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Comparative study of growth patterns and stature estimation of children and adults in Cross River State, Nigeria

Koko Ottoh Arikpo[1]*, Barnabas Danborno[1], James Abrak Timbuak[2], Murdakai Tanko[1], Anozeng O. Igiri[3], Regina Alorye Beshel[4], Runyi Inyang Ofem[5], Emem Christopher Umor[1]

[1]Department of Anatomy, Faculty of Basic Medical Sciences, College of Medical Sciences, Ahmadu Bello University, Zaria, Nigeria
[2]Department of Anatomy, Faculty of Basic Medical Sciences, Yusuf Maitama Sule University, Kano
[3]Department of Anatomy, Faculty of Basic Medical Sciences, University of Calabar, Calabar
[4]Department of Anatomy, Faculty of Basic Medical Sciences, University of Nigeria, Nsukka
[5]Department of Physiology, Faculty of Basic Medical Sciences, University of Cross River, Calabar

***Author for correspondence:** Email**:** ottohezra@gmail.com; Tel: 0806 267 9628;

ABSTRACT

Accurate stature estimation is a critical component of human identification in forensic, medical, and anthropological contexts, particularly in situations involving mass disasters and fragmented remains. Body dimensions have been widely applied in stature prediction, given their relative robustness and measurability. This study investigated growth patterns and developed regression models for stature estimation among children and adults in Cross River State, Nigeria. A total of 900 participants (450 males and 450 females), consisting of 300 children (5 – 11 years), young adults (18 – 30 years), and adults (31 – 45 years), were recruited. Anthropometric parameters measured included height, weight, body mass index, sitting height, biaxillary length, demispan length, hand length, thigh length, leg length, and foot length, following standard procedures. Data were analyzed using SPSS version 19 to generate sex-specific and age-specific regression models. The findings demonstrated that demispan length was the most reliable single predictor of stature across both children and adults, yielding the highest coefficients of determination in regression models. Conversely, biaxillary length consistently exhibited the weakest predictive accuracy, highlighting its limited usefulness in stature estimation. Comparative analysis between children and adults indicated distinct growth patterns, particularly in the proportional contributions of limb lengths to overall stature. These results provide valuable population-specific baseline data for stature estimation in Cross River State and reinforce the utility of demispan length as a robust and practical anthropometric parameter. The study holds significant relevance for forensic identification, clinical assessments, and anthropological research within the Nigerian context.

Keywords: Stature estimation, growth patterns, anthropometry, regression models, Nigeria.

INTRODUCTION

Anthropometry, the scientific quantification of human body dimensions, is a critical tool in forensic identification. It involves the assessment of biological characteristics such as sex, age, stature, and ethnicity, which collectively aid in establishing human identity [1,2]. Among these variables, stature is regarded as the most significant parameter in forensic anthropology. Its importance lies in its applicability to the identification of individuals in situations such as natural disasters, acts of mass violence, warfare, and cases involving unclaimed bodies [2,3,4]. Furthermore, accurate estimation of stature enables forensic investigators to considerably narrow the pool of potential matches or suspects during identification processes [5].

There is a consistent and measurable relationship between different parts of the body and stature due to genetic and biological factors, and this relationship has been extensively studied [6-11]. Researchers have demonstrated correlations between stature and measurements of specific body parts, particularly those of the long bones in the limbs, such as the femur, tibia, and humerus, due to their high correlation with height [12], usually expressed through linear regression models [12,13]. The human body follows a predictable growth trajectory [14], and this differs across age, sex, ethnicity, and population groups. These growth patterns are significantly influenced by genetic, hormonal, nutritional, and environmental factors, and vary from one population to another [15]. In children, growth is rapid and consistent, while in adults, stature stabilizes and may even decline with age due to spinal compression and posture changes [16,17]. Therefore, population-specific regression equations are essential for improving the accuracy of stature prediction models.

Research has been conducted focusing on some regional populations [18-22], but most have not analyzed comparative growth patterns across multiple age groups. This study, therefore, seeks to analyze growth patterns between children and adults and develop reliable, population-specific regression equations for stature estimation in Cross River State, Nigeria. By addressing these objectives, the study contributes to the growing field of forensic anthropology in Nigeria and supports more accurate biological profiling in medico-legal and clinical practice.

MATERIALS AND METHODS

Study design and sampling: This study adopted a descriptive cross-sectional design and employed a random sampling method. The sample size was determined using the formula described by Naing et al. [23]:

$$n = Z^2(pq)/ d^2$$

Where: n = the desired sample size per ethnic group

Z = the standard normal deviation, usually set at 1.96 at a 95% confidence level
p = the proportion in the target population within the desired age range (50% = 0.5)
q = the difference obtained when the value of p is subtracted from 1 (1-p = 1-0.5 = 0.5)
d = degree of accuracy desired usually set at 0.05.

$$n = \frac{(1.96)^2 \times 0.5 \times 0.5}{(0.05)^2} = 384.16$$

Based on this calculation, 300 participants were recruited from each of the three senatorial zones of Cross River State (Southern, Central, and Northern), giving a total of 900 participants (450 males and 450 females). Participants were indigenous to the following areas: Calabar Municipal, Odukpani, and Akamkpa (Southern zone); Yakurr, Abi, and Ikom (Central zone); and Ogoja, Obanliku, and Obudu (Northern zone). Subjects were stratified into three age categories: children (5 – 11 years), young adults (18 – 30 years), and adults (31 – 45 years).

Ethical considerations: The study adhered to the ethical principles outlined in the Belmont Report (1979). Approval was obtained from the Health Research Ethics Committee on Human

Subjects of Ahmadu Bello University, Zaria (Approval No: ABUCUHSR/2020/018). Written and verbal informed consent was obtained from all participants after full disclosure of the study objectives and procedures.

Inclusion and exclusion criteria: Eligibility was restricted to individuals of Cross River parentage within the defined age ranges who consented to participate. Participants with physical deformities, spinal defects, or anomalies affecting limb or trunk length were excluded.

Data collection: All anthropometric measurements were performed according to the standard procedures of the International Biological Program using calibrated instruments, including a caliper, anthropometric rod, measuring tape, and stadiometer. The following parameters were recorded:

Height was measured barefoot from the soles to the vertex with participants standing erect on a stadiometer, to the nearest centimeter (cm).

Weight was obtained using a digital weighing balance, to the nearest kilogram.

Body Mass Index (BMI) was calculated as weight (kg) divided by height squared (m²).

Sitting height was measured as the distance from the vertex of the head to the base of the seated surface. It gives a measure of the length of the trunk.

Biaxillary length was measured between the deltopectoral grooves at the anterior axillary folds, with arms adducted.

Demispan length was measured from the sternal notch to the tip of the middle finger in the coronal plane.

Hand length was measured from the distal wrist crease to the tip of the middle finger.

Thigh length was measured as distance from the midpoint of the inguinal ligament to the proximal border of the patella.

Leg length was measured as distance from the tibial tuberosity to the medial malleolus.

Foot length was measured as the maximum distance between the most prominent part of the heel to the most distal point of the longest toe (great or second toe) using a sliding caliper.

Fig 1: Sitting height

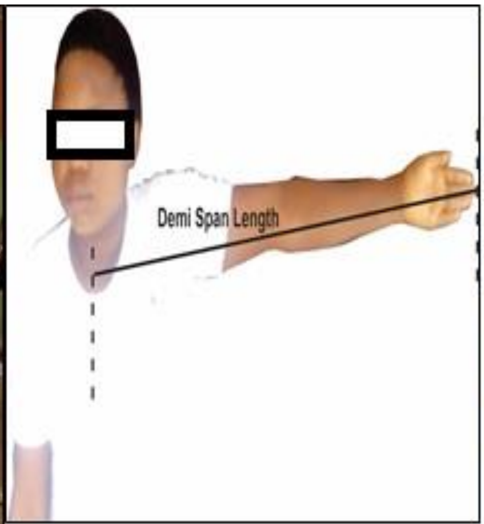

Fig 2: Demispan length

Fig 3: Biaxillary length

Data analysis

Data were analyzed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, Version 19.0; Armonk, NY: IBM Corp.). Descriptive statistics were presented as mean ± standard deviation (SD), range, minimum, and maximum values. Independent *t*-tests were employed to evaluate differences between sexes and across age groups. Pearson's correlation coefficient was used to determine the strength and direction of associations between stature and each anthropometric parameter. Simple linear regression was applied to assess the predictive value of individual anthropometric variables, while multiple linear regression models were developed to generate stature estimation equations for children and adults separately. A *p*-value of <0.05 was considered statistically significant.

RESULTS

The findings of the study indicate that sexual dimorphism is evident in most anthropometric variables, with the males having statistically significantly higher values than the females, with the exception of biaxillary length and thigh length (Table 1a). Although the males had slightly higher mean weight than the females (54.235 kg vs 52.188), the mean body mass index value of the females was significantly higher than the males (22.409 vs 21.013, $p < 0.01$), signifying greater adiposity in females, probably due to differences in fat distribution patterns.

Table 1a: Anthropometric variables by gender in Cross River State

Variables	Male (N = 450)		Female (N = 450)		Total sample (N = 900)		t-Test
	Mean ± SD	Min. - Max.	Mean ± SD	Min. - Max.	Mean ± SD	Min. - Max.	t-value
Height (cm)	156.321 ± 22.130	101 - 198	149.003 ± 16.587	100 - 191	152.662 ± 19.885	100 - 198	5.613**
Weight (kg)	54.235 ± 21.199	16 - 101	52.188 ± 21.287	14 - 113	53.211 ± 21.256	14 - 113	1.445**
BMI (kg/m^2)	21.013 ± 4.404	11.25 - 48.07	22.409 ± 6.300	10.06 - 47.65	21.711 ± 5.477	10.06 - 48.07	-3.854**
Sitting Ht. (cm)	76.620 ± 10.133	50 - 94	74.411 ± 8.646	50.6 - 90	75.516 ± 9.478	50 - 94	3.519**
BA Lt. (cm)	33.809 ± 5.558	20 - 48	33.491 ± 5.471	20 - 52	33.650 ± 5.514	20 - 52	0.864
DMS Lt. (cm)	84.498 ± 13.003	53 - 103	79.519 ± 9.833	51 - 98	82.009 ± 11.787	51 - 103	6.479**
Hand Lt. (cm)	18.631 ± 2.680	12.5 - 26	17.630 ± 2.075	11.5 - 25	18.130 ± 2.447	11.5 - 26	6.266**
Thigh Lt. (cm)	49.473 ± 7.996	30 - 66	49.318 ± 7.144	20 - 64	49.396 ± 7.578	20 - 66	0.308
Leg Lt. (cm)	39.522 ± 6.571	21 - 53	37.878 ± 5.056	24 - 52	38.700 ± 5.917	21 - 53	4.207**
Foot Lt. (cm)	24.642 ± 3.266	17 - 36	23.449 ± 2.382	16 - 29	24.046 ± 2.919	16 - 36	6.260**

BMI = Body mass index; sitting ht. = sitting height; BA Lt. = biaxillary length; DMS Lt. = Demispan length; Hand Lt. = hand length; Thigh Lt. = Thigh length; Leg Lt. = Leg length; Foot Lt. = Foot length. "**" represents statistical significance at the 1% level

All anthropometric variables showed highly significant differences ($p < 0.01$) between children and adults, confirming distinct growth patterns across age (Table 1b). Additionally, there were large differences observed especially in long bone-related measurements (thigh, leg, and demispan lengths), consistent with skeletal maturation and sexual dimorphism.

Table 1b: Anthropometric variables by age group in Cross River State

Variables	Children (N = 300)		Adults (N = 600)		t-Test
	Mean ± SD	Min. - Max.	Mean ± SD	Min. - Max.	t-value
Height (cm)	128.325 ± 11.200	100 - 160	170.484 ± 8.338	103 - 198	-51.877**
Weight (kg)	26.840 ± 6.325	14 - 56	67.882 ± 9.824	40 - 101	-54.900**
BMI (kg/m^2)	16.118 ± 2.025	10.06 - 27.76	23.376 ± 3.232	14.03 - 48.07	-31.308**
Sitting Ht. (cm)	63.924 ± 5.480	50 - 87	82.950 ± 4.287	65 - 94	-51.711**
BA Lt. (cm)	27.430 ± 2.862	20 - 39	37.070 ± 3.251	28 - 48	-39.697**
DMS Lt. (cm)	67.662 ± 6.472	51 - 89	92.861 ± 4.705	76 - 103	-50.761**
Hand Lt. (cm)	15.388 ± 1.476	11.5 - 19.2	20.275 ± 1.291	17 - 26	-38.977**
Thigh Lt. (cm)	40.537 ± 5.116	20 - 64	54.307 ± 3.774	42 - 66	-44.091**
Leg Lt. (cm)	32.213 ± 4.162	21 - 44	43.303 ± 3.600	33 - 53	-36.822**
Foot Lt. (cm)	20.988 ± 2.151	16 - 27	26.485 ± 1.847	20 - 36	-33.083**

BMI = Body mass index; sitting ht. = sitting height; BA Lt. = biaxillary length; DMS Lt. = Demispan length; Hand Lt. = hand length; Thigh Lt. = Thigh length; Leg Lt. = Leg length; Foot Lt. = Foot length. "**" represents statistical significance at the 1% level

The growth pattern of children aged 5 – 11 years in Cross River State is illustrated in Figure 4. A steady linear increase in height with advancing age was observed, with height rising from approximately 110 cm at age 5 to about 140 cm by age 11. The linear trendline confirmed a positive association between age and stature. Growth appears relatively consistent year-to-year, without abrupt spurts, which is expected in this pre-adolescent age group (5–11 years), before the pubertal growth spurt. However, variability in stature was noted within each age group, suggesting inter-individual differences in growth rates.

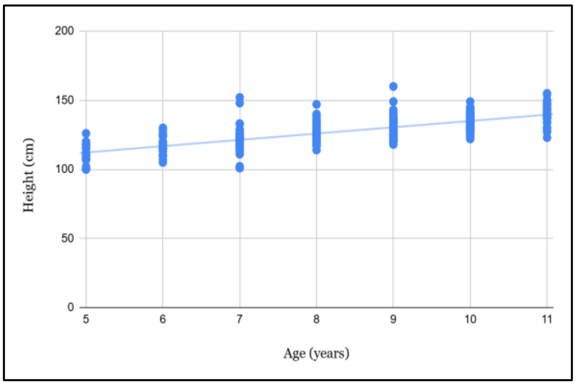

Figure 4: Growth patterns for children

Simple linear regression analysis revealed that demispan length was the most accurate single predictor of stature in both children (Adj. R^2 = 0.757, SEE = 5.526 cm) and adults (Adj. R^2 = 0.549, SEE = 6.220 cm). Hand length and sitting height also showed strong predictive value in children, while foot length and hand length were moderately useful among adults. Biaxillary length performed poorly across all age groups (Table 2a). Multiple regression models substantially improved prediction accuracy, particularly in children (Adj. R^2 = 0.819, SEE = 4.766 cm) compared to adults (Adj. R^2 = 0.630, SEE = 5.639 cm). These findings indicate that body proportions are more predictive of stature in children than in adults, possibly due to more consistent growth patterns in the pre-adolescent stage.

Table 2a: Simple regression models for estimating stature according to age group

Predictor	Age group	Model	R	Adj. R^2	SEE
Sitting Ht. (cm)	Children	H = 29.730 + 1.542(Sitting Ht.)	0.755	0.568	7.361
	Adults	H = 63.672 + 1.244(Sitting Ht.)	0.584	0.340	7.530
BA Lt. (cm)	Children	H = 66.566 + 2.252(BA Lt.)	0.575	0.329	9.175
	Adults	H = 145.698 + 0.520(BA Lt.)	0.198	0.038	9.090
Demispan Lt. (cm)	Children	H = 26.420 + 1.506 (Demispan Lt.)	0.870	0.757	5.526
	Adults	H = 58.102 + 1.197(Demispan Lt.)	0.742	0.549	6.220

Hand Lt. (cm)	Children	H = 33.806 + 6.142(Hand Lt.)	0.809	0.654	6.587
	Adults	H = 92.253 + 3.722(Hand Lt.)	0.603	0.362	7.401
Thigh Lt. (cm)	Children	H = 60.566 + 1.672(Thigh Lt.)	0.763	0.582	7.245
	Adults	H = 107.788 + 1.060(Thigh Lt.)	0.431	0.184	8.371
Leg Lt. (cm)	Children	H = 61.506 + 2.074(Leg Lt.)	0.771	0.593	7.146
	Adults	H = 105.118 + 1.423(Leg Lt.)	0.539	0.289	7.814
Foot Lt. (cm)	Children	H = 42.064 + 4.110(Foot Lt.)	0.790	0.622	6.885
	Adults	H = 90.647 + 2.901(Foot Lt.)	0.582	0.337	7.545
Combined	Children	H = 12.755+0.403(Sitting Ht.)+0.159(BA Lt.)+0.614(Demispan Lt.)+1.178(Hand Lt.)+0.195(Thigh Lt.)+0.362(Leg Lt.)+0.292(Foot Lt.)	0.907	0.819	4.766
	Adults	H = 21.360+0.480(Sitting Ht.)-0.033(BA Lt.)+0.648(Demispan Lt.)+0.276(Hand Lt.)+0.235(Thigh Lt.)+0.245(Leg Lt.)+0.763(Foot Lt.)	0.796	0.630	5.639

Sitting ht. = sitting height; BA Lt. = biaxillary length; DMS Lt. = Demispan length; Hand Lt. = hand length; Thigh Lt. = Thigh length; Leg Lt. = Leg length; Foot Lt. = Foot length. “**” represents statistical significance at the 1% level; “*” represents statistical significance at the 5% level.

Additionally, demispan length was the strongest single predictor of stature in both sexes (Adj. R^2 = 0.889 in males; 0.903 in females) (Table 2b). Sitting height also showed strong predictive value (Adj. R^2 = 0.841 in males; 0.835 in females), while biaxillary length was consistently the weakest predictor (Adj. $R^2 < 0.70$). In the multiple regression models, predictive accuracy improved substantially, with female models (Adj. R^2 = 0.940, SEE = 4.071 cm) outperforming male models (Adj. R^2 = 0.916, SEE = 6.425 cm).

Table 2b: Simple regression models for estimating stature according to gender

Predictor	Gender	Model	R	Adj. R^2	SEE
Sitting Ht. (cm)	Males	H = 2.792 + 2.004(Sitting Ht.)	0.918	0.841	8.812
	Females	H = 18.497 + 1.754(Sitting Ht.)	0.914	0.835	6.730
BA Lt. (cm)	Males	H = 44.617 + 3.304(BA Lt.)	0.830	0.688	12.365
	Females	H = 71.305 + 2.320(BA Lt.)	0.765	0.585	10.691
DMS Lt. (cm)	Males	H = 20.721 + 1.605(DMS Lt.)	0.943	0.889	7.377
	Females	H = 21.507 + 1.603(DMS Lt.)	0.950	0.903	5.163
Hand Lt. (cm)	Males	H = 17.827 + 7.434(Hand Lt.)	0.900	0.810	9.649
	Females	H = 26.530 + 6.947(Hand Lt.)	0.869	0.755	8.213
Thigh Lt. (cm)	Males	H = 30.066 + 2.491(Thigh Lt.)	0.900	0.810	9.651
	Females	H = 47.164 + 2.065(Thigh Lt.)	0.889	0.791	7.591
Leg Lt. (cm)	Males	H = 41.779 + 2.898(Leg Lt.)	0.861	0.740	11.285
	Females	H = 38.895 + 2.907(Leg Lt.)	0.886	0.785	7.697
Foot Lt. (cm)	Males	H = 12.241 + 5.847(Foot Lt.)	0.863	0.744	11.195
	Females	H = 9.114 + 5.966(Foot Lt.)	0.857	0.733	8.565
Combined	Males	H = 5.022+0.558(Sitting Ht.)+0.213(BA Lt.)+0.608(DMS Lt.)+0.520(Hand Lt.)+0.384(Thigh Lt.)+0.190(Leg Lt.)+0.559(Foot Lt.)	0.958	0.916	6.425
	Females	H = 11.997+0.510(Sitting Ht.)+0.068(BA Lt.)+0.614(DMS Lt.)+0.340(Hand Lt.)+0.376(Thigh Lt.)+0.430(Leg Lt.)+0.305(Foot Lt.)	0.970	0.940	4.071

Sitting ht. = sitting height; BA Lt. = biaxillary length; DMS Lt. = Demispan length; Hand Lt. = hand length; Thigh Lt. = Thigh length; Leg Lt. = Leg length; Foot Lt. = Foot length. "**" represents statistical significance at the 1% level; "*" represents statistical significance at the 5% level.

DISCUSSION

This study compared growth patterns and developed regression models for stature estimation across two age categories (children and adults) in Cross River State, Nigeria. The descriptive analysis confirmed the expected growth trajectories and sexual dimorphism in anthropometric variables. Adult males demonstrated significantly greater values for stature, sitting height, demispan, and limb dimensions compared with adult females, consistent with earlier studies on sexual differences in body proportions and stature estimation[24-27]. These differences can be attributed to hormonal influences, particularly the prolonged effects of testosterone on skeletal and muscular development in males [28]. In contrast, body mass index (BMI) was significantly higher among females, corroborating global observations of sex-specific adiposity patterns [29,30].

Demispan length emerged as the most reliable single predictor of stature across all groups. Interestingly, predictive accuracy was stronger among children, where demispan explained a greater proportion of variance in stature compared to adults. This observation aligns with previous research that identified demispan as a robust predictor of stature across diverse populations [24,31,32]. Conversely, biaxillary length demonstrated the weakest predictive capacity in both children and adults. When considered by sex, demispan length remained the strongest predictor in both males and females, followed by sitting height, supporting findings reported in other population-based studies [33,34,35].

A major strength of this study is the large, representative sample size drawn from all three senatorial zones of Cross River State, which enhances the generalizability of the findings. Additionally, the inclusion of both children and adults allowed for comparative evaluation of growth-related changes in anthropometric predictors. However, some limitations must be acknowledged. The study design was cross-sectional, which restricted the ability to capture longitudinal growth trajectories. Furthermore, the exclusion of adolescents (12 – 17 years) limited the assessment of stature prediction during the pubertal growth spurt, a period characterized by non-linear growth. Finally, the models are population-specific and may not be directly applicable to other Nigerian or African populations without validation.

Future research should address these limitations by employing longitudinal designs, incorporating adolescent cohorts, and testing the validity of the regression models across broader populations.

Conclusion

This study demonstrates that stature is linearly associated with age among children in Cross River State. Demispan length is the most powerful single predictor of stature across both children and adults, with predictive accuracy being greatest among children and within female subgroups. These findings underscore the relevance of demispan in forensic, clinical, and anthropological applications for stature estimation in this population and provide baseline data for further anthropometric research in Nigeria.

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