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Sexual Dimorphism of the Humerus in Contemporary Cretans—A Population-Specific Study and a Review of the Literature*

ABSTRACT: Sex determination is the first essential step for positive identification when a decomposed body is recovered. Taking into consideration the population aspect of sexual dimorphism of the skeleton, the present study aimed to create a sex identification technique using osteometric standards, derived from a contemporary Cretan population. A total of 168 left humeri were measured according to standard osteometric techniques. The differences between the means in males and females were significant ($p < 0.0005$). About 92.3% of cases were correctly classified when all measurements were applied jointly. Stepwise procedure produced an accuracy rate of 92.9%. The most effective single dimension was vertical head diameter (89.9%). The current study provides standards for a population that has not been represented so far in the existing databases. It demonstrates that the humerus is an effective bone for the estimation of sex because even in a fragmentary state it can give high classification accuracy.

KEYWORDS: forensic science, forensic anthropology, humerus, sex identification, Crete, Greece

When decomposed or skeletonized bodies or body parts of unknown identity are recovered, a forensic anthropologist is considered to be the expert in estimating biological identity from skeletal remains using a variety of techniques. It is noteworthy that sex determination is rarely based on any one skeletal feature alone. An expert forensic anthropologist is aware of the range of variation of sexual traits among skeletons and the degree of overlap that normally exists between males and females. As with the estimation of other parameters that lead toward a successful identification of the deceased, as many criteria as available are assessed before coming to a decision. In the medicolegal routine, however, such experts are not always available, especially in Greece where there are no forensic anthropologists. Hence it is imperative to develop rapid and easy techniques performed during autopsy to facilitate the identification procedure of skeletal remains.

Morphological (visual) examination remains the quickest and easiest method of assessing sex in the great majority of unknown skeletal remains, and in experienced hands will result in 95–100% accuracy when the whole skeleton is available (1). Yet, this is rarely the case in forensic investigations. When a skeletonized body is recovered, usually several parts are missing or are broken due to the effect of carnivores and environmental conditions. Furthermore, in mass disasters bones are usually commingled, burned, and broken off, and sometimes identification of sex is based on few components.

Among the bones that are studied to define sex, some are stronger indicators—for instance pelvis—while others are less reliable. When fragmentary patterns are assumed, the identification becomes even more difficult. A contribution from several scholars investigating complete and fragmented long bones concludes that sex assessment is possible but population affinity must be always taken into account (2–4).

Sexual dimorphism in the humerus has been studied intensively and standards have been obtained for several different ethnic groups. In Asia, an Indian population, two Japanese, a Thai, and a Chinese population were studied (5–7). In South Africa, both African Whites and Blacks were studied and compared (8). Standards for North Americans included humeral dimensions, among others, (9) while Latin America is represented by a modern Guatemalan sample (10). In Europe, among the few published studies one should refer to the work of Mall et al. (11) on a German forensic sample as well as the standards obtained from the Coimbra collection in Portugal (12). Some studies are based on archaeological material as is the case with a prehistoric Californian sample (13) and with a sample from Beneville, Canada (14).

Nonetheless, there is a lack of osteometric data in the Balkan area and more specifically in Greece. This phenomenon is most probably attributed to religious and local superstition. The few published studies deal with archaeological material (15,16), while recently some work has been done on cranial (17) and pelvic morphology (18,19). However, no data for long bones are available. As the extent of sexual variation in contemporary Greek populations has so far not been quantified by discriminant function analysis, the present study aimed to create a sex estimation technique using osteometric standards for the humerus, derived from a contemporary Cretan population.

Materials and Methods

The skeletal material for this study was selected from the cemeteries of St. Konstantinos and Pateles, Heraklion, Crete, Greece. According to the Greek burial habit, 3–5 years after burial, the bones are exhumed, cleaned and placed in boxes, and stored in an ossuary. Unless living members of a deceased person can afford to keep them in the tomb with a "rental" fee, skeletons are to be destroyed (20). The authors were given permission by the

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authorized district attorney, according to legal procedure, to analyze a limited number of unearthed remains in order to carry out a population-based investigation. The study population consisted of individuals who were born in Crete between 1867 and 1956, and died between 1968 and 1998. Age and cause of death were obtained from the Heraklion City Hall census archives for only part of the skeletal material, while sex was inferred from the names written on the boxes that contained the remains.

A total of 84 male and 84 female left humeri were measured according to standard osteometric techniques (1,21). Mean age for males was 68.57 ± 13.52 ($n = 61$) and for females 72.98 ± 16.90 ($n = 58$). The following measurements, easily assessed in skeletonized bodies, were taken: maximum length, vertical head diameter, midshaft maximum diameter, midshaft minimum diameter, midshaft circumference, and epicondylar breadth. Standard osteometric equipment was used in order to obtain measurements (1,21). Specimens with known or obvious pathology and trauma were excluded from the study.

Stepwise discriminant function analysis was used (Method: Wilk's lambda with $F = 3.84$ to enter and $F = 2.71$ to remove) to select the combination of variables that best discriminate males and females. Fragmentary patterns were assumed and combinations of selected variables or even single variables were subjected to direct discriminant function analysis to develop sex determination formulae for the humerus.

A leave-one-out classification procedure was applied in order to demonstrate the accuracy rate of the original sample and the one created by cross-validation. This procedure classified all individual bones by applying to each one of them the functions derived from all samples with the exception of one. Posterior probabilities of each individual were also calculated as they reflect the affinity of each case to be reassigned to the original group. Data analysis was carried out using the discriminant function subroutines of SPSS v16.0 (SPSS Inc., Chicago, IL).

Results

Descriptive statistics of six humeral measurements and the associated univariate F ratio to measure the differences between the sexes are shown in Table 1. The differences between the means in males and females were significant ($p < 0.0001$). Table 2 provides various discriminant functions statistics where the sex of an unknown humerus can be estimated. These functions are constructed so that different preservation conditions can be considered to make identification. F value gives an indication of the contribution of each variable entered in the equation to separate the sexes. Unstandardized coefficients indicate the correlation between the variables and the function. Sex can be estimated by multiplying each variable with its raw (unstandardized) coefficient plus adding the constant. The sectioning point for all functions is zero, therefore all scores greater than zero were assigned as male while all scores smaller than zero were assigned as female. Furthermore, Table 2 demonstrates demarking points for single dimensions. For example, a maximum length smaller than 307.4 mm was assigned as female while a length greater than that was assigned as male.

92.3% of cases were correctly classified when all measurements were applied jointly (Table 3). Stepwise discriminant function analysis selected only four dimensions (maximum length, vertical head diameter, midshaft minimum diameter, and epicondylar breadth), producing 92.9% of accuracy. Assuming different fragmentary patterns, multiple functions were generated giving an accuracy rate from 79.2% to 89.9%. The most effective single dimensions as demonstrated by direct discriminant analysis were vertical head diameter (89.9%), followed by minimum midshaft diameter (86.3%), distal breadth (85.1%), and length (85.1%). Crossvalidation procedure results were very close to the original classification in all cases. All classification results and leave-one-out classifications are presented in Table 3.

Figure 1 demonstrates the probability levels of correct group assessment according to the discriminant scores of each individual. For example, if a discriminant score based on the stepwise analysis of humeral dimensions (Function 2) is −2 (x coordinate), the posterior probability of that individual coming from a female group is 95.5% (y coordinate).

TABLE 1—*Descriptive statistics of humeral dimensions (in mm) and univariate* F *ratio of the differences between the sexes.*

	Males (n = 84)		Females (n = 84)		
Variables	Mean	SD	Mean	SD	F ratio*
Maximum length	321.33	14.72	293.44	14.03	157.98
Head vertical diameter	46.38	2.50	41.19	2.37	190.77
Maximum midshaft	22.55	1.64	20.11	1.62	94.04
Minimum midshaft	18.53	1.54	15.78	1.49	138.13
Midshaft circumference	65.93	4.76	58.12	4.36	123.17
Biepicondylar breadth	61.66	3.95	54.40	3.76	149.03

*$p < 0.0001$.

TABLE 2—*Discriminant function statistics,* F *ratios, and statistical significance of humeral dimensions in Cretans.*

Variables Entered*	Exact F	df	Raw Coefficient
F1: Total humerus (direct)			
Maximum length	157.98	1,167	0.028
Head vertical diameter	190.77	1,167	0.168
Maximum midshaft	94.04	1,167	0.168
Minimum midshaft	138.13	1,167	0.267
Midshaft circumference	123.17	1,167	−0.079
Biepicondylar breadth	149.03	1,167	0.068
Constant			−23.325
F2: Total humerus (stepwise)			
Maximum length	190.77	1,166	0.028
Vertical head diameter	126.97	2,165	0.174
Minimum midshaft	94.80	3,164	0.198
Biepicondylar breadth	73.30	4,163	0.060
Constant			−23.123
F3: Distal epiphysis missing (stepwise)			
Vertical head diameter	190.77	1,166	0.290
Minimum midshaft	120.25	1,165	0.326
Constant			−18.279
F4: Proximal epiphysis missing (stepwise)			
Minimum midshaft	149.03	1,166	0.370
Biepicondylar breadth	99.70	1,165	0.161
Constant			−15.671
F5: Midshaft (stepwise)			
Minimum midshaft	138.13	1,166	0.197
Maximum midshaft	73.26	1,165	0.506
Constant			−12.883
			Demarking Point
F6: Maximum length	157.98	1,167	M > 307.39 > F
F7: Vertical head diameter	190.77	1,167	M > 43.79 > F
F8: Maximum midshaft	94.04	1,167	M > 21.33 > F
F9: Minimum midshaft	138.13	1,167	M > 17.15 > F
F10: Midshaft circumference	149.03	1,167	M > 62.02 > F
F11: Biepicondylar breadth	123.17	1,167	M > 58.03 > F

*The sectioning point for all functions is zero, therefore all scores greater than zero are assigned as male while all scores smaller than zero are assigned as female.

TABLE 3—*Classification accuracy on humeral dimensions in Cretan population.*

	Predicted Group Membership					
	Original Group %			Crossvalidated %		
	Males	Females	Total	Males	Females	Total
F1: Total humerus:direct	92.86	91.67	92.30	91.67	90.48	91.10
F2: Total humerus:stepwise	92.86	92.86	92.90	91.67	90.48	91.10
F3: Distal epiphysis missing (stepwise)	88.10	90.48	89.30	88.10	90.48	89.30
F4: Proximal epiphysis missing (stepwise)	85.71	88.10	86.90	85.71	88.10	86.90
F5: Midshaft (stepwise)	78.57	88.10	83.30	78.57	86.90	82.70
F6: Maximum length	88.10	82.14	85.10	88.10	82.14	85.10
F7: Vertical head diameter	90.48	89.29	89.90	90.48	89.29	89.90
F8: Maximum midshaft diameter	77.38	80.95	79.20	77.38	80.95	79.20
F9: Minimum midshaft diameter	84.52	88.10	86.30	84.52	88.10	86.30
F10: Midshaft circumference	75.00	88.10	81.50	75.00	88.10	81.50
F11: Biepicondylar breadth	84.52	85.71	85.10	84.52	85.71	85.10

Table 4 shows the variables selected by the stepwise discriminant function analysis, the best discriminatory variable for group assessment, and the percentage of accuracy for several different populations (6–8,10–12) as well as for Cretans.

Discussion

Almost every bone in the human skeleton has been used for sex identification purposes, yielding different accuracy rates. The humerus is often recovered from crime scenes; thus it constitutes a reliable material for sex identification in forensic and archaeological cases. The results of this study indicated a high discriminatory value of the humerus in sex estimation, which concurred with several previous studies (8,10,11).

Given that osteometric methods for sex identification are population-specific, many researchers from around the world have conducted studies on the humerus, establishing specific standards of group assessment for several different populations (5–14). An interesting point to note is that most of the earlier studies suggest that epiphyseal breadth and circumferential measurements are better sex discriminators than length (22–24), while in the present study length was selected by the stepwise procedure (Table 4). The same observation was made in the study of the Chinese (6) and German (11) populations, while in the Guatemalan sample, a high eigenvalue of length among the other dimensions was observed, which indicated that this was a valuable discriminating factor despite its low percentage of accuracy (10). A similar result was produced when stepwise discriminant analysis was applied to cranial data of the same population; length was included among the selected variables indicating a higher discriminatory value of this variable in Cretans when compared with other populations (17).

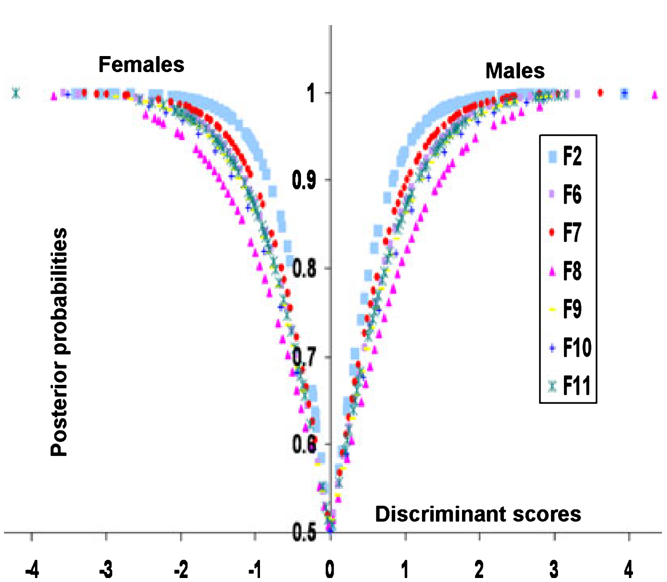

FIG. 1—*Probability levels of correct sexing according to the discriminant scores of each individual for functions 2, 6–11.*

Furthermore, minimum midshaft diameter seemed to have a high discriminatory value for the present population as it was not only selected by the stepwise procedure but also proved to be a very effective single variable with a classification accuracy of 86.7%. Interestingly, minimum midshaft diameter was highly significant in sex determination for the Guatemalan, Japanese, and Thai populations (6,10). These remarks are only to confirm the already known population-specific affinities concerning sexual dimorphism of the skeleton (3,4).

The current study addresses standards for sex estimation of humeral dimensions for contemporary Cretans, a population that has not been represented so far in the existing databases. It is demonstrated that the humerus is an effective bone in the identification of sex for forensic purposes because even in a fragmentary state it can give high classification accuracy. Interestingly, the humerus exhibits higher sexual dimorphism than the skull (88.2%) (17) or femur (91.1%) (25) in the same population.

Naturally, questions concerning the applicability of this method to other Greek and Balkan populations arise. As for the Balkans, recent analysis of sexual dimorphism of the femur revealed size differences of the femoral head and the total length among three groups (Croatians, Bosnians, and Kosovars) (26), suggesting that a population-specific methodology is required for each region (26,27). Furthermore, studies on craniofacial variation reveal significant differences even between populations which share common Slav ancestry, such as Bosnians and Croatians (28). A number of Greeks ($n = 14$) included in the study were found to be the furthest removed from the rest of the Balkan groups and closer to the American Whites (28).

The few published data on modern Greeks are restricted to a few studies on skull (17) and pelvis morphology (18,19). Papaloucas et al. (19) measured four dimensions on the pelvis and femur of a sample from Athens. They found slightly higher mean values for the acetabular diameter for both males and females when compared with Steyn and Iscan on Cretans (18). Femoral head diameter in the Athens collection was found to be higher in males (mean: 48.5 ± 2.3 mm) and lower in females (mean: 41.6 ± 1.9 mm) as compared to the Cretans (males: 47.1 ± 2.7 mm, $n = 53$, females 42.3 ± 2.2 mm, $n = 50$) (25). It must be emphasized, however, that Papaloucas et al. (19) measured right femora and pelvises, while data for Cretans were obtained from the left side (25). Nonetheless, the means on the two dimensions that we were able to compare do not differ tremendously between the two populations, implying that standards on Cretans can be applicable to other Greeks. Obviously, more comparative data are needed to test this hypothesis.

Lately, there has been a great deal of discussion on secular changes (29–31). Studies in the United States detected secular changes on long bones in a time interval of 170 years (29). It is noteworthy that secular trends in Americans are found to be more pronounced in lower limbs compared with upper limbs, and in distal bones when compared with proximal ones (29).

TABLE 4—*Variables selected by the stepwise discriminant function analysis, the best discriminatory variable for group assessment, and the percentage of accuracy for Cretans and several different populations.*

Population	n	Step	Variables Selected	Accuracy %	Best Variable	Accuracy %	Reference
Portuguese	154	1	Transversal diameter of the head	94.1	Vertical head diameter	89.0	(12)
		2	Epicondylar breadth				
Africans Whites	104	1	Epicondylar breadth	92.5	Epicondylar breadth	94.7	(8)
		2	Vertical head diameter				
Africans Blacks	88	1	Vertical head diameter	93.1	Vertical head diameter	96.0	
		2	Maximum length				
Chinese	82	1	Maximum length	86.8	Vertical head diameter	80.5	(6)
		2	Vertical head diameter				
		3	Epicondylar breadth				
		4	Midshaft circumference				
Japanese	79	1	Epicondylar breadth	92.4	Epicondylar breadth	89.9	
		2	Vertical head diameter				
		3	Minimum midshaft diameter				
		4	Midshaft circumference				
Thais	104	1	Epicondylar breadth	97.1	Epicondylar breadth	93.3	
		2	Vertical head diameter				
		3	Minimum midshaft diameter				
Japanese	64	1	Width of the distal articular surface	97	Width of the distal articular surface	95	(7)
		2	Epicondylar breadth				
Guatemalans	118	1	Maximum head diameter	98.5	Maximum head diameter	95.5	(10)
		2	Minimum midshaft diameter				
		3	Epicondylar breadth				
Germans	143	1	Maximum length	93.2	Vertical head diameter	90.4	(11)
		2	Vertical head diameter				
		3	Epicondylar breadth				
Cretans	178	1	Maximum length	92.9	Vertical head diameter	89.9	
		2	Vertical head diameter				
		3	Minimum midshaft diameter				
		4	Epicondylar breadth				

Consequently, the humerus exhibited high resistance on short-time secular changes. Notwithstanding the lack of similar studies on modern Greeks, the osteometric data derived from twentieth-century Cretans are expected to be applicable to the current population of Crete. Additional research is obviously needed to define the biological characteristics of other Greek subgroups from the mainland and the islands. Comparative data can provide the scientific proof of whether the metric standards produced in this study can be reliable for the rest of Greece.

The recovery of fragmentary and pathological skeletal remains in forensic investigations requires easy and rapid techniques for biological profiling and reconstruction of the scene history. Simple measurements performed during autopsy can provide an immediate and accurate prediction of sex, thus contributing significantly to positive identification in forensic cases. There is no doubt that population differences affect the sexual dimorphism reflected in the humeral dimensions. Hence, a specific standard for sex estimation in a modern Cretan population is addressed here. The results of this study demonstrate that the humerus is an effective bone for the identification of sex for forensic purposes because even in a fragmentary state it can give high classification accuracy. Naturally, additional research is required to test the applicability of this technique in other Greek and Balkan populations.

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