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Estimation of Staute from Toe Lengths: An Evaluation of the Hausa Population in Nigeria Using Linear Modeling

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ABSTRACT

Background: Statue determination has remained a basic requirement in determining human identity and ethnicity. Usually in situations when whole anatomical structures are unavailable, forensic expert would be expected to rely on smaller structures such as the phalanges, patella ribs and other fragmentary bones. Aim: The present study evaluates toe anthropometry and its usability as predictors of the stature of the Hausa ethnic group in Nigeria. **Methods:** Six hundred and sixty four (664) subjects comprising of equal percentage of adult males and females were included in the study group. Toe lengths of both feet (coded as big toe or first toe [1T] to the fifth toes [5T]) were measured using a digital Vernier calliper with accuracy of 0.01mm while stature was taken using a stadiometer with accuracy of 0.1m. SPSS (IBM®) t-test was to evaluate gender difference in the measured dimensions; while SPSS and XLSTAT (2015) Automatic & Generalized Linear Modelling were used to determine the predictability of stature from the toe lengths. The significance level was set at 95% as P≤0.05 was considered significant. **Results:** The automatic (multiple) regression analysis showed that the males displayed significantly higher mean values than the females for all measured parameters (P<0.001). The general population regression formulae were derived and only three (3) variables (R2T, R5T and L3T) significant contributors to the models for stature prediction for the general Gp (R2=0.385, F[3, 660]=137.68, P<0.001) and female F (R2=0.137, F[3, 328]=17.367, P<0.001) population, while only the L.1T could predict male M stature (R2=0.139, F[1, 330] = 54.489, P<0.001). Single regression gender-specific formulae were derived for the measurements that provided significant R2 values. **Conclusion:** This study suggested that estimation of a stature of Hausa ethnic group could be made possible by using specific toe measurements. However, lengths of toe may not be so reliable in the estimation of stature, but could be used for sex discrimination in forensic investigation.

Keywords: *Hausa, Length, Statue, Toe length, Regression.*

INTRODUCTION

The statue or height of an individual must be assertained if the biological profile and identity of the individual (living or dead) must be complete. When completed formed bodies are to be assessed, stature estimation is devoid of complications.[1] But when the human body is dismembered, even the most skilful forensic experts rely on various technicalities and consultations to reach logical inferences. However, it is the responsibility of anthropometrist to provided; even the minutest evidence that would assist the field forensic experts in completing their task accurately, within the shortest of time.

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Acurate identification of remains is hinged upon the availability and completeness of ante- and post-mortem records which is relied on as a fundamental comparative tool.[1,2] Thus, any available investigative documentation is most useful to the forensic expert. Many researchers have documented the relationship between stature and percutaneous measurements of various body parts such as the head,[2-9] bones of the upper extremity,[10-16] lower extremity,[17-23] and other irregular bones such as vertebrae column,[24-26] sternum as well as fragment of bones.[28] When the above documented bones are unavailable due to extensive dismemberment, experts must turn to smaller bones with small surface to volume ratio, which could escape such events.

In estimating stature, predictive models are developed which could be single or multiple regressions. However not all models derived can accurately predict stature. But, models resulting from using long bones have shown to be most accurate in predicting stature (R2>75) while irregulary shaped bone predicts less accurately(R2<50). Although foot parameters for the estimation of stature have been extensively studied,[18-21,23,29,30] little or nothing has been documented about the relationship between the toe lengths and stature.

Therefore, the present study has been carried out to evaluate the predictibility of stature from toe lengths measurements and the formulation of adequate gender-specific regression models.

MATERIALS ANDMETHODS

Sample

The present study was carried out on 664 (3 males and 233 females) Adults (≥18years) belonging to Hausa ethnicity in Nigeria. Samples were drawn from the different state representing the enthic groups with indiginicity traced to 2nd generation. Sample size was determined using chochran formulae for large population (>10,000) or infinite population ($SS = \frac{Z^2 \times p \times q}{d^2}$);[31] while stratified multistage random sampling method was used to select subjects from the regions covering the ethnic group.

Anthropometric measurement

With the knwoledge of the international agreement for paired measurements at Geneva (1912)[32], the toe lengths of both feet were measured during dorsi flexion (at well seated posittion) using a digital venier caliper; defined by the distance between the tip of the toe to the proximal metatarsophalangeal crease of that toe when fully extended for both feet. While the stature or height was taken in standing position to the vertex by using a standiometer. Measurements were taken twice and the average tabulated as the value for the toe length. Subject(s) with any disease of the foot or deformity, and/or statural deformity were not included in this study.

Statistical analysis

The data obtained were computed using EXCEL (2007) and analyzed using Statistical Package for Social Sciences, version 23.0 (SPSS, IBM®) and XLSTAT (2015; version 4.0.1). Variance result form Levene ANOVA informed the t-test analysis of mean differences between the sexes, while Automatic & Generalized Linear Modeling were used to determine the predictability of stature from the toe lengths; P values ≤0.05 were taken to be statistically significant.

RESULTS

In the presented result, continuous data are represented as mean (S.D) while frequency (%) for other categorical data. Population distribution of the contributing states from which the Hausa ethnic group were drawn are shown in [Table 1], Descriptive statistics and t-test of mean difference of the toe lengths in males and females are shown in [Tables 2].

The automatic and manual linear models were used to determine the strength of the contributing predictor variables. The multiple regress regression model (correlation) was used to determine the single variable prediction as well as the gender-specific regression model; thus, only those that showed satistically significance [Table 2] had their regresssion equation stated for single variable regression analysis [Table 3-5].

Sex comparison

The males and females had mean age of 24.98±7.8yrs and 24.73±7.43yrs respectively and thus was insignificant different (P>0.05). However, the males (1.71±0.07m) were significantly taller than the females (1.60±0.06m) with a mean difference (S.E.M) of 0.11±0.00m (t=22.855, P<0.001).

The observed mean (±S.D) values for the right (R) toes of the males were; 47.15±4.20mm [1T], 36.62±5.15mm [2T], 29.42±3.94mm [3T], 25.79±4.29mm [4T] and 22.52±2.57mm [5T] while the female values were 42.73±3.37mm [1T], 30.63±3.65mm [2T], 24.94±3.28mm [3T], 21.19±3.22mm [4T], and 18.24±2.48mm [5T] [Table 2].

The observed mean (±S.D) values for the left (L) toes of the males and females were; 1T (45.79±4.04mm and 42.46±3.13mm), 2T (36.34±5.22mm and

30.55±4.02mm), 3T (29.38±3.76mm and 24.47±3.34mm), 4T (25.51±3.28mm and 21.08±3.09mm), 5T (21.97±2.35mm and 18.01±2.35mm) respectively [Table 2].

Levene's analysis of variance in mean showed that the first 3 toes of both feet (R.1T, R.2T, R.3T, L.1T, L.2T, L.3T) varied significantly between the sexes (F>3.00; P<0.05). This prompted the assumption of unequal variance analysis of mean difference for the aforementioned variables while were assumed equal. The differences in the mean values of males and females were statistically significant for all measured toe dimensions (t>11.00; P<0.001) [Table 2].

Automatic & Generalized Linear Model

SPSS automatic linear model was used to determine the strength of the contributing predictor variable which only those that showed satistically significance were used for the multiple and single variable regression analysis. XLSTAT correlation was used to determine the independent predictor strength and accuracy, regression equation was therefore derived.

The F-ratio in the ANOVA shows that the overall regression model is a good fit for the data for the three population strata (Gp, F and M), and that the predictor variables statistically significantly predict the dependent variable, Gp (F[10, 653]=44.167, P<0.001), F (F[10, 321]=6.464, P<0.001) and M (F[10, 321]=133.782, P<0.001) [Table 2].

The multiple regression model for the general and male population showed that only three (3) variables were able to significantly contribute to the stature prediction. The quality of the prediction (R) of the dependent variable is 0.635 for the gneral Hausa population (Gp) which indicates a fairly above average level of prediction. The coefficient of determination (R2) showed that the model accounts for 0.403 (40.3%) of the variablility in the dependent variable [Table 3a]. For the Female population (F), the quality of the prediction (R) is 0.41 and the models predictability is 0.168 (16.8%) [Table 4a]. However, for males only L.1T significantly influenced the model but, the quality of predictability of stature was higher (R=43.2, R2=0.187) than female [Table 5a].

From the correlation analysis, all veriables (T1-T2 for both feet) significatly predicted the general Hausa and male population stature (P<0.01) [Table 3b & Table 5b]. However, all other parameters significantly predicted the female population stature (P<0.05) except R.5T (P=0.069), L.4T (P=0.165) and L.5T (P=0.428) [Table 4b]. The quality of prediction of stature form toe length for the general population was just above avrage (R; 0.50-0.55); whereas, the corelation between toe length and stature for female was significantly very poor for all veriable (R; 0.08-0.29) while males had weak prediction (R; 0.17-0.38) [Table 3b, 4b & 5b].

Table 1: Distribution of sample population by state.

State	Frequency	Percent	Cumulative Percent
Adamawa	34	5.1	5.1
Bauchi	22	3.3	8.4
Borno	24	3.6	12.0
Gombe	13	2.0	14.0
Jigawa	10	1.5	15.5
Kaduna	123	18.5	34.0
Kano	129	19.4	53.5
Katsina	50	7.5	61.0
Kebbi	43	6.5	67.5
Nasarawa	30	4.5	72.0
Niger	72	10.8	82.8
Plateau	10	1.5	84.3
Sokoto	52	7.8	92.2
Taraba	5	.8	92.9
Yobe	12	1.8	94.7
Zamfara	35	5.3	100.0
Total	664	100.0	

Table 2: Descriptive characteristics of measurements and test of mean difference between the sexes.

Group Statistics				t-test for Equality of Means					
Parameter	**SEX**	**Mean±S.D**	**S.E.M**	**df**	**M.D**	**S.E.D**	**t-value**	**P-value**	**Inf.**
AGE	Male	24.98±7.8	0.43	662	0.25	0.59	0.418	0.68	NS
	Female	24.73±7.43	0.41						
HEIGHT (m)	Male	1.71±0.07	0.00	657	0.11	0.00	22.855	<0.001	S
	Female	1.60±0.06	0.00						
R.1T(mm)	Male	47.15±4.20	0.23	632	4.42	0.29	14.947	<0.001	S
	Female	42.73±3.37	0.18						
R.2T(mm)	Male	36.62±5.15	0.28	596	5.99	0.35	17.285	<0.001	S
	Female	30.63±3.65	0.20						
R.3T(mm)	Male	29.42±3.94	0.22	641	4.48	0.28	15.936	<0.001	S

	Female	24.94±3.28	0.18						
R.4T(mm)	Male	25.79±4.29	0.24	662	4.61	0.29	15.648	<0.001	S
	Female	21.19±3.22	0.18						
R.5T(mm)	Male	22.52±2.57	0.14	662	4.28	0.20	21.797	<0.001	S
	Female	18.24±2.48	0.14						
L.1T(mm)	Male	45.79±4.04	0.22	623	3.33	0.28	11.880	<0.001	S
	Female	42.46±3.13	0.17						
L.2T(mm)	Male	36.34±5.22	0.29	621	5.79	0.36	16.013	<0.001	S
	Female	30.55±4.02	0.22						
L.3T(mm)	Male	29.38±3.76	0.21	653	4.91	0.28	17.764	<0.001	S
	Female	24.47±3.34	0.18						
L.4T(mm)	Male	25.51±3.28	0.18	662	4.43	0.25	17.917	<0.001	S
	Female	21.08±3.09	0.17						
L.5T(mm)	Male	21.97±2.35	0.13	662	3.95	0.18	21.678	<0.001	S
	Female	18.01±2.35	0.13						

R, Right; L, Left; S.D, Standard deviation; S.E.M, Standard error of mean; M.D, Mean difference; df, degree of freedom; M.D, Mean difference; t-value, t-calculated value; P-value, Probability value; Inf, Inference; NS, Not Significant; S, Significant.

Table 2: Effect of the overal regression model fittness for variables with significant predictability

Model Summary					**ANOVA**					
Modela	**R**	**R2**	**Adjusted R2**	**SEE**		**SS**	**df**	**MS**	**F-ratio**	**P-value**
Gp	0.635	0.403	0.394	0.067	Regression	10	1.959	0.196	44.167	<0.001
					Residual	653	2.897	0.004		
					Total	663	4.856			
F	0.410	0.168	0.142	0.057	Regression	10	0.2084	0.0208	6.464	<0.001
					Residual	321	1.0350	0.0032		
					Total	331	1.2434			
M	0.432	0.187	0.161	0.061	Regression	10	0.275	0.028	7.384	<0.001
					Residual	321	1.196	0.004		
					Total	331	1.471			

Note: R, Multiple correlation coefficient; R2, Coefficient of determination; SSE, Standard error of the estimate; SS, Sum of square; MS, Mean Square; F-ratio, Fisher's ratio; P-value, Probability value

Gpa, General population; Fb, Female population; Mc, Male population

Predictors included in the modela: (Constant), R1(mm), R.2T(mm), R.3T(mm), R.4T(mm), R.5T(mm), L.1T(mm) , L.2T(mm), L.3T(mm), L.4T(mm), L.5T(mm)

Table 3: Model characteristics and variables predictability of stature for the general population

Model	**Unstandardized Coefficients**		**Standardized Coefficients**	**t-value**	**P-value**	**Inference**
	B	**Std. Error**	**Beta**			
(Constant)	1.174	0.030		39.208	< 0.001	S
R1T	0.002	0.001	0.104	1.630	0.104	NS
R2T	0.004	0.001	0.237	3.501	< 0.001	S
R3T	-0.002	0.001	-0.084	-1.143	0.254	NS
R4T	0.0001	0.001	-0.005	-0.094	0.925	NS
R5T	0.005	0.002	0.2	3.406	0.001	S
L1T	0.002	0.001	0.113	1.837	0.067	NS
L2T	-0.001	0.001	-0.041	-0.650	0.516	NS
L3T	0.005	0.001	0.26	3.782	< 0.001	S
L4T	-0.003	0.001	-0.122	-1.871	0.062	NS
L5T	0.002	0.002	0.078	1.274	0.203	NS

Note: P-values in red indicates significant contribution to the prediction model

Table 3b: Correlation of independent variables and predictability of stature for the general population

Variables	**R**	**R2**	**RE for stature (m)**	**P-value**	**Inference**
R.1T(mm)	0.5250	0.2757	0.010 (R.1T) + 1.195	< 0.001	S
R.2T(mm)	0.5607	0.3143	0.008(R.2T)+ 1.354	< 0.001	S
R.3T(mm)	0.5256	0.2762	0.010(R.3T)+ 1.367	< 0.001	S
R.4T(mm)	0.4550	0.2070	0.008(R.4T)+ 1.448	< 0.001	S

R.5T(mm)	0.5237	0.2743	0.013(R.5T) + 1.378	< 0.001	S
L.1T(mm)	0.5054	0.2555	0.010(L.1T) + 1.174	< 0.001	S
L.2T(mm)	0.5152	0.2654	0.008(L.2T) + 1.385	< 0.001	S
L.3T(mm)	0.5460	0.2981	0.010(L.3T) + 1.363	< 0.001	S
L.4T(mm)	0.4896	0.2397	0.010(L.4T) + 1.402	< 0.001	S
L.5T(mm)	0.5097	0.2598	0.014(L.5T) + 1.37	< 0.001	S

Note: R, Multiple correlation coefficient; R2, Coefficient of determination; RE, Regression Equation; NS, Not Significant; S, Significant.

Table 4a: Model characteristics and variables predictability of stature for female population

Model	Unstandardized Coefficients		Standardized Coefficients	t-value	P-value	Inference
	B	Std. Error	Beta			
(Constant)	1.332	0.046		28.897	<0.001	S
R.1T(mm)	-0.0005	0.001	-0.026	-0.327	0.744	NS
R.2T(mm)	0.007	0.001	0.417	4.694	<0.001	S
R.3T(mm)	-0.004	0.002	-0.194	-1.754	0.08	NS
R.4T(mm)	0.002	0.002	0.090	0.897	0.37	NS
R.5T(mm)	0.001	0.002	0.021	0.276	0.783	NS
L.1T(mm)	0.006	0.002	0.304	3.630	<0.001	S
L.2T(mm)	-0.003	0.001	-0.192	-2.325	0.021	S
L.3T(mm)	0.003	0.002	0.167	1.854	0.065	NS
L.4T(mm)	-0.003	0.002	-0.161	-1.904	0.058	NS
L.5T(mm)	-0.003	0.002	-0.116	-1.512	0.131	NS

Note: P-values in red indicates significant predictors in the model

Table 4b: Correlation of independent variables and predictability of stature for female population

Variables	R	R2	RE for stature (m)	P-value	Inference
R.1T(mm)	0.234	0.055	0.004(R.1T) + 1.415	<0.001	S
R.2T(mm)	0.288	0.083	0.004(R.2T) + 1.449	<0.001	S
R.3T(mm)	0.170	0.029	0.003(R.3T) + 1.517	0.002	S
R.4T(mm)	0.176	0.031	0.003(R.4T) + 1.526	0.001	S
R.5T(mm)	0.100	0.010	No Prediction	0.069	NS
L.1T(mm)	0.278	0.078	0.005(L.1T) + 1.366	<0.001	S
L.2T(mm)	0.134	0.018	0.002(L.2T) + 1.535	0.015	S
L.3T(mm)	0.162	0.026	0.003(L.3T) + 1.524	0.003	S
L.4T(mm)	0.076	0.006	No Prediction	0.165	NS
L.5T(mm)	0.044	0.002	No Prediction	0.428	NS

Note: R, Multiple correlation coefficient; R2, Coefficient of determination; RE, Regression Equation; NS, Not Significant; S, Significant.

Table 5a: Model characteristics and variables predictability of stature for male population

Model	Unstandardized Coefficients		Standardized Coefficients	t-value	P-value	Inference
	B	Std. Error	Beta			
(Constant)	1.42	0.045		31.569	<0.001	S
R.1T(mm)	-0.001	0.002	-0.034	-0.313	0.754	NS
R.2T(mm)	0.0003	0.001	-0.021	-0.202	0.840	NS
R.3T(mm)	0.002	0.002	0.139	1.205	0.229	NS
R.4T(mm)	-0.001	0.001	-0.074	-1.120	0.263	NS
R.5T(mm)	0.001	0.002	0.042	0.528	0.598	NS
L.1T(mm)	0.004	0.002	0.220	2.080	0.038	S
L.2T(mm)	0.001	0.001	0.109	1.097	0.274	NS
L.3T(mm)	0.003	0.002	0.172	1.631	0.104	NS
L.4T(mm)	-0.002	0.002	-0.115	-1.157	0.248	NS
L.5T(mm)	0.001	0.002	0.025	0.294	0.769	NS

Note: P-values in red indicates significant predictors in the model

Table 5b: Correlation of independent variables and predictability of stature for male population

Variables	R	R2	RE for stature	P-value	Inference
R.1T	0.3430	0.0548	0.005(R.1T) + 1.454	<0.001	S
R.2T	0.3229	0.0830	0.004(R.2T) + 1.557	<0.001	S
R.3T	0.3586	0.0290	0.006(R.3T) + 1.532	<0.001	S
R.4T	0.1708	0.0310	0.002(R.4T) + 1.642	0.002	S
R.5T	0.2237	0.0100	0.005(R.4T) + 1.580	<0.001	S
L.1T	0.3765	0.0775	0.006(L.1T) + 1.426	<0.001	S

L.2T	0.3491	0.0179	0.004(L.2T) + 1.548	<0.001	S
L.3T	0.3656	0.0264	0.006(L.3T) + 1.520	<0.001	S
L.4T	0.2688	0.0058	0.005(L.4T) + 1.571	<0.001	S
L.5T	0.2344	0.0019	0.006(L.5T) + 1.565	<0.001	S

Note: R, Multiple correlation coefficient; R2, Coefficient of determination; RE, Regression Equation; NS, Not Significant; S, Significant.

Regression Model (Multiple)

A. **Total Population Linear model**
STATURE (in m) = 1.174 + 0.002(R1T) + 0.004(R2T) - 0.002(R3T) - 0.0001(R4T) + 0.005(R5T) + 0.002(L1T) - 0.001(L2T) +0.005(L3T)-0.003(L4T) + 0.002(L5T)

B. **Female linear model**
STATURE (in m) = 1.332 - 0.0005(R1T) + 0.007(R2T) - 0.004(R3T) + 0.002(R4T) + 0.001(R5T) + 0.006(L1T) - 0.003(L2T) + 0.004(L3T) - 0.003(L4T) - 0.003(L5T)

C. **Male linear model**
STATURE (in m) = 1.42 - 0.001(R.1T) - 0.0003(R.2T) + 0.002(R.3T)-0.001(R.4T) + 0.001(R.5T) + 0.004(L.1T) + 0.001(L.2T) + 0.003(L.3T) - 0.002(L.4T) + 0.001(L.5T)

DISCUSSION

Determining the stature of an individual, dead or alive is a perquisite for complete biological profiling; therefore, any segment of the human body used to provide good predictive models for estimation is well-appreciated by the forensic expert. Lots of scientific evidence have provided models for estimating stature using different body part; most especially osseous components.

The usability of any model by forensic investigator is dependent of the quality and accuracy of the model. Agnihotri et al.,[2] Krishna and Kumar and Krishna,[5,6] Pelin et al.,[7] Akhter et al.[8] and Wankhede et al.[9] have collectively studied over 20 cephalo-facial measurements in bid to estimate stature; however the accuracy (R2) was less than 50%; thus concluding that cephalo-facial parameters are not reliable for determining stature. Using long bones, Agnihotri et al.[2] estimated the stuture from the forearm length, armspan,[14] percutaneous ulna length,[12] hand length and hand breadth and formulated the regression models.[10,11,13,16] Result revealed that upper extremities can be efficiently used for stature prediction, but not hand breadth. However, arm span has been documented to be the most accurate predictor of stature (R≥0.90).[14,33-35] Lower extremities can also predict stature with good accuracy (R; 0.62-0.85).[17-23] According to Agnihotri et al.[20] and Ahmed tibia and foot length but not foot width are good prediction of height.[22]

Interest in the toes in this study is borne out of the knowledge that the foot is almost often preserved in mass disasters because of the protection by footwears.[1] Therefore, any possible forensic detail about the individual the toe can provide will be well-appreciated. The existence of significant sexual difference in all measured dimensions of the toe is an indication of discriminatory features; with males having higher mean values when compared to females (P<0.001). From the multiple regression for estimating the stature of the ethnic group in Nigeria, the toe lengths (big [1T] to small toe [5T]) provided (R=0.635) quality prediction and accuracy (R2) of 0.403. However, only 3 parameters R.2T, R.5T and L.3T contributed accurately to the model. Lower prediction was observed in the sex-specific models with better prediction for males (R=0.432) when compared with females (R=0.410). Conversely, Only 1 parameter (L.1T) significantly contributed to the effect in the multivariate regression model for male while 3 parameters (R.2T, L.1T, L.2T) were significant effectors in the female model.

All toe dimensions correlated positively with stature (P<00.1) for the general and male population; however, R.5T (P=0.069), L.4T (P=0.165) and L.5T (P=0.428) did not correlate significantly with stature for female. Hence cannot be used for estimating female stature accurately.

The low prediction and accuray observed in the model was not suprsing; as the toes are formed from two to three adjoining bones. Therefore, it is opinned that such configuration may have affected accuracy of the model.

CONCLUSION

The univariate regression models derived from the individual toe produced more accurate predictions than the multivariate analysis. It is concluded that stature estimation is possible from toe length measurements among the Hausa population.

Recommendation

This study strongly recommends a cadaveric investigation of the usuability of the indivudual bones that makes up the toe in estimating stature. This very important as it will provide good anthropometric details for the foot and in situations were the toes may have been dismembered, identification would still be possible.

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