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A retrospective radiological study on the morphometry of hand digits and phalanges: role in sex determination

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Abstract

Background: Forensic identification of dismembered or fragmented human remains is important following mass disasters. Sex determination is fundamental in narrowing down the pool of possible victims. *Aim and Objectives:* This study aimed at determining the accuracy of correct sex prediction using the radiological lengths of hand digits and phalanges of adult Nigerians. *Material and Methods:* In this retrospective cross-sectional study, the lengths of the digits and phalanges were measured on 280 (170 males and 110 females) unpaired hand radiographs archived in the Radiology Departments of two Teaching Hospitals in Nigeria. Ethics approval was obtained from the Institutions' Research committee. Statistical Package for Social Sciences Version 22 was used to analyse the data. Independent 't' test was used for gender comparisons in the mean lengths while discriminant function analysis was used to determine the percentage accuracy for correct sex allocation. Value of $p < 0.05$ was considered as the level of significance. *Results:* Male hands had significantly longer digits and phalanges compared to those of females on both sides ($p \leq 0.05$). The digit and phalanx with high accuracies of sex determination were D2 (90%), DP2 (74.2%) and D1 (68.5%), PP1 (85%) on the right and left hand correspondingly. Collectively, using all the digits (95%) and DP (72.9%) of the right hand as well as digits (80.7%) and PP (78.6%) of the left hand provided high accuracies. *Conclusion:* The findings of this study suggest that the phalanges of the hand digits could be used with other sexual dimorphic parameters to aid in sex determination in our studied population.

Keywords: Phalanges, Digits, Hand, Sex, Determination

Introduction

Identification of human remains is an important scientific process in medico-legal investigations [1]. Forensic anthropological data is useful in the identification of charred, fragmented and dismembered human remains following mass disasters such as explosions, plane crashes and motor vehicle accidents [2]. Forensic investigations aim at creating a biological profile that will aid in the positive identification of an individual. This entails sex and race determination in addition to age and stature estimation [3]. Sex determination is the first step in establishing the identity of an individual [4]. This step is fundamental in forensic medicine because it helps to narrow down the pool of possible victim matches by 50% and aids in accurate estimation of age and stature. However, sex differentiation of putrefied, mutilated or fragmented skeletal relics is complex and challenging [5]. As a result, developing sexing criteria from various skeletal features have been a major study in forensic anthropology [6]. Sex differences in anthropometric measurements of various body parts vary in different populations due to differences in the genetic makeup and exposure to different environmental and geographical factors [7].

Traditionally, the pelvis and skull provide the best accuracy in the determination of sex when recovered intact. However, in high impact disasters that involve fragmentary human relics, other bones with sexual dimorphic features become useful [8]. Small irregular bony structures such as scapula, clavicle, fingers, toes, patella, vertebrae, ribs, and palate have been proven to be efficient in sex estimation, though with variant accuracy levels [9]. Currently, there has been a growing interest in the application of statistical methods such as discriminant function analysis of skeletal parameters in order to determine their accuracy for correct sex discrimination [10].

The human hand is a diverse anatomical structure that is beneficial in forensic identification of unknown human remains [11]. This is due to the ability of the small, dense and compact bones of the hand to oppose taphonomic transitions, thus often remain complete [11-12]. They are more preferable in forensics compared to long bones whose epiphyses are prone to damage owing to the overlying cancellous bone which is fragile [8]. Hence, the recent interest of researchers in creating population specific parameters for sex prediction using hand anthropometry [13]. The phalanges of the hand are easily identified in mass disasters because they are many and possess small surface area that is exposed to alterations [11, 14]. The measurements of the hand digits and phalanges vary in different population groups, with some studies documenting the presence of sexual dimorphism in these variables [15-17]. Moreover, varying accuracies of using the osteometric parameters of hand digits and phalanges have also been reported in America, Egypt, India and South Africa [16, 18-19].

The use of radiography in forensic examinations is becoming more prevalent especially in situations where skeletal remains are highly putrefied [20]. Electronic radiographic archives contain a large data set that may be useful in forensic medicine [8]. Radiographs provide a clear visualization of bone with precise osteometric evaluation that is reliable in forensic investigations [12]. To the best of our knowledge, there is paucity of data regarding sex estimation using the linear measurements of the hand digits and phalanges in South Nigeria. This study therefore aimed at determining the radiographic lengths of the hand digits and phalanges and evaluate their accuracy in correct sex prediction.

Material and Methods

The study design adopted herein was the retrospective descriptive cross-sectional design. Hand radiographs stored in the Picture Archiving and Communications Systems (PACS) of the radiology departments of two teaching hospitals (in Delta and Edo States) in Nigeria were used in this study. Both institutions granted ethical approval prior to commencement of data collection (Approval Reference numbers: HREC/PAN/2021/003/0417 and ADM 22/A/ VOL. VII/ 14831067).

The radiographs were selected using the purposive sampling technique. The available digital hand radiographs taken in the two Teaching Hospitals from 1st January 2014 to 1st January 2020 were retrieved. Both right and left Postero-anterior (PA) hand radiographs (unpaired), of both male and female patients aged 20 years and above were included in this study. This age was appropriate since the bones are mature with limited ongoing development [12]. We excluded hand radiographs with no demographic data and radiographs of poor quality evidenced by inadequate exposure, over-exposure and inadequate field of view. Moreover, views other than the PA hand radiographs and radiographs with congenital and developmental dysplasia, fractures, metabolic bone diseases, osteoarthritis, bone tumours or evidence of previous surgery were excluded from this study. Therefore, 280 PA hand radiographs of 170 males and 110 females fit our inclusion criteria. The age, gender and side of the hand were recorded on the data sheets.

The digits were labelled D with numbers 1 to 5 consecutively with the thumb being the first digit (D1) and the small finger being the fifth (D5). The distal, middle and proximal phalanges were labelled DP, MP and PP. Additionally, these were labelled numbers 1-5 based on the digit they belonged to. For instance, the middle phalanx of the index finger was identified as MP2. On each digital hand radiograph, the lengths of the digits and phalanges were measured in cm using a digital callipers provided by PACS. The length of each phalanx was measured from the midpoint of the base to the midpoint of the apex [5]. The length of each digit was measured from the midpoint of the base of the proximal phalanx to the midpoint of the apex of the distal phalanx. To avoid inter-observer errors, one investigator carried out all the measurements. The parameters were measured three times and the average recorded in order to minimize intra-observer errors.

Data analysis was accomplished using Statistical Package for Social Sciences for windows version 22 (SPSS, Inc. Chicago, IL, USA). The continuous variables were summarized in means and standard deviations. The sex differences in the metric variables were assessed using the independent t test and considered significant at $p < 0.05$. The accuracy of predicting sex using each metric variable was analysed using the Discriminant Functional Analysis (DFA). Prior to DFA, the normality of data distribution was assessed using the Kolmogorov-Smirnov test while the Box's M test was used to test for the equality of covariance in the matrices. The coefficients and constants calculated in the univariate and multivariate analysis were used to derive the discriminate function equations. The means of the variables in each gender were incorporated in the equations to determine the discriminant function scores (Di) for each sex group. This was calculated as $(Di) = a + R1X1 + R2X2 + R3X3 + R4X4$ where (a) was a constant, R1–R4 were unstandardized coefficients and X1–X4 were the metric parameters. The male and female centroids obtained were averaged to determine the Sectioning Points (SP). Therefore, the variables that gave Di above the SP were considered male while Di less than SP were considered female. Wilk's lambda test was used to determine the variables that create significant predictions into classes (males and females) and values closer to zero suggested better discriminatory ability of the function [12]. To quantify the accuracy rate of the original sample and cross validated sample, the "leave one out" classification was applied [14].

Results

This study evaluated hand radiographs of 280 patients comprising 170 (60.7%) males and 110 (39.3%) females. These patients had a mean age of 37.4 ± 10.575 years and an age range of 20-60 years. Each radiograph had the image of a single hand of an individual, therefore, the sample involved unpaired hands with equal side distribution in males (85 right, 85 left) and females (55 right and 55 left). We evaluated 1400 digits and 3920 phalanges on 140 right and 140 left hand radiographs.

The mean lengths of the digits and phalanges in the two gender groups are shown in Tables 1 and 2. All these metric variables were longer in males than in females. The gender differences in the left hand variables were statistically significant except for the mean lengths of 3rd digit, middle phalanges of the 3rd, 4th and 5th digits, and proximal phalanx of the 2nd digit (Table 1).

Table 1: Gender differences in the lengths of the left hand digits and phalanges

Parameter measured	Mean ± SD (cm)		p
	Males (n:85)	Females (n:55)	
D1	5.39 ± 0.33	5.10 ± 0.25	0.001*
D2	8.25 ± 0.52	7.61 ± 0.49	0.001*
D3	9.17 ± 0.10	9.11 ± 0.53	0.670
D4	8.81 ± 0.51	7.71 ± 0.56	0.001*
D5	6.99 ± 0.48	6.83 ± 0.96	0.010*
DP1	2.30 ± 0.24	2.04 ± 0.24	0.001*
DP2	1.65 ± 0.20	1.57 ± 0.19	0.020*
DP3	1.85 ± 0.20	1.74 ± 0.19	0.010*
DP4	1.81 ± 0.21	1.72 ± 0.18	0.001*
DP5	1.57 ± 0.23	1.43 ± 0.20	0.001*
MP2	2.42 ± 0.22	2.26 ± 0.36	0.001*
MP3	2.80 ± 0.38	2.75 ± 0.31	0.380
MP4	2.61 ± 0.31	2.52 ± 0.33	0.110
MP5	1.91 ± 0.39	1.87 ± 0.27	0.480
PP1	3.58 ± 0.65	2.92 ± 0.38	0.001*
PP2	4.08 ± 0.35	3.99 ± 0.37	0.170
PP3	4.58 ± 0.27	4.43 ± 0.61	0.040*
PP4	4.46 ± 0.36	4.23 ± 0.28	0.001*
PP5	3.32 ± 0.45	2.99 ± 0.30	0.001*

*D1-thumb, D2-index, D3-middle, D4-ring, D5-little finger, DP-distal phalanx, MP-middle phalanx, PP-proximal phalanx, * p considered significant at <0.05*

Similarly, significant sexual differences were observed in the right hand variables except the length of the 3rd and 5th digits, distal and middle phalanx of the 3rd and 4th digits respectively and the proximal phalanges of the 3rd to 5th digits (Table 2).

Table 2: Gender differences in the lengths of the right hand digits and phalanges

Parameter measured	Mean ± SD (cm)		p
	Males (n:85)	Females (n:55)	
D1	5.65 ± 0.27	5.24 ± 0.26	0.001*
D2	8.42 ± 0.57	7.29 ± 0.41	0.001*
D3	9.33 ± 0.96	9.08 ± 0.93	0.130
D4	8.74 ± 0.85	7.59 ± 0.54	0.001*
D5	6.98 ± 0.51	6.73 ± 0.63	0.500
DP1	2.36 ± 0.26	2.17 ± 0.25	0.001*
DP2	1.76 ± 0.20	1.58 ± 0.20	0.001*
DP3	1.81 ± 0.21	1.80 ± 0.22	0.190
DP4	1.85 ± 0.22	1.73 ± 0.26	0.001*
DP5	1.46 ± 0.15	1.36 ± 0.20	0.001*
MP2	2.44 ± 0.25	2.31 ± 0.31	0.010*
MP3	2.84 ± 0.29	2.77 ± 0.38	0.020*
MP4	2.75 ± 0.31	2.65 ± 0.41	0.890
MP5	2.02 ± 0.26	1.89 ± 0.30	0.010*
PP1	3.29 ± 0.59	2.99 ± 0.32	0.001*
PP2	4.21 ± 0.37	4.02 ± 0.29	0.001*
PP3	4.62 ± 0.45	4.49 ± 0.35	0.120
PP4	4.33 ± 0.25	4.19 ± 0.35	0.120
PP5	3.47 ± 0.38	3.44 ± 0.46	0.630

*D1-thumb, D2-index, D3-middle, D4-ring, D5-little finger, DP-distal phalanx, MP-middle phalanx, PP-proximal phalanx, * p considered significant at <0.05*

In both right and left hands, the 3^{rd} digit was the longest followed by the 4^{th}, 2^{nd}, 5^{th} and 1^{st} in that order. The descending order in the length of the PP was PP3, PP4, PP2, PP1, PP5 and PP3, PP4, PP2, PP5, PP1 on the left and right respectively. On both sides, the MP of the 3^{rd} digit was the longest, followed by the MP of 4^{th}, 2^{nd} and lastly 5^{th} digits. The longest to shortest DP was DP1, DP3, DP4, DP2, DP5 and DP1, DP4, DP3, DP2, DP5 on the left and right hands correspondingly. These comparisons of the mean bone lengths were observed in both gender groups.

The Kolmogorov-Smirnov test showed that the sample used in this study had a normal distribution of variables (p=0.079) and can therefore be used to develop formulas for sex grouping. The data also demonstrated equality of covariance (p=0.001). From the univariate DFA, the centroids and calculated sectioning points of the right and left hand variables are summarized in Tables 3 and 4 respectively. The findings from the right hand variables showed that the D2 was the best sex discriminating digit with an overall accuracy of 90% (126) (91.8% males and 87.3% females). The DP2 was the best phalanx in sex prediction (104, 74.2%). Additionally, the best proximal and middle phalanges in determining sex was the PP4 (102, 72.8%) and MP2 (93, 66.4%) correspondingly (Table 3).

Table 3: Univariate Analysis using the lengths of the right digits and phalanges

Variables	Centroids		SP	Accuracy (%)		
	Males	Females		Males	Females	Overall
D1	0.602	-0.930	-0.164	72 (84.7)	40 (72.7)	112 (80)
D2	0.852	-1.316	-0.232	78 (91.8)	48 (87.3)	126 (90)
D3	0.102	-0.158	-0.028	84 (98.8)	3 (5.5)	87 (62.1)
D4	0.54	-0.83	-0.145	77 (90.6)	37 (67.3)	114 (81.4)
D5	0.135	-0.208	-0.0725	84 (98.8)	6 (10.9)	90 (64.2)
DP1	0.294	-0.454	-0.08	68 (80.0)	22 (40)	90 (64.2)
DP2	0.347	-0.537	-0.095	75 (88.2)	29 (52.7)	104 (74.2)
DP3	0.088	-0.137	-0.0245	84 (98.8)	2 (3.6)	86 (61.4)
DP4	0.137	-0.212	-0.0375	82 (96.5)	9 (16.4)	91 (65)
DP5	0.211	-0.333	-0.061	79 (92.9)	19 (35.2)	98 (70)
MP2	0.177	-0.273	-0.048	81 (95.3)	12 (21.8)	93 (66.4)
MP3	0.211	-0.325	-0.057	76 (89.4)	14 (25.5)	90 (64.2)
MP4	-0.01	0.14	0.065	85 (100)	0 (0)	85 (60.7)
MP5	0.173	-0.268	-0.0475	74 (87.1)	12 (21.8)	86 (61.4)
PP1	0.233	-0.359	-0.063	83 (97.6)	14 (25.5)	97 (69.3)
PP2	0.218	0.336	-0. 059	66 (77.6)	11 (20.0)	77 (55)
PP3	0.109	-0.169	-0.03	84 (98.8)	7 (12.7)	91 (65)
PP4	-0.187	-0.289	-0.051	80 (94.1)	18 (14.5)	102 (72.8)
PP5	0.032	-0.050	-0.009	85 (100)	0 (0)	85 (60.7)

D1-thumb, D2-index, D3-middle, D4-ring, D5-little finger, DP-distal phalanx, MP-middle phalanx, PP-proximal phalanx, SP-sectioning point

On the left hand, the digit and phalanx with the highest overall accuracy of correct sex allocation was D1 (96, 68.5%) and PP1 (119, 85%). The DP1 and MP2 were the best left distal and middle phalanges for correct sex grouping with overall accuracies of 98,70% and 91, 65% respectively (Table 4).

Table 4: Univariate Analysis using the lengths of the left digits and phalanges

Variables	Centroids		SP	Accuracy (%)		
	Males	Females		Males	Females	Overall
D1	0.385	-0.595	-0.105	60 (70.6%)	36 (65.5)	96 (68.5)
D2	0.232	-0.359	-0.0635	72 (84.7)	17 (30.9)	89 (63.6)
D3	0.025	-0.038	-0.0065	84 (98.8)	0 (0)	84 (60)
D4	0.233	-0.360	-0.0635	73 (85.9)	17 (30.9)	90 (64.2)
D5	0.116	-0.180	-0.032	80 (94.1)	7 (12.7)	87 (62.14)
DP1	0.425	-0.658	-0.1165	74 (87.1)	24 (43.6)	98 (70)
DP2	0.167	-0.258	-0.0455	75 (88.2)	9 (16.4)	84 (60)
DP3	0.171	-0.265	-0.047	70 (82.4)	8 (14.5)	78 (55.7)
DP4	0.182	-0.281	-0.099	75 (88.2)	17 (30.9)	92 (65.7)
DP5	0.251	-0.388	0.0685	71 (83.5)	18 (32.7)	89 (63.5)
MP2	0.225	-0.347	-0.061	78 (91.8)	13 (23.6)	91 (65)
MP3	0.060	-0.093	0.2535	85 (100)	0 (0)	85 (60.7)
MP4	0.109	0.168	-0.0295	85 (100)	1 (1.8)	86 (61.4)
MP5	0.048	-0.074	-0.013	85 (100)	0 (0)	85 (60.7)
PP1	0.463	-0.715	-0.126	82 (96.5)	37 (67.3)	119 (85)
PP2	0.095	-0.146	-0.0255	81 (95.3)	3 (5.5)	84 (60)
PP3	0.139	-0.215	-0.038	85 (100)	7 (12.7)	92 (65.7)
PP4	0.277	-0.428	-0.0755	68 (80.00)	19 (34.5)	87 (62.14)
PP5	0.314	0.486	-0.086	70 (82.4)	25 (45.5)	95 (67.8)

D1-thumb, D2-index, D3-middle, D4-ring, D5-little finger, DP-distal phalanx, MP-middle phalanx, PP-proximal phalanx, SP-sectioning point

The multivariate analysis of the length of phalanges and digits was conducted and the calculated coefficients and constants used to derive discriminate function equations are shown in Tables 5 and 6.

The discriminant equations deduced for the left hand variables were as follows (Table 5);

$Di (D) = (2.440 \times D1) + (0.6960 \times D2) + (-0.036 \times D3) + (0.830 \times D4) + (0.496 \times D5) - 28.868.$

$Di (DP) = (3.331 \times DP1) + (1.108 \times DP2) + (1.288 \times DP3) + (1.511 \times DP4) + (1.317 \times DP5) - 16.078.$

$Di (MP) = (3.073 \times MP2) + (0.590 \times MP3) + (1.154 \times MP4) + (-0.146 \times MP5) - 11.580.$

$Di (PP) = (1.322 \times PP1) + (0.257 \times PP2) + (0.452 \times PP3) + (1.095 \times PP4) + (1.017 \times PP5) - 15.512.$

Table 5: Multivariate analysis using the lengths of the left hand digits and phalanges

Variable	R	Centroid		Sectioning point	Wilk's Lambda	Eigen Value
		Males	Females			
D1	2.440	0.492	-0.760	-0.134	0.725	0.380
D2	0.696					
D3	-0.036					
D4	0.830					
D5	0.496					
Constant	-28.868					
DP1	3.331	0.559	-0.864	-0.153	0.671	0.490
DP2	1.108					
DP3	1.288					
DP4	1.511					
DP5	1.317					
Constant	-16.078					
MP2	3.073	0.248	-0.383	-0.068	0.912	0.096
MP3	0.590					
MP4	1.154					
MP5	-0.146					
Constant	-11.580					
PP1	1.322	0.609	-0.941	-0.166	0.632	0.581
PP2	0.257					
PP3	0.452					
PP4	1.095					
PP5	1.017					
Constant	-15.512					

R-unstandardized coefficient value, D1-thumb, D2-index, D3-middle, D4-ring, D5-little finger, DP-distal phalanx, MP-middle phalanx, PP-proximal phalanx

The discriminant equations deduced for the right hand phalanges were as shown below (Table 6);

Di (D) = $(1.098 \times D1) + (1.393 \times D2) + (-0.222 \times D3) + (0.681 \times D4) + (0.144 \times D5) - 25.043$.

Di (DP) = $(1.872 \times DP1) + (3.114 \times DP2) + (-0.74 \times DP3) + (0.210 \times DP4) + (3.097 \times DP5) - 12.947$

Di (MP) = $(2.008 \times MP2) + (1.627 \times MP3) + (-1.183 \times MP4) + (1.569 \times MP5) - 9.117$.

Di (PP) = $(1.178 \times PP1) + (1.438 \times PP2) + (0.570 \times PP3) + (1.354 \times PP4) + (-0.310 \times PP5) - 17.020$.

Table 6: Multivariate analysis using the lengths of the right hand digits and phalanges

Variable	R	Centroid		Sectioning point	Wilk's Lambda	Eigen Value
		Males	Females			
D1	1.098	1.157	-1.788	-0.316	0.323	0.298
D2	1.393					
D3	-0.222					
D4	0.681					
D5	0.144					
Constant	-25.043					
DP1	1.872	0.464	-0.730	-0.498	0.744	0.343
DP2	3.114					
DP3	-0.74					
DP4	0.210					
DP5	3.097					
Constant	-12.947					
MP2	2.008	0.301	-0.465	0.3145	0.876	0.142
MP3	1.627					
MP4	-1.183					
MP5	1.569					
Constant	-9.117					
PP1	1.178	0.346	-0.534	-0.094	0.842	0.187
PP2	1.438					
PP3	0.570					
PP4	1.354					
PP5	-0.310					
Constant	-17.020					

R-unstandardized coefficient value, D1-thumb, D2-index, D3-middle, D4-ring, D5-little finger, DP-distal phalanx, MP-middle phalanx, PP-proximal phalanx

The original and cross-validated percentage accuracies for sex prediction are summarized on Table 7. The accuracy of using combined digits' length was 95% (133) and 80.7% (113) on the right and left respectively. The lengths of the left hand phalanges showed the collective PP length as the best sex differentiating parameter (110, 78.6%) followed by the DP (108, 77.1%) and MP (96, 68.6%) lengths correspondingly. Using the right hand phalanges, the combined DP length showed the highest accuracy of sex grouping (102, 72.9%), followed by that of PP (99, 70.7%) and lastly the MP (96, 68.6%).

Table 7: Percentage accuracy of sex prediction from the multivariate analysis

Variable	Classification	Accuracy (%)		
		Males	Female	Overall
Right D	**Original**	81 (95.3)	52 (94.5)	133 (95)
	Cross Validated	81 (95.3)	51 (92.7)	132 (94.3)
Right DP	**Original**	70 (82.4)	32 (58.2)	102 (72.9)
	Cross Validated	69 (81.2)	31 (56.4)	100 (71.4)
Right MP	**Original**	72 (84.7)	24 (43.6)	96 (68.6)
	Cross Validated	71 (83.5)	23 (41.8)	94 (67.1)
Right PP	**Original**	75 (88.2)	24 (43.6)	99 (70.7)
	Cross Validated	71 (83.5)	22 (40.0)	93 (66.4)
Left D	**Original**	75 (88.2)	38 (69.1)	113 (80.7)
	Cross Validated	73 (85.9)	36 (65.5)	109 (77.9)
Left DP	**Original**	77 (90.6)	31 (56.4)	108 (77.1)
	Cross Validated	76 (89.4)	30 (54.5)	106 (75.7)
Left MP	**Original**	78 (91.8)	18 (32.7)	96 (68.6)
	Cross Validated	75 (88.2)	14 (25.5)	89 (63.6)
Left PP	**Original**	74 (87.1)	36 (65.5)	110 (78.6)
	Cross Validated	73 (85.9)	36 (65.5)	109 (77.9)

*D1-thumb, D2-index, D3-middle, D4-ring, D5-little finger, DP-distal phalanx, MP-middle phalanx, PP-proximal phalanx*cross validation is required for only cases in the analysis. In cross validation each case classified using functions obtained from all other cases.*

Figure 1: Posterior-anterior left hand radiograph showing the measurement of the digit length

Figure 2A: Posterior-anterior left hand radiographs showing the length of the phalanges: proximal phalanges

Figure 2B: Posterior-anterior left hand radiographs showing the length of the phalanges: middle phalanges

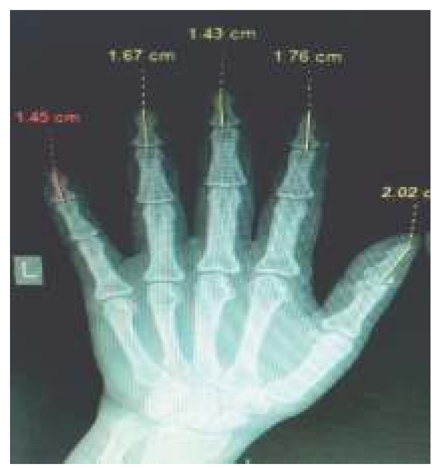

Figure 2C: Posterior-anterior left hand radiographs showing the length of the phalanges: Distal phalanges

Discussion

The mean lengths of the hand digits and phalanges differed from those documented in previous studies from several population groups [5, 15-16, 18]. These discrepancies have been ascribed to variances in genetics and environmental factors such as physical activity, diet and pathological conditions that influence the growth and development of bones [5]. The handedness of an individual determines the amount of physical stress exerted by muscles on the bones leading to bilateral asymmetry in the size of bones [14]. For instance, the dominant hand is associated with high physical activity, thus, possesses larger metric variables. Due to this, Alicioglu *et al*. [8] excluded the right hand radiographs from their study since majority of any given population is right handed. An Egyptian study by Morsi and Hawary [5] used radiographs of both hands to determine the lengths of the phalanges. However, these authors did not observe any significant differences between the lengths of the right and left phalanges in both males and females. Conversely, the present study could not compare the means from the unpaired right and left hand radiographs since the imaging protocol in the Hospitals where the study was conducted entails the imaging of only the hand with suspected pathology other than both hands of an individual.

In both males and females, the 3rd digit was the longest and this was followed by 4th, 2nd, 5th and 1st correspondingly on both sides. The order of the longest to shortest right PP, MP, DP and left MP corresponded with the findings of Morsi and Hawary [5]. We report significantly longer digits in males except the left D3 and right D3 and D5. Similarly, sexual dimorphism was observed in most phalanges except left MP3-MP5 and PP2 as well as right MP3, MP4, and PP3-PP5. Previous studies also documented sexual dimorphism in the lengths of the hand digits and phalanges with males having longer metric variables compared to their female counterparts [11, 15-17, 21]. On the contrary, previous studies by Kanchan and Kumar [22] and Ebeye, [23] documented higher mean lengths of the second digits in females than males. Another study carried out in Nigeria by Alabi *et al.*, [12] reported significantly longer proximal phalanges of the 3rd to 5th hand digits in males than females. However, these authors did not observe any sexual dimorphism in the lengths of the middle and distal phalanges. Eshak *et al.*, [24] measured the phalanges using computed tomographic hand images of Egyptians and reported sexual dimorphism in all distal phalanges, PP1 and PP3. However, the middle phalanges as well as the 2nd, 4th and 5th proximal phalanges did not show any significant gender differences.

From this comparison, it is clear that sexual dimorphism in the different metric parameters differs in population groups. This may be ascribed to the differences in geographical and environmental factors, besides ethnicity which influence the growth and remodelling of bones in the different sex groups [14]. According to Alabi *et al.*, [12], the phalanges have receptors for the sex steroids and therefore respond differently to androgens in males and oestrogen in females leading to cell proliferation and differential bone growth. The timing of the secondary sex development and fusion of the epiphysis is also different in the two gender groups [21]. Males have larger muscle bulk with greater mechanical effect on the bones [5]. Moreover, due to different gender roles, males are commonly involved in hand activities with more physical stress than females and this may explain the sexual dimorphism in the bones of the hands [14]. According to Kondo *et al*., [21] the gender differences in the phalanges alter the kinematics and change the ability of the hand to grasp. There is therefore the need for population specific studies to determine the accurate standard lengths of the hand bones in the gender groups.

Using the discriminant function equations of individual metric parameters, the best sex discriminating digit and phalanx was D2 (90%) and DP2 (74.2%) on the right hand and D1 (68.5%) and PP1 (85%) on the left hand. This suggests that the recovery of dismembered body remains with intact right second digit or the left PP1 in mass catastrophes will aid in accurate (85-90%) sex prediction of the remains. Morsi and Hawary (2012) [5] evaluated the accuracy of sex determination using radiographic lengths of the phalanges in 100 Egyptians. The phalanx with the highest accuracy of predicting sex was the proximal phalanx of the 1st digit on both right (83.9%) and left (85%) hands. High accuracies were also observed with DP1 of each hand (82.8% and 82%). It was concluded that DP1 and PP1 lengths can be used for sex determination in their population. Similarly, Eshak *et al*., [24] documented that the length of the 1st and 3rd proximal phalanges measured on computed tomographic hand images of Egyptian subjects were the best phalanges to be used in sex determination.

From the multivariate analysis, the best combination of phalanges for correct sex prediction was the PP (78.6%) and DP (72.9%) of the left and right hand respectively. This perhaps suggests that in mass disasters, the presence of all left PP or all right DP could provide some acceptable accuracy (72.9-78.6%) in sex determination. The assessment of phalangeal lengths of 259 white Americans of European Descent showed higher accuracy of sex prediction using the combined left phalanges than the right. Additionally, the length of the distal phalanges provided the highest accuracy for predicting sex on both sides (84.3% and 85.7%) [18]. According to the radiographs obtained from Ilorin, Kwara and Lagos States in Nigeria, Alabi *et al*., [12] documented a low accuracy of sex determination using the lengths of the PP (66%) with only 60% of males and 40% of females correctly classified. These scholars concluded that the length of the PP is not reliable in sex discrimination in the studied population. The use of the combined digit lengths in the present study provided higher accuracies of 95% (95.3% males, 94.5% females) and 80.7% (88.2% males, 69.1% females) on the right and left respectively. This possibly implies that in the presence of all the digits of the hand, sex can be determined with a greater accuracy compared to the use of a single digit or single phalanx.

The population discrepancies in the accuracy of using the digit and phalangeal lengths in sex determination could be attributed to the differences in the sample size, sex distribution of participants, statistical method used (DFA verses logistic regression) and misclassification of males with reduced dimensions or females with robust bones due to strong musculature [5,8]. The methodology used to measure the lengths vary in different studies based on modality used (CT, radiographs or sliding callipers) or the landmarks used (base and apices of bones versus phalangeal ridges) [5]. Factors such as genetics, body build, race, secular and social factors may also contribute to the variances in accuracy [8]. The differences between the accuracies obtained from the left and right metric parameters of the hands are associated with their varying physical activities attributable to hand dominance [14]. From these variations, equations for sex determination should be developed for each sex group of a population. Furthermore, the equations should be population specific to increase their accuracy.

Conclusion

This study has shown that the phalanges of the hands could be used to aid in sex determination in our studied population.

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