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Discriminant Function Sexing of Fragmentary and Complete Femora: Standards for Contemporary Croatia*

ABSTRACT: Determining sex is one of the first and most important steps in identifying decomposed corpses or skeletal remains. Previous studies have demonstrated that populations differ from each other in size and proportion and that these differences can affect metric assessment of sex. This paper establishes standards for determining sex from fragmentary and complete femurs in a modern Croatian population. The sample is composed of 195 femora (104 male and 91 female) from positively identified victims of the 1991 War in Croatia. Six discriminant functions were generated, one using seven variables, three using two variables, and two employing one variable. Results show that complete femora can be sexed with 94.4% accuracy. The same overall accuracy, with slight differences in male/female accuracy, was achieved using a combination of two variables defining the epiphyses, and with the variable maximum diameter of the femoral head.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, sex determination, discriminant functions, femur, positive identification, Croatia

The 1991 conflict between Croatia and Serbia, which followed the dissolution of the former Yugoslavia, caused extensive material destruction and loss of life. From 1991 to 1995 there were more than 14 000 war-related deaths in Croatia. A specific feature of this conflict was executions and mass burial of civilians. To deal with this humanitarian crisis, the Croatian government formed the Committee for Imprisoned and Missing Individuals. Collaborating closely with law enforcement and medico-legal communities in Croatia, the Committee, from 1993 to the present, recovered 3328 individuals from 131 mass graves and from a large number of individual graves. The number of individuals recovered from mass graves, defined as graves containing three or more individuals, is 2017. At present, 1385 individuals are unidentified or still missing. To identify and determine the cause of death of these individuals, a joint U.S.-Croatia forensic anthropology project was developed. In this project, forensic anthropologists from the Croatian Academy of Sciences and Arts and the Department of Forensic Medicine at the School of Medicine, University of Zagreb, together with forensic anthropologists from the Smithsonian Institution, Washington, D.C., and the University of Tennessee in Knoxville developed a forensic anthropology database in which data were collected on age, sex, stature, metric characteristics, osteological and dental pathology, and on perimortem trauma and possible cause of death. The purpose of this database, modeled on the forensic database developed at the University of Tennessee, was to: (1) identify a basic and standard set of measurements, observations, and definitions to ensure that data are comparable; (2) store the data in a computer in such a way that particular subsets can be quickly accessed, and (3) provide up-to-date discriminant formulae for determining sex, estimating stature, and defining other traits useful for comparative research and forensic analysis. This paper reports on one of these objectives—determination of sex by discriminant function analysis of the femur.

Determining sex is one of the first and most important steps in identifying decomposed corpses or skeletal remains. Because a complete pelvis is not always present, it is important to be able to determine sex from other skeletal elements. To date, almost all bones have been used in determining the sex of an individual through statistical analysis (1–4). Special emphasis has been given to long bones, particularly the femur, as this is the largest bone in the human skeleton and thus most likely to remain preserved. Studies have been conducted on North American blacks and whites (5–7), American Indians (8,9), European whites (10–16), Africans (17,18), Indians (19), Thai (20), Japanese (21), and Chinese (22–25). These studies have two common conclusions. The first is that in most population breadth and circumference dimensions tend to be more dimorphic than those of length. The second is that there are significant size differences between populations and that therefore all discriminant formulae for determining sex are population-specific. So far, no metric analyses of sexual dimorphism in the femur of modern Croatians have been published. Discriminant function analyses for sex assessment have been applied to 160 femora from four medieval sites in continental Croatia (14). The sites were in use from the seventh to the fourteenth century and are not representative of modern Croatians. The purpose of this paper is to conduct a discriminant function analysis of sexual dimorphism in the modern Croatian femur and to establish standards for this population that will facilitate future identifications.

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Materials and Methods

The analyzed sample consists of 195 femora (104 male and 91 female) from positively identified victims of the 1991 War in Croatia. Positive identification was achieved using a variety of methods including DNA analysis, dental records, and antemortem X-rays. All socioeconomic categories are represented in the sample. The mean age of the male individuals was 42.6 years (ranging from 18 to 82) and for females 51.0 years (29 to 80).

The following seven standard femoral dimensions were used in the analysis:

1. *Maximum length*—maximum length from the head of the femur to the medial condyle.
2. *Epicondylar breadth*—the distance between the two most laterally projecting points on the epicondyles.
3. *Maximum diameter of the femoral head*—the maximum diameter of the femur head measured on the border of the articular surface.
4. *Sagittal subtrochanteric diameter*—the anterio-posterior diameter of the proximal diaphysis measured 5 cm below the highest point of the lesser trochanter.
5. *Transverse subtrochanteric diameter*—the transverse diameter of the proximal diaphysis measured 5 cm below the highest point of the lesser trochanter.
6. *Sagittal diameter of the femur at midshaft*—the anterio-posterior diameter measured at the midpoint of the diaphysis.
7. *Transverse diameter of the femur at midshaft*—the transverse diameter measured at the midpoint of the diaphysis.

Maximum length and epicondylar breadth were measured with an osteometric board, the other dimensions with a Sylvac digital caliper with a precision of 0.01 mm. Measurements were taken from the left side whenever possible. Each variable was measured three times by the same author, using the mean value to reduce intraobserver error. Specimens with obvious gross pathological lesions and perimortem damage were excluded.

Sexual dimorphism was analyzed using univariate statistics with the Index $Mm/Mf \times 100$, where Mm is the average for males and Mf is the average for females. The multivariate statistics were performed using the DISCRIMINANT procedure of the statistical package Statgraphics 4.0.

Results

Table 1 shows the descriptive statistics for both sexes. The index of dimorphism is always greater than 100, indicating that males, as expected, have greater femoral dimensions. The highest value of the index is seen in the maximum diameter of the femoral head, which has a difference higher than 17%, while the lowest values are recorded in the midshaft and subtrochanteric transverse diameters of the femur (5.0 and 5.3%, respectively). The F-ratios for all variables indicate that the differences are statistically significant ($P < 0.0001$). The standard deviations suggest that males exhibit more variation than females. These results indicate strong sexual dimorphism in the analyzed sample and presuppose that the variables are useful in evaluating morphological differences between sexes. The variance-covariance matrix is presented in Table 2.

TABLE 1—*Sexual dimorphism and univariate statistics of the femur in the analyzed sample.*

	Males			Females			Sexual Dimorphism		
Variable	*N*	*M*	SD	*N*	*M*	SD	Index	*F*	Sig.
Max length	104	469.61	22.80	91	439.36	16.25	106.88	110.80	0.00001
Epicond. br.	104	86.72	4.36	91	75.17	4.10	115.35	359.39	0.00001
Max head dia	104	49.17	2.97	91	41.74	1.79	117.79	430.41	0.00001
A-P subtr. dia	104	28.88	2.33	91	25.87	2.24	111.63	84.30	0.00001
Trans.subtr. dia	104	32.09	2.48	91	30.47	1.95	105.32	24.93	0.00001
A-P midsh. dia	104	30.84	2.71	91	26.80	2.22	115.09	127.65	0.00001
Trans. midsh. dia	104	28.80	2.20	91	27.42	2.14	105.03	16.01	0.0001

TABLE 2—*The variance-covariance matrix.*

	Max Length	Epicond. Br.	Max Head Dia	A-P Subtr. Dia	Trans.subtr. Dia	A-P Midsh. Dia	Trans. Midsh. Dia
Max length	400.631						
Epicond. br.	33.7190	18.0005					
Max head dia	17.5618	5.72053	6.21799				
A-P subtr. dia	13.9877	4.22157	1.38365	5.23851			
Trans.subtr. dia	3.41945	1.58523	1.34358	0.48036	5.07203		
A-P midsh. dia	22.2447	4.42851	2.02186	2.82270	0.24295	6.21750	
Trans. midsh. dia	4.97897	2.26147	0.53492	1.45900	2.78685	0.49889	5.77664

TABLE 3—*Discriminant function analysis with all seven variables.*

Disc. Function	Eigenvalue	Cannonical Correlation	Wilks λ	χ^2	DF	Sig. Level
1	2.6941	0.8539	0.2707	247.63	7	0.00001

Table 3 shows the results of the discriminant function analysis when all seven variables are used. The posterior probability of group memberships, standardized and unstandardized discriminant function coefficients, are shown in Table 4. Standardized coefficients indicate the relative contribution of each variable to the function. In this sample, the maximum diameter of the femoral head makes the greatest contribution to the function, followed by epicondylar breadth and sagittal midshaft diameter. Sagittal subtrochanteric diameter and maximum length contribute the least. Unstandardized coefficients are used for calculating discriminant function scores from the raw data. A discriminant score is obtained by multiplying each variable with its unstandardized coefficient and adding them together along with the constant. If the score is greater than zero, the individual is considered male; a score lower than zero indicates a female. The posterior probability of group membership for a case at the centroid quantifies the relationship between the discriminant score and classification accuracy. This statistic makes more sense than giving group centroids because now the female centroid is just the negative of the male. Further, the posterior probability is more interpretable and can be converted to the centroid if need be with the formula: centroid $= -\ln(1/p - 1)$.

TABLE 4—*Standardized and unstandardized discriminant function coefficients and posterior probability of group memberships when all seven variables are used.*

Variable in Function 1	Standardized Coefficient	Unstandardized Coefficient
Max length	0.02037	0.003370
Epicond. br.	0.43629	0.337158
Max head dia	0.63954	0.839826
A-P subtr. dia	0.00092	−0.000522
Trans.subtr. dia	−0.02455	−0.034304
A-P midsh. dia	0.09441	0.123464
Trans. midsh. dia	0.02407	0.032249
Constant		−70.374603
Posterior probabilty		0.995326

TABLE 5—*Standardized and unstandardized discriminant function coefficients, and posterior probability of group memberships for Functions 2 to 6.*

Functions and Variables	Standardized Coefficient	Unstandardized Coefficient
2. Max head dia	0.65354	0.854413
Epicond. br.	0.48194	0.370118
Constant		−68.79652
Posterior probability		0.995090
3. Epicond. br.	0.97861	0.630885
Trans.subtr. dia	0.09973	0.122220
Constant		−54.890053
Posterior probability		0.976851
4. Epicond. br.	0.97195	0.625020
A-P subtr. dia	0.06104	0.070905
Constant		−52.533252
Posterior probability		0.976252
5. Max head dia		1.194920
Constant		−54.315084
Posterior probability		0.988332
Demarking point (mm)		Females < 45.45 < Males
6. Epicond. br.		0.641649
Constant		−51.938266
Posterior probability		0.976003
Demarking point (mm)		Females < 80.94 < Males

Because the recovered skeletal remains from the 1991 War in Croatia frequently exhibit perimortem or postmortem damage, several discriminant functions were generated to determine sex from fragmentary femoral remains. Five discriminant functions (Functions 2 to 6) were calculated, three employing two variables, and two using a single variable (Table 5). When a single variable is used (Functions 5 and 6), two approaches are possible. Unstandardized coefficients are provided to calculate a discriminant score, but it is easier to compare the dimensions of the analyzed specimen to a demarking point. The demarking point is the simple average of the means for each sex. A higher value indicates a male, a lower value a female.

Reclassification of the cases used to develop the functions shows that with fully preserved femora in which all seven variables can be measured, the overall accuracy for both sexes is 94.4% (Table 6). The same overall accuracy with slight differences in accuracy obtained for males and females is obtained with the single variable maximum diameter of the femoral head and, with a combination of two variables, maximum diameter of the femoral head and epicondylar breadth. Good overall separation is also provided by a combination of the variables epicondylar breadth and transverse subtrochanteric diameter (93.3%), with epicondylar breadth and sagittal subtrochanteric diameter (91.8%), and with the single variable epicondylar breadth (91.3%).

Discussion

To deal with the large number of unidentified victims from the 1991 War in Croatia, a joint U.S.-Croatia forensic anthropology project was developed. Because skeletal biologists have long recognized that each population group requires its own specific standards for accurate determination of sex, an important part of this project was collecting measurements from various skeletal elements. Osteometric analysis, with the use of discriminant function statistics, has become one of the most common ways of determining sex in unidentified remains. There are two main reasons for

TABLE 6—*Sexing accuracy for Functions 1 to 6.*

		Males			Females	
Functions and Variables	*N*	%	*N**	%	*N**	Average
1. Function (all seven variables)	195	93.3	97/104	95.6	87/91	94.4
2. Function (Max. head dia. and Epicond. br.)	195	92.3	96/104	96.7	88/91	94.4
3. Function (Epicond. br. and Trans.subtr. dia.)	195	90.4	94/104	96.7	88/91	93.3
4. Function (Epicond. br. and A-P subtr. dia.)	195	91.3	95/104	92.3	84/91	91.8
5. Function (Max. head dia.)	195	94.2	98/104	94.5	86/91	94.4
6. Function (Epicond. br.)	195	93.3	97/104	89.0	81/91	91.3

*N** = Ratio of cases correctly classified by a given function.

this. First, it reduces the subjective criterion for sexual determination by discrete characters, and, second, it is relatively simple to use and avoids the necessity of having previous experience in this type of analysis. The most serious problems in applying it may arise from small sample size and skewed distribution of the sexes. Therefore, all attempts were made to collect measurements from all intact skeletal remains.

The results of this study show that the Croatian femur is a good skeletal component from which to determine sex, with classification accuracy reaching 94.4%. This overall accuracy is achieved with three functions, one using all seven variables, one using a combination of two variables, maximum head diameter and epicondylar breadth, and one using only one variable, maximum head diameter. Slight differences in male/female accuracy are present in the three functions. Females are most accurately sexed with the function using maximum head diameter and epicondylar breadth (96.7%), while males are most accurately sexed by using just maximum head diameter (94.2%). The most noticeable gap in accuracy between the sexes is present in the Function 3, which uses epicondylar breadth and transverse subtrochanteric diameter. In females, accuracy with this function is as high as that achieved with maximum head diameter and epicondylar breadth (96.7%), while, in males, accuracy is just 90.4%, the lowest in all six functions developed. Differences in accuracy between the sexes can result from a number of factors including variation in sample size and intrasex variability.

Values of the standardized coefficients of the discriminant functions generated in this study are consistent with the results of previous studies of long bones in different populations that found that breadth dimensions provide better separation of the sexes than length. In the present study, maximum length of the femur has the second lowest standardized coefficient, and only sagittal subtrochanteric diameter contributes less to the first function. When calculating functions to determine sex from fragmentary femoral remains, maximum length contributed so little that it was not included in any of the generated functions. Black (8) believes that this is caused by differential bone remodeling between males and females that leads to greater cortical bone development in males during adolescence that remains unchanged throughout adulthood. This differential cortical bone development primarily affects breadth and circumference measurements. DiBennardo and Taylor (5) and Macho (17) suggest that epiphyseal measurements and midshaft circumference are more reliable indicators of sex because the functional demands of weight and musculature concentrate on these parts of the bone.

As human skeletal remains from forensic contexts are usually not complete, it is necessary to have sex determination techniques applicable to various parts of the body. This paper provides such standards for the modern Croatian population using the dimensions of the femur. The results obtained permit accurate diagnosis of sex from complete and fragmentary femora and thus constitute an important tool for forensic specialists involved in the ongoing identification of victims of the 1991 War in Croatia.

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