TECHNICAL NOTE

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Determination of Sex of White Femora by Discriminant Function Analysis: Forensic Science Applications

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ABSTRACT: Stepwise multiple discriminant function analysis is used to establish classification functions for sex assessment of North American white femora. The functions correctly assign sex for 82% of a sample consisting of 85 femora of verified age, sex, and race, and for a similarly verified test sample of 30. The objectives are to provide criteria for sexing poorly preserved and fragmentary unknown specimens and a statement of the probable accuracy of such assessments in individual cases. The application of the method to forensic casework is illustrated by a sample case.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, sexing, femur, discriminant analysis

Giles [1] has summarized the pros and cons of sexing the skeleton by the discriminant function technique. He notes two important reasons for using this method. First, its overall accuracy of prediction is roughly equal to that achieved by the expert using the inspectional approach. Second, it provides a quick, easy, and objective method of assessment that can be used by technical-level personnel without the need to consult any reference series. To Giles's remarks, we may add the observation of Stewart [2] that although it may seem rather a waste of time and effort for the expert to measure what he or she can quickly see with a trained eye, metric procedures, being objective, serve as a useful check on subjective inspectional assessments. As such, they may be expected to strengthen the testimony of an expert witness appearing in court.

Giles [1] also acknowledges three qualifications of the discriminant function method of sexing the skeleton: first, it is helpful to have some prior knowledge of the race of the individual to be sexed; second, age has been shown to enter into some discriminant functions

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and tend to misclassify some age groups; and third, when certain skeletal parts are missing or poorly preserved, so that some measurements cannot be taken, use of the discriminant functions now available is precluded.

The first two qualifications are not serious limitations. Often the isolated femur may be raced by the method of Stewart [3] and Walensky [4]. Even in cases where race assessment is impossible, sex can usually be assessed because sex differences generally override race differences in the cranium [1,5,6] and the postcranial skeleton [7,8]. In regard to the tendency of some discriminant functions to misclassify certain age groups, Giles [1] notes that in his cranial sample of American blacks and whites this is a tendency only, is probably also present in inspectional sexing methods, and is apparently of little practical effect. In sex assessment of the femur by discriminant function analysis, DiBennardo and Taylor [9] also find that age contributes minimally to the discriminant function in which it is used.

As Giles [1] admits, however, the third qualification is a serious limitation for the discriminant function technique. The discriminant functions now available are primarily designed to provide the highest accuracy of sex prediction, and not to cope with incomplete or poorly preserved skeletal remains. For example, Thieme's [10] discriminant function with the smallest number of measurements (three) requires two bones, the femur and innominate; all four of his discriminant functions require measurement of pubic length or femoral head diameter, neither of which is likely to be possible in poorly preserved archaeological or forensic remains. The work of Pons [11] on sex assessment of the isolated femur and sternum provides the advantage that only one bone is required; but two of the four femoral measurements, diameters of the head and the distal epiphysis, are similarly precluded in poorly preserved or mutilated remains.

In response to this problem, Black [12] utilized the circumference of the femoral shaft, a dimension likely to be preserved in fragmentary skeletal remains, to sex archaeologically derived Amerindian materials. DiBennardo and Taylor [9] tested this method on femora, obtained from dissecting rooms, of American whites of verified age, sex, and race, using femoral circumference alone and in combination with other femoral measurements, either directly measurable or extrapolative in poorly preserved bones. Their overall accuracy of prediction (82%) is less than that of Pons (95%), but the applicability of their method to forensic case work is often greater.

The primary concern of the present paper is to report two changes that expand the forensic applicability of our earlier work on sexing the femur [9] by modifying and expanding our statistical procedure. First, we have added criteria for evaluating the posterior probability of group membership for any case, including those in which multiple variables are available for discrimination and those in which circumference alone is available. This will permit the case worker to state the degree of confidence with which an assessment is made. Second, we have recomputed the discriminant functions for our sample of North American whites omitting age, because we found it was of minimal value in assessing sex of the femur.

Materials and Methods

Our sample of North American white femora represents 115 individuals (80 males and 35 females) chosen from a dissecting room collection of known age, sex, and race at the American Museum of Natural History, in New York City. Fifty males and 35 females composed the study series used to generate the discriminant functions, and the remaining 30 males were utilized as an independent test sample.

Discriminant function analysis has two broad objectives. The first is analysis—delineating the dimensions along which populations are maximally differentiated; the second is classification—assigning individuals to groups on the basis of shared similarities.

In analysis, by indicating which variables are highly weighted, the discriminant function coefficients highlight the dimensions along which the populations differ most. The stepwise procedure [*13,14*] additionally incorporates economy into this search by eliminating variables that contribute only minimally to discrimination.

Classification, on the other hand, is based on comparisons of an individual's profile with the average profiles of the two or more groups, into one of which he or she must be assigned. These comparisons are made by computing classification functions. For each group, an individual's measurements are combined after weighting by the classification function coefficients for that group. The individual is thus scored for each group and assigned to the one for which he or she scores highest. For our data there are only two groups and consequently two classification scores for any individual.

The posterior probability of an individual's membership in a particular group is given by the ratio of the exponential of his or her classification score for that group to the sum of the exponentials of his classification scores for all groups (see Ref *13*, Appendix A.26, p. 840.2). If c_{ij} = classification score for individual i for group j and P_{ij} = probability that individual i belongs to group j, then:

$$P_{ij} = \exp(c_{ij}) \Big/ \sum_{j=1}^{g} \exp(c_{ij})$$

where g = total number of groups.

In the stepwise procedure, variables are entered on the basis of their ability to discriminate between groups (here, sexes). The variable with the greatest discriminant power, accounting for the maximum difference between groups, is entered first; the next variable is added to account for the maximum residual difference between groups, and the process is repeated until the residual differences are insignificant. The criteria for assessing the discriminant power of the variables are the "*F*-to-enter" values in Table 1, which gives the classification function coefficients for the three significant steps in the procedure.

Results

As can be seen from Table 1, only three of the variables are significant for the process of discrimination. In order of importance these are circumference, length, and anteroposterior diameter. The classification functions for males and females for circumference alone, circumference and length, and circumference, length, and anteroposterior diameter are also given in Table 1. The overall accuracies of predictions for males, females, and the test sample are given in Table 2.

The statistics in Table 1 are easy to use and can be applied as follows. Assume a case has the following measurements: femoral circumference, 95 mm; femoral length, 453 mm; and femoral diameter (anteroposterior), 28 mm. In the three-variable case (Step 3 in Table 1) the multipliers for the male classification function are these:

1. Circumference: 2.83443
2. Length: 0.83965
3. Anteroposterior diameter: −3.28170

Constant: −270.04932

The products of the measurements and their respective multipliers are summed, and the constant is then added as follows:

$$95(2.83443) + 453(0.83965) + 28(-3.28170) + (-270.04932) = 287.69538$$

For the female classification function (see Table 1c for the multipliers) the equation is:

$$95(2.42105) + 453(0.79874) + 28(-2.72106) + (-232.29536) = 283.34393$$

TABLE 1—*Classification function coefficients.*

Step/Variable Entered	F to Enter	Degrees of Freedom	Variable		Constant	
			Male	Female	Male	Female
Step 1						
Circumference	50.878	1, 83	3.33790	3.03580	−151.53299	−125.46455
Step 2						
Circumference	50.878	1, 83	1.8086	1.57048	−261.47290	−226.39911
Length	4.852	1, 82	0.79482	0.76157		
Step 3						
Circumference	50.878	1, 83	2.83443	2.42105	−270.04932	−232.29536
Length	4.852	1, 82	0.83965	0.79874		
Anteroposterior diameter	5.888	1, 81	−3.28170	−2.72106		

TABLE 2—*Accurate predictions of sex, %.*[a]

Variables in Function	Sample Used to Derive Function: Males	Sample Used to Derive Function: Females	Test Sample (Males)	Average Across Samples
Circumference	72	86	83	80
Circumference and length	78	80	93	83
Circumference, length, and anteroposterior diameter	82	86	87	85
Average correct across variables, %	77	84	87	82

[a]Based on the classification functions given in Table 1.

Since the male classification score is higher, this individual is classified as male.

To ascertain the posterior probability of the individual's membership in the group male versus the group female, we must first use each classification score as the exponent of the constant *e* (the base of the natural logarithm). Thus:

$$\exp(c_{i1}) = \exp(287.69538) = 87750 \times 10^{120}$$

$$\exp(c_{i2}) = \exp(283.34393) = 1131 \times 10^{120}$$

$$\text{sum} = 88881 \times 10^{120}$$

The probability of membership in the group male is given by:

$$P_{i1} = \exp(c_{i1}) \Big/ \sum_{j=1}^{2} \exp(c_{ij})$$

$$= 87750/88881$$

$$= 0.987275$$

The probability of membership in the group female is:

$$1131/88881 = 0.0127248$$

Discussion

The overall accuracy of the various discriminant functions reported above is 82%. This is essentially comparable to the results reported in our previous paper [*9*]. This is to be expected since the materials are the same and the method has been altered in only two ways: age has been dropped and the entire analysis has been recast in terms of discriminant functions. This was dictated by an important difference in the objectives of our two studies. As mentioned above, discriminant function analysis can focus on either analytical or classificatory dimensions of the data. Our earlier study emphasized analysis; our present study, in line with its forensic science orientation, emphasizes classification.

There is an apparent difference between the results presented here when circumference is used as the sole discriminator and the results we reported earlier [*9*]. As shown in Table 2, the accuracy of predictions using circumference alone contrasts sharply between the sexes (85.71% for females versus 72.00% for males). In our earlier paper, where prediction was based on a sectioning point midway between male and female average circumferences, this disparity did not exist (83% for females and 84% for males). This is accounted for by the difference in the method of assigning individuals to groups. The discriminant function procedure of the present paper also uses the differences between group means, but in addition incorporates information regarding each group's variability. A priori, one would expect accuracy to decrease with an increase in group variability. Consequently, in the present context males should show greater variability in circumference than females. This is in fact the case (coefficient of variation for male is 0.066 and for females, 0.048; see Table 1).

Conclusions

The application of DiBennardo and Taylor's [*9*] method of sexing the femur, based on the work of Black [*12*], has the advantage of permitting sex assessment of fragmentary bones.

There are two advantages to the modifications of the discriminant function method incorporated into the present paper: first, it incorporates information regarding each group's variability and therefore provides additional insights into the nature of sexual dimorphism for the component traits; and second, generating discriminant functions for all combinations of variables, including circumference alone, permits calculation of posterior probabilities for individual cases. Black's method, and our modifications of it, seem particularly suitable to forensic science case work and provide the rationale for the present paper. We expect a further improvement in this regard when our current research on American black femora is completed.

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