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SEX DETERMINATION USING PROXIMAL HAND PHALANGES

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ABSTRACT

Sex determination is among the most important biological data to be obtained from human skeletal remains. In anthropological sciences, the applied methodology involves the analysis of the quantitative and qualitative characteristics of skeletal parts. Measurements of proximal hand phalanges have been shown to exhibit prominent sexual dimorphism, in different populations examined. The aim of this study is to assess the utility of proximal hand phalanges for the sex diagnosis and develop a discriminant formula to be applied to Modern Greek populations. The material utilized consists of 661 proximal hand phalanges (left and right) from the Athens Collection, corresponding to 160 adult individuals (86 males and 74 females). Classification accuracies ranged between 94.6% and 100% for left and between 87.7% and 100% for right proximal phalanges. The results of this study indicate that proximal hand phalanges can be used for accurate sex diagnosis.

Keywords: *forensic anthropology, sex determination, hand phalanges, Athens collection*

INTRODUCTION

In anthropological sciences, the term "sexual dimorphism" (SD) refers to the phenotypic differences between the bones of males and females of the same species. The fundamental importance of studying SD lies in the necessity

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of developing accurate methods for assessing sex from skeletal remains [1]. Indeed, the bibliography provides a plethora of publications on the development and appliance of sex diagnostic methods using pelvic and cranial features [2]. Recently, however, there is a growing trend towards sex determination from various parts of the skeleton, including hand bones, such as proximal phalanges [3–6].

Consequently, small bones are considered useful for sex assessment. That is often explained by their increased quantity in the field as well as by their small amount of external surface exposed to taphonomic alterations [7]. As a result, they could contribute to sex diagnosis of poorly preserved human remains. In forensic anthropology, they could assist in personal identification of decomposing or skeletonized bodies, while, in bioarchaeology, they could contribute to a more precise reconstruction of the demographic profile [4].

In the case of the skeletal remains recovered from different locations of Greece, bones have often been subjected to marked seasonal fluctuation as well as particular soil conditions (e.g. soil acidity). As a result, they are often found in a fragmentary state [8]. Therefore, the development of the sex determining methods using small and intact hand bones is of a great utility when analyzing skeletal remains from Greece. It is evident that hand phalanges consist of small, dense, and compact bones, with a small external surface. Thus, they are often found well-preserved [9].

Considering that the degree of SD differs among population groups, mathematical equations for sex diagnosis should be developed separately for each group. In fact, it is considered important to develop population-specific sex assessing methods for each anatomical part of the skeleton [10].

A recently conducted research utilized the biometric data of proximal hand phalanges for the purpose of quantifying SD from a Greek population sample [11]. Taking into consideration the bibliographical gap of similar research on proximal hand phalanges from Greece, the aim of this article is to assess the sex-determining ability of the data presented in this previous study.

MATERIAL AND METHODS

The material used in this study consists of 160 documented adult skeletons (86 males and 74 females) from the Athens collection, exhumed from two cemeteries in the greater area of the city of Athens [12]. According to their profile, the deceased individuals originated from various regions of Greece and were mainly of a lower or middle socioeconomic status. The mean age for males is 58.49 years (range: 19–96 years) and for females is 59.12 (range: 20–99 years) [11]. Only the

41.31% of the expected specimens (661) were available for this study due to the fact that in most skeletons there were left and right proximal hand phalanges that were either missing or extensively damaged.

A total of seven measurements was taken on each bone, including the maximum length of the shaft (ML) and the antero-posterior and medio-lateral widths at the base (APWB and MLWB), the midshaft (APWM and MLWM), and the head (APWH and MLWH) [3, 6, 13, 14]. However, several proximal hand phalanges exhibited the dimensions that were either damaged or pathologically altered. In these cases, only the intact dimensions of the bones were measured and included in the analysis.

In a previous study, a Student's independent samples t-test was run to quantify SD [11]. The authors of this study found that all variables presented a statistically significant degree of SD. In the present research, for the purpose of deriving sex assigning equations, stepwise discriminant function analysis (SDFA) was performed for each left and right proximal hand phalanx, using the IBM SPSS Statistics (IBM Inc., version 20 for Windows) software package. All seven measurements taken were utilized as independent variables. The SDFA was performed for the selection of the best-discriminating variables between males and females (Wilk's lambda). Left and right proximal hand phalanges were studied separately, due to the bilaterally asymmetrical SD reported in this sample [11]. Besides, bilateral asymmetry in proximal hand phalanges has been reported [14].

For this reason, twenty discriminant functions were used (Table 1). These functions were developed, in order to suggest sex assessing equations in the cases where a possible skeletal assemblage is incomplete (e.g. the presence of only the first proximal hand phalanx or fragments of several phalanges). Due to the fact that SDFA requires complete sets of data, each function analysis was carried out using individuals without missing values in the variables involved. Consequently, given that some phalanges (or phalangeal parts) were missing or not measurable, the number of individuals utilized varies among functions (Table 3).

Finally, a "leave one out classification" procedure was applied for the purpose of quantifying the accuracy rate of the original sample, as well as of the sample created by cross-validation [15].

Table 1. Stepwise discriminant function analysis of hand proximal phalanges (left and right)[a]

Steps and variables entered	Wilks' lambda statistic	Exact F statistic	d.f. 1	d.f. 2	Sig.
Function 1: All left hand proximal phalanges					
APWB 3rd	0.172	127.773	2	53.000	0.000
MLWH 1st	0.148	99.474	3	52.000	0.000
APWM 1st	0.126	888.139	4	51.000	0.000
MLWH 4th	0.115	77.102	5	50.000	0.000
MLWB 1st	0.105	69.426	6	49.000	0.000
MLWH 3rd	0.097	75.698	6	49.000	0.000
MLWM 2nd	0.089	70.187	7	48.000	0.000
MLWB 4th	0.080	67.367	8	47.000	0.000
Function 2: All right hand proximal phalanges					
MLWB 5th	0.386	90.770	1	57.000	0.000
APWB 1st	0.247	85.427	2	56.000	0.000
MLWB 3rd	0.195	75.897	3	55.000	0.000
APWB 4th	0.178	62.199	4	54.000	0.000
Function 3: Left hand proximal phalanges of 1st ray					
MLWH 1st	0.339	138.522	1	71.000	0.000
APWM 1st	0.240	110.918	2	70.000	0.000
MLWM 1st	0.215	84.164	3	69.000	0.000
Function 4: Left hand proximal phalanges of 2nd ray					
MLWM 2nd	0.466	89.093	1	75.000	0.000
APWB 2nd	0.396	56.432	2	74.000	0.000
Function 5: Left hand proximal phalanges of 3rd ray					
APWB 3rd	0.386	152.602	1	96.000	0.000
MLWM 3rd	0.329	96.892	2	95.000	0.000
MLWH 3rd	0.311	69.393	3	94.000	0.000
Function 6: Left hand proximal phalanges of 4th ray					
MLWM 4th	0.520	83.866	1	91.000	0.000
APWB 4th	0.427	60.428	2	90.000	0.000

Steps and variables entered	Wilks' lambda statistic	Exact F statistic	d.f. 1	d.f. 2	Sig.
Function 7: Left hand proximal phalanges of 5th ray					
APWB 5th	0.766	20.120	1	66.000	0.000
Function 8: Maximum length measurements of left hand proximal phalanges					
ML 3rd	0.444	67.607	1	54.000	0.000
ML 1st	0.363	46.455	2	53.000	0.000
ML 4th	0.331	35.094	3	52.000	0.000
ML 5th	0.303	29.338	4	51.000	0.000
Function 9: Head measurements of left hand proximal phalanges					
MLWH 1st	0.286	134.697	1	54.000	0.000
MLWH 3rd	0.236	86.009	2	53.000	0.000
Function 10: Basis measurements of left hand proximal phalanges					
MLWB 3rd	0.318	115.739	1	54.000	0.000
APWB 3rd	0.262	74.510	2	53.000	0.000
MLWB 1st	0.230	58.038	3	52.000	0.000
MLWB 5th	0.211	47.687	4	51.000	0.000
Function 11: Midshaft measurements of left hand proximal phalanges					
MLWM 1st	0.254	158.388	1	54.000	0.000
APWM 1st	0.196	108.789	2	53.000	0.000
Function 12: Right hand proximal phalanges of 1st ray					
APWM 1st	0.411	107.495	1	75.000	0.000
ML 1st	0.339	72.089	2	74.000	0.000
Function 13: Right hand proximal phalanges of 2nd ray					
MLWB 2nd	0.603	50.034	1	76.000	0.000
APWB 2nd	0.573	27.987	2	75.000	0.000
Function 14: Right hand proximal phalanges of 3rd ray					
MLWB 3rd	0.468	100.006	1	88.000	0.000
APWB 3rd	0.415	61.326	2	87.000	0.000

Steps and variables entered	Wilks' lambda statistic	Exact F statistic	d.f. 1	d.f. 2	Sig.
Function 15: Right hand proximal phalanges of 4th ray					
MLWM 4th	0.383	122.689	1	76.000	0.000
ML 4th	0.314	82.073	2	75.000	0.000
APWB 4th	0.297	58.331	3	74.000	0.000
Function 16: Right hand proximal phalanges of 5th ray					
MLWB 5th	0.547	60.535	1	73.000	0.000
APWB 5th	0.499	36.188	2	72.000	0.000
Function 17: Maximum length measurements of right hand proximal phalanges					
ML 4th	0.493	58.550	1	57.000	0.000
ML 1st	0.371	47.518	2	56.000	0.000
Function 18: Head measurements of right hand proximal phalanges					
MLWH 4th	0.469	64.522	1	57.000	0.000
MLWH 1st	0.382	45.387	2	56.000	0.000
Function 19: Basis measurements of right hand proximal phalanges					
MLWB 5th	0.386	90.770	1	57.000	0.000
APWB 1st	0.247	85.427	2	56.000	0.000
MLWB 3rd	0.195	75.897	3	55.000	0.000
APWB 4th	0.178	62.199	4	54.000	0.000
Function 20: Midshaft measurements of right hand proximal phalanges					
APWM 1st	0.417	79.818	1	57.000	0.000
MLWM 4th	0.293	67.461	2	56.000	0.000
MLWM 5th	0.274	48.674	3	55.000	0.000

RESULTS

Table 1 shows the variables in each function that contributed to SDFA. Wilks' lambda is the criterion for variable selection. It is used to add or remove variables from the analysis. The p-value of Wilk's lambda was 0 in all cases, indicating a high degree of differentiation attribute of all the discriminant functions. The stepwise procedure is "guided" by the respective F to enter and F to remove

values. The F value for a variable indicates its statistical significance in the discrimination between groups, i.e. it is a measure of the extent to which a variable makes a unique contribution to the prediction of group membership [16].

A comparison between functions 1 and 2 – where all the left and the right proximal phalanges were tested respectively – showed that more variables entered in the analysis of the left phalanges. In the left proximal hand phalanges (function 1), the measurements of the medio-lateral width at the head, basis and midshaft entered more frequently in the discriminant analysis than those of the equivalent antero-posterior width. Most variables entered from the 1st proximal phalanges, followed by these of the 3rd and the 4th ray, with the APWB of the 3rd ray entered first in the SDFA. From the 5th ray, there were not any variables entered in the analysis. In the right proximal hand phalanges (function 2), only four of the variables entered in the SDFA and they all involved widths at the basis. Interestingly, the variable that entered first in the analysis is the MLWB of the 5th proximal phalanx.

In functions 3, 4, 5, 6, and 7, where each left proximal phalanx was tested separately, the variable MLWM contributed to all functions, with the exception of function 7. In function 7, where only measurements of the 5th ray were tested, the only variable entered was APWB. The APWB also contributed to all functions, with the exemption of function 3.

In ML of the left proximal hand phalanges (function 8), the variables of almost all rays were entered, except for the ML of the 2nd ray. In widths at the head, basis and midshaft of the left proximal phalanges (functions 9, 10, 11), the variables that contributed more to discriminant analysis involved the medio-lateral measurements.

In the right proximal hand phalanges (functions 12, 13, 14, 15, and 16), where each phalanx was tested separately, the variables that contributed most to discriminant analysis were the medio-lateral and antero-posterior measurements at the base. The ML of the proximal phalanx of the 1st and the 4th ray proved also important, contrary to the case of the equivalent proximal left phalanges. When ML and the widths at the head were tested separately (functions 17, 18), only the variables of the 1st and the 4th ray entered in the analysis. However, in functions 19 and 20, only measurements of the 2nd finger did not contribute to the analysis.

Table 2 depicts unstandardized coefficients, the structure matrix, standardized coefficients, group centroids, and the sectioning point, for each function. The standardized coefficient shows the contribution of the respective variable to the

discrimination between the two sexes. The structure matrix presents the correlations between the variables and discriminant functions. Group centroids are the mean discriminant score for each sex. These means can be used to determine the degree of separation between the two sexes. The sectioning point is the average of male and female group centroids. The unstandardized coefficient is used in the calculation of the discriminant function score (Y).

Table 2. Canonical discriminant function coefficients for hand left and right proximal phalanges' groups

Functions	Unstandardized coefficients[a]	Structure matrix[b]	Standardized coefficients	Group centroids		Sectioning point[c]
				Male	Female	
Function 1: All left hand proximal phalanges						
APWB 3rd	1.030	0.401	0.498	2.675	–4.134	–0.7295
MLWH 1st	1.904	0.466	1.123			
APWM 1st	2.926	0.429	1.010			
MLWH 4th	–0.900	0.189	–0.721			
MLWB 1st	–0.881	0.338	–0.681			
MLWH 3rd	–0.954	0.398	0.546			
MLWM 2nd	0.679	0.301	0.408			
MLWB 4th	–0.622	0.265	–0.494			
(constant)	–40.083					
Function 2: All right hand proximal phalanges						
MLWB 5th	0.682	0.588	0.404	2.005	–2.220	–0.1075
APWB 1st	0.676	0.558	0.583			
MLWB 3rd	0.531	0.513	0.465			
APWB 4th	0.695	0.567	0.349			
(constant)	–34.149					
Function 3: Left hand proximal phalanges of 1st ray						
MLWH 1st	0.886	0.730	0.577	1.667	–2.135	–0.234
APWM 1st	1.201	0.590	0.542			
MLWM 1st	0.651	0.656	0.395			
(constant)	–24.510					

Functions	Unstandardized coefficients[a]	Structure matrix[b]	Standardized coefficients	Group centroids		Sectioning point[c]
				Male	Female	
Function 4: Left hand proximal phalanges of 2nd ray						
MLWM 2nd	0.986	0.868	0.617	1.001	–1.485	–0.242
APWB 2nd	1.098	0.835	0.557			
(constant)	–22.075					
Function 5: Left hand proximal phalanges of 3rd ray						
APWB 3rd	0.893	0.847	0.496	1.276	–1.701	–0.2125
MLWM 3rd	0.585	0.759	0.385			
MLWH 3rd	0.555	0.810	0.355			
(constant)	–23.422					
Function 6: Left hand proximal phalanges of 4th ray						
MLWM 4th	0.862	0.828	0.628	1.040	–1.263	–0.1115
APWB 4th	1.013	0.807	0.595			
(constant)	–19.183					
Function 7: Left hand proximal phalanges of 5th ray						
APWB 5th	1.701	1.000	1.000	0.441	–0.670	–0.1145
(constant)	–17.187					
Function 8: Maximum length measurements of left hand proximal phalanges						–0.327
ML 3rd	0.590	0.738	0.889	1.198	–1.852	
ML 1st	0.454	0.716	0.696			
ML 4th	–0.448	0.475	–0.799			
ML 5th	0.393	0.540	0.418			
(constant)	–35.259					

Functions	Unstandardized coefficients[a]	Structure matrix[b]	Standardized coefficients	Group centroids		Sectioning point[c]
				Male	Female	
Function 9: Head measurements of left hand proximal phalanges						
MLWH 1st	.194	0.877	0.704	1.423	–2.199	–0.388
MLWH 3rd	0.893	0.749	0.511			
(constant)	–25.518					
Function 10: Basis measurements of left hand proximal phalanges						
MLWB 3rd	0.774	0.757	0.492	1.528	–2.361	–0.4165
APWB 3rd	1.241	0.703	0.600			
MLWB 1st	0.676	0.592	0.522			
MLWB 5th	–0.578	0.260	–0.398			
(constant)	–30.636					
Function 11: Mid-shaft measurements of left hand proximal phalanges						
MLWM 1st	1.764	0.845	0.717	1.600	–2.473	–0.4365
APWM 1st	1.593	0.717	0.550			
(constant)	-26.591					
Function 12: Right hand proximal phalanges of 1st ray						
APWM 1st	1.190	0.858	0.726	1.291	–1.470	–0.0895
ML 1st	0.333	0.711	0.531			
(constant)	–18.203					
Function 13: Right hand proximal phalanges of 2nd ray						
MLWB 2nd	0.761	0.939	0.713	0.875	–0.831	0.022
APWB 2nd	0.567	0.804	0.411			
(constant)	–18.968					

Functions	Unstandardized coefficients[a]	Structure matrix[b]	Standardized coefficients	Group centroids		Sectioning point[c]
				Male	Female	
Function 14: Right hand proximal phalanges of 3rd ray						
MLWB 3rd	0.642	0.898	.569	1.148	–1.200	–0.026
APWB 3rd	0.918	0.890	0.549			
(constant)	–21.629					
Function 15: Right hand proximal phalanges of 4th ray						
MLWM 4th	0.904	0.826	0.553	1.518	–1.518	0.000
ML 4th	0.235	0.666	0.465			
APWB 4th	0.638	0.722	0.323			
(constant)	–25.466					
Function 16: Right hand proximal phalanges of 5th ray						
MLWB 5th	0.912	0.908	0.631	0.901	–1.086	–0.0925
APWB 5th	1.041	0.850	0.502			
(constant)	–23.770					
Function 17: Maximum length measurements of right hand proximal phalanges						
ML 4th	0.349	0.778	0.653	1.217	–1.347	–0.065
ML 1st	0.402	0.768	0.640			
(constant)	–27.056					
Function 18: Head measurements of right hand proximal phalanges						
MLWH 4th	1.202	0.836	0.674	1.189	–1.317	–0.064
MLWH 1st	0.713	0.763	0.573			
(constant)	–22.007					

Functions	Unstandardized coefficients[a]	Structure matrix[b]	Standardized coefficients	Group centroids		Sectioning point[c]
				Male	Female	
Function 19: Basis measurements of right hand proximal phalanges						
MLWB 5th	0.682	0.588	0.404	2.005	–2.220	–0.1075
APWB 1st	0.676	0.558	0.583			
MLWB 3rd	0.531	0.513	0.465			
APWB 4th	0.695	0.567	0.349			
(constant)	–34.149					
Function 20: Mid-shaft measurements of right hand proximal phalanges						
APWM 1st	1.099	0.726	0.648	1.522	–1.685	–0.0815
MLWM 4th	0.638	0.701	0.407			
MLWM 5th	0.740	0.656	0.372			
(constant)	–19.492					

For sex assessment, it is necessary to create a mathematical equation, in order to produce the discriminant function score (Y). For that purpose, the phalangeal measurements that were entered in each function should multiply with the respective unstandardized coefficients and the outcome should be added to the "constant". When the value of this calculation is above the sectioning point, the equations suggest that the individual is male, whereas if the value is below the sectioning point, then the individual is considered female. The form of the equation is:

$$Y = b_1 * X_1 + b_2 * X_2 + b_3 * X_3 + \ldots + b_i * X_i + a$$

where,
b_1–b_i = regression coefficients (unstandardized coefficients)
X_1–X_i = the value of each variable
a = constant
i = the number of predictor variables

The classification accuracy of each function is presented in Table 3 (the accuracies for the original groups, the cross-validated groups, and the total value from both

sides and sexes). Remarkably, the accuracy rate of correct sex determination is extremely high, reaching 100% when all phalanges are present (function 1 and 2) from the left or the right side. All estimations were based on the amount of cases in which our model gave the correct sex classification. In case where each finger was tested separately, the accuracy ranged between 88.2% and 97.3% for the left phalanges and between 84.6% and 92.2% for the right phalanges. The 1st proximal phalanges display the highest classification accuracy observed (97.3% for the left 1st phalanges and 92.2% for the right 1st phalanges), while the lowest accuracy rate was obtained for the left 5th proximal phalanges (88.2%) and the right 2nd proximal phalanges (84.6%). The variables of the left phalanges presented higher classification accuracy rates than the equivalent right. In the functions that each measurement was tested separately (using all 5 proximal phalanges of each side), the classification accuracy rate ranged between 94.6% and 98.3% for the left phalanges and between 87.7% and 100% for the right phalanges. Additionally, in the same functions, the measurements of the left side gave better classification accuracies than those of the right side, with the exception of the widths at base. Among measurements, the widths at the head present the most accurate classification rate in the left proximal phalanges (98.3%), whereas, in the right proximal phalanges, the widths at the base predict sex in the 100% of cases.

Table 3. Accuracy of classification results of the original and cross-validated[a] samples

Functions	Predicted group membership				Total average (%)
	Male		Female		
	N	%	*N*	%	
Function 1: All left hand proximal phalanges					
Original	35/35	100%	24/24	100%	100%
Cross-validated	35/35	100%	22/24	91.7%	96.6%
Function 2: All right hand proximal phalanges					
Original	32/32	100%	28/28	100%	100%
Cross-validated	31/32	96.9%	28/28	100%	98.3%
Function 3: Left hand proximal phalanges of 1st ray					
Original	40/41	97.6%	31/32	96.9%	97.3%
Cross-validated	40/41	97.6%	30/32	93.8%	95.9%

Functions	Predicted group membership				Total average (%)
	Male		Female		
	N	%	*N*	%	
Function 4: Left hand proximal phalanges of 2nd ray					
Original	43/46	93.5%	28/31	90.3%	92.2%
Cross-validated	42/46	91.3%	28/31	90.3%	90.9%
Function 5: Left hand proximal phalanges of 3rd ray					
Original	54/56	96.4%	37/42	88.1%	92.9%
Cross-validated	54/56	96.4%	37/42	88.1%	92.9%
Function 6: Left hand proximal phalanges of 4th ray					
Original	46/51	90.2%	37/42	88.1%	89.2%
Cross-validated	45/51	88.2%	36/42	85.7%	87.1%
Function 7: Left hand proximal phalanges of 5th ray					
Original	37/41	90.2%	23/27	85.2%	88.2%
Cross-validated	37/41	90.2%	23/27	85.2%	88.2%
Function 8: Maximum length measurements of left hand proximal phalanges					
Original	32/34	94.1%	21/22	95.5%	94.6%
Cross-validated	31/34	91.2%	20/22	90.9%	91.1%
Function 9: Head measurements of left hand proximal phalanges					
Original	35/35	100%	24/25	96.0%	98.3%
Cross-validated	35/35	100%	24/25	96.0%	98.3%
Function 10: Basis measurements of left hand proximal phalanges					
Original	33/34	97.1%	20/22	90.9%	94.6%
Cross-validated	33/34	97.1%	20/22	90.9%	94.6%
Function 11: Midshaft measurements of left hand proximal phalanges					
Original	40/41	97.6%	30/32	93.8%	95.9%
Cross-validated	38/41	92.7%	28/32	87.5%	90.4%
Function 12: Right hand proximal phalanges of 1st ray					
Original	36/41	87.8%	35/36	97.2%	92.2%
Cross-validated	36/41	87.8%	35/36	97.2%	92.2%

Functions	Predicted group membership				Total average (%)
	Male		Female		
	N	%	*N*	%	
Function 13: Right hand proximal phalanges of 2nd ray					
Original	31/38	81.6%	35/40	87.5%	84.6%
Cross-validated	30/38	78.8%	35/40	85.0%	82.1%
Function 14: Right hand proximal phalanges of 3rd ray					
Original	39/46	84.8%	42/44	95.1%	90.0%
Cross-validated	39/46	84.8%	41/44	93.2%	88.9%
Function 15: Right hand proximal phalanges of 4th ray					
Original	36/39	92.3%	35/39	89.7%	91.0%
Cross-validated	35/39	89.7%	35/39	89.7%	89.7%
Function 16: Right hand proximal phalanges of 5th ray					
Original	36/41	87.8%	28/34	82.4%	85.3%
Cross-validated	35/41	85.4%	28/34	82.4%	84.0%
Function 17: Maximum length measurements of right hand proximal phalanges					
Original	33/34	97.1%	27/31	87.1%	92.3%
Cross-validated	32/34	94.1%	27/31	87.1%	90.8%
Function 18: Head measurements of right hand proximal phalanges					
Original	30/34	88.2%	27/31	87.1%	87.7%
Cross-validated	30/34	88.2%	26/31	87.1%	86.2%
Function 19: Basis measurements of right hand proximal phalanges					
Original	32/32	100%	28/28	100%	100%
Cross-validated	31/31	96.9%	28/28	100%	98.3%
Function 20: Midshaft measurements of right hand proximal phalanges					
Original	29/32	90.6%	27/28	96.4%	93.3%
Cross-validated	29/32	90.6%	25/28	89.3%	90.0%

[a] Cross-validation is performed only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.

The "leave one out classification" procedure compares the accuracies between the original sample and the one created by cross-validation. It should be mentioned that there are slight differences between the accuracy rates (misclassification of 1 or 2 individuals); which result, however, to non-significant lowering of the predictive potential of the discriminant function equations. The accuracies of the cross-validated sample remain in all cases over 82%, a very high percentage of correct classification.

DISCUSSION

The results of the SDFA indicate that proximal hand phalanges are very useful bones for a highly accurate assessment of sex in Greek populations. Indeed, there were functions in which the accuracy rate reached 100%. This performance can be justified by the high degree of SD (reached 24.78%) reported for our population sample [11].

The difference between the accuracy rates of the left and the right proximal hand phalanges may be due to various patterns of lifelong physical activity. In bones, physical stress is considered to be mainly responsible for both SD and bilateral asymmetry. Due to the fact that upper limbs are used for less uniform activities than the lower limbs, they often present a higher degree of SD and bilateral asymmetry [17].

In literature, there have been numerous studies on sex determination using hand bones, such as the metacarpals [3, 18–20]. Concerning proximal hand phalanges, however, there are few researches investigating sex determination. Among them, some utilize multiple functions from all ten proximal hand phalanges [4, 6] while others focus on specific phalanges or phalangeal dimensions [3, 5, 21]. Due to the fact that most functions selected vary among studies, a direct comparison was rarely possible.

Scheuer and Elkington [3] conducted a research on a sample of 60 individuals from the United Kingdom. Their published discriminant equations for sex diagnosis using 1st proximal phalanges produced accuracy rates between 74% and 78%. Case and Ross [5] studied the ML of proximal phalanges in a sample of 259 skeletons from the Terry Collection. The discriminant equations that derived from their data provided an accuracy of 80.8% using the ML of all left proximal hand phalanges [1–5] and an accuracy of 83.1% using all right proximal hand phalanges [1–5].

Smith ([4] conducted a research on the hand bones of 40 individuals of Black and White ancestry from the United States. In her research, she used

multiple functions that provided the classification rates that ranged between 81.88% and 94.38% for the left proximal phalanges and between 83.02% and 90.57% for the right proximal phalanges. Navsa [6] developed discriminant equations for sex determination using proximal phalanges of 200 Black and White individuals from South Africa. Classification accuracies ranged between 83.2% and 86.4%. The highest accuracies were obtained for the 1st (86.4%) and the 3rd (84.8%) proximal hand phalanges, whereas the lowest accuracy was reported for the 2nd proximal phalanges (83.2%). Among measurements, the highest classification accuracies were obtained for the APWM and the MLWM (86.4% and 85%, respectively). Finally, a recent study on a Thai population of 249 individuals provided discriminant function equations for sex assessment. Correct classification rates ranged from 87.6% to 92.3%, with left 1st proximal phalanges presenting the highest accuracy (92.3%), followed by the left 2nd proximal phalanges (91.9%) [21].

In our research, in functions using all five phalanges from each side, the discriminant equations provided classification accuracies ranging between 94.6% and 98.3% in the left proximal phalanges and between 87.7% and 100% in the right proximal phalanges. The left and the right 1st proximal phalanges presented the highest classification accuracy (97.3% and 92.2% respectively), whereas the lowest accuracy was obtained for the 2nd right proximal phalanges (84.6%). The two functions involving ML of either all left (1–5) or all right (1–5) proximal hand phalanges provided successful classification in the 94.6% and 92.3% of cases respectively. Among measurements, the widths at the head of the left phalanges and at the base of the right phalanges provided the highest classification accuracies (98.3% and 100%, respectively).

However, it should be mentioned again that, as described in the material and methods section, each function is based on a different number of specimens (Table 3). This is due to the fact that the SDFA requires complete sets of data, while many proximal hand phalanges were either missing or damaged. As a result, the functions using multiple rays of left or right proximal hand phalanges [1, 2, 8, 9, 10, 11, 17, 18, 19, and 20] were represented by less individuals (ranging between 22 and 41 specimens for each sex) than those functions based on isolated left or right bones (ranging between 27 and 56 specimens for each sex). Indeed, all of the latter functions involved – at all times – over 31 individuals in each sex, with the exemption of the seventh one that utilizes female left 5th proximal foot phalanges (27 individuals). Consequently, the functions based on single rays rely on more powerful samples.

Furthermore, it should be noticed that the excellent accuracy rates (100%) of three functions –1, 2, and 19– present slight drop after cross-validation (96.6%, 98.3%, and 98.3% respectively). This suggests that, even though the accuracy of these three functions using multiple rays is extremely high, it should not be expected to be flawless. Nevertheless, given that the SDFA utilizes the best-discriminating variables between males and females, the functions involving multiple bones (thus more variables) are indeed more possible to provide more accurate sex discrimination than those based on a single ray.

In bones, physical activity is a major factor for SD. Through the process of bone remodeling, width dimensions are subjected to size transformations that occur during early life, puberty, and adulthood. As a result, the degree of SD reported is influenced by the particular social and occupational background of male and female individuals composing the sample. Concerning bone length, most development is completed before adulthood. In that case, the biological origin of a population sample is a restrictive factor in developing and using mathematical equations for sex determination [22].

Consequently, SD is directly affected by secular and biological factors. Therefore, it is vital to derive mathematical sex-assessing equations for each population group analyzed [23]. Until present, there are no other studies on sex determination using proximal hand phalanges from Greece.

The results of our research suggest highly accurate equations for sex diagnosis using proximal hand phalanges. In forensic anthropology, these linear discriminant function equations could be very useful when other major bones are missing from the skeletal remains found. Moreover, phalanges consist of small and compact bones, which are often preserved intact in the field.[7] In addition, they could also prove useful in bioarchaeology and for that reason the accuracy of the proposed equations should be further tested on archaeological skeletal populations. Besides the contribution of sex assessment in ancient demographics, the analyses of gender-specific occupational stress-markers in proximal hand phalanges could set the basis for speculations on sexual distribution of labor in societies of the past [24, 25].

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