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Determination of Sex with a Discriminant Analysis of New Pelvic Bone Measurements: Part II

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ABSTRACT: The pelves of 100 white skeletons were measured on both sides for the following: (1) length from the superiormost aspect of the pubic symphysis to the nearest rim of the acetabulum (PS-A), (2) length from the highest point of the pubic tubercle to the nearest rim of the acetabulum (PT-A), (3) acetabular diameter (AD), (4) the vertical distance from the anterior aspect of the ischial tuberosity to the farthest rim of the acetabulum (IT-A), and (5) greatest femur head diameter. From these, three indices were derived: AD/PS-A (acetabulum/pubis index), AD/PT-A (acetabular diameter/pubic tubercle-acetabular rim index), and IT-A/PS-A (ischium-acetabulum height/pubic symphysis-acetabular rim index). The left AD/PS-A ratio and left IT-A height proved statistically to be of greatest discriminating value. Using these two variables, a discriminant function was derived which correctly separated 98% of our sample. The acetabulum/pubis ratio alone correctly assigned 95%. With either the discriminant function analysis of two variables or the acetabulum/pubis index as a single predictor, 97% of our sample of known sex was correctly identified if all specimens that fell within a doubtful or overlapping range of values were sorted by femur head diameter.

KEYWORDS: physical anthropology, musculoskeletal system, human identification

In a recent paper, we reported the results of a study of new pelvic bone measurements that we defined and used for the determination of sex on a known sample of black skeletons in the Terry Collection at the Smithsonian Institution [*1*]. The measurements were variations of ones that had been suggested by Washburn [*2*], Thieme [*3*], and Last [*4*] as possibly better indicators of sex than the ischium/pubis index. They were also more easily referenced than the latter and, therefore, less subject to observer errors.[4] Our results were comparable to those obtained with the ischium/pubis index by Washburn [*2,5*] and Thieme and Schull [*6*] in their respective studies of Bantu and American black skeletal populations. Since it is known that sex differences in the pelvis are less marked among blacks than whites [*7*], we have used our method to study a sample of white skeletons. The results form the substance of this paper.

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[4] The details of the historical background and rationale for using the newly defined measurements were given in our previous paper Part 1.

Materials and Methods

Except that sexes were equally divided, 100 white skeletons were randomly selected from the Terry Collection. Only those showing obvious pathology or breakage in critical areas were rejected during the sampling process. The following four pelvic measurements were taken to the nearest millimetre from both sides and are illustrated graphically in Fig. 1: lengths, *parallel to the pubic axis*, from (1) the superiormost aspect of the pubic symphysis to the nearest rim of the acetabulum (PS-A) and (2) the highest point of the pubic tubercle to the nearest rim of the acetabulum (PT-A); (3) a diameter of the acetabulum (AD) representing a parallel extension of measurements (1) and (2); and (4) a line from the anterior aspect of the ischial tuberosity to the opposite (farthest) rim of the acetabulum (IT-A) hereinafter referred to as ischium-acetabulum height. Greatest femur head diameter (FHD) was also measured. Three indices were calculated: AD/PS-A (the acetabulum/pubis index); AD/PT-A (acetabular diameter/pubic tubercle-acetabular rim index); and IT-A/PS-A (ischium-acetabulum height/pubic symphysis-acetabular rim index).

Statistical Analysis

Descriptive studies, univariate t tests on the means, and F tests on the variances were calculated by sex and by side for each measurement and ratio. All variables found to be useful in diagnosing sex were included in a stepwise discriminant analysis after assumptions were tested. The solution to this multivariate analysis involves obtaining the weight to be applied to each original variable in order that the resulting composite score will have maxi-

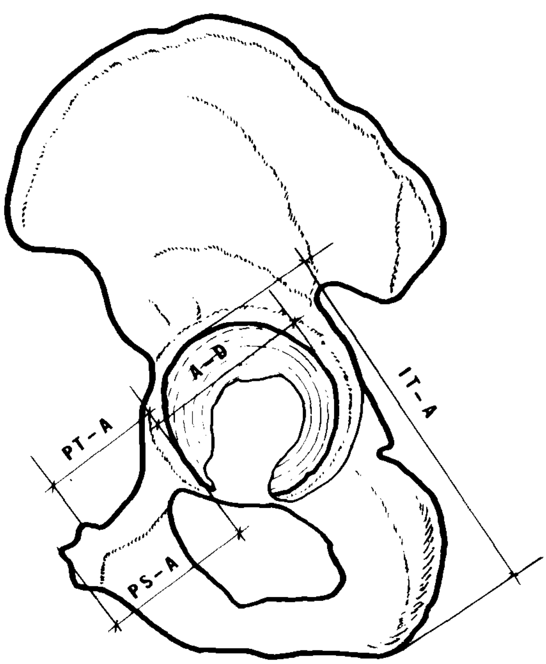

FIG. 1—*Left pelvic bone illustrating: length, parallel to the pubic axis, from the (1) superiormost point of the pubic symphysis to the nearest rim of the acetabulum (PS-A) and (2) highest point of the pubic tubercle to the nearest rim of the acetabulum (PT-A); (3) the diameter of the acetabulum (AD); and (4) a length from the anterior aspect of the ischial tuberosity to the opposite rim of the acetabulum (IT-A).*

mum use for distinguishing between male and female specimens. This is essentially a regression method where the result best predicts group membership. A stepwise procedure was used to select the single, best discriminating variable and then to improve group separation by adding each of the remaining variables in turn. Using specimens of known sex, a classification analysis was then performed. Thus, the proportion of specimens correctly sexed indicates the accuracy of the procedure giving the most intuitive description of discrimination as a percentage. It also indirectly confirms the degree of group separation. Finally, since no one original or discriminant variable was expected to predict sex with total accuracy, and in order to compare our results with those of previous studies, femur head diameter was used in a final sorting after misclassification percentages were determined at each step.

Results and Discussion

The means of males and females differed significantly on all measurements except both right and left lengths from the pubic tubercle to the acetabular rim (PT-A). Those which differed were used as independent variables in the stepwise discriminant analysis. Six of these were of value in separating the sexes (Table 1) and with them, we obtained 99% classification. The only specimen incorrectly sexed was a male (Terry Collection No. 622).

Based on the larger standardized weights which indicate greater relative discriminating efficiency (Table 1), our four most important variables were the left acetabulum/pubis index (AD/PS-A), left ischium-acetabulum height (IT-A), and both left and right femur head diameters. Since the latter two represent essentially the same structure, we opted to use only that of the left. In this way, we had three variables for our discriminant models all of which were measured on only one side of the skeleton. Their basic descriptive statistics are given in Table 2.

When the acetabulum/pubis index was in the model with any one or two additional variables, the classification was always 98%. The same male (Specimen No. 622, as above) and one female (No. 925) were consistently misclassified. The picture of any two-variable model was typical of any other two- or three-variable one. Therefore, because of their greater standardized weights, we have elected to describe the two-variable model which uses the acetabulum/pubis index and ischium-acetabulum height. (These were also the most important discriminators for our previously reported black sample.) Group means for this model were 2.15 for males and −2.15 for females. The 99% confidence intervals were −0.725 to 5.025 for males and 0.289 to −4.589 for females.

Figure 2 is a histogram of the discriminant scores for both sexes based upon the function:

$$Y = 25.1462\,(\text{AD/PS-A}) + 0.1318\,(\text{IT-A}) - 31.8388$$

TABLE 1—*Results of stepwise discriminant function analysis on twelve variables.*

Variable	F	Standardized Weights	Correlations of Variable with Discriminant Function
AD/PS-A(L)	103.65	1.15	0.70
IT-A(L)	24.21	0.84	0.49
AD/PT-A(R)	8.44	−0.39	0.28
FHD(R)	7.93	0.94	0.50
FHD(L)	4.81	−0.84	0.48
AD(L)	2.02	−0.33	0.55

TABLE 2—*Basic descriptive statistics.*[a]

Variable	Sex	Sample Size	Mean	Standard Deviation	Standard Error	Maximum	Minimum	Median	Male Versus Female *t* (98 d.f.)[b]
AD/PS-A(L)	M	50	0.758	0.036	0.005	0.842	0.675	0.758	16.760
	F	50	0.645	0.031	0.004	0.702	0.561	0.646	
IT-A(L)	M	50	113.160	5.330	0.754	123.500	102.000	113.250	11.570
	F	50	102.100	4.150	0.587	111.000	92.000	102.000	
FHD(L)	M	50	48.490	2.700	0.381	55.500	43.000	48.750	11.304
	F	50	42.940	2.190	0.309	47.000	38.000	43.000	
AD/PS-A(L)[c]	M	50	0.788	0.034	0.005	0.855	0.697	0.792	13.949
(Black sample)	F	50	0.688	0.038	0.005	0.810	0.616	0.686	

[a] All *F* tests of variance were not significant.

[b] Two-tail test was significant at the 0.01 level. d.f. = degrees of freedom.

[c] In Table 2 of our earlier paper [*1*], these statistics for the acetabulum/pubis index of our black sample were incorrectly given. The above values are correct.

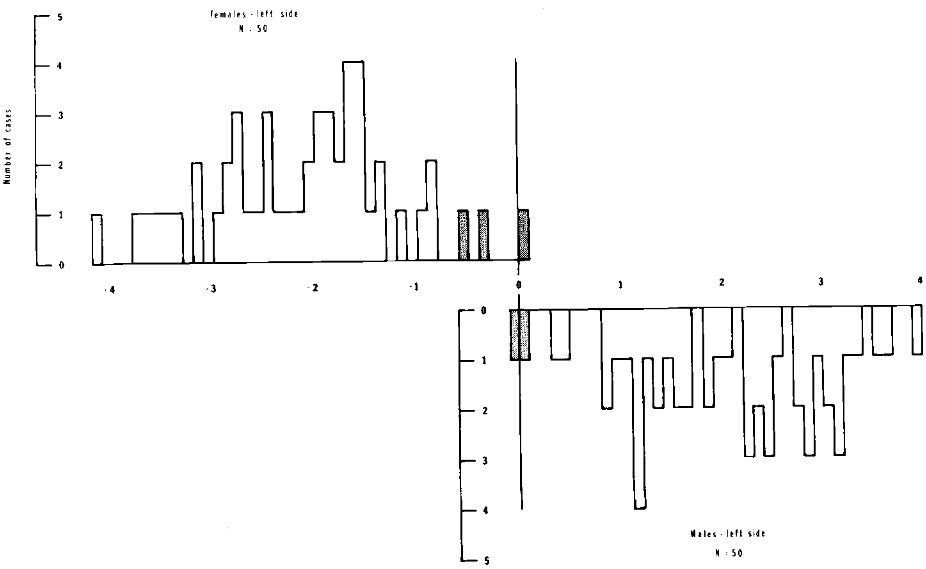

FIG. 2—*Histogram giving the discriminant score distribution by sex for 100 Terry Collection white skeletons. The shaded area includes five individuals with scores in the doubtful range of −0.7 to 0.3.*

The region from −0.725 to 0 constitutes the doubtful range for males and 0 to 0.289 is the doubtful area for classifying females. Given an unknown but similar white population, theoretically, only 3% of the individual scores should be expected to fall in these ranges. A summary of the variable function relationships is provided in Table 3.

Although only one male and one female were misclassified in our sample of known sex, these, plus one additional male and two females, would be considered doubtful if sex were unknown because their scores were within the value range of −0.7 to 0.3. The three females failed to classify with subsequent sorting by femur head diameter for which 45 mm or less identified females in our sample. This 97% correct assignment of sex is the same as that achieved for our black skeletons. However, there was a larger number of black than white specimens (14 as opposed to 5) with scores in the doubtful range and all of those that then failed to sort with femur head diameter were males.

Both variables used in the above described model included a measurement of the acetabulum. Therefore, since the standardized weights (Table 1) and variable/function correlations (Table 3) show that the left acetabulum/pubis ratio predominates in the final discriminating value, we examined the ratio as a sole predictor. With the separating value of 0.71, it correctly classified 95% of our specimens (Fig. 3). All of the improperly assigned specimens

TABLE 3—*Canonical discriminant function coefficient.*[a]

Variable	Unstandardized Weights	Standardized Weights	Correlations of Variables With Discriminant Function
AD/PS-A(L)	25.146 18	0.85	0.78
IT-A(L)	0.131 827	0.63	0.54

[a]Constant is −31.83880.

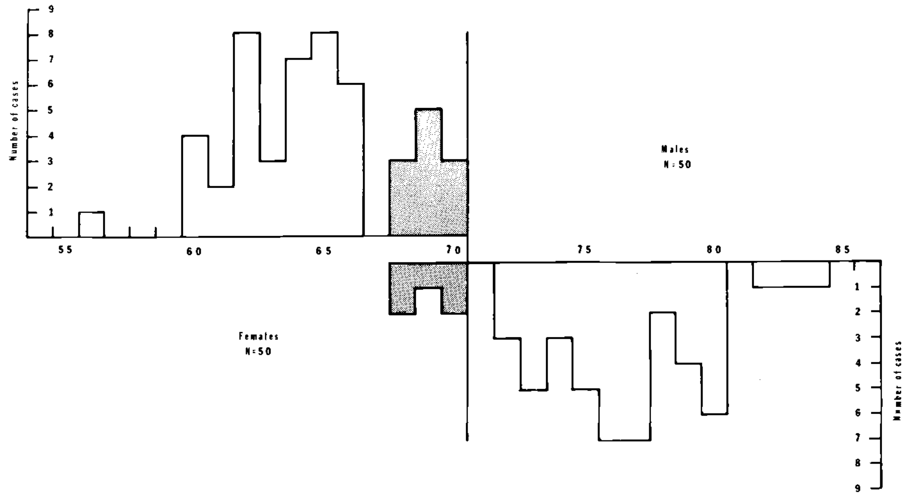

FIG. 3—*Histogram giving the acetabulum/pubis index distribution by sex for 100 Terry Collection white skeletons. The shaded (overlap) area includes 16 individuals with index values between 0.68 and 0.70.*

were males, and they were successfully sorted by femur head diameter. Therefore, the index with femur head diameter provides 100% predictability in our sample of known sex. However, as can be seen in Fig. 3, there were 16 specimens with overlapping index values. They are listed with their summary data in Table 4. Sorting all of these resulted in an overall classification rate of 97%. Three females failed to separate properly and they were the same specimens that were not identified by femur head diameter following our two-variable discriminant function model. The probability of correct assignment of unknown specimens us-

TABLE 4—*Summary data on specimens in the overlap area for the acetabulum/pubis index values.*

Specimen	Sex	AD/PS-A[a]	Femur Head Diameter, mm
543	F	0.6857	42
580	F	0.6912	41
736	F	0.6849	45
808	F	0.6901	40
880[c]	F	0.6892	47[b]
925[c]	F	0.6974	47[b]
1139	F	0.7015	42
1302	F	0.6901	45
1174	F	0.7000	43
1186	F	0.6818	41
1071[c]	F	0.6750	46[b]
566	M	0.6790	50
620[c]	M	0.6750	48
812	M	0.6933	47
622[c]	M	0.7039	46
575	M	0.7020	49

[a]0.71 = male.
[b]Misclassified by femur head diameter.
[c]Specimens in overlap area for two-variable model.

ing the index value followed by sorting doubtful specimens with femur head diameter is not known since the procedure neither derives nor generalizes an estimate of probability from sample variability.

Comparison of White and Black Samples

The two methods described above were the same as those used in our efforts to sex black skeletons, and they have provided practically the same overall predictive results both within and between the two sample populations. However, in both studies, the method using a two-variable discriminant function analysis provided two advantages over using the acetabulum/pubis index as the sole predictor—there were fewer specimens to be considered doubtful, and a statement of probability could be made.

Mean acetabulum/pubis index values were higher for both sexes in our black sample than in our white one (Table 2). This reflects known racial differences in mean pubic length.

Finally, there were fewer white than black skeletons that had discriminant function scores in the uncertain area. The same was true for overlapping index values. These were the only indications that we found of greater sex differences in the pelvis in whites. It is interesting that all of the white specimens that failed to sort with femur head diameter were females, and all of the black specimens that failed were males. We can offer no explanation for such findings except, perhaps, "flukes of samples."

Summary

1. (a) A discriminant function analysis of three pelvic bone variables (two of which were used for calculating an acetabulum/pubis index) correctly identified 98% of 100 randomly selected Terry Collection white skeletons (50 each of males and females). Theoretically, only 3% of individuals should have scores in the doubtful range given a similar but unknown white sample.

(b) One of the incorrectly assigned specimens (a male) was then correctly sexed by femur head diameter with 46 or greater representing males and 45 or less representing females. (These were the same separating values for our Terry Collection black skeletons [*1*].)

2. (a) The acetabulum/pubis index accurately classified 95% of the sample. Index values of 0.71 or greater identified males, 0.70 or less identified females.

(b) The five improperly assigned males had femur head diameters in the male range.

3. When all specimens with doubtful discriminant function scores or overlapping index values were subsequently sorted by femur head diameter, 97% were correctly assigned by either the two-variable (AD/PS-A and IT-A) discriminant function analysis or the acetabulum/pubis index (AD/PS-A) alone. The same three females represented the unidentified specimens in either case.

The overall results reported in this paper for a sample of white skeletons are essentially equal to those we reported previously for the same variables when used to separate the sexes of a black skeletal sample. There was, however, a greater number of black than white specimens with uncertain discriminant functions scores and with overlapping acetabulum/pubis index values. This probably reflects pelvic differences known to exist between these two groups in the general population.

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