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Estimation of Body Mass Index from Radiogrammetric Analysis of the Humerus and Femur of a Yoruba Population

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ABSTRACT

Nigeria is currently facing severe security challenges, often resulting in dismembered bodies that are difficult to identify due to limited relevant data and guiding research. This study evaluated the radiogrammetric features of the femur and humerus to estimate Body Mass Index (BMI) in a Yoruba population. It specifically sought to obtain linear and angular measurements from radiographic images and assess their correlation with BMI. A total of 195 Yoruba participants (61 males and 134 females), aged 21 to 65 years, were recruited from the Radiology Department of the University of Ilorin Teaching Hospital, Ilorin, Nigeria, using a purposive convenience sampling technique. Digital radiographic linear and angular measurements of the proximal humerus and femur of subjects were obtained using Radiant-DICOM viewer (2025c). Subjects' weights and heights were recorded to calculate BMI. The data were analyzed using SPSS (version 29), and Pearson's correlation was used to determine the relationship between bone measurements and BMI. The results revealed that the correlations between the bone measurements and BMI were generally weak, negative, or average. The study concluded that radiogrammetric analysis of the femur and humerus is not significantly reliable for BMI estimation in the Yoruba population of Nigeria, even though it had proven useful in some other ethnic groups for profiling.

Keywords: radiogrammetry, femur, humerus, BMI, Yoruba

INTRODUCTION

In forensic anthropology, biological profiling is applied to the analysis of human remains for the purposes of identifying a victim and determining the possible cause of death. Forensic anthropologists can determine the age, sex, weight, height and other unique features of a deceased person. Forensic Radiology, a subset of Forensic Medicine, utilizes medical radiological examinations to address legal questions[1]. A post-mortem radiological examination allows the detection of metallic foreign bodies like bullets or bullets/bomb fragments on the body[2, 3]. This is of particular value in cases of highly decomposed bodies where the necropsy gives limited information on the circumstances of death. There are two specific reasons why the femur and humerus are essential for biological profiling. Firstly, they are the most robust and largest bones (the femur being larger) in the human skeleton and, as such, will most likely resist environmental insult and animal activities. Body Mass Index (BMI), defined as weight in kilograms divided by the square of height in meters (kg/m^2), is a standard metric for assessing body composition and categorizing individuals into underweight, normal weight, overweight, or obese. Radiogrammetric analysis of long bones offers a promising approach to refine BMI estimations by assessing skeletal robusticity and body composition. Similarly, Monda *et al.*[4] conducted a meta-analysis identifying genetic loci associated with BMI in African ancestry populations, highlighting genetic diversity that impacts BMI interpretation in groups like the Yoruba. For the Yoruba population, radiogrammetric analysis of the humerus and femur could enhance BMI assessments by providing insights into skeletal structure and body composition, addressing unique genetic and environmental influences in this West African group.

The purpose of this study is to develop and validate a rapid, easy, and inexpensive method for BMI estimation of unprofiled individuals using fragmentary models of the humerus and femur with the aid of digital radiographic images of these bones, specifically in the context of a Nigerian Yoruba population.

MATERIALS AND METHODS

Ethical consideration: Ethical approval was sought from the Research Ethics Committee for human experimentation of the University of Ilorin, Ilorin, Nigeria and this was approved.

This study is a descriptive cross-sectional research conducted within hospital settings, encompassing 195 digital radiographs of the proximal segments of the humerus and femur. These radiographs were sourced from healthy and non-pathological living volunteers selected from the Radiology department of the University of Ilorin Teaching Hospital, Ilorin, Kwara State, Nigeria, West Africa. The volunteers, all of Yoruba descent, were patients undergoing chest and pelvic X-rays for unrelated health issues. Ethical clearance for the study was obtained from the Research Ethics Committee of the University of Ilorin, and written informed consent was secured from each participant.

For this study, a convenient sampling method was employed[5]. A non-probability stratified sampling technique was utilized. The digitized images were ultimately assessed and analyzed. All individuals included in the study fell within the 21 to 65 age range and were of pure Yoruba ethnicity, as determined by tracing lineage back to the second generation through their grandparents.

A digital X-ray machine (GE Optima XR24) was used to obtain the images of the proximal humerus and femur of each subject. DICOM (digital imaging and communication in Medicine) viewer (2025c) was the image software for taking various linear and angular measurements on each bone image. Seca 769 Digital Column Scale with Height Rod was used to measure the weight and height of patients, from which the BMI of each subject was calculated. Ethical approval was sought from the Research Ethics Committee for human experimentation of the University of Ilorin, Ilorin, Nigeria and this was approved with

ethical approval number: UERC/ASN/2020/2023.

Procedures for data collection

Data collection utilized an interviewer-administered semi-structured questionnaire. This questionnaire gathered socio-demographic information from each participant.

Anthropometric measurements of parameters/variables

Each consented participant was made to stand or sit comfortably to take all the measurements after an adequate explanation of the procedure was done since none of the procedures was invasive. The height was taken in meters (m) and weight in kilograms (kg). The procedures for measurement were as follows:

1. Height (stature): Each subject was made to stand erect and straight with minimal clothing, with bare heads and feet, arms hanging loosely to the side, feet together, and with heels, buttocks and shoulder blades in contact with the vertical surface of the Seca 769 Digital Column Scale with Height Rod. Stature was taken following the method of Krishan & Sharma[6], from the vertex to a flat surface; in anatomical position.

Fig 1: Measurement of Height Using the Seca 769 Digital Column Scale with Height Rod

2. Weight: The weight of each subject was checked at the same time while the height was being measured using the digital weighing scale part of the Seca 769 Digital Column Scale with Height Rod.

Fig 2: Measurement of Weight Using the Seca 769 Digital Column Scale with Height Rod

3. Body Mass Index: The body mass index of an individual is defined by the ratio of their body mass to the square of their height. Each subject's weight (kilograms) and height (meter) are used for the calculation.

$$Body\ Mass\ Index\ (kgm^{-2}) = \frac{Mass\ (kg)}{Height^2\ (m^2)}$$

Procedures for the measurements of linear and angular parameters on the proximal humerus and femur

The Proximal Humerus

The posteroanterior view image of each participant's proximal part of each humerus was obtained and computed using the GE digital X-ray machine. Each image was obtained while the patient stood erect in front of the X-ray machine with a focus film distance of 180 cm. Using the Radiant DICOM (Digital Imaging and Communications in Medicine) viewer, version 2025, six (6) anatomical landmarks (A–E), according to Elena Kranioti[7], were selected on the image to generate ten (10) linear (in

millimeters) and three (3) angular measurements (in degrees) each on the left and right side of the participant, representing all possible combinations of these landmarks[7].

Anatomical landmarks

A -The projection of the medial and inferior parts of the head.

B -The projection of the superior part of the anatomical neck

C -The sectioning point on the humeral head outline of the orthogonal projection of the middle point between landmarks A and B.

D - The maximum curvature points of the greater tubercle.

E - The most lateral point that defines the maximum distance from landmark A.

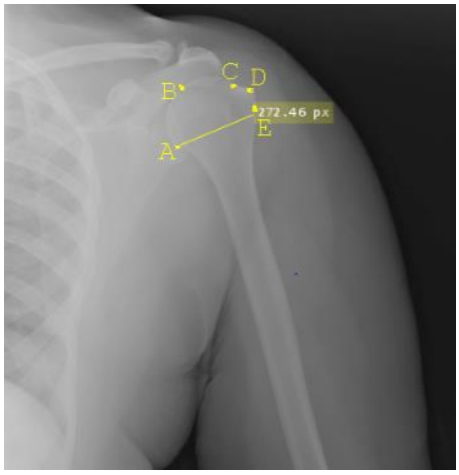

Figure 3: Anatomical Landmarks (A, B, C, D, E) Selected on the Digital X-Ray Image of the Proximal Humerus, Showing Distance AE. Quoted from One of the Digital Radiography Workstations Used in the Study.

Angular measurements

FAE – Angle between the acromion and the anatomical neck of the humerus.

BAC – Angle between the superior-most part of the humeral head and the neck of the humerus (medially --proximal)

BAE – Angle between the superior-most part of the humeral head and the neck of the humerus (medially distal).

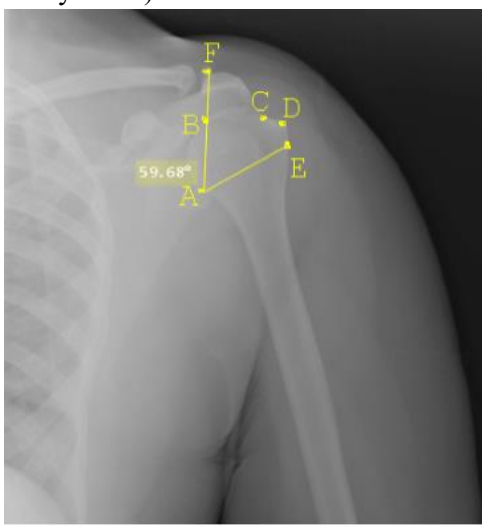

Figure 4: Landmarks Selected on The Digital X-Ray Image of The Proximal Humerus Showing Angle FAE. Quoted from One of The Digital Radiography Workstations Used in The Study.

Table 1: Definition of Variables for The Proximal Humerus

Distance	Variables		Angles	Variables	
AB	L-PH1	R-PH1	FAE	L-PHA1	R-PHA1
AC	L-PH2	R-PH2	BAC	L-PHA2	R-PHA2
AD	L-PH3	R-PH3	BAE	L-PHA3	R-PHA3
AE	L-PH4	R-PH4			
BC	L-PH5	R-PH5			
BD	L-PH6	R-PH6			
BE	L-PH7	R-PH7			
CD	L-PH8	R-PH8			
CE	L-PH9	R-PH9			
DE	L-PH10	R-PH10			

Keys:

L-PH1 –Left Proximal humerus 1 R-PH1 –Right Proximal humerus 1

L-PHA1 –Left Proximal humerus angle 1 R-PHA1 – Right Proximal humerus angle1

The Proximal Femur

The anteroposterior view of each participant's proximal part of both femurs was obtained and computed using the GE digital X-ray machine. Each image was obtained and computed while the patient was lying supine with a focus film distance of 100 cm. Using the Radiant DICOM (Digital Imaging and Communications in Medicine) viewer, version 2025, eight (8) anatomical landmarks (A–H), according to Elena Kranioti[8], were selected on the image to generate twenty-eight (28) linear (in millimeters) and five (5) angular measurements (in degrees) each on the left and right side of the participant, representing all possible combinations of these landmarks[8].

Anatomical landmarks

A - Point under the lower end of the lesser trochanter in continuance with the vertical axis of the shaft.

B and E - Points selected on the femoral neck at the points where the curvature changes, forming the head so that the distance from B to E is the minimum neck diameter.

C and D - Points on the femoral head so that the distance C-D is the maximum femoral diameter parallel to the BE.

F - Point on the most superior projection of the greater trochanter

G - Point on the most lateral projection of the proximal epiphysis of the greater trochanter.

H -A landmark in the longitudinal axis of the shaft with the distance A-H (representing the sub-trochanteric diameter in the radiograph) is vertical to the axis of the shaft.

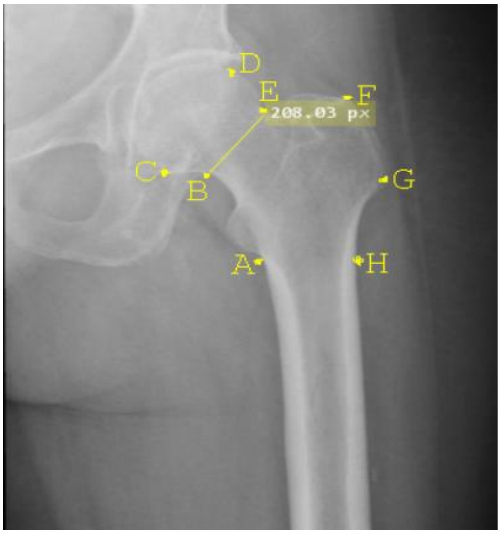

Figure 5: Landmarks Selected on the Digital X-Ray Image of the Proximal Femur, showing Distance BE: quoted from one of the digital radiography workstations used in this study.

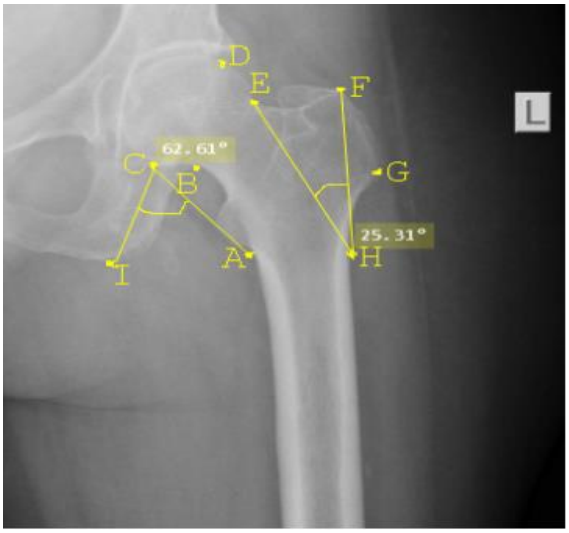

Figure 6: Landmarks selected on the digital X-ray image of the proximal femur showing angles ICA and EHF. Quoted from one of the digital radiography workstations used in the study.

Table 2: Definition of variables for the proximal femur

Distance	Variables		Angles	Variables	
AB	L-PF1	R-PF1	ICA	L-PFA1	R-PFA1
AC	L-PF2	R-PF2	EHF	L-PFA2	R-PFA2
AD	L-PF3	R-PF3	CAD	L-PFA3	R-PFA3
AE	L-PF4	R-PF4	BDE	L-PFA4	R-PFA4
AF	L-PF5	R-PF5	CAE	L-PFA5	R-PFA5
AG	L-PF6	R-PF6			
AH	L-PF7	R-PF7			
BC	L-PF8	R-PF8			
BD	L-PF9	R-PF9			
BE	L-PF10	R-PF10			
BF	L-PF11	R-PF11			
BG	L-PF12	R-PF12			
BH	L-PF13	R-PF13			
CD	L-PF14	R-PF14			
CE	L-PF15	R-PF15			
CF	L-PF16	R-PF16			
CG	L-PF17	R-PF17			
CH	L-PF18	R-PF18			
DE	L-PF19	R-PF19			
DF	L-PF20	R-PF20			
DG	L-PF21	R-PF21			
DH	L-PF22	R-PF22			
EF	L-PF23	R-PF23			
EG	L-PF24	R-PF24			
EH	L-PF25	R-PF25			
FG	L-PF26	R-PF26			
FH	L-PF27	R-PF27			
GH	L-PF28	R-PF28			

Keys:

L-PF1 –Left Proximal femur1 R-PF1 –Right Proximal femur 1

L-PFA1 –Left Proximal femur angle 1 R-PFA1 – Right Proximal femur angle

Statistical analysis

The data were analyzed using SPSS (Statistical Products and Service Solutions) (IBM®, version 29, Armonk, New York, USA. BMI was correlated with the bone measurements using Pearson's correlation.

RESULTS

The descriptive characteristics of selected anthropometric variables for the study population (femoral category) is shown in table 3. The male participants are taller than the females, while the females are heavier than the males. The female participants had higher BMI than the males.

The descriptive characteristics of selected anthropometric variables for the study population (humeral category) are shown in table 4. The males are taller and heavier than the females, while the females had higher BMI than males.

The mean values for the geometric (linear and angular) measurements of the right (R) proximal femur (PF) are shown in table 7. The mean values for the geometric (linear and angular) measurements of the right (R) proximal humerus (PH) are shown in table 8.

The linear relationship (correlation) between the measured geometric parameters of the femur and humerus and the BMI in the male and female participants using Pearson's correlation are presented in Tables 9 - 12. In the right femur in males, PF6(AG) showed significant weak negative correlation with BMI, while PF8(BC) showed significant average correlation with BMI (table 9). In the left femur in males, PF8(BC) showed a significant weak positive correlation with BMI, while PF26(FG) showed a significant average correlation with BMI (Table 9).

BMI correlated with the following parameters of the right femur in females: PF3(AD) showed a significant weak negative correlation, PFA4(BDE) showed a significant weak positive correlation. For the left femur in the female participants, BMI only correlated with PFA4(BDE) having a significant weak correlation. However, PF1(AB), PF2(AC), PF3(AD) and PF4(AE) showed average positive correlation (Table 10).

For the right humerus, BMI did not show any significant correlation with the measured parameters in the male participants. For the right humerus in the female participants, BMI did not show any significant correlation with the measured parameters. For the left humerus, PHA2(BAC) showed weak correlation with BMI (Table 12).

Table 3: Descriptive Characteristics of Anthropometric Variables for the Femur Group

Measured parameters	***MALE [N = 24]***			***FEMALE [N = 46]***			***TOTAL [N = 70]***		
	Min	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***
Age (years)	21.00	68.00	43.92±11.59	18.00	67.00	45.98±13.13	18.00	68.00	45.27±12.58
Weight (kg)	40.00	85.00	64.58±12.24	45.00	105.00	66.52±11.80	40.00	105.00	65.86±11.90
Height (m)	1.40	1.75	1.62±0.09	1.40	1.78	1.60±0.10	1.40	1.78	1.61±0.10
BMI (kg/m^2)	15.06	42.86	24.78±5.97	17.92	39.52	26.20±5.05	15.06	42.86	25.71±5.38

BMI = *Body Mass Index*

Table 4: Descriptive Characteristics of Anthropometric Variables for the Humerus Group

Measured parameters	**Male [N = 37]**			**Female [N = 88]**			**Female [N = 125]**		
	Min	**Max**	**Mean±SD**	**Min**	**Max**	**Mean±SD**	**Min**	**Max**	**Mean±SD**
Age (years)	20.00	65.00	41.51±14.92	20.00	64.00	41.85±11.31	20.00	65.00	41.75±12.42
Weight (kg)	49.00	98.00	70.80±14.25	39.00	90.00	61.65±13.95	39.00	98.00	64.36±14.59
Height (m)	1.51	1.98	1.68±0.11	1.30	1.80	1.56±0.10	1.30	1.98	1.59±0.12
BMI (kg/m^2)	15.74	38.54	25.40±5.76	14.86	39.56	25.42±5.25	14.86	39.56	25.42±5.38

Table 5: Descriptive Characteristics of Geometric Measurements of the Left Femur

Left Femur	*MALE [N = 24]*			*FEMALE [N = 46]*			*TOTAL [N = 70]*		
	Min	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***
L-PF1(AB)	41.42	67.92	59.26±6.35	38.76	62.79	49.40±5.46	38.76	67.92	52.78±7.42
L-PF2(AC)	47.39	76.09	67.29±6.11	45.75	70.69	56.20±6.00	45.75	76.09	60.00±8.00
L-PF3(AD)	78.35	118.11	102.80±8.29	76.68	103.74	87.68±6.44	76.68	118.11	92.87±10.11
L-PF4(AE)	66.42	94.96	81.96±6.47	60.42	80.74	69.42±5.17	60.42	94.96	73.72±8.20
L-PF5(AF)	81.00	104.00	93.42±6.90	69.02	96.06	81.67±5.90	69.02	104.00	85.70±8.37
L-PF6(AG)	56.62	76.78	66.88±5.39	51.05	70.33	59.40±4.22	51.05	76.78	61.97±5.84
L-PF7(AH)	25.65	41.97	35.73±3.77	23.07	40.55	33.74±3.54	23.07	41.97	34.42±3.72
L-PF8(BC)	10.21	21.42	15.10±2.93	9.67	18.87	12.61±1.79	9.67	21.42	13.46±2.52
L-PF9(BD)	42.95	57.27	50.02±3.43	38.93	48.77	44.67±2.40	38.93	57.27	46.51±3.77
L-PF10(BE)	32.57	46.28	38.91±3.08	29.78	38.78	34.09±2.18	29.78	46.28	35.74±3.40
L-PF11(BF)	53.59	74.00	62.80±5.65	48.25	67.12	58.71±5.05	48.25	74.00	60.11±5.58

	MALE [N = 24]			***FEMALE [N = 46]***			***TOTAL [N = 70]***		
Left Femur	***Min***	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***
L-PF12(BG)	59.15	83.74	72.36±6.43	57.44	80.25	67.21±5.59	57.44	83.74	68.98±6.34
L-PF13(BH)	57.42	86.86	78.33±6.86	57.95	82.04	69.24±6.41	57.42	86.86	72.35±7.84
L-PF14(CD)	48.11	61.76	55.20±3.72	42.61	53.61	49.36±2.57	42.61	61.76	51.36±4.09
L-PF15(CE)	38.81	57.48	50.00±4.40	38.34	48.88	43.45±2.56	38.34	57.48	45.70±4.53
L-PF16(CF)	64.02	87.00	75.17±5.84	56.25	78.81	69.35±5.49	56.25	87.00	71.35±6.23
L-PF17(CG)	76.83	95.98	87.13±5.41	67.33	93.69	79.53±6.23	67.33	95.98	82.13±6.95
L-PF18(CH)	67.09	98.06	90.35±6.36	65.33	93.49	79.64±6.95	65.33	98.06	83.31±8.44
L-PF19(DE)	16.12	32.38	24.98±3.84	16.44	26.56	20.93±2.73	16.12	32.38	22.32±3.68
L-PF20(DF)	24.87	54.22	41.16±8.13	26.67	52.27	37.84±6.39	24.87	54.22	38.98±7.15
L-PF21(DG)	70.41	93.48	80.98±5.70	58.93	88.19	73.10±7.24	58.93	93.48	75.80±7.70
L-PF22(DH)	84.16	121.89	108.40±7.68	82.89	110.61	94.87±6.90	82.89	121.89	99.51±9.62
L-PF23(EF)	13.97	38.43	26.48±6.65	16.52	38.61	27.13±4.87	13.97	38.61	26.91±5.50
L-PF24(EG)	45.55	66.83	57.13±5.31	41.81	69.04	53.60±6.28	41.81	69.04	54.81±6.16
L-PF25(EH)	69.36	95.21	84.31±6.12	62.95	85.73	74.18±5.72	62.95	95.21	77.65±7.57

	MALE [N = 24]			***FEMALE [N = 46]***			***TOTAL [N = 70]***		
Left Femur	***Min***	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***
L-PF26(FG)	36.57	59.49	47.10±6.25	29.29	53.47	42.73±5.26	29.29	59.49	44.23±5.95
L-PF27(FH)	70.44	97.29	85.35±7.17	66.17	88.44	74.83±5.55	66.17	97.29	78.43±7.90
L-PF28(GH)	33.26	53.87	44.50±5.82	28.37	47.13	37.97±4.22	28.37	53.87	40.21±5.72
L-PFA1(ICA)	41.49	86.66	63.78±9.79	43.75	85.55	63.52±10.23	41.49	86.66	63.61±10.01
L-PFA2(EHF)	8.42	24.02	17.55±4.86	13.52	27.59	20.59±3.45	8.42	27.59	19.55±4.21
L-PFA3(CAD)	17.91	37.23	29.56±3.57	25.68	41.54	31.43±3.57	17.91	41.54	30.79±3.66
L-PFA4(BDE)	35.85	59.48	49.44±7.18	38.26	54.06	47.09±3.73	35.85	59.48	47.89±5.25
L-PFA5(CAE)	26.21	44.93	37.84±3.86	32.89	46.48	38.75±3.48	26.21	46.48	38.44±3.62

Min *= Minimum,* ***Max*** *= Maximum,* ***N*** *= Number of samples,* ***SD*** *= Standard deviation,* ***PF*** *= Proximal femur,* ***L*** *= Left*

Table 6: Descriptive Characteristics of Geometric Measurements of the Left Humerus

Left Humerus	Male [N = 37]			Female [N = 88]			Total [N = 125]		
	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD
L-PH1(AB)	26.41	82.73	66.16±12.42	26.26	80.45	60.24±14.44	26.26	82.73	61.99±14.09
L-PH2(AC)	39.24	105.06	85.66±14.48	37.31	96.22	75.29±18.04	37.31	105.06	78.36±17.66
L-PH3(AD)	40.44	110.41	88.05±15.61	38.29	105.71	75.60±18.76	38.29	110.41	79.28±18.71
L-PH4(AE)	35.13	90.86	53.27±18.39	31.06	84.93	49.82±17.41	31.06	90.86	50.84±17.70
L-PH5(BC)	18.35	55.38	32.20±12.05	16.30	55.46	30.20±11.13	16.30	55.46	30.79±11.40
L-PH6(BD)	31.59	79.12	47.44±16.48	26.63	74.94	44.88±15.62	26.63	79.12	45.64±15.86
L-PH7(BE)	37.21	90.53	55.79±19.85	31.22	83.66	52.24±17.77	31.22	90.53	53.29±18.40
L-PH8(CD)	10.98	37.60	19.49±7.47	10.18	33.50	18.82±6.83	10.18	37.60	19.01±7.01
L-PH9(CE)	19.45	62.23	34.82±13.67	17.81	56.09	33.18±11.71	17.81	62.23	33.66±12.29
L-PH10(DE)	9.77	44.56	18.37±8.35	7.97	32.88	16.64±6.40	7.97	44.56	17.15±7.04
L-PHA1(FAE)	30.31	76.23	49.31±12.06	15.11	79.35	49.40±17.39	15.11	79.35	49.37±15.95
L-PHA2(BAC)	25.00	39.55	32.41±3.68	23.46	42.70	32.30±4.74	23.46	42.70	32.33±4.44
L-PHA3(BAE)	56.43	78.03	67.47±6.00	52.96	80.90	66.81±6.41	52.96	80.90	67.01±6.28

Min *= Minimum,* ***Max*** *= Maximum,* ***N*** *= Number of samples,* ***SD*** *= Standard deviation,* ***PH*** *= Proximal humerus,* ***L*** *= Left*

Table 7: Descriptive Characteristics of Geometric Measurements of the Right Femur

Right Femur	***MALE [N = 24]***			***FEMALE [N = 46]***			***TOTAL [N = 70]***		
	Min	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***	***Min***	***Max***	***Mean±SD***
R-PF1(AB)	40.81	68.92	59.28±6.61	38.76	63.79	49.65±5.40	38.76	68.92	52.95±7.40
R-PF2(AC)	47.39	76.09	67.39±6.04	45.75	71.69	56.49±5.77	45.75	76.09	60.23±7.81
R-PF3(AD)	79.39	119.11	102.89±8.09	75.86	105.74	88.26±6.54	75.86	119.11	93.28±9.93
R-PF4(AE)	66.42	96.96	81.92±6.48	60.42	82.74	69.51±5.02	60.42	96.96	73.76±8.10
R-PF5(AF)	81.00	107.04	93.68±6.98	69.02	99.62	83.15±7.16	69.02	107.04	86.76±8.66
R-PF6(AG)	57.95	75.78	67.69±5.00	51.71	72.33	59.72±4.85	51.71	75.78	62.45±6.18
R-PF7(AH)	27.68	42.74	35.79±3.70	22.93	40.55	34.00±3.74	22.93	42.74	34.62±3.79
R-PF8(BC)	10.72	21.42	15.26±2.81	10.56	18.87	13.26±1.82	10.56	21.42	13.95±2.39
R-PF9(BD)	42.95	58.27	51.19±3.54	38.93	50.77	44.88±2.74	38.93	58.27	47.05±4.26
R-PF10(BE)	34.52	48.28	40.49±3.52	31.00	39.38	35.26±2.27	31.00	48.28	37.05±3.71
R-PF11(BF)	56.84	75.26	64.21±5.33	48.85	80.55	60.54±6.17	48.85	80.55	61.80±6.11
R-PF12(BG)	63.15	86.82	73.18±6.56	55.93	81.25	67.95±5.89	55.93	86.82	69.74±6.57
R-PF13(BH)	57.42	86.86	78.37±6.91	57.95	82.04	69.43±6.32	57.42	86.86	72.50±7.76

R-PF14(CD)	49.90	67.76	56.39±4.47	42.61	55.26	49.86±2.74	42.61	67.76	52.10±4.62
R-PF15(CE)	40.81	60.48	50.86±4.82	37.39	52.63	45.00±3.36	37.39	60.48	47.01±4.79
R-PF16(CF)	61.76	89.00	76.13±6.55	57.81	80.81	69.96±5.92	57.81	89.00	72.07±6.77
R-PF17(CG)	71.83	98.71	87.69±7.25	63.33	96.48	80.09±7.30	63.33	98.71	82.69±8.09
R-PF10(BE)	34.52	48.28	40.49±3.52	31.00	39.38	35.26±2.27	31.00	48.28	37.05±3.71
R-PF11(BF)	56.84	75.26	64.21±5.33	48.85	80.55	60.54±6.17	48.85	80.55	61.80±6.11
R-PF12(BG)	63.15	86.82	73.18±6.56	55.93	81.25	67.95±5.89	55.93	86.82	69.74±6.57
R-PF13(BH)	57.42	86.86	78.37±6.91	57.95	82.04	69.43±6.32	57.42	86.86	72.50±7.76
R-PF14(CD)	49.90	67.76	56.39±4.47	42.61	55.26	49.86±2.74	42.61	67.76	52.10±4.62
R-PF15(CE)	40.81	60.48	50.86±4.82	37.39	52.63	45.00±3.36	37.39	60.48	47.01±4.79
R-PF16(CF)	61.76	89.00	76.13±6.55	57.81	80.81	69.96±5.92	57.81	89.00	72.07±6.77
R-PF17(CG)	71.83	98.71	87.69±7.25	63.33	96.48	80.09±7.30	63.33	98.71	82.69±8.09
R-PF18(CH)	63.05	99.83	91.77±8.36	66.15	96.44	80.58±7.20	63.05	99.83	84.42±9.26
R-PF19(DE)	16.12	33.81	25.94±4.71	16.44	29.87	22.22±3.40	16.12	33.81	23.49±4.25
R-PF20(DF)	24.87	57.22	41.71±8.39	22.67	52.83	38.71±7.10	22.67	57.22	39.74±7.64
R-PF21(DG)	71.41	90.48	82.54±5.92	60.76	89.49	73.72±7.79	60.76	90.48	76.74±8.31

R-PF22(DH)	84.73	120.89	107.99±8.47	80.58	114.45	96.32±7.43	80.58	120.89	100.32±9.54
R-PF23(EF)	20.13	42.43	29.03±7.08	20.33	40.61	29.10±4.66	20.13	42.43	29.08±5.56
R-PF24(EG)	49.55	70.83	58.25±5.56	40.32	70.04	54.40±6.61	40.32	70.83	55.72±6.49
R-PF25(EH)	68.15	95.64	83.69±6.82	61.23	89.61	74.91±7.47	61.23	95.64	77.92±8.34
R-PF26(FG)	39.92	57.61	47.95±4.89	30.31	55.72	44.21±5.72	30.31	57.61	45.49±5.70
R-PF27(FH)	71.55	98.29	85.52±8.21	63.52	90.44	76.35±5.79	63.52	98.29	76.35±5.79
R-PF28(GH)	34.18	55.87	46.40±5.92	30.95	49.25	39.93±4.80	30.95	55.87	42.14±6.03
R-PFA1(ICA)	49.22	87.66	67.20±8.99	40.46	89.55	65.80±10.93	40.46	89.55	66.28±10.27
R-PFA2(EHF)	12.42	29.89	21.10±5.73	14.21	30.52	22.98±3.92	12.42	30.52	22.34±4.67
R-PFA3(CAD)	19.91	35.78	30.50±3.42	21.28	42.54	31.93±4.21	19.91	42.54	31.44±3.99
R-PFA4(BDE)	30.85	60.98	50.85±7.58	39.83	59.38	48.19±5.12	30.85	60.98	49.10±6.15
R-PFA5(CAE)	29.91	49.44	38.04±5.33	31.89	48.88	39.74±4.44	29.91	49.44	39.16±4.80

Min *= Minimum;* ***Max*** *= Maximum;* ***N*** *= Number of samples,* ***SD*** *= Standard deviation,* ***PF*** *= Proximal femur,* ***R*** *= Right*

Table 8: Descriptive characteristics of geometric measurements of the right humerus

Right humerus	Male [N = 37]			Female [N = 88]			Total [N = 125]		
	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean± SD
R-PH1(AB)	26.47	85.95	55.46±18.87	27.05	80.14	56.98±16.87	26.47	85.95	56.53±17.42
R-PH2(AC)	38.07	107.57	68.84±22.85	32.03	98.35	69.40±20.40	32.03	107.57	69.23±21.06
R-PH3(AD)	30.19	105.71	67.66±23.12	33.10	95.66	68.19±20.17	30.19	105.71	68.03±20.99
R-PH4(AE)	30.09	91.52	51.05±19.10	20.86	84.18	48.68±17.37	20.86	91.52	49.38±17.85
R-PH5(BC)	19.26	55.64	30.96±11.73	15.09	62.15	29.80±11.11	15.09	62.15	30.15±11.26
R-PH6(BD)	29.81	75.08	45.58±17.27	24.52	72.78	44.13±15.28	24.52	75.08	44.56±15.84
R-PH7(BE)	30.14	94.96	54.49±20.73	30.71	84.35	52.32±18.21	30.14	94.96	52.96±18.93
R-PH8(CD)	12.23	51.48	20.47±8.73	9.64	64.05	19.92±8.40	9.64	64.05	20.09±8.47
R-PH9(CE)	22.36	62.74	36.21±13.84	18.47	69.15	35.23±13.15	18.47	69.15	35.52±13.31
R-PH10(DE)	10.99	40.39	19.25±8.12	8.49	63.15	18.33±9.45	8.49	63.15	18.60±9.06
R-PHA1(FAE)	30.96	75.64	54.71±13.89	14.96	77.64	51.16±17.83	14.96	77.64	52.21±16.78

Table 9: Correlation of Femur Geometric Measurements with BMI In Male Subjects

Measured variables	Right femur [N = 24] $BMI_{[r]}$ *(P-value)*	Left femur [N = 24] $BMI_{[l]}$ *(P-value)*
PF1(AB)	-0.254 (0.231)	-0.292 (0.166)
PF2(AC)	-0.079 (0.713)	-0.068 (0.752)
PF3(AD)	-0.134 (0.532)	-0.167 (0.435)
PF4(AE)	-0.130 (0.544)	-0.134 (0.534)
PF5(AF)	0.072 (0.737)	0.042 (0.845)
PF6(AG)	**-0.441 (0.031)***	-0.384 (0.064)
PF7(AH)	-0.143 (0.505)	-0.129 (0.549)
PF8(BC)	**0.558 (0.005)****	**0.460 (0.024)***
PF9(BD)	0.100 (0.642)	0.080 (0.712)
PF10(BE)	-0.160 (0.455)	-0.015 (0.945)
PF11(BF)	-0.192 (0.368)	-0.102 (0.635)
PF12(BG)	-0.175 (0.414)	-0.169 (0.431)
PF13(BH)	-0.212 (0.320)	-0.218 (0.307)
PF14(CD)	0.062 (0.773)	0.047 (0.827)
PF15(CE)	-0.003 (0.990)	0.077 (0.721)
PF16(CF)	-0.045 (0.835)	0.013 (0.952)
PF17(CG)	0.032 (0.882)	0.076 (0.725)
PF18(CH)	0.036 (0.869)	-0.027 (0.900)
PF19(DE)	-0.218 (0.307)	-0.198 (0.353)
PF20(DF)	-0.252 (0.235)	-0.291 (0.168)
PF21(DG)	0.052 (0.810)	0.087 (0.685)
PF22(DH)	-0.224 (0.292)	-0.169 (0.429)
PF23(EF)	-0.062 (0.773)	-0.073 (0.736)
PF24(EG)	0.114 (0.594)	0.170 (0.428)
PF25(EH)	0.136 (0.528)	-0.104 (0.630)
PF26(FG)	0.334 (0.111)	**0.530 (0.008)****
PF27(FH)	0.063 (0.770)	0.153 (0.476)
PF28(GH)	**-0.429 (0.036)***	-0.365 (0.079)
PFA1(ICA)	0.144 (0.503)	0.164 (0.445)
PFA2(EHF)	0.001 (0.997)	-0.072 (0.739)
PFA3(CAD)	0.361 (0.083)	0.290 (0.169)
PFA4(BDE)	-0.056 (0.796)	-0.144 (0.503)
PFA5(CAE)	0.315 (0.134)	0.233 (0.274)

** = Correlation is significant at the 0.01 level (2-tailed); * = Correlation is significant at the

Table 10: Correlation of Femur Geometric Measurements with BMI In Female Subjects

Measured variables	Right femur $BMI_{[r/}$ *(P-value)*	Left femur $BMI_{[r/}$ *(P-value)*
PF1(AB)	-0.098 (0.519)	-0.089 (0.556)
PF2(AC)	-0.151 (0.315)	-0.131 (0.387)
PF3(AD)	**-0.300 (0.043)***	-0.229 (0.126)
PF4(AE)	-0.190 (0.205)	-0.200 (0.182)
PF5(AF)	-0.121 (0.423)	-0.048 (0.752)
PF6(AG)	-0.065 (0.670)	-0.054 (0.722)
PF7(AH)	0.110 (0.466)	0.139 (0.358)
PF8(BC)	-0.090 (0.554)	-0.075 (0.622)
PF9(BD)	-0.159 (0.291)	-0.270 (0.070)
PF10(BE)	0.084 (0.580)	0.072 (0.633)
PF11(BF)	0.173 (0.250)	0.075 (0.621)
PF12(BG)	-0.035 (0.816)	0.011 (0.944)
PF13(BH)	0.067 (0.657)	0.055 (0.718)
PF14(CD)	-0.146 (0.333)	-0.094 (0.535)
PF15(CE)	0.051 (0.736)	0.139 (0.355)
PF16(CF)	0.173 (0.249)	0.069 (0.649)
PF17(CG)	0.009 (0.955)	-0.001 (0.992)
PF18(CH)	-0.129 (0.392)	0.019 (0.900)
PF19(DE)	-0.126 (0.405)	-0.070 (0.643)
PF20(DF)	-0.124 (0.413)	-0.071 (0.641)
PF21(DG)	-0.115 (0.446)	-0.117 (0.440)
PF22(DH)	-0.192 (0.200)	-0.142 (0.346)
PF23(EF)	-0.059 (0.699)	-0.041 (0.788)
PF24(EG)	0.004 (0.981)	-0.127 (0.401)
PF25(EH)	-0.047 (0.758)	-0.133 (0.379)
PF26(FG)	0.017 (0.909)	0.010 (0.946)
PF27(FH)	0.010 (0.946)	-0.002 (0.992)
PF28(GH)	-0.168 (0.263)	-0.093 (0.540)
PFA1(ICA)	0.144 (0.341)	0.179 (0.235)
PFA2(EHF)	-0.105 (0.487)	-0.011 (0.940)
PFA3(CAD)	0.290 (0.051)	0.229 (0.126)
PFA4(BDE)	**0.373 (0.011)***	**0.479 (0.001)****
PFA5(CAE)	0.213 (0.156)	0.283 (0.057)

** = Correlation is significant at the 0.01 level (2-tailed); * = Correlation is significant at the 0.05 level (2-tailed); **BMI** = Body Mass Index

Table 11: Correlation of humerus geometric measurements with BMI in male subjects

Measured variables	**Right humerus [N = 37]**	**Left humerus [N = 37]**
	$BMI_{[r/}$ ***(Pvalue)***	**$BMI_{[r/}$** ***(P-value)***
PH1(AB)	0.140 (0.409)	-0.029 (0.863)
PH2(AC)	0.107 (0.530)	0.088 (0.604)
PH3(AD)	0.094 (0.581)	0.078 (0.645)
PH4(AE)	-0.153 (0.365)	-0.108 (0.526)
PH5(BC)	-0.208 (0.217)	-0.107 (0.529)
PH6(BD)	-0.214 (0.203)	-0.176 (0.297)
PH7(BE)	-0.221 (0.189)	-0.230 (0.170)
PH8(CD)	-0.107 (0.529)	-0.271 (0.105)
PH9(CE)	-0.257 (0.125)	**-0.334 (0.043)***
PH10(DE)	-0.318 (0.055)	**-0.390 (0.017)***
PHA1(FAE)	0.160 (0.344)	0.278 (0.095)
PHA2(BAC)	-0.188 (0.265)	0.204 (0.225)
PHA3(BAE)	-0.136 (0.423)	**-0.416 (0.010)***

** = Correlation is significant at the 0.01 level (2-tailed); * = Correlation is significant at the 0.05 level (2-tailed); **BMI** = Body Mass Index

Table 12: Correlation of Humerus Geometric Measurements with BMI in Female Subjects

Measured variables	Right humerus [N = 88]	Left humerus [N = 88]
	$BMI_{[r]}$ *(P-value)*	**$BMI_{[r]}$ *(P-value)***
PH1(AB)	-0.051 (0.634)	0.013 (0.904)
PH2(AC)	0.000 (1.000)	-0.016 (0.879)
PH3(AD)	-0.001 (0.996)	-0.030 (0.780)
PH4(AE)	0.106 (0.326)	0.093 (0.389)
PH5(BC)	0.069 (0.521)	0.110 (0.308)
PH6(BD)	0.073 (0.498)	0.104 (0.333)
PH7(BE)	0.073 (0.500)	0.093 (0.387)
PH8(CD)	0.082 (0.447)	0.057 (0.598)
PH9(CE)	0.064 (0.551)	0.037 (0.733)
PH10(DE)	-0.009 (0.932)	0.023 (0.832)
PHA1(FAE)	-0.020 (0.856)	0.004 (0.971)
PHA2(BAC)	-0.035 (0.749)	**0.363 (0.001)****
PHA3(BAE)	0.059 (0.584)	0.115 (0.287)

** = Correlation is significant at the 0.01 level (2-tailed); * = Correlation is significant at the 0.05 level (2-tailed); **BMI** = Body Mass Index

DISCUSSION

Various studies have provided insight into the use of radiogrammetric measurements for anthropometric predictions across diverse populations. Inyang *et al.*[9] examined 3D morphometric data of the proximal humerus in Swiss and South African populations, identifying notable morphological differences but no direct correlation with BMI. This present study reveals weak, negative, and moderate correlations between the geometric measurements of the humerus and femur and body mass index (BMI) in both male and female populations used in this study, indicating that these skeletal parameters are not reliable for predicting BMI in the Yoruba population. These results are similar to the findings of Msamati & Igbigbi[10], they examined 898 urban adult black Malawians and found weak correlations between BMI and anthropometric measurements, with mean BMI values of 21.56 ± 1.71 for males and 25.54 ± 5.59 for females which the authors attributed to nutritional and genetic factors. These factors may also explain the weak correlations observed in our Yoruba sample population. Similarly, Alabi *et al.*[11] identified a significant positive correlation between foot length (FL) and BMI, particularly in females, but noted that the predictive accuracy was low, further supporting the limitations of skeletal measurements for body morphology prediction.

The weak correlations with BMI suggest that skeletal measurements alone are inadequate for accurate body morphology prediction. Future studies could leverage on 3D imaging or machine learning to improve the predictive accuracy and explore the influence of genetic, nutritional, and cultural factors on anthropometric relationships in various populations.

CONCLUSION

This study's findings showed weak, negative, and moderate correlations of geometric measurements of radiographic images of the humerus and femur with body mass index (BMI), suggesting that the geometric measurements obtained in this study have limited utility for predicting body morphology. However, these results add to the existing literature on skeletal anthropometric correlations, emphasizing the intricate relationship between skeletal structure and body composition.

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