.0. All the measurements were presented in descriptive statistics. Independent T-test was used to compare the right and left foot measurements between sex, BMI, weight and height measurements between sex. Correlation analysis was carried out by Pearson Correlation Analysis. Linear and Multiple Regression Analysis were used to develop formulae for

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stature while the Standard Average Foot Length as obtained from the formula given below was used to estimate one's sex.

Standard average foot length = $\frac{\text{(Male Mean AFL – S.E) + (Female mean AFL + S.E)}}{2}$

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