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Discriminant Function Sexing of the Tibia

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ABSTRACT: The objective of the study was to test whether the shaft dimensions of the tibia were as sexually dimorphic as those of the femur and to develop a new sex determination technique from the tibia. Stepwise discriminant function subroutine based on a sample of 159 tibiae of blacks and whites of both sexes of the Terry Collection was employed for the study. Osteometric measurements included were the length, proximal and distal breadths, the circumference of the nutrient foramen and of the smallest shaft regions, and anteroposterior and transverse diameters at the nutrient foramen levels. The results indicated that in all dimensions proximal epiphyseal breadth and the minimum circumference were the variables selected by the stepwise function in blacks and that all but the transverse diameter participated in the function in whites. Average accuracy of sex determination was 87.3% for whites and 90.0% for blacks. For both races proximal epiphysis was a better indicator of sex differences than the remaining dimensions. While the study provided statistically reliable results sexual dimorphism was observed to be race dependent. This was especially true for blacks who provided higher prediction accuracy and more dimorphism than whites. Thus it was suggested that determination of sex required a consideration of not only growth related sex differences, and physical activity, but also the genetic (racial) nature of a population.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, sex determination, tibia, discriminant function

Determination of sex from the postcranial skeleton has received renewed interest from physical and forensic anthropologists [*1-3*]. Several studies on long bones have indicated that sexual dimorphism can be assessed more effectively from the measurements of the circumference and breadth than length of long bones. Theoretical support for this statement was provided by research on metacarpals [*4*] and the femur [*5*]. The main premise in this sexual variation was supported since there was differential bone remodelling between the sexes. Moreover, the rate of cortical bone development in the shaft of a tubular bone was shown to be greater in males than in females. It was also pointed out that differential remodelling in the cortical bone remained essentially unchanged throughout adulthood.

These findings have provided a practical contribution to the determination of sex from the femur and were claimed to be applicable to fragmentary and commingled skeletal remains [*4-6*].

The present study has two objectives: first, to test whether the shaft dimensions of the tibia were as sexually dimorphic as those of the femur and, second, to provide a new sex determination technique from the tibia for American blacks and whites. Although there have been several studies on Asiatic Indians [*7*], the St. Bride's collection, an old cemetery population [*8*], and

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Japanese [9] to assess sex differences, the present study differs from those in three ways. First, these studies [7-9] dealt with genetically distant, geographically isolated or temporally older populations or both. Second, the present study emphasized the discriminant function technique as an analysis. Third, there has not been any controlled study on the tibia of the American black and white.

Materials and Methods

The sample of the study consisted of 159 tibiae with a distribution of 40 white males, 39 white females, 40 black males, and 40 black females. All of the specimens were from the Terry Collection of the Smithsonian Institute with known age, sex, race, and other characteristics. Seven osteometric dimensions were taken from each left tibia. The tibial length was measured from the medial malleolus to the lateral condyle taken with an osteometric board [10]. Of the two circumference measurements, the first one was taken at the nutrient foramen level with a plastic-covered cloth tape. The second, minimum shaft circumference, was measured as the minimum value of the shaft with the same type of tape. In general, this minimum value was at the distal end of the shaft. In taking these dimensions the tape followed the contour of the bone. The anteroposterior and transverse dimensions were taken at the nutrient foramen level. The proximal epiphyseal breadth was the maximum distance between the condyles. During this process care was taken not to incorporate osteoarthritic exostosis. With most of the cases, the maximum distance was slightly below the articular surfaces. The last measurement, the distal breadth, was taken between the medial malleolus and the center of the fibular notch. In all of these measurements a sliding caliper was used.

In the analysis of the sample, several programs of the Statistical Package for the Social Sciences (SPSS) were employed [11,12]. The first analysis was to determine the relative contribution of the variables to the discriminant function. The stepwise procedure (METHOD = WILKS) identified the variables which determined variables to discriminate sexes most efficiently. This procedure was followed by an individually selected METHOD = DIRECT approach based on one or more variables with the selection criterion based on the highest Wilks' Lambda level.

Results

Table 1 shows the descriptive statistics and the statistical significance between the sexes as determined by the ONEWAY analysis (univariate) of variance. The difference between the sexes was statistically significant. In all variables males exceeded females in both racial groups. Table 2 illustrates the results of the stepwise discriminant analyses for both races. As shown in the table, among seven variables in the analysis all but the transverse breadth entered the function as determinants of sex for whites. For blacks, however, only two variables, the proximal epiphyseal breadth and the minimum circumference, satisfied the stepwise process.

In Table 3 nine discriminant function analyses are presented. The selection of variable combination(s) was based on the DIRECT method [11] according to the entry sequence into the stepwise analysis as shown in Table 2. Further combinations, such as the proximal and distal epiphyseal breadths in Function 4, the distal epiphyseal breadth and minimum circumference in Function 5, and the proximal epiphyseal breadth and the circumference at the nutrient foramen in Function 7 were made to attain a solution for fragmented remains (Table 3). In the same table are standardized and structure coefficients that may be interpreted as measures of the relative contribution of each variable to a function and the correlation between the variables and the discriminant function coefficients, respectively. Although the structure coefficient measures correlation between canonical discriminant function and discriminating variables, it was also used as an indicator of the contribution of a variable to a function when variables in a function were correlated.

TABLE 1—*Mean, standard deviation, and univariate* F *ratios.*

Variables, mm	Males		Females		*F* Ratio[a]
	Mean	SD	Mean	SD	
		WHITE			
N =	40		39		
Length of tibia	371.03	24.65	350.15	25.04	13.94
Prox. epiphy. br.	75.50	3.62	68.41	3.45	79.49
Anteroposterior dia.	34.60	3.30	30.59	2.73	34.59
Transverse br.	26.63	3.97	23.67	3.30	12.92
Circum. nut. for.	96.13	5.84	86.44	7.87	38.77
Distal epiphy. br.	47.80	3.23	43.56	2.74	39.43
Min. circumference	72.48	4.78	69.51	5.73	24.43
		BLACK			
N =	40		40		
Length of tibia	404.48	34.15	365.63	21.34	37.23
Prox. epiphy. br.	77.23	4.14	68.08	3.50	114.20
Anteroposterior dia.	35.45	2.71	32.40	2.68	25.48
Transverse dia.	27.98	3.08	24.73	2.28	28.76
Circum. nut. for.	100.43	6.63	90.08	6.09	52.81
Distal epiphy. br.	47.93	3.54	43.10	2.80	45.72
Min. circum.	79.40	5.50	71.15	4.81	50.98

[a] Degrees of freedom = 1, 77 for whites and 1, 78 for blacks.

It can be seen that in all functions proximal epiphyseal breadth had the largest structured coefficient value. Thus the proximal epiphyseal breadth was the most significant sexually dimorphic characteristic in the sexes of both races. This was followed by the distal epiphyseal breadth and the circumference at the nutrient foramen level, as seen, especially, in Function 8 in Table 3. Length of the tibia was the least contributing variable in both races.

The accuracy of the functions is tabulated in Table 4. On the average, blacks were sexed better than whites. This was true for all functions except Function 3 involving the distal epiphyseal breadth. The highest prediction was 87.3% (Function 1) for whites and 91.3% (Function 9) for blacks. It seemed that proximal epiphyseal breadth (Function 1) was the only variable that pro-

TABLE 2—*Stepwise discriminant function analysis for both blacks and whites. Variables in the analysis include length of the tibia, circumference at the nutrient foramen level, proximal epiphyseal breadth, anteroposterior and transverse diameters, distal epiphyseal breadth, and minimum circumference.*

Step Variable Entered	Wilks' Lambda	Equivalent *F* Ratio	Degrees of Freedom
	WHITES		
1. Prox. epiphy. br.	0.492	79.49	1, 77
2. Anteroposterior dia.	0.455	45.44	2, 76
3. Distal epiphy. br.	0.439	31.90	3, 75
4. Min. circum.	0.429	24.59	4, 74
5. Circum. nut. for.	0.422	20.00	5, 73
6. Length of tibia	0.416	16.84	6, 72
	BLACKS		
1. Prox. epiphy. br.	0.406	114.42	1, 78
2. Min. circum.	0.400	57.66	2, 77

TABLE 3—*Canonical discriminant function coefficients.*

Variables	Whites			Blacks		
	Stand. Coeff.	Raw[a] Coeff.	Struc. Coeff.	Stand. Coeff.	Raw[a] Coeff.	Struc. Coeff.
1. Prox. epiphy. br.	males > 74 mm		...	males > 75 mm		...
	females < 73 mm		...	females < 74 mm		...
2. Circum. nut. for.	males > 92 mm		...	males > 96 mm		...
	females < 91 mm		...	females < 95 mm		...
3. Distal epiphy. br.	males > 45 mm		...	males > 46 mm		...
	females < 44 mm		...	females < 45 mm		...
4. Prox. epiphy. br.	0.83	0.234 60	0.97	0.97	0.254 00	1.00
Distal epiphy. br.	0.29	0.097 73	0.68	0.04	0.013 85	0.63
Constant		−21.359 23			−19.083 74	
5. Distal epiphy. br.	0.76	0.254 18	0.94	0.55	0.170 93	0.83
Min. circum.	0.38	0.072 09	0.74	0.93	0.121 75	0.87
Constant		−16.843 82			−16.944 51	
6. Length of tibia	−0.04	−0.001 62	0.42	0.07	0.002 47	0.57
Prox. epiphy. br.	1.02	0.287 95	1.00	0.97	0.251 09	1.00
Constant		−20.148 31			−19.196 73	
7. Prox. epiphy. br.	0.83	0.235 41	0.97	0.91	0.240 19	0.99
Circum. nut. for.	0.29	0.042 10	0.67	0.12	0.019 70	0.68
Constant		−20.794 71			−19.326 19	
8. Length of tibia	−0.25	−0.010 19	0.39	0.05	0.001 61	0.57
Prox. epiphy. br.	0.73	0.208 04	0.92	0.89	0.231 73	0.99
Distal epiphy. br.	0.26	0.087 92	0.65	0.03	0.009 04	0.63
Circum. nut. for.	0.39	0.055 85	0.64	0.11	0.017 16	0.68
Constant		−20.422 35			−19.498 78	
9. Length of tibia	−0.20	−0.008 17	0.36	...	...	...
Anteroposterior dia.	0.35	0.114 53	0.57	...	...	...
Prox. epiphy. br.	0.71	0.201 21	0.86	0.89	0.233 00	0.99
Distal epiphy. br.	0.38	0.126 89	0.60	0.18	0.034 54	0.66
Circum. nut. for.	0.41	0.059 34	0.60	...	...	...
Min. circum.	−0.44	−0.083 37	0.48	...	...	...
Constant		−20.451 33			−19.527 40	

[a]These coefficients are used in the calculation of a discriminant score. A score less than 0 would classify as female.

vided approximately the same predictive value for both races. It was also noted that the prediction for females was better than males for both races.

Discussion

Classification Accuracy

A comparison of the results of this study was made with those found for the femur [*4-6*]. Determination of sex from the circumference of the femur of American Indians was predicted with 85.0% accuracy. The same measurement provided 83.5% accuracy in American whites and only 73.0% in American blacks. In the present study, the circumference taken at the nutrient foramen level of the tibia provided 77.2% accuracy for whites and 80.0% for blacks. In this respect, it was obvious that the tibia provided a more diagnostic sexual difference in the blacks than the femoral circumference. The opposite was true for the whites and Indians. Furthermore the present study achieved a maximum accuracy of 87.3% for whites using only one variable and 90.0% for blacks using two variables. The corresponding figures from the femur were 89.0% using only the femoral length for Indians, 85.0% using four femoral variables for whites,

TABLE 4—*Percentage of correct prediction of the discriminant functions.*

Functions	Whites			Blacks		
	Males	Females	Average	Males	Females	Average
1. Prox. epiphy. br.	82.5	92.3	87.3	82.5	90.0	86.3
2. Circum. nut. for.	75.0	79.5	77.2	77.5	82.5	80.0
3. Distal epiphy. br.	82.5	87.2	84.8	80.0	80.0	80.0
4. Prox. epiphy. br. Distal epiphy. br.	85.0	84.6	84.8	87.5	92.5	90.0
5. Distal epiphy. br. Min. circum.	75.0	84.6	79.8	82.5	85.0	83.8
6. Length of tibia Prox. epiphy. br.	82.5	87.2	84.8	87.5	92.5	90.0
7. Proximal epiphy. br. Circum. nut. for.	87.5	84.6	86.1	87.5	92.5	90.0
8. Length of tibia Prox. epiphy. br. Distal epiphy. br. Circum. nut. for.	85.0	84.6	84.8	85.0	92.5	88.8
9. Length of tibia Anteroposterior dia. Prox. epiphy. br. Distal epiphy. br. Circum. nut. for. Min. circum.	87.5	84.6	86.1	87.5	95.0	91.3

and 78.4% using the femoral circumference and length for blacks. In this respect, the data indicated that sexual dimorphism was better predicted by the tibia than the femur.

To identify sex from a fragmentary tibia and provide a practical solution for forensic anthropologists and pathologists several additional functions were developed. These functions were based on a single variable shown in Functions 1 through 3 or two variables seen in Functions 4, 5, and 7 (Table 3). The accuracy of these functions ranged from 77.2 to 87.3% in whites and 80.0 to 90.0% in blacks (Table 4).

Sexual Dimorphism

The results of the present study can be interpreted according to the hypothesis provided in the introduction that breadth and circumference measurements of tubular bones are better indicators of sex difference than of length measurements as observed in the metacarpals and the femur [*4,5*]. This hypothesis was clearly supported in this study by use of the tibia. There were, however, additional factors and refinements to be made to the original hypothesis. First, the differences between the sexes were more clearly demonstrated in the epiphyseal breadth measurement of a long bone than the circumference and the length measurements. The exception was the distal epiphyseal breadth in blacks which provided the same accuracy as that of the nutrient foramen circumference. This difference in the epiphyseal dimensions was followed by circumferences and bone length (Tables 2, 3, and 4). It might then be expected that the epiphyseal breadths among the variables considered responded directly to musculoskeletal activity more than the other variables.

Second, blacks were more dimorphic than whites. Out of nine functions in whites five (Functions 1 through 3, 5, and 6) provided higher prediction accuracy, for females two functions (Functions 4 and 8) gave equal results and males exceeded females in the remaining two (Functions 7 and 9). In blacks eight functions predicted females more successfully than males and the remaining one function (Function 3) was the same in both sexes. Furthermore in blacks the most dimorphic dimension was the circumference at the nutrient foramen level. In whites the corres-

ponding dimension was the proximal epiphysis. This suggested that genetical differences in the sample may have played a role in the accurate assessment of sex.

A third matter must consider the health status of the sample. Previous studies indicated that both white and black groups were in the low socioeconomic class and probably less healthy than their contemporaries [*13–15*]. Support for these assumptions was derived from the fact that majority of the Terry skeletons were taken from indigent individuals indicating a socioeconomic poor background [*16*]. The number of individuals who willed their bodies was very few in the Collection [*16*]. The second support came from the fact that many of the individuals were born during the antebellum period [*17*]. The second factor was thought to have diverse effect especially on the black population nutritionally and otherwise [*15*]. Although it is not known which dimension(s) would be most affected by an inadequate diet it is possible that differential growth factors might exaggerate size differences between the sexes. If this were the case the present study may explain why the sexual dimorphism was more pronounced in blacks than in whites.

The purpose of this study was not to assess which of these three factors contributed most to the difference between the sexes. In the determination of sex, however, an understanding of racial origin, nutritional status, and physical activity level must be taken into account. From a physical standpoint, however, nutritional status and physical activity of a person are rarely known or difficult to assess from the skeleton. Based on the variables selected by the stepwise discriminant function analysis it is suggested that Function 9 should be considered if the bone was well preserved.

In our future study we will be testing the results of this work with a sample from the Hamann-Todd Collection of the Cleveland Museum of Natural History and developing the same model for American Indians.

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References

[*1*] Bass, W. M., *Human Osteology: A Laboratory and Field Manual of the Human Skeleton*, Missouri Archaeological Society, Columbia, MO, 1971.

[*2*] Kerley, E. R., "Recent Developments in Forensic Anthropology," *Yearbook of Physical Anthropology*, Vol. 21, 1978, pp. 160–173.

[*3*] Snow, C. C., "Forensic Anthropology," *Annual Review of Anthropology*, Vol. 11, 1982, pp. 97–131.

[*4*] Black, T. K., III, "A New Method for Assessing the Sex of Fragmentary Skeletal Remains in Femoral Shaft Circumference, *American Journal of Physical Anthropology*, Vol. 48, No. 2, 1978, pp. 227–231.

[*5*] Di Bennardo, R. and Taylor, J. V., "Sex Assessment of the Femur: A Test of a New Method," *American Journal of Physical Anthropology*, Vol. 50, No. 4, 1979, pp. 635–637.

[*6*] DiBennardo, R. and Taylor, J. V., "Classification and Misclassification in Sexing the Black Femur by Discriminant Function Analysis," *American Journal of Physical Anthropology*, Vol. 58, No. 2, 1982, pp. 145–151.

[*7*] Singh, G., Singh, S., and Singh, S. P., "Identification of Sex from Tibia," *Journal of the Anatomical Society of India*, Vol. 24, 1975, pp. 20–24.

[*8*] 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, 1972, pp. 212–222.

[*9*] Hanihara, K., "Sexual Diagnosis of Japanese Long Bones by Means of Discriminant Function," *Journal of the Anthropological Society of Nippon*, Vol. 66, 1958, pp. 187–196 (in Japanese).

[*10*] Trotter, M. and Gleser, G. C., "Estimation of Stature from Long Bones of American Whites and Negroes," *American Journal of Physical Anthropology*, Vol. 10, No. 4, 1952, pp. 463–514.

[*11*] Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K., and Bent, D. H., *Statistical Package for the Social Sciences*, McGraw-Hill, New York, 1975.

[12] Hull, C. H. and Nie, N. H., *Statistical Package for the Social Sciences Update 7-9*, McGraw-Hill, New York, 1981.
[13] Angel, J. L., "Colonial to Modern Skeletal Change in the U.S.A.," *American Journal of Physical Anthropology*, Vol. 45, No. 3 (part 2), 1976, pp. 723-735.
[14] İşcan, M. Y., "Assessment of Race from the Pelvis," *American Journal of Physical Anthropology*, Vol. 62, No. 2, 1983, pp. 205-208.
[15] Savitt, T. L., *Medicine and Slavery: The Diseases and Health Care of Blacks in Antebellum Virginia*, University of Illinois Press, Urbana, IL, 1978.
[16] Ericksen, M. F., "How 'Representative' Is the Terry Collection? Evidence from the Proximal Femur," *American Journal of Physical Anthropology*, Vol. 59, No. 3, 1982, pp. 345-350.
[17] İşcan, M. Y., "Effect of Age on Pelvic Dimensions," *Florida Scientist*, Vol. 43, Supplement 1, 1980, p. 48.

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