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Adult Sex Discrimination Using Metric Measurements of Hand Digital Radiographs in Egyptian Population

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Abstract

Objective: The aim of the present study is to discriminate functions for sex determination in a subjected sample of the Egyptian population using the morphology of metacarpals and phalanges for gender comparison. Furthermore, the measurements discussed in this study will aid in predicting the differentiation independently and guaranteeing sex determination in the subjected population individually. **Methods:** Forty measurements were taken from the right metacarpals and phalangeal bones of 100 subjects, whose ages ranged from 19 to 60. Moreover, the measurements of nine metacarpals and four phalangeal bones were used for sex discrimination in each sample population. **Results:** Males had significantly greater mean values ($P < 0.05$) for the lengths of the metacarpals and the proximal phalangeal bones of all right-hand fingers than females. The cut-off value and the accuracy percentage for precise sex classification of males and females using individual and grouped bones showed that a value higher than the marking point classified an individual as male and that a lower value suggested female. Besides, the multiple stepwise discriminant functional analysis of the most predictable internal variables of the metacarpals revealed a cross-validated sex classification accuracy of 100%. In contrast, the most predictable internal variables of the phalanges showed a cross-validated sex classification accuracy of 93%. **Conclusion:** The results revealed a new forensic suggestion for the determination of sex based on the measurements of the metacarpals and the phalanges. Moreover, various discriminant equations were applied for the declaration of this conceivable recommendation.

Keywords

Sex Discrimination, Metacarpals, Phalanges, Osteometric Measurements

1. Introduction

The identification of the sex of an unknown cadaver is relatively simple when performed on fresh and complete bodies. However, crime scenes frequently contain incomplete, mutilated, or dismembered cadavers exposed to animal scavengers, fires, and various other environmental conditions that hinder the identification process, for example, completely burnt or dismembered human remains with somewhat exposed skeletons during a mass disaster [1].

Human bones can provide a biological profile that includes the deceased's race, sex, age, and stature. These data can significantly narrow down the possible matching identities. Following ancestry recognition, biological sex determination is one of the first steps performed to identify an individual. This is a primary step, as the standards of age and stature are highly sex-specific [2].

The basis of sex estimation is sexual dimorphism, which is the physical and behavioral difference between males and females. Bone growth is influenced by a combination of genetic markers and hormone exposure. During puberty, differences in the shape, size, and appearance of bones emerge in the sexes as a result of individual genetics and sex hormone production. Several population-specific genetic and environmental factors govern the age at which these skeletal morphological changes occur. Therefore, sex estimation standards must be population-specific, as the degree of sexual dimorphism and the age at which it occurs differs between populations [3].

Three approaches can be used to identify sex: morphologic methods, osteometric measurements, and DNA analysis. Each of these methods has particular restrictions. The disadvantages of the morphologic methods are their subjectivity and deficiency of statistical analysis, while the osteometric measurements have the crucial limitation of population specificity. On the other hand, the limitations of DNA analysis are contamination, inhibition, and degradation, as well as higher cost and workload. Moreover, amelogenin analysis, part of the Combined DNA Index System (CODIS), can also mistake an individual's sex. In recent times, it has been observed that collecting data from well-documented physical and virtual osteological studies using radiographic pictures of individuals with a known biological profile improves both the morphologic and osteometric approaches [4] [5].

To use standard osteometric measurements in cases where the integrity of the cadaver has been compromised, maceration is required. However, maceration of the retrieved remains is considered an arduous process in the case of mass disasters due to the workload and the time restraints. An alternative way is the use of image processing techniques (e.g., radiography and computed tomography) rather than actual bones. These radiographs permit the identification of semi-fleshed bodies without the need for maceration, thus speeding up and facilitating forensic investigation. Lately, digital radiographs of the femur and humerus have been employed for sex estimation with a high degree of accuracy, up to 93% [1].

The preferred and most reliable bone for sex estimation is the pelvis, as it is highly sexually dimorphic. However, it is a fragile bone and is often exposed to damage. Therefore, recent studies have worked towards the sex estimation potential of other skeletal remains such as the sternum [6], humerus [7], femur [8], metatarsals [9], and metacarpals [10].

With particular reference to the hand, the application of skeletal standards for metacarpals and phalanges formulated for one population are less reliable when used on another. Thus, population-specific standards are crucial for the interpretation of sex from hands [11].

The current study is aimed to discriminate functions for sex determination in a subjected sample of the Egyptian population using the morphology of metacarpals and phalanges for gender comparison. At the same time, further measurements will aid in predicting the differentiation independently and guaranteeing sex determination in the subjected population individually.

2. Subjects and Methods

2.1. Technical Design

The sample comprised 100 posterior-anterior (PA) digital radiographs acquired from the radiology department of Zagazig University Hospitals. The right hands of 50 adult males and 50 adult females from Sharkia Governorate were examined with the inclusion criteria of age ranging from ≥19 to 60 years. The exclusion criteria were age being <19 or >60 years, presence of hand fracture or fixation, known congenital or acquired skeletal diseases, hand trauma, metacarpal fracture, bone malformation, or bone tumor. Assuming that means the first metacarpal medullary length (MC ML) in males is 4.54 versus 4.1 in females at 95% CI and effect size = 1, the estimated sample will be 100 subjects using Open epi. This work was carried on for six months in the Department of Forensic Medicine and Clinical Toxicology, Faculty of Medicine at Zagazig University, and the Radiology Department in Zagazig University Hospitals, Sharkia Governorate, Egypt.

2.2. Ethical Approval

Approval for the study was obtained from the Department of Forensic Medicine and Clinical Toxicology and the Institutional Review Board (IRB), Faculty of Medicine, Zagazig University (ZU-IRB 9278/7-2-2022).

2.3. Methods

2.3.1. X-Ray Hand Radiograph (Cross-Sectional Study)

The standardized protocol for acquiring the hand-wrist X-rays was as follows: Focus Receptor Distance (FRD) = 100 cm; Focus Object Distance (FOD) ~98 cm; Object Receptor Distance (ORD) ~2 cm, with the resultant magnification standardized at ≤2, which is generally less than the variation introduced by intra-observer measurement precision.

Only radiographs that showed little or complete absence of skeletal trauma

and anomalies in the metacarpals and proximal phalanges were included. Under standard research ethics requirements and the inherent constraints of using medical data, the radiographs received were anonymized, and only the age and sex information of each individual was retained. The participants also filled in an informed consent form.

2.3.2. Measurements from Digital Radiographs

The 40 linear measurements used in this study follow previously published definitions adapted by DeSilva *et al.* [3] for 2D images. Four measurements were acquired for each metacarpal (MC) and proximal phalanx (Ph): length superior (LS), medullary length (ML), mid-bone length (MB), and length of the base (LB). The OsiriX1 line-tool function was used to define the linear measurements (in millimetres) (Figure 1 and Figure 2).

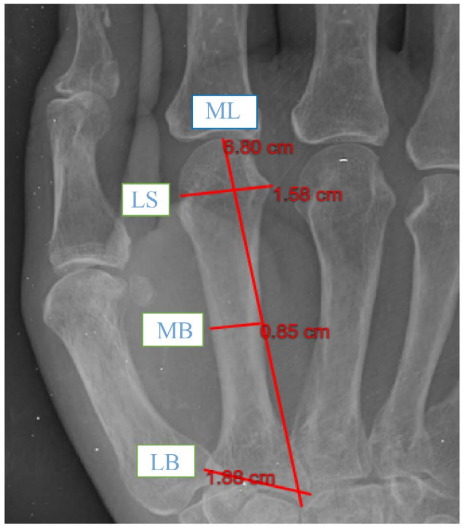

Figure 1. Radiograph of an adult male right hand showing measurement taken from second metacarpal bone.

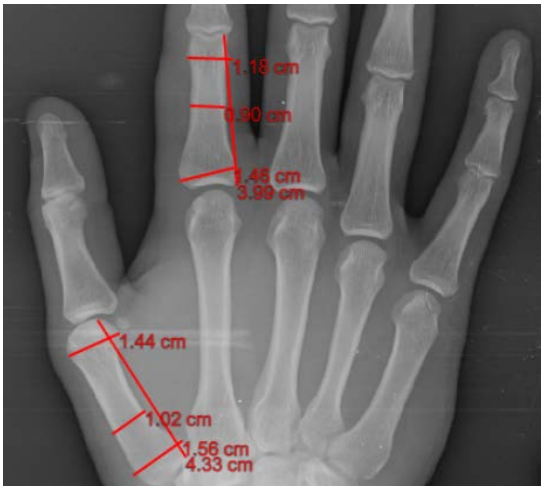

Figure 2. Radiograph of an adult female right hand showing measurement taken from first metacarpal bone and proximal phalanx of the index.

3. Statistical Analysis

All data were collected, tabulated, and statistically analyzed using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA). Quantitative data were expressed as the mean ± SD and median (range); qualitative data were expressed as absolute frequencies (number) and relative frequencies (percentage). Finally, the independent samples Student's t-test was used to compare the two groups of normally distributed variables.

4. Results

4.1. Demographic Data of the Studied Group

The mean age of the assessed participants between 19 and 60 years old was 36.98 ± 10.84 years. There was no significant difference in the mean value of age between males and females (Table 1 and Table 2).

4.2. Sex Estimation of Metacarpal and Phalangeal Parameters

The descriptive statistics of different internal parameters and the independent samples t-test of the metacarpals and phalanges among all the cases revealed a highly significant increase in males' parameters compared with females ($P < 0.001$), as shown in (Table 3 and Table 4).

4.3. Sex Determination Depending on Cut-Off and Accuracy Levels

The cut-off value-defined-sex classification for males and females in individual and grouped bones showed that values higher than the marking point belonged

Table 1. Age and sex distribution among studied group (n = 100).

		Age (years)	
Mean ± SD		36.98 ± 10.84	
Median (range)		36 (19 - 60)	
		No.	**%**
Sex	**Male**	50	50.0
	Female	50	50.0
	Total	100	100.0

SD: standard deviation; %: percent.

Table 2. Statistical comparison between male and female as regard mean value of age using student t-test.

	Male (n = 50)	**Female (n = 50)**	**t**	**P-value**
	Mean ± SD			
Age	38.00 ± 11.05	35.96 ± 10.63	0.941	0.349 NS

NS: non-significant ($P > 0.05$); SD: standard deviation.

Table 3. Statistical comparison between male and female regarding mean values of metacarpal parameters using t-test.

	Male (n = 50)	Female (n = 50)	t	P-value
	Mean ± SD			
1st MC ML	4.54 ± 0.35	4.10 ± 0.35	6.230	0.001**
1st MC LS	1.45 ± 0.12	1.26 ± 0.13	7.603	0.001**
1st MC LB	1.46 ± 0.06	1.28 ± 0.16	7.287	0.001**
1st MC MB	0.91 ± 0.13	0.78 ± 0.12	5.276	0.001**
2nd MC ML	6.85 ± 0.36	6.48 ± 0.45	4.483	0.001**
2nd MC LS	1.44 ± 0.11	1.33 ± 0.21	3.336	0.001**
2nd MC LB	1.65 ± 0.14	1.53 ± 0.15	4.161	0.001**
2nd MC MB	0.89 ± 0.09	0.72 ± 0.07	10.642	0.001**
3rd MC ML	6.65 ± 0.48	6.03 ± 0.48	6.475	0.001**
3rd MC LS	1.47 ± 0.11	1.23 ± 0.15	9.239	0.001**
3rd MC LB	1.28 ± 0.09	1.11 ± 0.11	8.321	0.001**
3rd MC MB	1.02 ± 0.76	0.73 ± 0.08	2.721	0.001**
4th MC ML	5.74 ± 0.45	5.26 ± 0.45	5.329	0.001**
4th MC LS	1.24 ± 0.11	1.05 ± 0.11	8.815	0.001**
4th MC LB	1.19 ± 0.12	1.02 ± 0.11	7.206	0.001**
4th MC MB	0.73 ± 0.09	0.65 ± 0.10	3.828	0.001**
5th MC ML	5.30 ± 0.37	4.79 ± 0.36	6.941	0.001**
5th MC LS	1.11 ± 0.14	1.01 ± 0.11	4.149	0.001**
5th MC LB	1.29 ± 0.10	1.11 ± 0.12	7.806	0.001**
5th MC MB	0.82 ± 0.09	0.63 ± 0.05	12.127	0.001**

t: student t-test; **: statistically highly significant (P < 0.001).

Table 4. Statistical comparison between male and female regarding mean values of phalangeal parameters using t-test.

	Male (n = 50)	Female(n = 50)	t	P-value
	Mean ± SD			
1st Ph. ML	3.09 ± 0.29	2.69 ± 0.11	9.100	0.001**
1st Ph. LS	1.03 ± 0.25	0.91 ± 0.09	3.063	0.001**
1st Ph. LB	1.37 ± 0.15	1.18 ± 0.07	8.210	0.001**
1st Ph. MB	0.86 ± 0.16	0.69 ± 0.08	6.256	0.001**
2nd Ph. ML	4.02 ± 0.26	3.65 ± 0.22	7.629	0.001**
2nd Ph. LS	1.12 ± 0.12	0.99 ± 0.07	6.545	0.001**

Continued

2nd Ph. LB	1.62 ± 0.08	1.43 ± 0.08	11.942	0.001**
2nd Ph. MB	0.95 ± 0.17	0.79 ± 0.08	8.229	0.001**
3rd Ph. ML	4.52 ± 0.29	4.03 ± 0.23	9.277	0.001**
3rd Ph. LS	1.19 ± 0.12	1.02 ± 0.08	8.123	0.001**
3rd Ph. LB	1.52 ± 0.08	1.36 ± 0.10	8.490	0.001**
3rd Ph. MB	0.96 ± 0.12	0.84 ± 0.09	5.975	0.001**
4th Ph. ML	4.21 ± 0.29	3.78 ± 0.21	8.541	0.001**
4th Ph. LS	1.05 ± 0.097	0.96 ± 0.06	5.814	0.001**
4th Ph. LB	1.38 ± 0.10	1.19 ± 0.10	9.571	0.001**
4th Ph. MB	0.85 ± 0.11	0.78 ± 0.09	3.412	0.001**
5th Ph. ML	3.28 ± 0.19	2.89 ± 0.13	12.116	0.001**
5th Ph. LS	0.88 ± 0.12	0.77 ± 0.07	5.390	0.001**
5th Ph. LB	1.29 ± 0.09	1.13 ± 0.08	8.815	0.001**
5th Ph. MB	0.77 ± 0.12	0.66 ± 0.08	5.623	0.001**

t: student t-test; **: statistically highly significant (P < 0.001).

to males and that lower values suggested females. Additionally, sex prediction using the metacarpals and phalanges' internal measurements revealed that the most sexually dimorphic individual measurements yielded the highest expected sex classification accuracy. The accuracy of the first MC LB, second MC MB, third MC LS, fifth MC MB, first Ph. ML, first Ph. LB, second Ph. LB, third Ph. ML, third Ph. LB, and fifth Ph. ML were 84%, 84%, 84%, 80.5%, 85%, 85%, 88%, 85%, 84%, and 89% respectively (Table 5 and Table 6; Figure 3).

4.4. Sex Determination throughout the Stepwise Discriminant Analysis

Regarding multiple stepwise discriminant functional analysis, nine metacarpal and four phalangeal measurements were selected, and the most predictable internal variables of the metacarpals (first MCLB, second MCMB, third MCLS, third MCLB, third MCMB, fourth MCML, fourth MCLB, fifth MCLS, and fifth MCMB) showed a cross-validated sex classification accuracy of 100% (Table 7). However, the most predictable internal variables of the phalanges (second Ph. LB, fourth Ph. LB, fourth Ph. MB, and fifth Ph. ML) showed a cross-validated sex classification accuracy of 93% (Table 8).

Moreover, the sex can be predicted from the equation provided below. If the value of −15.395 + 3.153 * first MCLB + 7.364 * second MCMB + 3.952 * third MCLS + 3.878 * third MCLB + 1.014 * third MCMB + (−1.119) * fourth MCML + (−2.992) * fourth MCLB + (−4.745) * fifth MCLS + 12.147 * fifth MCMB is ≥0.0, it predicts that the hand belonged to a male. However, if the value is below

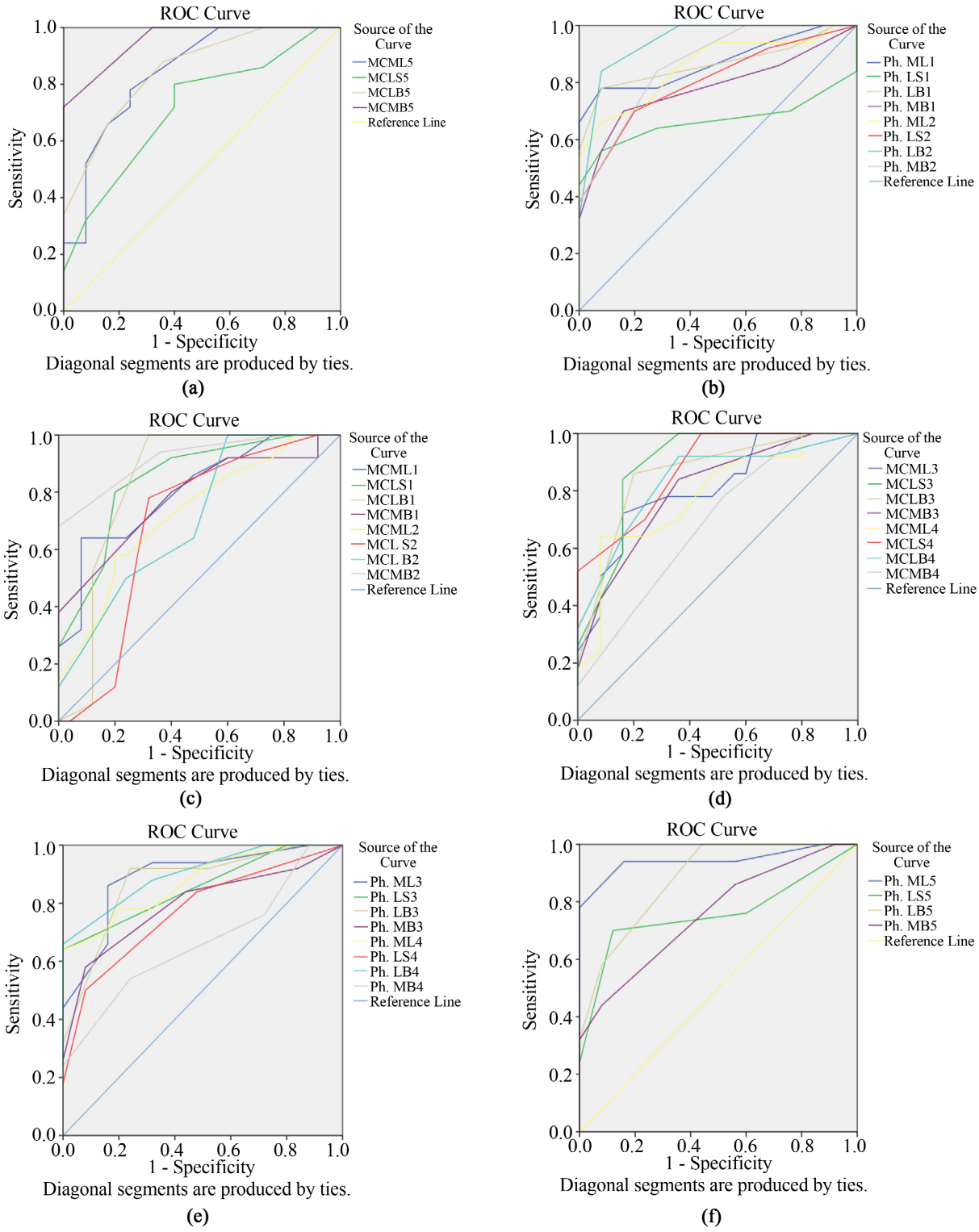

Figure 3. Roc curve showing diagnostic performance of (a) 1st MC ML, 1st MC LS, 1st MC LB, 1st MC MB, 2nd MC ML, 2nd MC LS, 2nd MC LB, and 2nd MC MB in the diagnosis of sex. (b) 3rd MC ML, 3rd MC LS, 3rd MC LB, 3rd MC MB, 4th MC ML, 4th MC LS, 4th MC LB, and 4th MC MB in the diagnosis of sex. (c) 5th MC ML, 5th MC LS, 5th MC LB, and 5th MC MB in the diagnosis of sex. (d) 1st Ph. ML, 1st Ph. LS, 1st Ph. LB, 1st Ph. MB, 2nd Ph. ML, 2nd Ph. LS, 2nd Ph. LB, and 2nd Ph. MB in the diagnosis of sex. (e) 3rd Ph. ML, 3rd Ph. LS, 3rd Ph. LB, 3rd Ph. MB, 4th Ph. ML, 4th Ph. LS, 4th Ph. LB, and 4th Ph. MB in the diagnosis of sex. (f) 5th Ph. ML, 5th Ph. LS, 5th Ph. LB, and 5th Ph. MB in the diagnosis of sex.

Table 5. Area under curve (AUC), cut-off and accuracy of metacarpal parameters to determine sex.

Variables	AUC	Cut off value	Studied group (n = 100)		True diagnose cases	Accuracy %
			Male (n = 50)	Female (n = 50)		
1st MC ML	0.804	>4.15 <4.15	43 7	24 26	43 + 26	69
1st MC LS	0.845	>1.25 <1.25	46 4	20 30	46 + 30	76
1st MC LB	0.836	>1.35 <1.35	50 0	16 34	50 + 34	84
1st MC MB	0.782	>0.85 <0.85	40 10	20 30	40 + 30	70
2nd MC ML	0.724	>6.65 <6.65	36 14	20 30	36 + 30	66
2nd MC LS	0.686	>1.35 <1.35	39 11	16 34	39 + 34	73
2nd MC LB	0.709	>1.55 <1.55	32 18	24 26	32 + 26	58
2nd MC MB	0.918	>0.85 <0.85	34 16	0 50	34 + 50	84
3rd MC ML	0.809	>6.4 <6.4	36 14	8 42	36 + 42	78
3rd MC LS	0.891	>1.35 <1.35	42 8	8 42	42 + 42	84
3rd MC LB	0.860	>1.25 <1.25	36 14	8 42	36 + 42	78
3rd MC MB	0.802	>0.75 <0.75	42 8	18 32	42 + 32	74
4th MC ML	0.784	>5.55 <5.55	32 18	12 38	32 + 38	70
4th MC LS	0.876	>1.15 <1.15	35 15	12 38	35 + 38	73
4th MC LB	0.834	>1.05 <1.05	46 4	18 32	46 + 32	78
4th MC MB	0.685	>0.65 <0.65	39 11	26 24	39 + 24	63
5th MC ML	0.846	>4.95 <4.95	39 11	12 38	39 + 38	77
5th MC LS	0.716	>1.01 <1.01	40 10	20 30	40 + 30	70
5th MC LB	0.852	>1.15 <1.15	44 6	18 32	44 + 32	76
5th MC MB	0.955	>0.75 <0.75	36 14	0 50	36 + 50	86

%: percent; Accuracy: true detected males + true detect females/total studied * 100.

Table 6. Area under curve (AUC), cut-off and accuracy of phalangeal parameters to determine sex.

Variables	AUC	Cut off value	Studied group (n = 100)		True diagnose cases	Accuracy %
			Male (n = 50)	Female (n = 50)		
1st Ph. ML	0.872	>2.85 <2.85	39 11	4 46	39 + 46	85
1st Ph. LS	0.666	>0.95 <0.95	32 18	14 36	32 + 36	68
1st Ph. LB	0.865	>1.25 <1.25	39 11	4 46	39 + 46	85
1st Ph. MB	0.783	>0.75 <0.75	35 15	8 42	35 + 42	77
2nd Ph. ML	0.857	>3.85 <3.85	36 14	12 38	36 + 38	74
2nd Ph. LS	0.804	>1.05 <1.05	35 15	10 40	35 + 40	75
2nd Ph. LB	0.944	>1.55 <1.55	42 8	4 46	42 + 46	88
2nd Ph. MB	0.865	>0.85 <0.85	42 8	14 36	42 + 36	78
3rd Ph. ML	0.889	>4.15 <4.15	43 7	8 42	43 + 42	85
3rd Ph. LS	0.857	>1.05 <1.05	42 8	22 28	42 + 28	70
3rd Ph. LB	0.874	>1.45 <1.45	46 4	12 38	46 + 38	84
3rd Ph. MB	0.795	>0.85 <0.85	42 8	22 28	42 + 28	70
4th Ph. ML	0.874	>3.95 <3.95	39 11	10 40	39 + 40	79
4th Ph. LS	0.774	>0.95 <0.95	42 8	24 26	42 + 26	68
4th Ph. LB	0.902	>1.25 <1.25	44 6	16 34	44 + 34	78
4th Ph. MB	0.666	>0.85 <0.85	27 23	12 38	27 + 38	65
5th Ph. ML	0.944	>3.05 <3.05	47 3	8 42	47 + 42	89
5th Ph. LS	0.759	>0.85 <0.85	35 15	6 44	35 + 44	79
5th Ph. LB	0.880	>1.25 <1.25	29 21	4 46	29 + 46	75
5th Ph. MB	0.757	>0.65 <0.65	43 7	28 22	43 + 22	65

%: percent; Accuracy: true detected males + true detect females/total studied * 100.

Table 7. Stepwise discriminant analysis of metacarpal parameters to detect sex.

	Canonical Discriminant Function Coefficients						
	Unstandardized	**Standardized**	**Wilks' Lambda**	**Functions at Group Centroids**	**Sectioning point**	**Accuracy**	**Sex bias**
1st MCLB	3.153	0.385					
2nd MCMB	7.364	0.595					
3rd MCLS	3.952	0.526					
3rd MCLB	3.878	0.396		**Male** = 2.264			
3rd MCMB	1.014	0.552	**0.161**		**0.0**	**100 %**	**0%**
4th MCML	−1.119	−0.504					
4th MCLB	−2.992	−0.345					
5th MCLS	−4.745	−0.581		**Female** = −2.264			
5th MCMB	12.147	0.942					
constant	−15.395						

%: percent.

Table 8. Stepwise discriminant analysis of phalangeal parameters to detect sex.

	Canonical Discriminant Function Coefficients						
	Unstandardized	**Standardized**	**Wilks' Lambda**	**Functions at Group Centroids**	**Sectioning point**	**Accuracy %**	**Sex bias**
2nd Ph. LB	6.069	0.493		**Male = 1.777**			
4th Ph. LB	5.395	0.547	**0.237**		**0.0**	**93**	**2%**
4th Ph. MB	−4.618	−0.474		**Female = −1.777**			
5th Ph. ML	4.240	0.682					
constant	−25.477						

%: percent.

0.0, it is concluded that the hand belonged to a female. The accuracy of this calculation when considering the metacarpal parameters is 100%.

Additionally, concerning phalangeal parameters, sex can be predicted from the equation provided below. If the value of 25.477 + 6.069 * second Ph. LB + 5.395 * fourth Ph. LB + (−4.618) * fourth Ph. MB + 4.240 * fifth Ph. ML is ≥0.0, the hand mostly belonged to a male. However, a lower value concludes that the hand belonged to a female. The accuracy of both the findings is 93%.

5. Discussion

The anthropometric forensic method serves as a beneficial tool, since it avoids the unnecessary expense of time and effort when confirming the identity of the victims where only a few parts of the body are available. Accordingly, it has been

broadly used for determining the identity of victims in natural disasters and terrorist attacks [12].

Sexual diagnosis is the most vital component when creating a biological profile in the field of forensic anthropology. The ability to determine sex from isolated bones or bone fragments is a vital requirement in medicolegal investigations. However, the pelvis and cranium, the most favourable bones for these determinations, are not always accessible [13] [14] [15].

Throughout the process of establishing the identity of an individual, certain complications exist. These include the bodies being in an advanced state of putrefaction, with only mutilated and fragmented parts remaining. In such cases, it is common to recover dismembered and peripheral parts of the body. Consequently, it was found that anthropometric measurements of the hand are appropriate and suitable for sexual identification [16], with the metacarpals and phalanges being potential bones used for sex determination in forensic science as these bones are more durable than other bones. Radiologic measurements are an optimal alternative to population studies where well-protected cadavers are limited or unavailable [17].

The results of the current study revealed that the mean values of male measurements shown throughout the digital hand radiographs were significantly greater than those of females. There was a non-significant difference in the mean values of age between males and females (**Table 1** and **Table 2**). The right hand was used in this study in the determination of sex in the Egyptian population sample, and non-significant differences were seen between the right and left hands in both males and females, as conferred and matched by El-Morsi and Al-Hawary [18]. This hypothesis also aligned with Manolis *et al.* [19], who concluded that there were no statistically significant differences between the left and right mean values in their study. Moreover, Barrio *et al.* [20] reported, assured, and declared this fact and stated that both right and left sides did not exceed the limits of statistical significance. Furthermore, no significant differences were recorded with respect to cortical thickness for either hand due to the functional handedness of one of them. Increased metacarpal bone strength was observed without increased cortical thickness.

The results of this study showed that the base, head, and mid-shaft width measurements of all ten bones exhibited different levels of sexual dimorphism among these groups. Additionally, the length of all metacarpals and phalanges disclosed statistically significant differences ($P < 0.001$) between males and females in the Egyptian population samples (**Table 3** and **Table 4**). Males had longer metacarpals and phalanges than females, as expected. This aligns with the previous findings of Ameri *et al.* [21], who revealed that both metacarpals and proximal phalanges might be ideal for sex determination.

In addition, these findings align with Alicioglu *et al.* [13], who disclosed in their study that the metacarpals play an essential role in sexual dimorphism with regard to osteometric and geometric characteristics, which can be attributed to the racial and population variances between males and females. Furthermore,

males and females perform different things to various degrees. Correspondingly, these findings were also parallel to those of Kanchan *et al.* [22], who reported that the cortical thickness from all quadrants was more in males than females even after covariate alteration of the body size. This may be explained by the cortical bone in males that has a higher growth in them when compared to females. Furthermore, the findings of this study also align with that of Krishan and Kanchan [23], who conducted independent samples t-test for males and females trials and exhibited that there was a significant difference between male and female metacarpals in both the first and third proximal phalanges.

Conclusively, the results of the present study harmonize with the research outcomes by Mohamed *et al.* [12], who affirmed that the cortical width of the third metacarpal is greater in male subjects than the females throughout, right from infancy up to 70 years. Additionally, Torres *et al.* and Morgan *et al.* discovered that changes in cortical thickness are greater in males than females as they grow older due to many differences, including the physiological and hormonal ones along with skeletal variances [24] [25].

Controversially, our findings presented in this study (**Table 3** and **Table 4**) were in contrast with the results mentioned by Mohamed *et al.* [12], who measured the cortical and total widths of the third metacarpal on the X-ray from 629 volunteers and observed that there was no significant difference between the total metacarpal diameters and the cortical widths of male and female subjects.

Concerning the metacarpal bones, our findings were concurrent with the findings of Manolis *et al.* [19], in Athens and McFadden and Bracht in the USA, who affirmed that male metacarpals were longer than those of females. Besides, McFadden and Bracht [26], mentioned that the order of metacarpals by length from the longest to the shortest was 2 > 3 > 4 > 5 > 1 (**Table 3**). Regarding the ordering of proximal phalanges, the existing results were similar to Garrido and Thompson [27], who assured that the length order of proximal phalanges was 3 > 4 > 2 > 5 > 1 (**Table 4**).

Moreover, the discriminant function analysis of the metacarpals and proximal phalanges displays sexual dimorphism. This is supported by the research results of Eshak *et al.* [28], who revealed that the volumes of the second and fourth metacarpal bones, showed a significant difference between males and females, indicating the presence of significant sexual dimorphism in the hand measurements of Egyptian people. Furthermore, they explained that alterations in body size between both sexes were due to men and women performing dissimilar things to different degrees. Male metacarpals having larger dimensions than female ones, could be the mechanical response of the bones to the greater muscular demand of males.

Additionally, Alicioglu *et al.* [13], achieved 74% - 94% accuracy in the correct determination of sex through metacarpals and the first phalanx of British whites, and the first metacarpal was found to give the highest degree of accuracy in identifying sex. However, this contradicts the findings of this study, which proved that the first metacarpals' LB, second metacarpals' MB, third metacar-

pals' LS, and fifth metacarpals' MB have the highest accuracy compared to the other metacarpal' measurements (Table 5).

Similarly, the second phalangeal LB and the fifth phalangeal ML were more accurate for sex identification (Table 6). The outcome of this study is correlative with the study of Karakostis *et al.* [29], who assessed the utility of proximal hand phalanges for sex diagnosis and developed a discriminant formula to be applied to modern Greek populations. The material utilized consists of 661 proximal hand phalanges from the Athens Collection, corresponding to 160 adult individuals. Classification accuracies ranged from 94.6% to 100% for left and 87.7% to 100% for right proximal phalanges. The results of this study indicate that proximal hand phalanges can be used for accurate sex diagnosis.

In this study, the stepwise discriminant analysis of the metacarpal and phalangeal parameters ascertained that the metacarpals are better for sex determination than the phalanges, with the accuracy of metacarpals being 100% and that of phalanges being 93% (Table 7 and Table 8). These findings are in line with those of Habib and Kamal [30], who clarified that the metacarpals are favoured over other hand bones because of their size and easy identifiability. The findings also harmonize with data shown by Eshak *et al.* [28], who affirmed that the metacarpal length and the length of the first and the third proximal phalanges are the best three variables that can be used together for correct sex determination with a percentage accuracy of 90%, which is the same result obtained by the three linear measurements together.

Moreover, the average values of the total variables (the maximum length and the anteroposterior and transverse widths of the head and base) analyzed in metacarpals and phalanges displayed those male measurements were higher than that of females. These cut-off points may be used as fairly reliable support for sexual estimation (a priori 64% - 83% of correct classification) when bone fragments are involved [30].

Finally, our results revealed that additional research should be further in this area and shed attention to the potential concerning applying these suggestions to forensic contexts wherever the bony elements may be found isolated or fragmented, is not limited, since its application from the univariate analysis provides the opportunity to obtain results above 80% of firmness.

6. Conclusion

Finally, the finding of this study presents a series of mathematical models that allow the sex of an individual to be diagnosed from their metacarpals, even if fragmented or partial. The equations obtained yielded acceptable results for the Egyptian population, and they can be readily applied in the absence of other bone structures.

Conflicts of Interest

The authors declare that they have no conflicts of interest to disclose.

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