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PAPER

ANTHROPOLOGY

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Sexual Dimorphism of the Arm Bones in a Modern Greek Population

ABSTRACT: Several studies have shown that sex determination methods based on measurements of the skeleton are population specific. Metric traits of the long bones of the arm have been reported as reliable indicators of sex. This study was designed to determine whether the three long bones of the arm can be used for sex determination on a skeletal population from Greece. The material used consists of the arm bones of 204 adult individuals (111 males and 93 females) coming from the Modern Human Skeletal Collection of the University of Athens. The age range is 19–96 years for males and 20–99 years for females. The maximum lengths and epiphyseal widths were measured in the long bones of the arm (humerus, radius, and ulna). The discriminant analysis of the metrical data of each long bone gave very high discrimination accuracies. The rate of correct sex discrimination based on different long bones ranges from 90.30% (ulna) to 95.70% (humerus). In addition, intra- and inter-observer error tests were performed. These indicated that replication of measurements was satisfactory for the same observer over time and between observers. The results of this study show that metric characteristics of the arm bones can be used for the determination of sex in skeletal remains from Greece and that bone dimensions are population specific.

KEYWORDS: forensic science, sex determination, discriminant function, humerus, radius, ulna

Sexual dimorphism, as a characteristic of living organisms, and its different forms of expression is a topic that has attracted the interest of many researchers. According to a general definition, "sexual dimorphism is the development of visible morphological differences between males and females in a species or population." A more specific definition in reference to the human species is that by Relethford (1), according to which sexual dimorphism is the average difference in body size between male and female adult individuals. The main dimorphic characteristic of primates, which is evident in humans, is body size. The general rule in the animal kingdom is that the female is the larger of the two sexes (2). In mammals and birds, however, the opposite is true, with few exceptions. It is believed that the smaller size allows females to make a better use of the energy required for developing a greater body mass. Instead, the energy is used for the creation of offspring through processes, such as gestation and nursing (2).

In humans, the trait most indicative of sexual dimorphism is stature. The fact that on average males are taller than females is common across all human populations (3,4). This is attributed to the different rate of growth in the lower limbs and not the torso (5). Body size in males has been estimated to be 8–20% larger than that of females (6,7). Sexual dimorphism is present in the human skeleton as well. In many skeletal elements, it is present in the form of shape differences, while in others it is only the result of size variation. According to Plavcan (6), sexual dimorphism in the skeleton of primates is related to overall body size differences. Therefore, the human skeleton displays sexually dimorphic characteristics that are expressed by larger and more robust bones in males (7,8). These differences become evident only after the end of puberty, when the skeleton has completed its growth (9).

A large number of studies have demonstrated that there is variation in the degree of sexual dimorphism among different populations (4,10,11). This variation is related to body size and consequently to metric differences in the dimensions of individual skeletal elements (12–17). In addition, sexual dimorphism is present not only between populations, but within populations as well. Many factors contribute to sexual dimorphism in a population; however, the most important is believed to be its genetic composition (3,10,18). It has been observed that the size of bones is determined genetically, although not in the same manner in different populations. For example, a team of researchers has located a chromosomal area thought to be responsible for the variation in the size of the femur and vertebrae between different populations (19). The above observation in combination with the fact that the genes that determine bone size interact with sex genes (18) suggest that sexually dimorphic changes have a strong genetic basis.

Another very important factor affecting the expression of sexual dimorphism is the environment, especially diet (12,20–22). An acute environmental stress, e.g., malnutrition, usually leads to a reduction of sexual dimorphism. However, once optimal conditions have been restored males tend to grow faster than females, leading

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to an increase in sexual dimorphism (17). Evidence suggests that populations that have an either very low or very high protein intake demonstrate the least amount of sexually dimorphic variation (23). An additional environmental factor believed to contribute to changes between the two sexes is mechanical load, which is dependent on the division of labor according to sex (10,24,25). For example, Carlson et al. (25) studied hunter-gatherer Australian aboriginal groups and found that sexual dimorphism was greater among groups where division of labor was practiced. In those groups, males were responsible for hunting while females for food gathering. Other groups, which had adopted agriculture and both sexes were engaged in similar food-producing tasks, exhibited a low degree of dimorphism. This example offers a mechanical but also a social explanation for the presence of sexual dimorphism. The nature of the economy or survival strategy of a society goes far beyond the input and output and affects the biology of its members.

Another study that supports this view was conducted by Holden and Mace (4) on nonindustrialized populations and found that when females had a significant contribution to production, sexual dimorphism was low. The view supporting that the greater mechanical loading sustained by males is responsible for their more robust skeletons offers an explanation for the trend of continued reduction in sexual dimorphism in the genus *Homo*. In the Upper Paleolithic period, the hunt of large game with spears by males was very common. However, during the Mesolithic and with the aid of the bow and arrow, smaller game was hunted (26). Hunting large game required large-bodied males who could respond to this strenuous activity. The shift to smaller game reduced the need for large-bodied hunters and a smaller, more energy efficient body type was favored. Size differences were further reduced after the adoption of agriculture and are very low in industrialized countries today, where both sexes have a sedentary lifestyle (3). The degree of sexual dimorphism differs not only in geographically but also temporally isolated populations. This is caused by secular changes that are the result of lifestyle modifications (16,27).

A review of the studies on this topic leads to the conclusion that there is no single factor that affects sexual dimorphism, but rather the interaction of many factors. The multitude of combinations among these factors may partly explain why it is so difficult to draw unambiguous conclusions on the etiology of the differences observed between the two sexes.

Previous Studies on the Sexual Dimorphism of the Arm Bones

The determination of sex is a very important parameter of the anthropological examination and along with the estimation of age and assessment of ancestry is essential in the identification of a skeleton. Hence, many studies have been conducted with the purpose of developing both morphological and metric methods for determination of sex in skeletal remains (13,28–30). Of particular interest have been metric methods for the arm bones, as research has indicated that they produce high levels of accuracy (27,31,32).

Holman and Bennett (31) studied one white and one black sample from the Terry Collection. The lengths of the arm bones were measured, as well as the widths of the distal ends. The resulting discriminant equations predicted sex with an accuracy of 85–96% for the whites and 68–92% for the blacks. Although the measurements were well defined and identical for the two samples, the accuracy rates differed dramatically. This finding may suggest that metric methods for the bones of the arm are population specific. It should be noted that the variation in accuracy in the above example reflects the fact that different bones and different dimensions were measured and each produced a different accuracy rate.

Additional studies utilizing metric data from the arm bones supported the view of population differences. After analyzing measurements from three different, yet neighboring populations (Chinese, Japanese, and Thai), a team of researchers developed formulae for determining the sex in each one (12). The results showed that while the Chinese had the larger dimensions, they were the least dimorphic between the two sexes (87% accuracy). On the contrary, Thais had the smaller dimensions and highest degree of dimorphism (97% accuracy). In addition, when the formulae were tested on the other groups and not those used to develop them, the values of correct classification were lower. These results indicate that the dimensions of the arm bones are specific for each population, even if they have geographic proximity.

In another study, Steyn and İşcan (27) took six different measurements of the humerus in South African whites and blacks from the Raymond Dart and Pretoria collections. The highest accuracy rates were 96% for the bicondylar width in the whites and 93% for the humeral head diameter in the blacks. These data demonstrate that populations may be different not only in the degree of sexual dimorphism but also in the various dimensions of the same skeletal element. The two collections from South Africa were used for an analysis of the radius and ulna (11). Here, correct classification reached 87% for males and 89% for females, using a combination of all available measurements. The same study produced equations for fragmentary remains, because incomplete bones are frequently found in both forensic and archeological contexts. The most accurate formulae were those of dimensions of the epiphyses. A similar work on a German sample (32) utilizing measurements from the humerus, radius, and ulna found that the radius generated the highest accuracy rates (almost 95%). Of the individual dimensions, the humeral head diameter proved to be the most accurate. The same results were found in a study of a Guatemalan sample (16) where the diameter of the head of the humerus correctly distinguished between the two sexes in 95.5% of the cases examined. In a more recent study that employed a modern forensic sample from Turkey, the maximum lengths of the radius and ulna were assessed and correct sex determination reached a rate of 96% (33).

All the studies presented above suggest that there is a need for the development of population-specific sexing methods, as different groups appear to vary in overall size and dimensions of individual skeletal elements.

Purpose of the Present Work

The aim of this study is to determine the degree of sexual dimorphism in a Modern Greek population and to develop metric standards for the determination of sex. The bones of the arm will be examined for this purpose (humerus, ulna, radius). In particular, the objective is to collect metric data that will generate formulae suitable for modern Greeks. These formulae will produce the highest accuracy rates possible for determining the sex in skeletal remains from this geographic region. The rationale for the development of a metric method stems from the fact that skeletons recovered from archeological or forensic contexts are frequently fragmentary and the most sexually dimorphic elements (skull, pelvis) are incomplete or missing. Furthermore, a previous study on the Athens Collection has demonstrated that some metric traits may have higher accuracy rates than those of the skull or pelvis. For example, the bicondylar breadth of the femur had a correct sex classification of 77.2%, while the nuchal crest only reached 65.8% and the shape of the obturator foramen 43.8% (34). These two morphological sexing traits had been developed and defined on a different population and as a result they produced very poor results on the Greek sample. A number of morphological sexing traits have been developed on skeletal collections from North America and may not be applicable on other populations (8). It is therefore important to have a wide range of sex determination methods, so that the maximum amount of information can be obtained, especially from incomplete skeletons.

Materials and Methods

The skeletal material utilized for the present research is derived from the modern, human skeletal reference collection of the University of Athens, known as the "Athens Collection." All 225 specimens are housed at the Department of Animal and Human Physiology (35). The collection is well documented from death certificate information and data, such as sex, age, occupation, and cause of death, are known for the vast majority of the individuals (Fig. 1). Year of death ranges between 1960 and 1996, making this a recent sample and information on occupation indicates that both the lower and middle socioeconomic classes are represented. Only adults were included in the sample. The mean age is 57.7 (range: 19–96 years) and 59.7 (range: 20–99 years) for males and females, respectively. A total of 204 adult skeletons were examined (111 males and 93 females). Table 1 presents the number of available specimens that were measured. The measurements taken are according to well-known sources (36,37) and include maximum lengths and epiphyseal widths (Tables 2–4).

Humeral dimensions: maximum humeral length (MHL), vertical head diameter (VHD), humeral epicondylar width (HEW). Ulnar dimensions: maximum ulnar length (MUL), maximum ulnar proximal width (MUPW), maximum ulnar distal width (MUDW). Radial dimensions: maximum radial length (MRL), maximum radial proximal width (MRPW), maximum radial distal width (MRDW). A standard osteometric board was used for maximum lengths and a Mitutoyo® Digimatic Caliper (Chengdu Tengqiang Industry Co., Ltd, Sinchuan, China) for the widths of the epiphyses. Specimens that were excluded from the study included those with unfused epiphyses, because only elements that had completed their growth are suitable for metric analyses. Other specimens were excluded on the basis of size alteration, such as pathological conditions, healed antemortem trauma, or postmortem fractures, as these conditions may be a factor of bias.

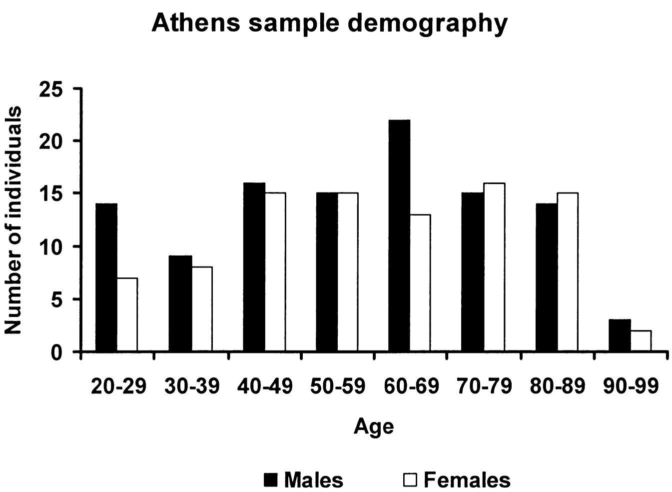

FIG. 1—*Age distribution in the Athens Collection (includes only the sample studied).*

All measurements were taken by the first author (DC) and a random subsample of 60 individuals was re-examined after a period

TABLE 1—*Distribution of the arm bones studied (male, female, left, right, total).*

		Humerus		Radius		Ulna	
Sex	No. of Individuals	Left	Right	Left	Right	Left	Right
Males	111	107	107	105	108	106	107
Females	93	90	87	84	86	88	86
Total	204	197	194	189	194	194	193

TABLE 2—*Summary statistics for humerus (mean, SD, minimum and maximum value, number of bones) and* t*-test comparison between males and females.*

Humerus	Left			Right		
Variables (mm)	MHL	VHD	HEW	MHL	VHD	HEW
Males						
Mean	324.65	47.38	60.87	327.09	47.64	61.45
Standard deviation	16.79	2.62	2.94	16.71	2.72	3.39
Minimum value	271.00	39.42	56.00	272.00	39.09	54.00
Maximum value	366.00	55.33	68.00	367.00	55.96	70.00
N	104	99	103	104	101	102
Confidence interval (95%)	3.266	0.522	0.575	3.248	0.536	0.665
Females						
Mean	294.42	40.77	52.76	297.53	40.83	53.53
Standard deviation	14.56	2.24	3.03	14.59	2.22	2.78
Minimum value	257.00	34.55	42.00	261.00	34.71	48.00
Maximum value	338.00	46.53	59.00	340.00	46.02	59.00
N	86	80	85	83	74	79
Confidence interval (95%)	3.121	0.499	0.654	3.185	0.513	0.622
t-test	13.109	17.890	18.566	12.707	17.653	16.836
p-value	0.0	0.0	0.0	0.0	0.0	0.0

MHL, maximum humeral length; VHD, vertical head diameter; HEW, humeral epicondylar width.

TABLE 3—*Summary statistics for ulna (mean, SD, minimum and maximum value, number of bones) and* t*-test comparison between males and females.*

Ulna	Left			Right		
Variables (mm)	MUL	MUPW	MUDW	MUL	MUPW	MUDW
Males						
Mean	259.11	25.74	17.01	261.78	25.57	17.29
Standard deviation	12.72	1.97	1.56	12.75	1.68	1.63
Minimum value	230.00	17.36	13.35	231.00	21.88	14.07
Maximum value	289.00	30.79	20.60	294.00	29.33	21.52
N	85	99	91	96	103	95
Confidence interval (95%)	2.743	0.392	0.325	2.583	0.328	0.332
Females						
Mean	230.66	22.21	14.62	229.93	21.70	15.03
Standard deviation	11.53	1.65	1.50	26.91	1.48	1.54
Minimum value	206.00	18.11	10.84	211.00	18.40	11.86
Maximum value	263.00	26.75	18.02	256.00	25.48	19.50
N	68	84	72	71	81	74
Confidence interval (95%)	2.792	0.358	0.352	6.370	0.328	0.356
t-test	14.326	13.002	9.879	10.164	16.336	9.039
p-value	0.0	0.0	0.0	0.0	0.0	0.0

MUL, maximum ulnar length; MUPW, maximum ulnar proximal width; MUDW, maximum ulnar distal width.

of 3 months. The same sample of 60 was also measured by the second author (CE). These two sets of measurements were used for intra- and inter-observer error analyses, respectively. The subsample was composed of 35 males and 25 females and the same procedure for all measurements was followed. Intra-observer error ranges from 0.1 to 1.6% except in the case of the MUPW in which is higher (3.42%). Inter-observer error ranges from 0.1 to 2.65% in most measurements. There are higher values in the case of MRPW (4.8%) and in MUPW (4.2%).

Statistical analyses were conducted with the aid of SPSS (v. 12; SPSS Inc., Chicago, IL). Initially, descriptive statistics were generated for each dimension measured. In addition, a *t*-test and discriminant analysis were performed. Specifically, two *t*-tests were carried out. The first compared the measurements of the right and left sides to ascertain whether any bilateral asymmetry exists. The second *t*-test compared the data from males and females, with the purpose of determining whether statistically significant differences exist in their mean values. This served as an initial assessment of sexual dimorphism in the sample.

The sexual dimorphism index (SDI), which is a whole scale measure of dimorphism, was also computed for each sample (left and right arm bones). The SDI formula applied here is

$$\frac{\bar{X}_{\mathrm{m}} - \bar{X}_{\mathrm{f}}}{\bar{X}_{\mathrm{m}}} \mathrm{x}100$$

after Riclan and Tobias (38).

The data were then analyzed using discriminant analysis, from which equations for assigning sex were created. Table 1 details the precise number of bones by sex and type included in the study. Discriminant function analysis for sex determination was performed for each left and right arm bones in which all three measurements taken were utilized as independent variables. Prior probability was set as "compute from groups' sizes" for all analyses, and the covariance matrix was set as "within groups," given that the *p*-value of Box's M was high. The *p*-value for all variables was 0, indicating a significant difference in mean values and in the contribution of all seven variables to group assignment. Furthermore, the *p*-value of Wilks' lambda was 0 in all cases, indicating a considerable differentiation attribute of the discriminant functions. Fisher coefficients for the discriminant functions were derived from each analysis, and the percentages of correct group assignment of the original grouped cases were also cross-validated. Each pair of $w1$ and $w2$ discriminant functions were inserted in a $Y = w1–w2$ formula where if the value of $Y > 0$ (male) and $Y < 0$ (female).

A stepwise discriminant function analysis was used (Wilks' lambda) to select the combination of variables that best discriminate between the two sexes. A "leave one out classification" procedure was applied to present the accuracy rate of the original sample, as well as of the sample created by cross-validation (39).

Results

Descriptive statistics for each set of measurements include mean value, standard deviation, range, confidence intervals, and number of specimens (Tables 2–4). It is apparent that males have higher values than females for all dimensions examined. *t*-Test results also demonstrate that the differences of the mean values between males and females are statistically significant in all cases ($p < 0.05$, 95% confidence interval). These data indicate the existence of sexual dimorphism in the sample under examination, because all dimensions have a discriminatory power between the two sexes.

Table 5 presents the results of the intra- and inter-observer error. It is worth mentioning that only MUPW has high percentage (3.42%) of intra-observer error. In the case of inter-observer error, only two dimensions have high value, the MUPW and MRPW, with percentages 4.17% and 4.80%, respectively.

In regard to bilateral asymmetry, in most cases, measurements from the right side are slightly higher than those of the left side (Table 6). The differences, however, are small in absolute values. This is confirmed by the results of the *t*-test, where all differences of mean values between the two sides are not statistically significant, with the exception of two cases (MUPW and MRL).

TABLE 4—*Summary statistics for radius (mean, SD, minimum and maximum value, number of bones) and* t-*test comparison between males and females.*

Radius	Left			Right		
Variables (mm)	MRL	MRPW	MRDW	MRL	MRPW	MRDW
Males						
Mean	237.38	22.14	32.72	240.57	22.29	32.71
Standard deviation	12.63	1.25	2.01	12.65	1.34	2.36
Minimum value	206.00	18.99	29.00	208.00	18.66	27.00
Maximum value	270.00	24.66	38.00	272.00	25.21	40.00
N	100	82	101	106	94	105
Confidence interval (95%)	2.506	0.274	0.397	2.436	0.275	0.457
Females						
Mean	208.80	18.71	28.05	212.83	18.84	28.01
Standard deviation	11.18	1.00	1.85	11.97	0.96	1.92
Minimum value	186.00	16.18	24.00	186.00	15.73	23.00
Maximum value	240.00	21.76	33.00	242.00	21.59	34.00
N	79	66	79	83	58	83
Confidence interval (95%)	2.505	0.246	0.413	2.615	0.253	0.420
t-test	15.806	18.108	16.015	15.320	17.080	14.699
p-value	0.0	0.0	0.0	0.0	0.0	0.0

MRL, maximum radial length; MRPW, maximum radial proximal width; MRDW, maximum radial distal width.

TABLE 5—*Intra- and inter-observer error for humerus, radius, and ulna.*

	Side	Variables		
Intra-observer error				
Humerus		MHL (%)	VHD (%)	HEW (%)
	L	0.12	0.63	0.53
	R	0.27	0.88	0.61
Ulna		MUL (%)	MUPW (%)	MUDW (%)
	L	0.20	**3.42**	1.18
	R	0.14	1.01	0.97
		MRL (%)	MRPW (%)	MRDW (%)
Radius	L	0.53	0.68	1.06
	R	0.37	0.40	1.60
Inter-observer error				
Humerus		MHL (%)	VHD (%)	HEW (%)
	L	0.11%	1.12%	0.61
	R	0.39%	1.15%	0.78
Ulna		MUL (%)	MUPW (%)	MUDW (%)
	L	0.20	**4.17**	1.98
	R	0.24	2.32	1.88
		MRL (%)	MRPW (%)	MRDW (%)
Radius	L	1.19	**4.80**	2.64
	R	0.74	0.92	2.58

HEW, humeral epicondylar width; MHL, maximum humeral length; MRDW, maximum radial distal width; MRL, maximum radial length; MRPW, maximum radial proximal width; MUDW, maximum ulnar distal width; MUL, maximum ulnar length; MUPW, maximum ulnar proximal width; VHD, vertical head diameter. The highest intra- and inter-observer errors are in bold print.

TABLE 6—t-*Test results for laterality (confidence limit 95.0%) for humerus, radius, and ulna.*

Humerus	Males			Females		
Variables (mm)	MHL	VHD	HEW	MHL	VHD	HEW
t-test	−1.050	−0.688	−1.309	−1.387	−0.167	−1.692
p-value	0.295	0.492	0.192	0.167	0.868	0.093
Ulna						
Variables (mm)	MUL	MUPW	MUDW	MUL	MUPW	MUDW
t-test	−1.4076	0.6608	−1.1960	0.2063	2.0875*	−1.6018
p-value	0.1610	0.5095	0.2333	0.8369	0.0384	0.1114
Radius						
Variables (mm)	MRL	MRPW	MRDW	MRL	MRPW	MRDW
t-test	−1.8103	−0.7643	0.0327	−2.2119*	−0.7359	0.1349
p-value	0.0717	0.4458	0.9740	0.0284	0.4632	0.8928

*Statistically significant difference at level of 95.0% of confidence interval.

HEW, humeral epicondylar width; MHL, maximum humeral length; MRDW, maximum radial distal width; MRL, maximum radial length; MRPW, maximum radial proximal width; MUDW, maximum ulnar distal width; MUL, maximum ulnar length; MUPW, maximum ulnar proximal width; VHD, vertical head diameter.

TABLE 7—*Sexual dimorphism index for all three arm bones (left and right).*

	Variables	L	R
Sexual dimorphism index			
Humerus	MHL	9.31	9.04
	VHD	13.97	14.30
	HEW	13.32	12.89
Ulna	MUL	10.98	12.17
	MUPW	13.69	15.15
	MUDW	14.10	13.10
Radius	MRL	12.04	11.53
	MRPW	15.49	15.47
	MRDW	14.28	14.37

HEW, humeral epicondylar width; MHL, maximum humeral length; MRDW, maximum radial distal width; MRL, maximum radial length; MRPW, maximum radial proximal width; MUDW, maximum ulnar distal width; MUL, maximum ulnar length; MUPW, maximum ulnar proximal width; VHD, vertical head diameter.

The results of the calculation of the SDI demonstrate that the lengths of the three bones have the least amount of discriminatory power (Table 7). In the humerus, the highest SDI value was that of the head diameter (14.3%), in the radius the width of the proximal end (15.4%), and in the ulna the width of the proximal end (15.1%).

The discriminant analysis results are presented in Table 8. Two functions were generated for the different bones (left and right). Wilks' lambda has low values and its significance was zero. This signifies that the functions have a high discriminatory power. Furthermore, discriminant function constants were generated according to Fischer. The combination of each pair of functions (*w1* and *w2*) produced a discriminant function ($Z = w1–w2$) for each bone. For the calculation of each function (*Z*), every measurement is multiplied by the coefficient of the respective variable and then summarized with the constant. For example the value of the function for the humerus is calculated in the following manner: $Z = 0.03$ (MHL) + 0.69 (VHD) + 0.48 (HEW) − 68.69.

The sectioning point for all cases is zero. Therefore, for a value $Z > 0$, the specimen is classified as a male and for $Z < 0$ as a female.

Table 8 also contains the correct classification rates for each bone, which ranged between 90.3% for the left ulna to 95.7% for the right humerus. The highest accuracy rates are those of the right humerus and ulna and for the left radius. It is worth to mention that in both forms (of discriminant analyses) (canonical and stepwise) the accuracy rate is highest (original and/or cross-validated) in the right side (92.4–96.3%). Another observation is that in the case of the humerus the maximum length (MHL) is excluded in stepwise discriminant analysis whereas the maximum distal width (MDW) is excluded for the other two arm bones.

Table 9 presents the summary results of the discriminant function analyses for all three arm bones and the accuracies (original samples and cross-validated). In all cases except for the left ulna, accuracy rates are over 90.0%.

Table 10 presents the results of the discriminant function analysis of each single variable for humerus, ulna, and radius (original and cross-validated). It is worth mentioning that in this case of maximum length the most dimorphic element is the right ulna (90.4%). In the case of vertical head diameter/maximum proximal width (MPW), the most dimorphic appears to be both radii (94.6–94.1% left and right, respectively), whereas in the case of epicondylar width/MDW, the most dimorphic are both humeri (92.0–90.1% left and right, respectively).

Discussion

The results indicate that there is a significant degree of sexual dimorphism in the Athens sample. Upper limb bones were used and all mean values were higher in males in relation to females. These results are in accordance with previous studies that have used the same measurements. However, there are some differences in the size of the individual skeletal elements. For example, a study of a German population produced mean values that are much higher than those of the present work (32).

In addition, an analysis of South African humeri (27) found that mean values of the white population were higher than those of the present study. Studies on other populations have produced lower mean values that those of the sample examined in this work. All three humeral dimensions in a rural Guatemalan sample are lower than those of the Greeks (16). Lower values were also found in a review of Chinese, Japanese, and Thai humeri (12). The examples presented above are indicative of the variation that exists on skeletal dimensions in different populations. The existence of this variation has been demonstrated in studies of other skeletal elements, such as the femur (13,40).

A considerable degree of sexual dimorphism is present in the Greek sample examined in this work, as the results suggest. The values between males and females were statistically significant. Moreover, the accuracy rates for sex classification were high, ranging from 90.3% for the left ulna to 95.7% for the right humerus. These results are slightly higher than those of Mall et al. (32) who used the same measurements and obtained accuracy rates between 90.5% and 94.9%. According to their findings, the most accurate results were derived from the radius, making it the most dimorphic bone in the German population, in contrast to the Greek sample where the humerus was the bone to surpass both the radius and ulna. The ranges in correct classification results that are presented above reflect the fact that different bones and measurements produce different accuracy rates.

A closer look at the results of the discriminant analysis shows that the greater coefficient for the two different functions is found

TABLE 8—*Discriminant function (DF) equations for the studied arm bones.*

DF Equation	ML	VHD/MPW	HEW/MDW	Constant	Accuracy (%)	Cross-validated (%)
F1 humerus L	0.00031	0.75645	0.55083	−64.4297	94.7	94.1
F2 humerus R	0.03400	0.69295	0.47795	−68.3179	96.3	95.7
F3 humerus L*		0.75658	0.55084	−64.4262	94.7	94.7
F4 humerus R*		0.81097	0.48332	−63.2281	95.1	95.1
F5 radius L	0.09206	1.74226	0.34817	−66.6076	94.2	93.5
F5 radius R	0.08319	1.69590	0.21441	−59.7476	94.6	94.6
F7 radius L*	0.09933	2.07841		−64.4662	95.1	95.1
F8 radius R*	0.08900	1.90695		−58.9050	94.7	94.7
F9 ulna L	0.13948	0.88217	0.14822	−57.1034	90.3	89.6
F10 ulna R	0.15206	0.84750	0.30031	−62.0694	92.4	92.4
F11 ulna L*	0.14281	0.94413		−57.0509	88.4	87.0
F12 ulna R*	0.15504	0.97473		−60.9783	93.0	93.0

F = discriminant function equation; *Stepwise discriminant function analysis.
HEW, humeral epicondylar width; MDW, maximum distal width; VHD, vertical head diameter; MPW, maximum proximal width; ML, maximum length.

TABLE 9—*Classification accuracies on arm bones.*

Discriminant Functions for Arm Bones	Predicted Groups	Male		Female		Total
		N	%	*N*	%	
Humerus L	Original	92/95	96.84	69/75	92.00	94.70
	Cross-validated	91/95	95.79	69/75	92.00	94.10
Humerus R	Original	92/96	95.83	64/66	96.97	96.30
	Cross-validated	91/96	94.79	64/66	96.97	95.70
Radius L	Original	73/78	93.59	58/61	95.08	94.20
	Cross-validated	72/78	92.30	58/61	95.08	93.50
Radius R	Original	87/92	94.56	53/56	94.64	94.60
	Cross-validated	87/92	94.56	53/56	94.64	94.60
Ulna L	Original	67/74	90.54	54/60	90.00	90.30
	Cross-validated	66/74	89.19	54/60	90.00	89.60
Ulna R	Original	80/86	93.02	53/58	91.38	92.40
	Cross-validated	80/86	93.02	53/58	91.38	92.40

TABLE 10—*Discriminant function (DF) equations for maximum length, distal and proximal end in left and right arm bones.*

DF Equation	ML	VHD/MPW	EW/MDW	Constant	Accuracy (%)	Cross-validated (%)
F13 humerus L	0.12076			−37.1895	85.3	85.3
F14		1.09569		−48.0799	89.9	89.9
F15			0.91044	−51.5386	92.0	92.0
F16 humerus R	0.11837			−36.7429	84.0	84.0
F17		1.07591		−47.2795	92.0	91.4
F18			0.80501	−46.0255	90.1	90.1
F19 radius L	0.19804			−43.9440	89.4	89.4
F20		2.61492		−53.1841	94.6	94.6
F21			1.24119	−37.4700	86.7	86.7
F22 radius R	0.18156			−40.9148	87.8	87.8
F23		2.34768		−47.7878	94.1	94.1
F24			0.99116	−29.8596	85.1	85.1
F25 ulna L	1.90864			−46.7395	89.5	89.5
F26		1.21579		−29.1991	86.3	86.3
F27			1.02121	−16.1512	79.1	78.5
F28 ulna R	0.21251			−52.5638	90.4	90.4
F29		1.52259		−35.9847	88.0	88.0
F30			0.89476	−14.4582	79.3	79.3

MDW, maximum distal width; VHD, vertical head diameter; MPW, maximum proximal width; ML, maximum length; EC, epicondylar width.

in variable VHD, followed by HEW and MHL. This illustrates the fact that the humeral head diameter is the most dimorphic of all dimensions in the humerus. The same pattern is observed in the German sample (32). In the case of the radius, the highest discriminating power is found in variable MRPW, while MRDW and MRL rank second and third, respectively. The ulna follows the exact same order: proximal width (MUPW), followed by distal width (MUDW) and then length (MUL). However, in these two skeletal elements, the German study found a different ranking order: MRPW, MRDW and MRL for the radius and MUL, MUDW, MUPW for the ulna (32).

In addition, when the discriminant equations by Mall et al. (32) were applied to the Greek sample, they produced the following accuracy rates: humerus 66%, ulna 51%, and radius 85%. It is noteworthy that only the measurements of the radius resulted in satisfactory classification results. When the mean values of the German sample are compared to those of the present study, it is evident that those from the German population are higher and in the cases of the humerus and ulna the differences are statistically significant (data not shown here). This observation explains the low accuracy rates. In particular, when the correct classification results of the Mall et al. (32) equations on the Greek sample are examined by each sex separately, females have accuracy rates of 100% for the humerus and ulna and 97.5% for the radius. The opposite is true for males, where accuracy rates are 43.7% for the humerus, 17.5% for the ulna, and 77.7% for the radius. When the very low success rate of the ulna was closely examined, it was found that for the proximal and distal widths mean values of Greek males are equal or lower than those of German females. Therefore, the low mean values of the bone widths account for the low accuracy rates of the ulna. This observation supports the view of many researchers who state that because of differences between groups, discriminant function formulae are population specific (10,12,27).

In a study of the humerus in South African whites and blacks (27), the accuracy rates were very high (96% for whites and 95% for blacks). Here too, the head diameter and epicondylar width were the most discriminating for the white group, while for the blacks these were head diameter and maximum length. When a larger sample of blacks from the same skeletal series was examined, Barrier and L'Abbe (11) found that in the radius the best results were obtained from the width of the distal end, followed by the minimum diameter of the diaphysis. In the ulna, the minimum diameter of the diaphysis was the most discriminating variable and the width of the proximal end was ranked second. Overall, the correct classification results found in that study were relatively low, ranging from 76 to 89% for different bones and measurements.

The study of the humerus in a Guatemalan population by Ríos Frutos (16) found that the most useful measurements for the determination of sex were the head diameter, followed by the epicondylar width and the maximum length. The overall accuracy ranged from 76.8 to 95.5% for that study. A review of Asian populations had similar findings: the epicondylar width of the humerus was found to be most dimorphic in Japanese and Thai groups, while the diameter of the head of the humerus was ranked first in the Chinese group (12).

The studies presented above are suggestive of two trends. The first is that the epiphyseal dimensions are in most cases the best discriminators between the two sexes. This is consistent with the findings of the present work, where it was determined that the head diameter was the most dimorphic measurement for the humerus, while for the radius and ulna it was the proximal width. This variation has been reported in numerous research projects concerned with the dimensions of the upper limb bones, but even in some where other skeletal elements were examined. For example, studies using the femur and tibia (13,30,31,40–42) have found the epiphyses to be more sexually dimorphic. Some attribute this phenomenon to the mechanical stress received by the epiphyses during loading (24,43). According to this view, the stress on the epiphyses is higher than that on the diaphysis and causes them to increase in size. This theory may very well account for the findings of the present study.

In the Greek sample, individuals come from the lower and middle socioeconomic classes, where most males had occupations with a high physical component and females were mostly homemakers. On the other hand, there is a view proposing that the dimensions affected by intense physical activity are not those of the epiphyses, but instead the diaphyses, especially in their cross-section (10,24,25,44). However, measurements of the diaphyses were not taken for the present study therefore this theory cannot be verified at this point.

Genetic factors are known to play an important role in the size that individual bones will attain, but they are related predominantly to dimensions that are responsible for their length (22). This may offer an explanation for the fact that the maximum length of the radius was found to be the most dimorphic in the German sample (32).

The second trend that becomes evident when the various studies are compared is that the degree of sexual dimorphism, as well as which dimension is most dimorphic, differ significantly between populations. There are many factors affecting how the differences between the two sexes are expressed. They include environmental conditions, such as diet (12,16,20,21,27), mechanical stress and physical activity patterns (4,10,24,25), and genetic background and secular trends (3,4,27).

Stini (20) was one of the first researchers to conduct a detailed analysis of the differential response of the two sexes to nutritional stress. He proposed that a long-term protein deficiency reduces the growth rate of the skeleton, and it does so to a greater degree in males than females. Therefore, males cannot reach their maximum potential for stature and sexual dimorphism is reduced. This view was also supported by Stinson (21) who added that there are factors other than protein deficiency that may affect the expression of sexual dimorphism. For example, Gray and Wolfe (23) suggest that within a population, those who consume either excessive or deficient amount of protein, exhibit the least sexual dimorphism. The groups with an intermediate intake of protein tend to be more dimorphic. The findings on the Greek population examined here may be explained by this theory. Given the fact that the Mediterranean diet is the norm for Greece and that it contains an adequate amount of protein (45), it is not surprising that a high degree of sexual dimorphism was found in this sample.

As mentioned earlier, the various forces exerted on bones are responsible for their size. It is therefore expected that sexual dimorphism will depend on activity patterns according to sex and by extension to the division of labor between males and females (24,27). An affluent society it is expected to have a low degree of sexual dimorphism because both males and females have equally sedentary lifestyles. In contrast, developing societies where the population is more physically active, will exhibit a marked differences between the two sexes. An example of this is a study of hunter-gatherer groups in Australia (25) where long bones were examined. It was observed that there was a marked sexual dimorphism in the bones of the upper limb. This was attributed to the differential use of the arms: males used spears to hunt, while women were engaged in food gathering. Such an extreme type of sexual division of labor does not exist in Greek society, although prior to a large wave of urbanization in the 1960s, there were differential activity patterns between the two sexes. The individuals from the Athens Collection lived during this time period. Greek males in the second half of the 20th century generally worked as farmers, construction workers, and manual laborers, while females were housewives. It is evident that although homemaking is an important task, it is not as physically strenuous as the occupations that males had at the time.

The environmental and physical activity factors for the development of sexual dimorphism outlined above are only forces acting upon a predetermined genetic model, unique for each population (3,4,10,18). The fact that between groups different bones or their individual structures display varying degrees of sexual dimorphism is dependent to a great extent on the existence of specific genes that dictate their size (18). This may offer an explanation for the differences observed in the mean values between the Greek and German populations. Although they have a geographic proximity and similar lifestyles, they differ in their expression of sexual dimorphism. Additionally, the specific measurements that predicted the correct sex were different for each bone between these two European groups.

In another example, where three different populations from Asia were examined the findings were similar (12). The formulae derived from each group (Japanese, Chinese, Thai), were applied to the others. As expected, accuracy rates were much lower when the standards of one population were applied on the other samples. The highest rate was found with the application of Japanese formulae on the Thai population (*c.* 92%), while the lowest when the Chinese standards were tested on the other two groups.

Every population is idiosyncratic with respect to the degree and nature of sexual dimorphism. Hence, the standards developed on one group should not be used on others, unless there is evidence that they have common traits in their skeletal biology (10,12,27). In addition, secular trends that take place within a population may change its metric characteristics and make inappropriate the application of modern standards on an archeological sample (4,16,27).

The results of the present study demonstrate that the bones of the arm are suitable for the determination of sex in Greek skeletal samples. However, caution should be used because the correct classification rates presented are only valid for skeletons of Greek origin and even possibly some neighboring populations of Southeast Europe. If the equations produced by the examination of this sample are applied on a sample of remote geographic origin, the success rate will most likely be much lower. Similarly, it is unknown whether the present standards will be suitable for archeological populations from Greece. A study on an ancient sample where sex has been determined by other methods should be conducted to answer this question.

Another aim of this study was to ascertain whether bilateral asymmetry exists in this skeletal sample. Table 5 indicates that there is no statistically significant asymmetry between the bones of the right and left sides. The only exceptions are the MRL and MUPW of females, where significant bilateral differences were found. Many authors have suggested that asymmetry in the arm bones is caused by the preferential use of one arm for everyday tasks (46–50). The increased apposition of bone tissue on one side is attributed to the greater mechanical stress sustained by the bones of the preferred side because of their increased use. Considering the fact that the vast majority of humans are right-handed regardless of population or sex, it is believed that this asymmetry is directed, not random (47,48). Bilateral asymmetry is a complex issue and some studies have proposed that other factors other than preferential use may be responsible for its existence. Stirland (48) has suggested that the greater robustness of the right side is a condition present at birth for all individuals and some of the bone dimensions are genetically determined. In that study, the absence of asymmetry was attributed to the equal use of both arms, related to occupational activities. This practice is believed to reduce the genetic influence for bilateral asymmetry. However, when a person is engaged in activities that systematically make use of one side the genetic predisposition is strengthened.

This view is supported by another study (46) where the sample was separated into right-handed, left-handed, and bimanual individuals and measured their second metacarpals. The results indicated that in all three groups the bones of the right side were larger than those of the left. It is of interest to note that the right-handed individuals exhibited the greater degree of asymmetry, followed by the bimanual group, while the side difference in left-handed individuals was not found statistically significant. The conclusion of the study was that there is a genetically determined trend for larger bones on the right side. This trend is diminished in individuals who are left-handed, it is present but not significant for bimanual persons and is reinforced in the right-handed group. The present study cannot reach any definite conclusions in regard to bilateral asymmetry because no information on the sidedness of the individuals is available.

However, the lack of sidedness in the Greek sample may be explained by the measurements taken for this project. According to Trinkaus et al. (51), bilateral asymmetry is best observed in the diaphyses and especially their circumference or other cross-section characteristics. It is possible then, that the exclusion of such measurements in the present work is responsible for not finding any significant differences between the bones from the left and right sides. Research on other skeletal elements has demonstrated that preferential use of one arm is best reflected on bones, such as the scapula (47,52,53). The mechanical stress caused by the movements of the upper limb leads to differences in the morphology of the glenoid fossa. Moreover, studies have suggested that the metacarpal bones are affected more than the other skeletal elements of the arm because they are used more in everyday activities (46,49,50).

Conclusions

The results of the present work lead to two observations regarding skeletons of Modern Greek origin. The first is that the population exhibits a high degree of sexual dimorphism. In addition, when the results of this study are compared to those on other populations it becomes apparent that there are differences in the skeletal elements that reflect sexual dimorphism and their specific dimensions (11,12,16,27,32). The marked differences between the two sexes may be attributed to the Mediterranean diet consumed by the population in Greece today and in the recent past. This type of diet contains an intermediate amount of protein, which is a necessary condition for the expression of sexual differences in the skeleton. In addition, during the latter half of the 20th century sexual division of labor was very common, with males engaging in physically demanding activities, while females were mostly homemakers. It is possible that a combination of these two factors may have led to a high degree of sexual dimorphism in the sample examined.

The second conclusion of this study is that no significant bilateral asymmetry was detected for the major bones of the arms in modern Greeks. Other measurements of these bones or dimensions of other skeletal elements may reveal significant differences between the right and left side.

Overall, the data generated by the present investigation suggest that this metric method for the determination of sex in skeletons of Greek origin can be very useful, as it produced correct classification results that reached 96%. However, the application of this method is not recommended for geographically remote populations or archeological samples before further studies confirm their suitability.

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