J Forensic Sci, Jan. 1979, Vol. 24, No. 1

E. A. Richman,[1] *M.S.; M. E. Michel,*[1] *M.S.;*
F. P. Schulter-Ellis, [1] *Ph.D.; and R. S. Corruccini,* [2] *Ph.D.*

Determination of Sex by Discriminant Function Analysis of Postcranial Skeletal Measurements

---

Techniques for accurately determining the sex of skeletal material are invaluable to workers concerned with the identification of human remains. Well-known methods that have been employed include traditional qualitative evaluations of morphological characteristics and statistical analyses of metrical data [*1-10*]. Some measurements have been found to be more valuable discriminators than others, showing that sexual dimorphism differs according to the measurements [*11-15*].

Thieme and Schull [*16*] conducted a study to determine how accurately several postcranial skeletal measurements would discriminate between the sexes when applied separately or in various combinations. They randomly selected 200 black skeletons of known sex from the Terry Collection (now housed at the Smithsonian Institution Museum of Natural History, Division of Physical Anthropology). The data were collected from easily measured features such as (1) femur length, (2) femur head diameter, (3) humerus length, (4) humerus epicondylar width, (5) clavicle length, (6) ischium length, and (7) pubis length. An ischium-pubis (I/P) index was calculated for each specimen. Measure-by-measure comparisons were made to find the nature of sex difference present for each measurement. The I/P index proved to be the best single discriminator. This series of measurements was followed by a sorting procedure to test other methods for identifying those specimens not separated clearly by the index. Finally, the seven measurements were used in a discriminant function analysis, which provides a formula for assigning sex to individual specimens and a statement of probability that all the specimens in the series have been assigned correctly. Thieme and Schull attained 95% accuracy by using femur head diameter, the second-best discriminator, to sort all individuals not clearly sexed with the I/P index. With their discriminant function analysis, they sexed 99% of their sample correctly. The I/P index value that discriminated between females and males for the Terry Collection blacks worked equally well for Washburn [*4,11*] on his black sample from the Hamann Museum collection and his Bantu series. Based on this evidence Thieme and Schull suggest that their technique should provide the same degree of accuracy for other black populations. Further, they present a formula for deriving limit values for other races that should carry the same probability of error since the expression of sexual dimorphism in humans follows a highly homogeneous pattern.

This paper reports the results of a study conducted to test the efficiency of the Thieme and Schull methods when employed by other investigators on two different skeletal populations and another sample of Terry Collection blacks.

Presented at the Southern Society of Anatomists Annual Meeting, Oct. 1976. Received for publication 12 April 1978; accepted for publication 1 June 1978.
[1]Graduate student, graduate student, and assistant professor, respectively, Anatomy Department, University of Maryland School of Medicine, Baltimore.
[2]Research associate, Division of Physical Anthropology, Smithsonian Institution, Washington, D.C., and assistant professor, Anthropology Department, Southern Illinois University, Carbondale.

Material and Methods

The following samples of known adult skeletons were randomly selected: 140 (69 male, 71 female) from the black specimens in the Terry Collection; 101 (56 male, 45 female) from the white specimens in the Terry Collection; and 95 (49 male, 46 female)[3] from the Howard University Medical School Collection. The same measurements as those used by Thieme and Schull were made on the right side of the Terry blacks; left and right sides of the Terry whites; and left side of the Howard blacks. The measurements had been made on the last group at an earlier date and collection of additional data was no longer feasible. Each of three investigators was responsible for measuring a single sample. To check the possibility of observer differences, specimens were periodically chosen at random from each sample and measured by other members of the team. These proved highly consistent for all except clavicle length. Therefore, that measurement was excluded from the study.

The data were analyzed by the same sorting and statistical methods as those used by Thieme and Schull. A discriminating value for the white sample was derived by the formula they provided. Finally, we performed a multiple discriminant function analysis to examine all the obvious sources of variation: sex, race, side, and investigator technique.

Results

Ischium-Pubis Index

The limit (discriminating) value for the I/P index being tested (89) sorts all but two males and two females (95.8%) of the Howard University black specimens (Fig. 1). An overlap area, ranging from 85 to 95, includes 28 skeletons considered doubtful. Femur head diameter (44 mm and above are considered to be male) sorts all but eight of these. Therefore, the two measurements applied in sequence identify 91.6% of specimens in this sample. Thieme and Schull identified 93.5% of their sample by I/P index alone and 99% with femur head diameter separating the doubtful individuals. The overlap area for the Howard University specimens is larger than that for the Thieme and Schull sample (Fig. 2) and includes a proportionately larger number of specimens, that is, 28/95 as compared to 40/200.

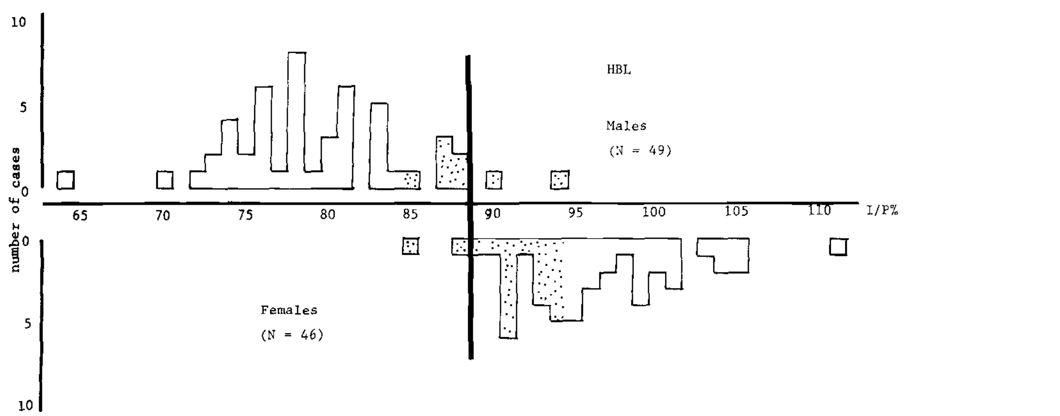

FIG. 1—*Histogram of the I/P index distribution by sex for 95 American blacks of the Howard University School of Medicine skeletal collection. Stippling indicates those individuals in the overlap area (between 84 and 94) which were sorted by femur head diameter.*

[3]The original sample contained 99 specimens. Four of these were eliminated because of strong evidence that the accompanying records were not reliable.

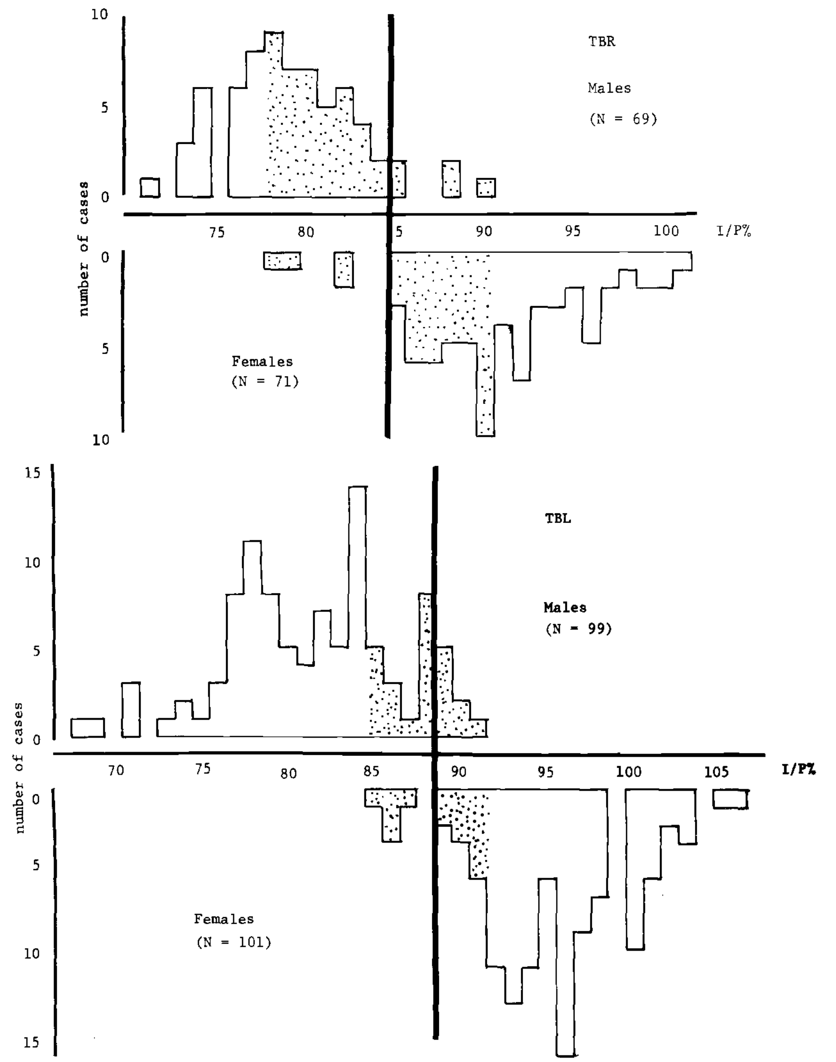

FIG. 2—*Histograms of the I/P index distribution by sex for* (upper half) *140 American blacks of this study, measured on the right side, and* (lower half) *200 American blacks of Thieme's study, measured on the left side. The overlap areas are stippled. Both samples are of the Terry Collection now housed at the Smithsonian Institution.*

The index for the right side of our Terry Collection black sample separated 82.2% of specimens. If a limit value of 85 rather than 89 is used, 93.6% is realized (Fig. 2). In either case, the overlap area ranges from 78 to 90. Sorting these individuals by femur head diameter leaves 12 females incorrectly sexed and therefore 91.5% of the total sample correctly identified. Using a cutoff value of 45 instead of 44 mm identifies all but eight females, or 94.3% of the samples. As in the Howard sample, one sees a much wider overlap area between our sample of Terry blacks measured on the right side and Thieme's and Schull's sample measured on the left side.

Consistent with Washburn's findings [*11*] for white pelves, an I/P index of 92 and above for females served best on both sides for separating the sexes in the Terry white sample (Fig. 3). Ninety-one and 95.2% are identified on the left and right sides, respectively. The range

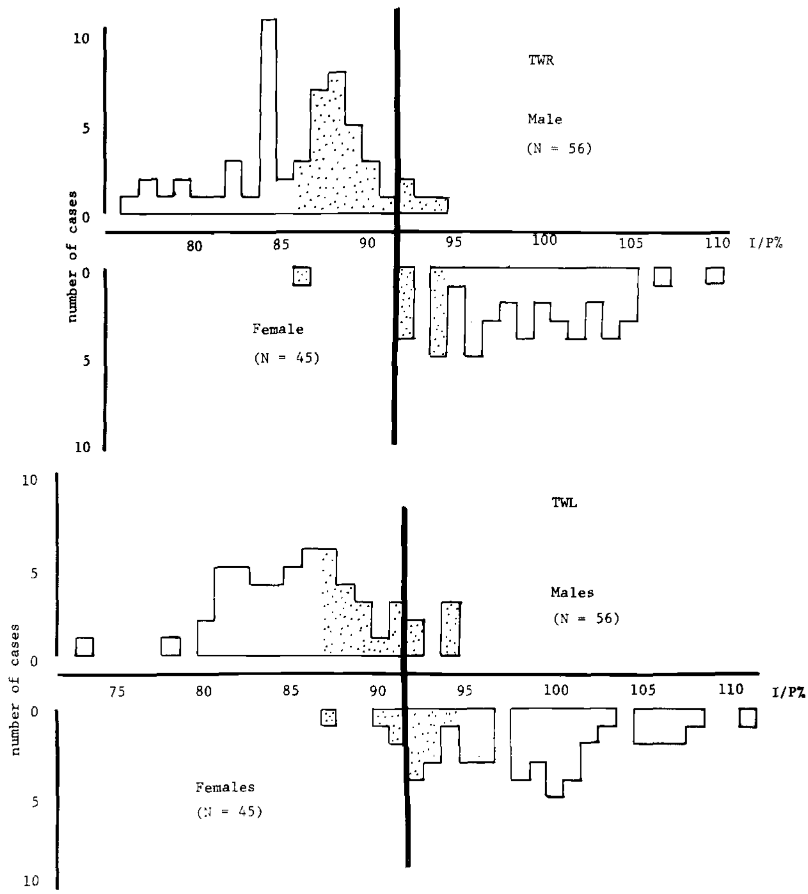

FIG. 3—*Histograms of the I/P index distribution by sex for* (upper half) *101 American whites of the Terry Collection, measured on the right side, and* (lower half) *the same sample measured on the left. The overlap areas are stippled.*

of I/P index values in the overlap area is similar. Sorting of doubtful individuals by femur head diameter leaves four specimens incorrectly sexed on the left and two on the right, or 96 and 98% correct identification on the left and right sides, respectively. Changing the limit value to 45 mm leads to only slight improvement, 97% left and 99% right.

Linear Discriminant Function Analysis

Table 1 gives the results reported by Thieme and Schull for combinations of six and seven measurements. This table lists a limit value of 1953 with a 2.5% probability of error for a combination of six measurements. With this value the discriminant function classified 88% of our black sample from the Terry Collection[4] and 96% of our Howard University black sample.[5] Limit values of 1765 (left side) and 1799 (right side) were derived for the Terry

[4]A new discriminating value of 2127 was derived for the right side of the Terry black specimens. This value classified 95% correctly.

[5]Clavicle length was included in the original analysis of the Howard sample. This measurement provided a combination of seven measurements with a limit value of 4099, which classified 97% of the specimens.

TABLE 1—*The results of the discriminant analysis for combinations of six and seven measurements as given in multipliers to be used, limit values, probabilities of misclassification, and expected ranges (after Thieme and Schull* [16, *p. 265, Table 4*]; *reprinted by permission of Dr. W. J. Schull*).

Measurement	7 × 7	6 × 6
A. femur length	0.07	1.00
B. femur head diameter	58.14	31.40
F. ischium length	16.25	11.12
G. pubis length	−63.64	−34.47
C. humerus length	2.68	2.45
D. epicondylar width of humerus	27.68	16.24
E. clavicle length	16.09	...
Value separating the sexes (females are less than the value)	4099	1953
Probability of error in classification, %	1.5	2.5
Range within which 99% will fall	2664–5533	1205–2701

white skeletons. The left value correctly sexed 95%, while that for the right side sexed 98%. These results are summarized in Table 2.

Multiple Discriminant Function Analysis

One way of synthesizing this series of univariate results is by inclusion of all eight samples in the multivariate comparison by canonical variates analysis (multiple discriminant functions). The procedure allows us to consider all the obvious sources of variation (sex, race, side, and investigator) at once. Table 3 lists the basic results in terms of the mean and range of discriminant scores (which are the positions occupied by individual cases when projected onto the discriminant functions). The first canonical axis accounts for a predominant fraction of the total variance between samples and acts primarily to separate the sexes. The discriminant coefficients of measurements corresponding to this axis weights pubis length negatively, in contrast to all the other measurements (Table 4). There is some superimposition of whites and blacks in terms of the sex separation, that is, the whites fall lower on the axis while males and females still separate in the same direction and by the same amount.

The second canonical axis (Table 3) accounts for most of the variance left over after removing the first. This variate separates the races at opposite poles. There is again some superimposition of sex difference onto the race variation, in that males and females differ in the way the races separate.

While the first and second discriminant axes together effect a separation both of sexes and races, the third axis does not seem to be explainable in terms of the sources of variation included in the study. Since this variate falls to a very low level of variance (2.5%), and the ensuing variates are negligible, we consider only the first two to be meaningful. No single canonical axis appears to be segregating specimens according to side or measurement technique (investigator); only sex and race differences are evident.

Discussion

The evidence gathered from this study indicates that the efficiency of the methods used does not quite attain the levels predicted by Thieme and Schull [*16*, p. 253]:

> It is quite accurate to conclude that *in this sample* where sex is known we can sex with 90% accuracy if we first sort for ischium-pubis index, calling all individuals male if under 85.0 mm and all female who are 92.0 or over, and next sort those remaining, calling all under 44 mm for femur head female and all others male.

TABLE 2—*The percentage of skeletons in each population sample correctly identified with I/P index values, I/P index with femur head diameter in sequence, and discriminant analysis limit values for six and seven combinations of measurements.*

	I/P Index			I/P Index + Femur Head Diameter		Discriminant Analysis				
						6 × 6				7 × 7
Population Sample	85	89	92	44 mm	45 mm	1953	2127	1765	1799	4099
Terry Collection										
Black, left side [a] (n = 200)	...	93.5	...	99	...	99	...	...	...	99
Black, right side (n = 140)	93.6	82.2	...	91.5	94.3	88	95	...	...	...
White, left side [b] (n = 100)	...	...	91	96	97	...	...	95	...	...
White, right side (n = 101)	...	...	95.2	98	99	...	...	...	98	...
Howard U. Collection										
Black, left side (n = 95)	...	95.8	...	91.6	...	96	...	...	...	97

[a] From Thieme and Schull [*16*] for comparison.
[b] Measurements could not be taken on the left side of one of the 101 skeletons in the sample.

TABLE 3—*Discriminant function scores (canonical variate positions).*

Sample	Variate One		Variate Two	
	Mean	SD	Mean	SD
Howard black				
Male	12.099	1.35	15.250	0.91
Female	7.908	0.92	14.840	1.48
Terry black				
Male	12.057	1.11	15.562	1.05
Female	8.643	1.01	14.533	1.16
Terry white				
Male, right	10.052	1.06	17.288	0.98
Male, left	10.089	1.00	17.272	0.87
Female, right	6.455	1.01	16.173	1.33
Female, left	6.396	0.74	16.335	1.42

TABLE 4—*Discriminant function coefficients (adjusted canonical variates).*

Measurement	First Variate (Sex), 78.6% Variance	Second Variate (Race), 18.3% Variance
Femur		
Length	0.004	−0.012
Head diameter	0.173	0.128
Humerus		
Length	0.014	−0.012
Bicondylar width	0.107	−0.071
Ischium length	0.066	0.189
Pubis length	−0.222	0.096

With this method, 91.5% of the Terry blacks measured by us on the right side were correctly assigned as compared to the 99% which Thieme and Schull report for their sample measured on the left. The discriminant function analysis sexed only 88% of our sample. It correctly sexed 99% of theirs.

Our multiple discriminant function analysis strongly indicates that neither side nor observer techniques affect results achieved. Nevertheless, it is worth noting that, in testing side differences to determine their usefulness for sexing, Thieme and Schull found a pronounced dominance for humerus length on the right side in females. Also, the overlap area for our sample had a wider range owing to several very deviate individuals. This overlap resulted in a larger number of doubtful individuals to be identified by femur head diameter. Therefore, side and sample variability could conceivably account for the differences in results between our studies of this particular population.

Since the sorting procedures do not derive or generalize an estimate of probability from sample variability, the exact level of accuracy that they would produce on other black populations cannot be known [*12*]. While none of our samples achieved the rate predicted by Thieme and Schull, both the Howard black and the Terry white samples reached 91% or better. Such results indicate that these methods do have considerable value if used with appropriate precautions.

In the multiple discriminant analysis, the first function (discriminating sex) is virtually identical to the six-variable coefficients given by Thieme [*12*, p. 77] except for a difference in scale. Thus, this particular linear function does appear to have somewhat universal significance for sex discrimination. Nevertheless, the centroids and the discrimination points differ in different populations (similar to the shifts in discrimination points in the histograms of different investigators in Figs. 2 and 3), showing that the criteria of identification must be adjusted for whatever particular problem is at hand even though the discriminant function remains the same.

Finally, like Thieme and Schull, we found that the two most heavily weighted and contrasting variables on the sex discriminant function were pubis length versus femur head diameter. This may indicate, as they have suggested, that a ratio of pubis length to femur head diameter could be a better bivariate discriminator than the more traditional I/P index.

The accuracy of sex identification (95 to 98%) was slightly less in each sample when the first canonical variate shown in Table 4 was used than when Thieme's and Schull's discriminant function with adjusted discrimination points or the I/P index with femur head diameter was used (generally around 99%). This difference could be a result of combining several samples and mixing some race or side effects with the sex variation, or it may result from heterogeneity of the covariance matrices between the most different samples.

Summary

Thieme and Schull [16] took measurements of seven postcranial traits from black skeletons of known sex to devise a method for accurately sexing human remains. With a linear discriminant function analysis of the data they obtained a 98.5% accuracy. The research reported here was designed to assess the accuracy of their method in the hands of other investigators using a sample of the same black population and its applicability to other populations of the same and different races.

None of the samples used in this study were sexed with the same rate of accuracy either achieved or predicted by Thieme and Schull. However, two samples did reach 91% or better. Such results suggest that the methods employed have considerable value if used with appropriate precautions.

Our multiple discriminant function analysis strongly indicates that neither side nor observer techniques affected the results. Sex accounts for a predominant fraction of the total variation among samples and race accounts for most of that remaining.

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 Dr. W. Montague Cobb, distinguished professor, Department of Anatomy, Howard University Medical School, Washington, D.C. for permission to use his department's skeletal collection; and to Dr. T. Dale Stewart, senior scientist, Museum of Natural History, Smithsonian Institution, for his patient instruction in measuring techniques.

References

[1] Schultz, A. H., "Proportions, Variability, and Asymmetries of the Long Bones of the Limbs and the Clavicles in Man and Apes," *Human Biology*, Vol. 9, No. 3, Sept. 1937, pp. 281-328.

[2] Greulich, W. W. and Thoms, H., "The Dimensions of the Pelvic Inlet of 789 White Females," *Anatomical Record*, Vol. 72, No. 1, Sept. 1938, pp. 45-51.

[3] Greulich, W. W. and Thoms, H., "An X-Ray Study of the Male Pelvis," *Anatomical Record*, Vol. 75, No. 3, Nov. 1939, pp. 289-299.

[4] Washburn, S. L., "Sex Differences in the Pubic Bone of Bantu and Bushman," *American Journal of Physical Anthropology*, Vol. 7, No. 3, Sept. 1949, pp. 425-432.

[5] Hanna, R. E. and Washburn, S. L., "The Determination of the Sex of Skeletons, as Illustrated by a Study of the Eskimo Pelvis," *Human Biology*, Vol. 25, No. 1, Feb. 1953, pp. 21-27.

[6] Stewart, T. D., "Sex Determination of the Skeleton by Guess and by Measurement," *American Journal of Physical Anthropology*, Vol. 12, No. 3, Sept. 1954, pp. 385-392.

[7] Krogman, W. M., "Sexing Skeletal Remains," in *The Human Skeleton in Forensic Medicine*, Charles C Thomas, Springfield, Ill., 1962, pp. 112-152.

[8] Giles, E. and Elliot, O., "Sex Determination by Discriminant Analysis," *American Journal of Physical Anthropology*, Vol. 21, No. 1, March 1963, pp. 53-68.

[9] Witschel, H. and Mangelsdorf, R., "Geschlechtsunterschiede am Menschlichen Brustbein," *Zeitschrift Rechtsmedizin*, Vol. 69, No. 2, 1971, pp. 161-167.

[*10*] Singh, S. and Singh, S. P., "Identification of Sex from the Humerus," *Indian Journal of Medical Research*, Vol. 60, No. 7, July 1972, pp. 1061-1066.
[*11*] Washburn, S. L., "Sex Differences in the Pubic Bone," *American Journal of Physical Anthropology*, Vol. 6, No. 2, June 1948, pp. 199-208.
[*12*] Thieme, F. P., "Sex in Negro Skeletons," *Journal of Forensic Medicine*, Vol. 4, No. 1, March 1957, pp. 72-81.
[*13*] Steel, F. L. D., "The Sexing of Long Bones, with Reference to the St. Bride's Series of Identified Skeletons," *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, Vol. 92, 1962, pp. 212-222.
[*14*] Jit, I. and Singh, S., "The Sexing of the Adult Clavicles," *Indian Journal of Medical Research*, Vol. 54, No. 6, June 1966, pp. 551-571.
[*15*] Singh, S., Singh, G., and Singh, S. P., "Identification of Sex from the Ulna," *Indian Journal of Medical Research*, Vol. 62, No. 5, May 1974, pp. 731-735.
[*16*] Thieme, F. P. and Schull, W. J., "Sex Determination from the Skeleton," *Human Biology*, Vol. 29, No. 3, Sept. 1957, pp. 242-273.

Address requests for reprints or additional information to
Elaine A. Richman
Anatomy Department
University of Maryland School of Medicine
Medical School Teaching Facility
Baltimore, Md. 21201