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Sexual Determination of the Femur Using Discriminant Functions. Analysis of a Spanish Population of Known Sex and Age

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ABSTRACT: Until present, functions for sexual discrimination of a Spanish population from series of known sex and age were not available. In this work, we present a sample of 132 femora (72 females and 60 males) belonging to a Spanish population of adult individuals of known filiation deposited in the Complutense University of Madrid. The ten mathematical functions which yield a higher sexual discrimination in each part of the femur, were selected. The resulting percentages of correspondence varied between 84 and 97% when each variable was considered independently, and a 99% is obtained with two variables of the epiphyses combined.

KEYWORDS: forensic science, forensic anthropology, sex determination, femur, discriminant functions, Spain

Biological anthropology is always seeking accurate methods and techniques in order to determine the sex of osseus remains. Therefore, the study of sexual dimorphism in human populations has been a matter of interest for anthropologists and forensic scientists. There are at least two reasons for this interest: Sexual determination is critical for individual identification and also, it is essential in the analysis of the way of life of ancient human populations.

Almost all bones have been used in determining the sex of an individual through statistical analysis (1–4). It can be said that predictions reach 100% of correspondence if well-preserved skeletons are available. However, anatomical structures that permit us an accurate visual sexual determination are not always available (5). Therefore, it has been necessary to elaborate multifactorial methods on the basis of skeletal structures that allow to sex individuals accurately. Sometimes, the use of discriminant functions based on several variables does not improve significantly the prediction obtained using a single variable. Also, in conditions of fragmentation, it would be desirable to use mathematical techniques that require only few variables, although the decrease in number can limit the reliability of these methods.

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There are functions for the postcranial skeleton based on quantitative variables of world-wide use. However, none of the equations was elaborated using Spanish series of known sex and age. Besides, most discriminant functions for the sexual diagnosis of the femur are based on the study of well-preserved remains, and this is not the usual condition of archaeological or forensic remains. Sexual determination depends on the anatomical area preserved and on the degree of preservation, which varies greatly between anatomical zones. For this reason, it is important to elaborate different equations which could be used alternatively in case of the fragmentation of human remains.

Given the tubular structure of long bones, they are often better preserved than other bones. Consequently, a number of authors (6–9) have suggested the analysis of the diaphysis of bones of the extremities, considering the circumference at mid-shaft as a good indicator of sexual dimorphism. However, although this measurement is useful, we consider it a problematic one because it is difficult to obtain if the material is fragmented (10).

Previous works have shown some limitations in the applicability of the functions (6,11–17). They consider that the formulae cannot be applied to other populations if there are large differences in size or in sexual dimorphism. However, until the present work, there were not any functions elaborated with Spanish series of known sex and age and the researchers worked applying, essentially, equations based on series on North America (Terry and Hamman-Todd Collections) or European (Coimbra and Bolonia) series.

From the above, it is deduced that it is necessary to develop equations from skeletal parts often preserved using Spanish populations of known sex and age. The first aim of this work is to obtain mathematical functions to be applied to fragmentary archaeological or forensic material. The second aim is to obtain discriminant functions based on the least number of variables that, simultaneously, permit us the highest reliability in the sexual determination of fragmented remains.

Material and Methods

The analyzed sample consists of 132 femora (60 males and 72 females, 66 right and 66 left of different individuals) corresponding to a series of known affiliation deposited in the Universidad Complutense (UCM), with a range of age varying between 34 and 97 years.

Name, family name, date of birth, date of death, and cause of death are known. The sample consists of individuals recently exhumed (1991) from a cemetery of Madrid (Spain). The affiliation is known from the records of the cemetery. All socioeconomic levels are represented. The range of birth dates of the individuals varies from 1880 to 1945. The anthropological study was based on a total of 18 variables, 10 quantitative, and 8 qualitative. Both epiphyses and shaft were analyzed. In this work, we consider the dimensions at subtrochanteric level to be able to measure fragmented femora whose mid-shaft dimensions cannot be evaluated. Five variables were used: The vertical (DVERTCAB) (M18) and horizontal (DHORICAB) (M19) head diameters; anteroposterior (DANTPOST) (M10) and transversal (DTRANSVT) (M9) subtrochanteric diameters, and the distal epicondylar breadth (ANCHEPIF) (M21). Each measurement was obtained by one of the authors using a Sylvac digital caliper, with precision 0.01 mm, following the protocol defined by Martin and Saller (18). The subtrochanteric diameters were measured 5 cm below the highest point of the lesser trochanter. Each variable was measured three times by the same author, using the mean value to reduce the intraobserver bias.

The sexual dimorphism was analyzed using unifactorial statistics with the Index 100 × Mm/Mf. Mm is the average for males and Mf is the average for females. The multifactorial statistics were performed using the DSCRIMINANT procedure of the statistical package SPSS 3.0. The criterion of selection used was METHOD = MAHALANOBIS, with a level of significance of 0.05. The misclassification probability of the femur discriminant functions for sexing Spanish series was evaluated using a resubstitution procedure.

Results

Table 1 shows the descriptive statistics for both sexes obtained in the series of the UCM. The index of dimorphism is always significantly higher than 100, so males, as expected, have greater femoral dimensions. The highest value of the index is seen in the anteroposterior subtrochanteric diameter, with a difference higher than 16%, whereas the transversal diameter has the lowest value (9%). These results demonstrate the existence of a strong sexual dimorphism in the osteological series analyzed and presuppose that the variables are useful in evaluating morphological differences between sexes.

After evaluating the existence of a strong sexual dimorphism, several discriminant functions were obtained from the three anatomical areas of the femur in relation of their possible different grades of preservation. First, functions based on a single variable in order to get the highest applicability were obtained.

Table 2 shows the coefficients of the discriminant functions obtained for the five variables considered as well as the sectioning points. Their methodological application is very simple: It is only

TABLE 1—*Sexual dimorphism and unifactorial statistics of the femur in the analyzed series.*

Collection UCM	Males			Females			Sexual Dimorphism		
	n	m	sd	n	m	sd	Index	F	Sig.
Dvertcab	52	47.15	2.46	62	41.13	1.93	114.64	214.25	0.001
Dhoricab	54	46.55	2.35	60	40.39	1.92	115.25	235.80	0.001
Dantpost	60	27.70	2.24	72	23.71	1.95	116.83	119.92	0.001
Dtransvt	60	30.71	1.85	72	28.14	2.10	109.13	54.34	0.001
Anchepif	55	80.60	2.99	68	70.82	2.36	113.81	410.29	0.001

necessary to substitute the value of the variable in the function and to compare the result obtained with the sectioning point. Values above the tabular value will be diagnosed as males, and values below that point will be females.

The probability of correspondence in the sexual determination of each variable is different. The results obtained with the series of the UCM are shown in Table 3. The percentage of concurrence is represented in the sample analyzed, together with the percentage of male and female femora whose sexes were assigned incorrectly. Clearly, the results obtained point out that the variables of the epiphyses permit the most reliable diagnosis in relation to sexual determination. The dimensions of the diaphysis do not reach, in the present study, 90% of positive correspondence. The highest rate (next to 98%) was obtained with Function 5 which is based on the distal epicondylar breadth, whereas the lowest value (near 74%) was detected in the Function 4 defined by the transversal subtrochanteric diameter.

Similarly, the probability of assigning a wrong sex is not the same if males and females series are analyzed separately (Table 3). The first three functions show an excess of male cases diagnosed as females. The two last ones offer the opposite result, there are more male diagnoses, of female femora. The Function 2 is the most balanced in the distribution of misclassifications (1.48:1), whereas Function 1 shows a rate almost twice high (2.81:1).

Occasionally, when long bone are particularly well preserved, sexual diagnosis can be attempted on the basis of the use of functions composed of more than one quantitative variable. Actually, functions are sought to reduce the uncertainty of the sexual determination without complicating their use or decrease the sample size. Hence, several functions, based on the combination of two of the analyzed variables, were obtained. The new functions should improve the percentage of correspondence obtained with only one of the two variables. If this is not true, it would be more useful to apply the function using only one variable.

Following these premises, five new functions were obtained (Table 4). The distal epicondylar breadth which was the variable that permitted the best sexual discrimination, appears in the first three functions. In the same way, the transversal subtrochanteric diameter is in three equations, twice combined with dimensions of both epiphyses and once with the measure of the diaphysis. The rest of possible combinations do not increase the percentage of correspondence obtained with the individual equations and are therefore not included.

Once these discriminant functions were obtained, it seemed important to show the increase in the correspondence in the sexual determination. Functions 6 and 7 (Table 5) classify 99% correctly.

When these equations are used, wrong determinations are only detected in male femora, because they can be sexed as females. The Function 8 represents the opposite situation, with a total percentage slightly lower than preceding ones, the misclassifications are produced with female femora. Worse results are offered by Functions 9 and 10, and in both cases, the male femora are sexed with lower reliability. The increase of correct determinations between the equations formed by one or two variables is 1.51% in the distal epiphysis and 1.52% in the diaphysis. There is no improvement in the proximal epiphysis.

Discussion

The morphological differences between both sexes can be the result of genetic factors, environmental factors affecting growth and development (nutrition, physical activity, pathologies, etc.),

TABLE 2—*Coefficients and sectioning points of the functions of the femur, based on one variable. Individuals with a score on a discriminant function greater than 0.0 are classified as males; those with a score less than 0.0 are classified as females; those with a score equal to 0.0 are unclassified.*

Variables	Discriminant Functions	Sectioning Points	Male if
1. Vertical diameter head	0.4572 × Dvertcab − 20.1776	0	>44.133
2. Transverse diameter head	0.4681 × Dhoricab − 20.3496	0	>43.473
3. AP. subtrochanteric diam.	0.4792 × Dantpost − 12.3172	0	>25.704
4. Transv. subtrochanteric diam.	0.5017 × Dtransvt − 14.7629	0	>29.426
5. Epicondylar breadth	0.3757 × Anchepif − 28.4475	0	>75.719

TABLE 3—*Classification accuracy of the discriminant functions from the femur based on one variable.*

Variables	Cases	Correspondence	No Correspondence Male	Female
1. Vertical diameter head	114	91.23%	13.5%	4.8%
2. Transverse diameter head	114	93.86%	7.4%	5.0%
3. AP. Subtrochanteric diam.	132	84.09%	21.7%	11.1%
4. Transv. subtrochanteric diam.	132	74.24%	20.0%	30.6%
5. Epicondylar breadth	123	97.56%	1.8%	2.9%

and the interaction of previous factors. It is well known (4) that the sexual dimorphism of long bones is related to differences in body size and in muscular activity of the individual. Cortical bone in males has a higher growth than in females, therefore the circumference of long bones increases more in males than in females after puberty (6). Although these differences are logically higher in the forelimb, it is obvious that the results from the unifactorial analysis here performed, show a higher development of the femur of the male series in each analyzed variable. This is the expected result because males show larger body sizes, on average, in all human populations.

More information is offered by the multifactorial analysis performed to obtain the first mathematical equations of known sex and age from Spanish populations. Actually, the use of discriminant functions at least presents two advantages. It permits us, first, to reduce the subjective criterion of sexual determination by discrete characters and, second, to avoid the necessity of having previous experience in this kind of analysis, mainly when the morphological characteristics of the sample are not well known.

The analytical procedure is supported by the assumption that both sexes produce a bimodal distribution for each variable. In function of the degree of overlap of the distributions, the considered variable will be useful or not, in the diagnosis. The most interesting variables, from an applied point of view, will be those offering a full correspondence between the estimated and the real sex. However, it is logical to think that a correct classification of 100% never is practically reached, because this would mean that the distributions of both sexes do not overlap, something really uncommon, excepting when dimorphism is extreme.

Richman et al. (19) showed in 1979 that neither the observer, nor the laterality of the individual, affects the multifactorial study of the bones of the hindlimb. Therefore, it is not necessary to evaluate separately osseus remains of both left and right sides. However, the situation seems to differ if the study is made with the bones of the forelimb, especially if metacarpals are considered, due to the strong laterality of the manual activity (20).

Another methodological factor to consider is that the technically useful variables in sexual determination depend on the preserved area of skeletal material. The grade of preservation varies greatly from some anatomical zones to others, even from some skeletal series to others, in function of several taphonomic factors. Hence, the importance of obtaining mathematical functions that permit us to estimate the sex in all kinds of fragmentary remains is evident. Given the different preservation of epiphysis and diaphysis, it is logical to elaborate discriminant functions that permit us to accomplish the sexual diagnosis on the basis of well preserved osseus remains. We do not consider, in this work, to evaluate variables such as maximum length or the circumference at midshaft, because they are difficult to obtain if both extremes are not preserved. Dittrick and Suchey (21) have suggested that is relatively more frequent to find epiphyses of fragmented long bones susceptible to be measured than diaphysis, and our experience in archaeological sites agree with this observation.

With these antecedents, it was necessary to develop functions supported by this type of skeletal portions. Dimensions of both epiphyses were chosen to facilitate the choice of the equations in function of the sample, and subtrochanteric because were evaluated, as a measure of the development of the diaphysis, because if the femur is fragmented, this zone is easy to measure. The initial discriminant analysis was performed accepting that functions

TABLE 4—*Coefficients and sectioning points of the functions from the femur, based on two variables. Individuals with a score on a discriminant function greater than 0.0 are classified as males; those with a score less than 0.0 are classified as females; those with a score equal to 0.0 are unclassified.*

Functions	Discriminant Functions	Sectioning Points
Function 6	0.1395 × Dvertcab + 0.3341 × Anchepif − 31.4207	0
Function 7	0.1847 × Dhoricab + 0.3004 × Anchepif − 30.7075	0
Function 8	0.1186 × Dantpost + 0.3356 × Anchepif − 28.4691	0
Function 9	0.3652 × Dvertcab + 0.2161 × Dantpost − 21.6439	0
Function 10	0.2186 × Dtransvt + 0.3890 × Dantpost − 16.4310	0

TABLE 5—*Classification accuracy of the discriminant functions from the femur based on two variables.*

Functions	Cases	Correspondence	No Correspondence Male	No Correspondence Female
Function 6	107	99.07%	2.1%	0.0%
Function 7	106	99.06%	2.0%	0.0%
Function 8	123	98.37%	0.0%	2.9%
Function 9	114	92.11%	9.6%	6.5%
Function 10	132	85.61%	15.0%	13.9%

composed by a single variable are, due to their simplicity, the most useful ones both in field work and in the laboratory. It is only necessary to obtain one dimension and to contrast the numerical datum with a tabular value previously elaborated.

In the present series, the functions that offer the highest correspondence between the real and estimated sex correspond to both epiphyses, especially to the distal one. In a Bolonian series of sex and age known, a higher discriminant power in dimensions of epiphyses was also found (22). Dittrick and Suchey (21) report similar results to ours in a nonrobust historic series with sex estimated on the basis of the coxae bone, but with percentages of correspondence of 89% in the distal epiphysis and of 91% in the maximum diameter of the head. Similarly, Iscan and Miller-Shaivitz (4) suggest that, to evaluate the sexual dimorphism, the dimensions of epiphyses are preferred.

Our results confirm that the articular surfaces of the femur permit a reliable sexual determination above 90%. This discrimination can be explained because the functional activity provokes a higher robusticity, with a theoretical higher average in males, imposed by muscular development and body weight (23,24). Accepting this explanation, how can we explain the differences in fit of the different equations? It can be admitted, according to DiBennardo and Taylor (25), that the misclassifications in sexual determination are of two kinds: Constants, wrong classified cases in all functions (males of reduced dimensions or females very strong respecting the average) and inconstants, cases that are included in one sex in some functions and other times in others (slender males and robust females with body dimensions similar to the average of each sex). In function of the distribution of each variable and the general morphological characteristics of the series, a different degree of fit will be obtained. In theory, platykurtic distributions and/or with wide overlap between sexes, will imply a higher risk in the application of the function, because the percentage of lack of correspondence increases. Therefore, it is expected that sexual discrimination will vary from some populations to others. For instance, Hoyme and Iscan (26) offers, for the femur of North American series, a maximum fit of 90% with equations based on the diameter of the head. However, in this study, 94% is almost reached with the horizontal diameter and a value above 97% is obtained with the distal epicondylar breadth.

Without any doubt, the intrapopulational variability is important to explain the fit of the functions. The percentage of correspondence differs if femora of both sexes are considered separately in regard to this variability. The observed tabular scores permit to estimate the potential risk of making the wrong choice, for each function. So, a priori, the researcher can evaluate that some functions are more reliable in relation to male femora whereas other ones are more successful with female femora. The reason is the different degree of overlap between the distributions of both sexes for the variable involved in the discriminant function.

The combination of two variables does not always improve the percentage of correspondence in sexual determination. In only five occasions, mathematical models could be built to improve the efficacy obtained with a single variable. However, an increase of less than 2%, is small if it is compared with the function based on the distal epicondylar breadth. The researcher ought to evaluate whether the effort is worthwhile in view of the sample size. In any way, more reliability can be reached applying the several functions obtained on the same femur and assigning the sex given by the majority of the diagnoses.

In our opinion, there are limitations in the use of discriminant functions for sexual determination. The most important one is referred to the representativeness of the sample when the function is applied to different series from the one which was used to define the equations. López-Bueis (17) showed the lack of validity of American and European tibial functions in the Spanish population of Wamba. There is also, a great correlation with the body size, which limits their use if there are large differences between the dimensions of the series, particularly if longitudinal variables related to stature are considered. So, it must be noted the secular increase (3). In spite of these problems, some authors (8) show that the functions can be applied when the populations are both chronologically and geographically similar. Without doubt, actual populations are biologically more heterogeneous than prehistoric and historic populations. This will be another factor to consider in the sexual diagnosis based on mathematical functions. Similarly, many physical changes (dimorphism included) are the result of socioeconomical and nutritional changes. These are fields to evaluate in this area of the biological anthropology and legal medicine.

Another limiting factor could be the age of the individuals of the sample analyzed. Does the age affect the applicability of the discriminant functions? Scheuer and Elkington (27) analyze two series of known sex with a range of age varying between 19 and 98 years. DiBennardo and Taylor (7) consider samples with an average age of 62.9 years in males and 64.7 in females. Nakahashi and Nagai (8) consider Japanese between 34 and 97 years, with an average of 68 years in males and 73 in females. As it can be observed, there is great heterogeneity. It is difficult to evaluate the grade of influence, especially if we consider the sample sizes. However, DiBennardo and Taylor (7) affirm that age has a minimum influence and it has not to be taken in account in future studies.

Without doubt, the functions obtained in this study can be improved. It is therefore necessary to analyze more individuals, to increase the number of Spanish populations studied, and to determine whether age, and other parameters, have an effect. We hope that these will be active fields of research in the future.

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