F. P. Schulter-Ellis,[1] Ph.D.; D. J. Schmidt,[2] B.S.; L.-A. Hayek,[3] Ph.D.; and James Craig,[3] B.A.

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

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ABSTRACT: The pelves of 100 black 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, followed by sorting with femur head diameter, accurately classified 97% of our sample.

The acetabulum/pubis index alone with subsequent sorting by femur head diameter correctly assigned 96% of our sample. While this does not represent an improvement of predicatability over similar methods using the ischium/pubis index, measurements required for the acetabulum/pubis index are more easily defined and should, therefore, reduce the chance of observer error.

KEYWORDS: physical anthropology, musculoskeletal system, human identification

An understanding of the nature and degree of skeletal variation between the sexes is of practical importance to all whose profession requires the identification of skeletal remains. None of the efforts of numerous investigators has resulted in a procedure for sorting a skeletal population as to sex, much less one for determining the sex of an individual skeleton, with absolute certainty. Given the range of human variation, it is unrealistic to expect ever to achieve 100% predictability. However, results of past studies admit the need for

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[1]Assistant professor, Anatomy Department, University of Maryland School of Medicine, Baltimore, MD.

[2]Museum technician, Division of Physical Anthropology, Museum of Natural History, Smithsonian Institution, Washington, DC.

[3]Senior mathematical statistician and statistician, respectively, Scientific Application Division, Smithsonian Institution, Washington, DC.

improved methods and for new methods; even ones that do not increase predictability could prove useful when skeletal remains are fragmentary.

Washburn studied Bantu [*1*] and American black and white skeletons [*2*] using measurements described by Schultz [*3*] and an index calculated from them, the well known ischium/pubis index. Indices, of course, allow comparison of skeletons of different size. The ischium/pubis index was, and still is, considered valuable because, not only may the measurements used in its calculation be obtained from a single disarticulated pelvic bone when other skeletal parts may be missing but, as Washburn points out, the difference in the length of the ischium is approximately proportional to size difference while pubic length is sex related and is proportionately longer in the female. An index value of 0.89 correctly sexed 96% of Washburn's Bantu and American black samples of known sex. However, 22 (14%) of his 152 Bantu and 17 of his 100 black skeletons had values in an overlap area and could not be considered to be correctly identified if his samples were thought of as unknown.

Later, Thieme and Schull [*4*] studied a random sample of Terry Collection black skeletons to determine the discriminating value of several postcranial measurements when used separately or in various combinations. They also calculated the ischium/pubis index which proved to be their best discriminator. The same index value of 0.89 separated 93.5% of their series. However, 40 of their 200 specimens had values in the overlap area of male and female ranges. They sorted those with femur head diameter (male > 43), their second best discriminator, and thereby achieved 95% accuracy. With a discriminant function analysis using femur length and head diameter; humerus length and epicondylar width; clavicle, ischium, and pubis lengths, they classified 99% of their sample. They reported a probability of 93.5% correct classification if a combination of any three of the above measurements were used on known material.

To assess the applicability of Thieme's and Schull's method to other populations of the same and different races, Richman et al [*5*] studied samples of the Howard University collection of black skeletons and Terry collection blacks and whites. None of their samples were sexed with the same rate of accuracy as that achieved or predicted by Thieme and Schull. However, two samples did reach 91% or better, reaffirming that the method provides a useful tool.

Admitting the considerable value of the ischium/pubis index and Thieme's and Schull's application of discriminant function analysis, both have distinct disadvantages. The former requires identifying a reference point in the acetabulum which is not always easily discerned. Even though the latter method employs measurements most of which are easily defined, it requires a number of separate bones. A statistical procedure using easily defined measurements obtained from a single bone, even without increasing predictability, would be more useful. Guidelines for such have been suggested by the very same authors cited above.

Washburn [*2*] states:

> Since absolute size bears no relation to the ischium-pubis index—and since the sex difference in the size of the ischium is pronounced, small ischia will tend to be female. Also, the greater size of the femoral heads (and hence acetabulae) in the males may be unrelated to the other characters. Size of ischia and acetabulae will afford additional evidence of sex in doubtful cases.

Thieme [*6*] reiterates this idea when he writes that "an improved index could be gotten by taking the shortest distance from the rim of the acetabulum to the superior point of the pubic symphysis and dividing it by the distance from the ischium point to the far rim of the acetabulum." A third reference to the usefulness of acetabular dimensions is made by Last [*7*]. He describes what he considers the "surest single feature" of sex difference in the pelvic bone as "the distance from the pubic tubercle to the acetabular margin is greater than the diameter of the acetabulum in the female, equal or less in the male bone."

Acetabular dimensions have been found to be of minor value when used alone [*8,9*]. Kelley [*10*] obtained 90% or better reliability with a sciatic notch acetabulum index.

However, to our knowledge, the measurements suggested in the foregoing statements have not been tested. This paper reports the results of our efforts to do so.

Materials and Methods

One-hundred black skeletons, sexes equally divided, were randomly selected from the Terry Collection at the Smithsonian Institution. Only those showing obvious pathology or breakage in critical areas were rejected during the sampling process. The following five, easily referenced measurements were taken on both sides (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), that is, a diameter representing a parallel extension of measurements (1) and (2); (4) a line from the anterior aspect of the ischial tuberosity to the opposite (farthest) rim of the acetabulum (IT-A); and (5) greatest femur head diameter. In this way, the pubis length measurements referred to by both Thieme (PS-A) and Last (PT-A) have been incorporated into our study. A careful reading of Thieme's paper [*6*] suggests two possible definitions for his "ischium point": (1) that point in the acetabulum at which pubis, ischium, and ilium meet and (2) the most prominent point on the ischial tuberosity. Using the former and measuring to the farthest rim of the acetabulum would include no measurement of the ischium and only a portion of acetabulum *size*. Use of the latter to farthest acetabular rim would measure the entire *diameter* of the acetabulum but only a portion of ischium length, or vice versa. We opted for the ischial

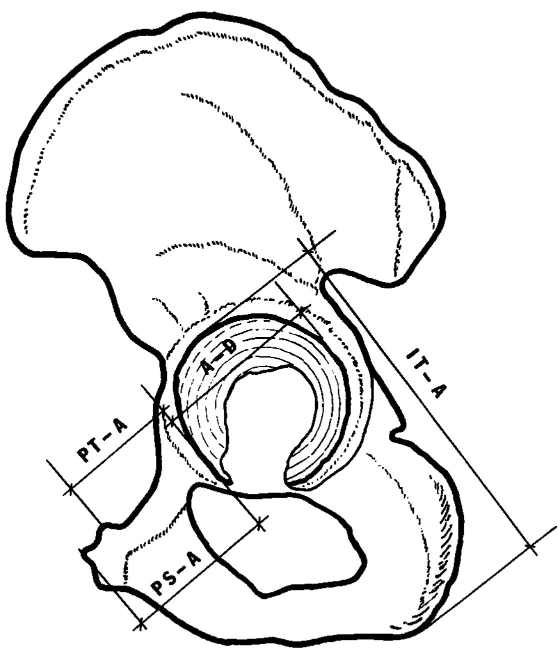

FIG. 1—*Left pelvic bone illustrating: lengths, parallel to the pubic axis, from the (1) superiormost point of the pubic symphysis to the nearest rim of the acetabulum (PS-A) and (2) highest point of the pubic tubercle to the nearest rim of the acetabulum (PT-A); (3) the diameter of the acetabulum (AD);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

tuberosity reference point because Thieme's initial discussion of what he thought might be an improved index included a measurement of the ischium. Also, the difficulty of being consistently accurate in finding that point in the acetabulum at which the three elements of the pelvic bone meet is obviated.

Three indices were calculated: AD/PS-A (hereinafter referred to as 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 statistics, univariate *t*-tests on the means, and *F*-tests on the variances were calculated for each measurement and ratio by sex and by side. Based upon these, all variables (measurements or ratios) useful in making decisions between the sexes 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 maximum use for distinguishing between groups of 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.

A classification analysis was then performed by using the specimens of known sex. In this manner, the proportion of specimens correctly sexed indicates the accuracy of the procedure giving, as a percentage, the most intuitive description of discrimination. 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 each of the six (three right, three left) ratios and ten (five right, five left) measurements except both right and left PS-A and PT-A lengths. However, the stepwise discriminant analysis showed only five to be of value in separating the sexes (Table 1). With these five we obtained 96% correct classification—three males and one female were incorrectly sexed.

The largest *F* values are for those variables that are responsible for the greatest amounts of group separation. The standardized weights give the variables' relative contribution to the calculation of the discriminant score and the correlations give the proportion of variance in the function explained by each variable. The discrepancy between the significance of the univariate test and the nonsignificant contribution of the same variable to the multivariate test is expected because the former series of tests ignore the intercorrelation among the variables.

A discriminant function was derived using only the left acetabulum/pubis index and left ischium-acetabulum height, the two variables shown to be of greatest discriminating value.[4] Exactly the same classification rate of 96% was obtained and the substantive utility of this function was not significantly different from that with all variables. Basic descriptive statistics on the variables considered, plus those on femur head diameter (FHD) used for

[4]The left ischium-acetabulum height/pubic symphysis-acetabular rim ration was available for inclusion but provided redundant information.

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

Variable	F	Standardized Weights	Correlation of Variable with Discriminant Function
AD/PS-A(L)	46.9930	1.208	0.73
IT-A HT(L)	19.2270	1.488	0.55
IT-A/PS-A(L)	9.7668	−1.007	0.59
PS-A(R)	4.4259	−0.662	−0.08
IT-A HT(R)	1.4104	−0.343	0.47

final sorting, are listed in Table 2. Table 3 provides a summary of the variable function relationships. First substituting the variable means for males into the equation

$$Y = 22.5888\,(AD/PS\text{-}A) + 0.1196\,(IT\text{-}A) - 29.3502$$

gives an average value (group centroid) of 1.77 then substituting means for females gives −1.77. The overlap area of ranges for male and female values is illustrated in Fig. 2. The 99% confidence limits for the male distribution are −0.80 to 4.33 and 0.82 to −4.35 for the female distribution. Theoretically, misclassified specimens will have values in the range of −0.80 to 0.82, and only 7% of any similar black population can be expected to have scores falling in this area.

In our sample of known sex, with negative scores representing females and positive scores representing males, we misclassified one male with −0.80 and three females with 0.24, 0.63, and 0.80 (Table 4). However, all four were accurately identified using femur head diameter for which, in our sample, 46 mm and above identified males. The classification of five females and nine males would be considered doubtful to some degree if sex were unknown since they have overlapping values (Fig. 2). Femur head diameter failed to sort three of the males (Table 4 and Fig. 3). We suggest that the 97% correct assignment of sex thus arrived at is deceptive for our sample because all three specimens unidentified as males by femur head diameter had discriminant scores well within the range for males.

The standardized weights and the variable/function correlations show that the left acetabulum/pubis ratio predominates in the final discriminating value in our discriminant function analysis (Table 3). Also, both variables used included a measurement of the acetabulum. Considering this, we examined the ratio as a sole predictor of sex. With the separating value of 0.74, it correctly classified 92% of our sample (Fig. 4). The eight improperly assigned specimens, four males and four females, could all be identified by femur head diameter. Sorting all specimens in the overlap area by femur head diameter resulted in an overall classification rate of 96%. Four males failed to separate properly, including the three that failed to sort subsequent to the discriminant function analysis, as should be expected (Fig. 5). The index values for two of the four are quite high (No. 667 = 0.79 and No. 551 = 0.81). Therefore, it seems reasonable to conclude that the above methods have satisfactorily classified 98 to 100% of the specimens in our sample of known sex.

Certainty, of course, is a function of the distance and direction of the individual value from the group value. The probability of correct assignment of unknown specimens by separating first with the index, then sorting misclassified ones with femur head diameter, is not known since this procedure neither derives nor generalizes an estimate of probability from sample variability.

Some mention is owed Last's premise that the distance from the pubic tubercle to the

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	1.057	0.067	0.009	1.256	0.922	1.058	
	F	50	0.920	0.078	0.011	1.333	0.929	1.060	9.967[b]
IT-A HT(L),	M	50	111.39	5.48	0.77	124.50	101.00	111.000	
mm	F	50	100.67	4.78	0.68	110.00	90.00	101.50	10.427[b]
FHD(L),	M	50	48.39	2.82	0.40	57.00	41.00	48.30	
mm	F	50	42.80	2.00	0.28	47.00	38.00	43.00	11.438[b]

[a] All F-tests for variance were not significant.
[b] 2-tail test was significant at the 0.01 level. d.f. = degrees of freedom.

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

Variable	Unstandardized Weights	Standardized Weights	Correlations of Variable With Discriminant Function
AD/PS-A	22.58881	0.81	0.79
IT-A HT	0.119611	0.61	0.59

[a]Constant is −29.3502.

nearest rim of the acetabulum is greater than the acetabulum diameter in females, equal to or less in males. The ratio thus suggested was not among the five variables found to be useful in separating the sexes (Table 1). Raw data reveals that 87% of our sample was correctly identified by it—seven females and six males being misclassified. Two of these females and one male failed to separate by femur head diameter. No effort was made to determine distribution of the index values according to sex, therefore, the number of specimens that would fall in an overlap area is not known. We had expected this ratio to be less valuable than the acetabulum/pubis ratio because most of the growth that produces the comparatively longer pubic bone in females occurs at the symphysis, that is, medial to the pubic tubercle.

Since femur head and acetabulum sizes are probably unrelated to other skeletal characteristics as Washburn pointed out [*2*], it is disappointing that, when tested separately, neither if used alone was found to be a sufficiently effective discriminator of sex for our sample. The same findings have been reported by others, however [*6,8,9*].

Summary

1. (a) A discriminant function analysis using three pelvic bone variables (two of which were used for calculating an acetabulum/pubis index) correctly identified 96% of 100 randomly selected black skeletons of known sex (50 each of males and females).

(b) All incorrectly assigned specimens were then correctly sexed by femur head diameter with 46 or greater representing males and 45 or less representing females. This is higher than the discriminating value reported by Thieme, that is, 44 or greater representing males. However, only when sample sizes are equal is the cut point calculated to be halfway between the group means. Thieme used the halfway point but had slightly unequal group sizes and, therefore, possibly underestimated the femur head diameter cut value for his sample.

2. (a) An acetabulum/pubis index has been defined which accurately classified 92% of the sample. All specimens with an index value of 0.74 or over are males, those with smaller values are females, and there is a less than 8% chance of error.

(b) The eight incorrectly assigned specimens were classified with femur head diameter.

3. If all specimens in the area of overlapping values are considered uncertain and subsequently sorted by femur head diameter: (1) the discriminant analysis procedure with PS-A and IT-A assigns 97% of our sample accurately and (2) that method using the acetabulum/pubis index assigns 96% correctly.

One objective of our study was to test measurements of the pelvic bone which Washburn [*2*], Thieme [*6*], and Last [*7*] had suggested might provide better indicators of sex than the ischium/pubis index. We also tested combinations of the measurements in a discriminant function analysis for comparison with Thieme's and Schull's method [*4*] and to derive a probability statement applicable to all series from similar populations.

That procedure we followed which rendered the best results was the discriminant function analysis using an acetabulum/pubis index and an ischium-acetabulum height, mea-

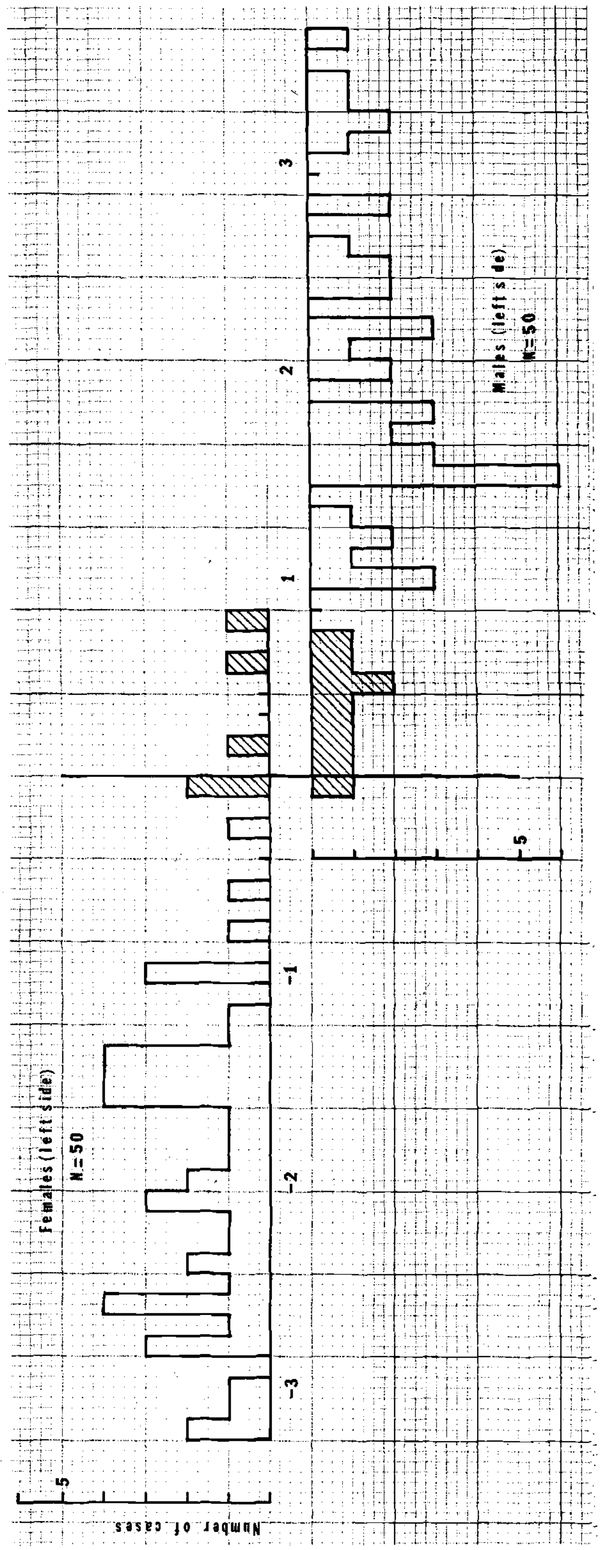

FIG. 2—*Histogram giving the discriminant score distribution by sex for 100 Terry Collection black skeletons. The overlap area is striated and is for those individuals with scores between −0.1 and 0.8. The results of sorting these 14 cases by femur head diameter are shown in Fig. 3. One female and one male with extreme scores of −3.9 and 4.4, respectively, are not represented in the histogram.*

TABLE 4—*Summary data on misclassified specimens in the discriminant analysis overlap area.*

Specimen	Sex	AD/PS-A[a]	IT-A HT	Discriminant Score[b]	Femur Head Diameter
535[c]	F	0.7538	105.0	0.2364	45
626[c]	F	0.7869	102.0	0.6253	44
532[c]	F	0.8103	99.0	0.7950	42
1030	M	0.7661	101.0	0.0358	41[d]
656	M	0.7482	108.5	0.5285	45[d]
667	M	0.7937	101.5	0.7191	45[d]
660[c]	M	0.6974	113.0	−0.0807	48

[a]0.74> = male.
[b]Positive values = male.
[c]Misclassified by discriminant function.
[d]Misclassified by femur head diameter.

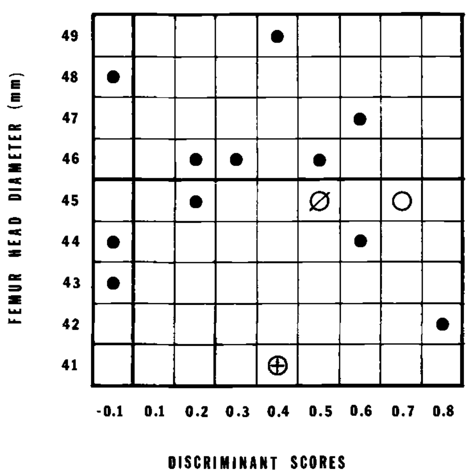

FIG. 3—*Distributions, according to femur head diameter, of the 14 individuals shown in the striated area of Fig. 2 who have discriminant scores between −0.1 and 0.8. Solid circles indicate skeletons that are correctly sexed by the delimiting value indicated with heavy vertical lines. The following special symbols are assigned to those incorrectly sexed: Specimen No. 667 is represented by* ○. *656 by* ø, *and 1030 by* ⊕.

surements for each of which we have defined. The 96% correct classification of our sample and 93% probability of accurately classifying similar series that it provided equals Thieme's and Schull's results of 93.5% probability for combinations of three measurements taken from specimens of known sex. However, our method offers the distinct advantages of using only measurements that are easily defined and taken from a single bone.

Using a single discriminating value (disregarding the overlap area), the 92% correct classification of our sample with only the acetabulum/pubis index is less than that provided by the ischium/pubis index for Washburn's Bantu (96%) and American black series (96%) and Thieme's Terry Collection black sample (93.5%). However, subsequent sorting of all specimens in the overlap area with femur head diameter increases the chance that sex will be correctly assigned to about 96% which equals that reported by Thieme for the same procedure using the ischium pubis/index.

Some investigators may prefer the acetabulum/pubis index because of the easily defined measurements involved.

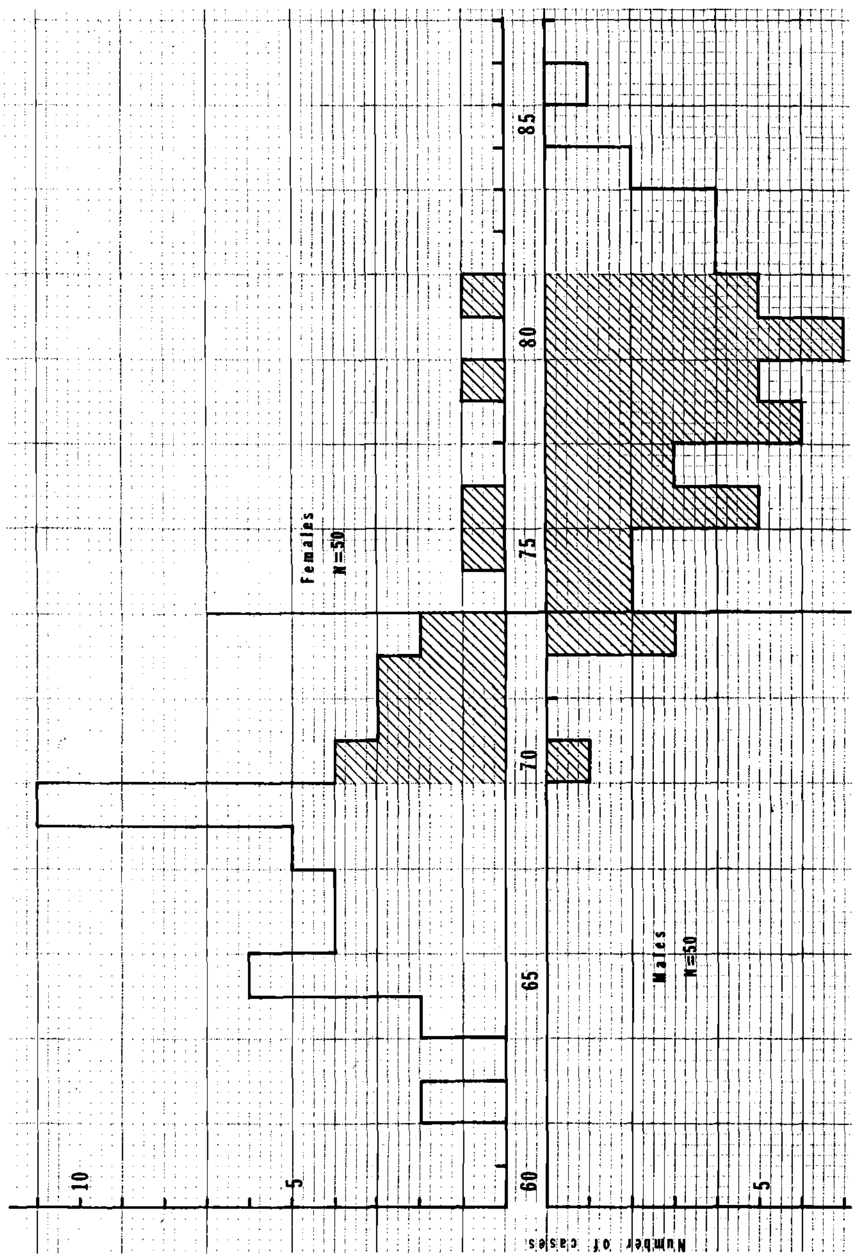

FIG. 4—*Histogram giving the acetabulum/pubis index distribution by sex for 100 Terry Collection black skeletons. The striated (overlap) area is for those individuals with index values between 0.70 and 0.81. The results of sorting these 55 cases by femur head diameter are shown in Fig. 5.*

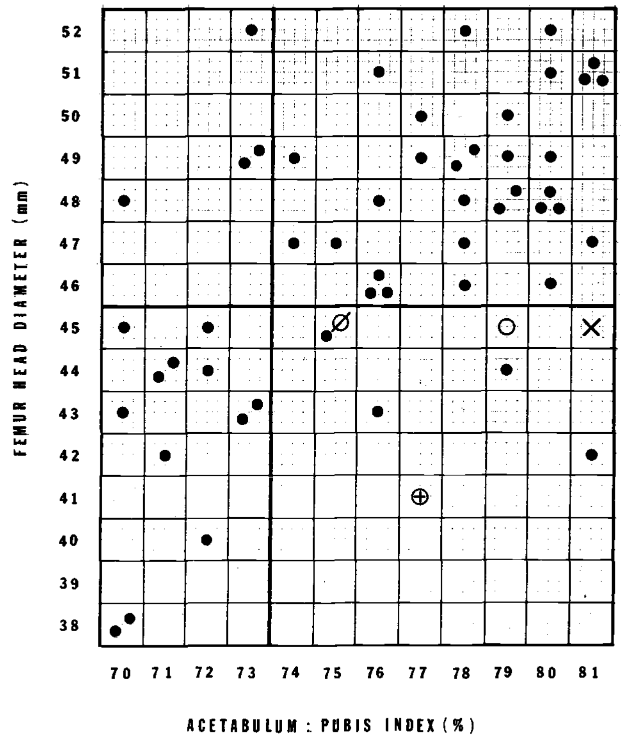

FIG. 5—*Distributions, according to femur head diameter, of 55 individuals shown in the striated area of Fig. 4 who have an acetabulum/pubis index between 0.70 and 0.81. Solid circles indicate skeletons that are correctly sexed by the delimiting value indicated with heavy vertical lines. The following special symbols are assigned to those incorrectly sexed: Specimen No. 667 is represented by* ○, *656 by* ø, *1030 by* ⊕, *and 551 by X.*

Acknowledgments

We are grateful to Dr. J. Lawrence Angel, Curator, Division of Physical Anthropology, Museum of Natural History, Smithsonian Institution for allowing us to use the Terry Collection material; to Col. Spencer P. Ellis for rendering the illustrations; and to Mrs. Eloise DeLong for her careful typing of the manuscript.

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Address requests for reprints or additional information to
Frances P. Schulter-Ellis, Ph.D.
University of Maryland School of Medicine
Department of Anatomy
655 W. Baltimore St.
Baltimore, MD 21201

ERRATA

Corrected Table 2 of "Determination of Sex with a Discriminant Analysis of New Pelvic Bone Measurements: Part 1," *Journal of Forensic Sciences*, Vol. 28, No. 1, Jan. 1983, pp. 169-180.

Frances P. Schulter-Ellis, Ph.D.
Assistant Professor of Anatomy
University of Maryland
Dept. of Anatomy
655 W. Baltimore St.
Baltimore, MD 21201

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	0.788	0.034	0.005	0.855	0.697	0.792	
	F	50	0.688	0.038	0.005	0.810	0.616	0.686	13.949
IT-A HT (L)	M	50	111.390	5.480	0.770	124.500	101.000	111.000	
(mm)	F	50	100.670	4.780	0.680	110.000	90.000	101.000	10.427
FHD (L)	M	50	48.390	2.820	0.400	57.000	41.000	48.300	
(mm)	F	50	42.800	2.000	0.280	47.000	38.000	43.000	11.438

[a] All F tests for variance were nonsignificant.
[b] 2-tail test was significant at the 0.01 level; d.f. = degrees of freedom.