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TECHNICAL NOTE

PHYSICAL ANTHROPOLOGY

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Sexual Dimorphism of Anterior Sacral Curvature

ABSTRACT: This study assesses the predictive value of anterior sacral curvature for sex estimation from skeletonized remains. Sacra from a sample of 125 American adults of known age and sex were examined. Nine measurements describing anterior sacral curvature were used in the analysis. Statistical treatment of the data included univariate statistics and discriminant function analysis for sex classification. A bootstrap validation method was employed to assess the classification error rates. Sacral curvature was significantly greater in men than in women at the level of the S2–S3 and S3–S4 articulations ($p < 0.05$). Correct classification estimates for the discriminant function range from 66–72%. Although sexually dimorphic, metric observations of sacral curvature are not as reliable at predicting sex as other skeletal elements. Anterior sacral curvature should only be used for sex estimation in the absence of other, more reliable, indicators.

KEYWORDS: forensic science, anthropology, sex estimation, sacrum, sacral curvature, discriminant function, bootstrap

Estimation of sex from skeletal remains for identification purposes is frequently required in forensic casework and paleodemographic research. For over a century, it has been reported that the sacrum is more curved in men than in women (1,2). Reduced sacral curvature, along with posterior angulation of the sacrum, serves to enlarge the female pelvic outlet for childbirth (3) and may therefore be a reliable indicator of sex. Several methods for assessing sex based on, or including, anterior sacral curvature have been developed but have yielded varying results (4–9). Trotter (4) molded a lead strip along the median longitudinal curve of the sacrum to compare modern American male and female averages. She concluded that, although the curvature in men tended to be greater than in women, the sexual dimorphism was not marked. Stradalova (6), however, has shown that the maximum depth of the sacral curvature and curved length of the sacrum differ significantly between men and women in an Eastern European sample. Huffman and Hunt (9) also examined sexual dimorphism of maximum sacral curvature depth but concluded that depth alone is not a reliable sex discriminator.

The aim of this research was to provide a discriminant model for estimating sex from measurements of the anterior sacral curvature. Instead of examining maximum depth or curved lengths as other studies have described (4–9), this study quantitatively describes sacral curvature using depth and length measurements to each sacral segmental articulation taken along the anterior height. An American sample was utilized for development and testing of the discriminant function. The bootstrap method was used in conjunction with discriminant analysis to simulate additional samples to test the classification error rate of the function.

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Materials and Methods

The sample used in the analysis was provided by the Hamann–Todd skeletal collection of the Cleveland Museum of Natural History. Sacra of 125 individuals were measured, 59 of which were women and 66 men, with roughly half of each designated as American blacks and whites. Individuals were of known age and sex. Data collection was limited to complete sacra with five segments. Sacra that exhibited pathology or where pathology was noted in the case record were omitted from the sample. Individuals included in the investigation ranged between 18 and 82 years of age with a mean age of 38 and median age of 33.

Nine dimensions were measured on each sacrum to the nearest millimeter (Fig. 1). All of the measurements were taken by one observer. A test of intra-observer error calculated as $[(M_1-M_2)/M_1]*100$ yielded an error rate of 1.1%. This error rate is sufficiently low to avoid misallocation of sex using metric techniques (10). Anterior height of the sacrum was taken in the manner described by Moore-Jansen et al. (11). Additionally, four sacral depths and four fractions of the sacral height were measured from the midline of the anterior sacrum in the position of the anterior height using a small coordinate caliper. These measurements were taken after Moore-Jansen and Plochocki (12). Depths of the sacral curvature were recorded at the articulation of each sacral segment. Sacral fractions were recorded as the distance from the sacral promontory to each sacral segmental articulation (e.g., the first sacral fraction would be the distance along the anterior height of the sacrum from the promontory to the articulation of S1 and S2).

Because the sample included individuals designated as African American or European American, a general linear model (GLM) was used to test for a significant sex and population interaction. Such an interaction could reduce the discriminating power of the discriminant function and would suggest that variability related to sex is not independent from variability related to population

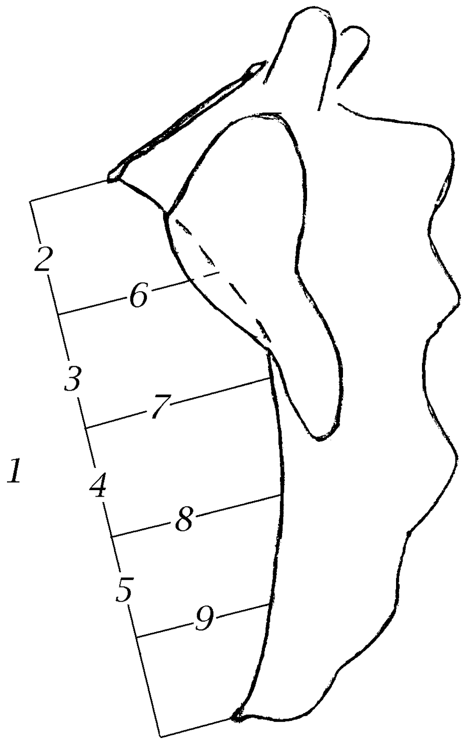

FIG. 1—*Measurements of sacral curvature. 1: Anterior height of the sacrum; 2–5: fractions of sacral height taken from the sacral promontory to the articulation of each sacral segment; 6–9: sacral depths at the articulation of each sacral segment.*

affiliation. It would further suggest that population affiliation should be considered in the application of the discriminant function.

Independent sample *t*-tests were used to assess the sexual dimorphism of each variable in the study and the potential for the use of univariate statistics for sex determination. Discriminant function analysis was employed to provide a model for predicting sex based on multiple measurements of sacral curvature. One function was generated from all of the variables in the sample. A second function was generated using a stepwise procedure that selects a subset of the variables that have the greatest discriminating power based on the largest F ratio. Within-group scatterplot matrices were examined prior to the analyses to ensure that there was no gross inequality of the covariance matrices, an assumption of the discriminant analysis.

One drawback of discriminant analysis is that it is difficult to assess the reliability of the functions. The classification results provided by the analysis are generally overly optimistic because they reflect how well the function can discriminate using the cases from the dataset on which it is based. The functions will not perform as well on cases from the actual population unless the parameters of the sample are identical to those of the population. In forensic anthropology, this is a problematic assumption to make.

To further assess classification error, a bootstrap method was used (13). Bootstrapping is frequently employed to assess classification error rates in the biological sciences and is similar to cross-validation in that it reduces classification bias and error classification variability (14–16). It has been demonstrated that the standard deviation of estimated statistics from bootstrapped samples are roughly equal to the standard error of an estimated statistic drawn with repeated sampling without replacement from the actual population (17). While other methods for assessing classification error like jackknifing and cross-validation reduce the bias of the classification results, their results tend to be highly variable (13). The bootstrap method employed here is an extension of the cross-validation method that reduces the variability by resampling many times with replacement.

The original sample was bootstrapped 100 times. During the bootstrapping process, each bootstrapped sample was randomly split into two subsamples by way of a weight variable that randomly selected roughly 64% of the cases. The larger subsample, or training sample, was kept the same size as the original sample ($n = 125$). Because the training sample was formed through resampling with replacement, there is a very strong likelihood that it will contain duplicates of many cases while omitting others. The unselected cases of each bootstrapped training sample were used to form the test sample. The discriminant function was then created from the learning sample and tested on the test sample. The classification results for each trial were recorded and used to calculate a weighted mean of the percentage of correctly classified cases for the learning and test samples combined. The mean was weighted posteriorly by the most probable percentage of sample size division, 0.632 for the learning and 0.328 for the test sample.

Results

The sample used in this analysis included individuals with two population affiliations, American blacks and American whites. To test for a significant interaction between population affiliation and sex that could confound further analyses, a GLM test was employed. The multivariate GLM test for sex and population interaction using all variables in the study was not significant ($p > 0.05$). Univariate results indicate that no single variable exhibited a sex–population interaction ($p > 0.05$). These statistical treatments suggest variability related to sex is largely independent of variability related to population affiliation. Following these results, all subsequent analyses were performed with the African American and European American samples pooled.

Results of the independent sample *t*-test for sex differences are displayed in Table 1. Anterior height of the sacrum and sacral fractions were similar in men and women with the exception of the first sacral fraction. The length from the sacral promontory to the S1–S2 articulation taken along the sacral height was significantly larger in men ($p < 0.05$). The depth of the sacral curvature was also larger in men. On average, sacral curvature depths at each segmental articulation were 11.8% greater in men than in women. Sacral depths at S2–S3 and S3–S4 were significantly greater in men in comparison with women ($p < 0.05$). The maximum depth occurred at the S2–S3 articulation. This depth was 2.8 mm larger on average in men ($p < 0.01$).

One discriminant function for sex classification was derived from the pooled sample using all the variables in the study (Table 2). The squared canonical correlation of the discriminant function, although significant, was low (0.490, $p < 0.01$). A second function was generated using a stepwise procedure (Table 3). This method selected the sacral fractions to the S1–S2 and S4–S5 articulations and the sacral depths at the S2–S3 and S3–S4 articulations as the most discriminating variables for sex estimation. However, the stepwise function failed to improve the canonical correlation (0.469, $p < 0.05$). Canonical correlations from the stepwise model indicate that most of the morphological variation of the sacral curvature related to sex is attributable to the vertical height from the promontory to the first and last sacral segmental articulations and the depth of the middle portion of the curvature.

Classification percentages of the discriminant functions are shown in Table 4. These are used to compare predicted group

TABLE 1—*Independent samples* t-*test for sex differences in sacral variables**†.

Variable	Males	Females	% Difference	p (t-test)
Anterior height	98.3 ± 10.03	100.1 ± 8.00	−1.83	N.S.
Sacral fraction at S1–S2	26.9 ± 3.01	25.5 ± 3.19	5.20	< 0.05
Sacral fraction at S2–S3	51.9 ± 5.01	51.5 ± 3.85	0.77	N.S.
Sacral fraction at S3–S4	71.1 ± 6.26	71.7 ± 5.25	−0.84	N.S.
Sacral fraction at S4–S5	87.9 ± 8.02	89.3 ± 6.52	−1.59	N.S.
Sacral depth at S1–S2	12.1 ± 4.89	10.5 ± 4.44	13.22	N.S.
Sacral depth at S2–S3	19.1 ± 6.58	16.3 ± 5.84	14.66	< 0.05
Sacral depth at S3–S4	18.5 ± 5.33	15.8 ± 5.22	14.60	< 0.01
Sacral depth at S4–S5	10.4 ± 2.42	9.9 ± 2.76	4.81	N.S.

*Means are shown with standard deviations.
†Measurements are in millimeters.

TABLE 2—*Discriminant function analysis of all sacral variables.*

Variable	Unstandardized Coefficients
Anterior height	0.027
Sacral fraction at S1–S2	0.307
Sacral fraction at S2–S3	0.164
Sacral fraction at S3–S4	−0.085
Sacral fraction at S4–S5	−0.124
Sacral depth at S1–S2	0.000
Sacral depth at S2–S3	0.037
Sacral depth at S3–S4	0.204
Sacral depth at S4–S5	−0.302
Constant	−3.269
Female centroid	−0.538
Male centroid	0.538
Eigenvalue	0.316
Canonical correlation	0.490
Wilks' lambda significance	<0.01

TABLE 3—*Stepwise selection of variables for sex discrimination.*

Variable	Unstandardized Coefficients
Sacral fraction at S1–S2	0.365
Sacral fraction at S4–S5	0.233
Sacral depth at S2–S3	−0.312
Sacral depth at S3–S4	−0.091
Constant	−1.981
Female centroid	−0.551
Male centroid	0.551
Eigenvalue	0.282
Canonical correlation	0.469
Wilks' lambda significance	<0.01

membership to actual group membership to assess the adequacy of the functions. Classification percentages from the original models and from the bootstrapping method of validation are shown. The bootstrap-weighted means provide a method for more rigorously assessing the robusticity of the function as they more accurately reflect the likelihood of successful classification of new cases from the population. Bootstrap-weighted mean percentages of correctly classified cases for the function using all nine variables show that 69.8% of men and 70.2% of women were classified correctly. For the stepwise model, these percentages dropped to 66.3% for men and 69.4% for women.

Discussion

Warren's observation in 1897 that sacral curvature differs between the sexes is correct (1). The depth of the sacral curvature

TABLE 4—*Correct classification results of the discriminant function.*

		Percent Correctly Classified		
Model	Classification Type	Males	Females	Total
All variables	Original	70.0	72.7	71.3
	Bootstrap-weighted mean	69.8	70.2	70.0
Stepwise	Original	72.5	72.7	72.6
	Bootstrap-weighted mean	66.3	69.4	67.8

is significantly greater in men at the articulation of S2–S3 and S3–S4. The greatest sacral curvature depth was consistently located at the level of the S2–S3 junction in both men and women. The first sacral fraction from the promontory to the S1–S2 articulation along the anterior height of the sacrum was also significantly dimorphic between the sexes. The lengthened first sacral fraction in men relative to women may explain the lack of difference between the sexes in anterior height of the sacrum despite a greater curvature in men. Increased curvature should reduce the anterior height, but does not, as indicated by comparisons both between sexes and within sexes (6). By significantly increasing the vertical distance to the S1–S2 articulation while maintaining a comparable sacral depth to women at that anatomical level, the anterior height of the male sacrum would remain similar to that of women despite having a greater sacral curvature and similar sacral fractions distal to S2.

The use of any one sacral dimension as a univariate statistic for sex assessment is not recommended. Although several sacral dimensions differed significantly by sex, there is substantial variation around the mean for each variable, as indicated by the large standard deviations. The degree of overlap in the range of variation is sufficiently large that an accurate determination of sex from an unidentified specimen cannot be made with statistical confidence. This problem was not overcome using multivariate statistics. The discriminant function analysis demonstrated that measurements describing sacral curvature can be used to estimate sex with only moderate accuracy. Sex was correctly assigned for 68.9% of cases using bootstrap validation. The canonical correlations derived from each function were also small, suggesting variation attributable to sex explains only a portion of variation in sacral curvature. As more reliable methods exist for the estimation of sex from other skeletal elements (18), the discriminant function described here should only be used in the absence of more dependable skeletal indicators of sex. Caution is also warranted when applying the function to archaeological specimens or specimens from other populations as the function is untested in other samples.

The primary difficulty in using the sacrum for sex determination is that sacral morphology is highly variable (5,19,20). Based on the canonical correlations from this analysis, variation from sexual dimorphism contributed to less than half of the variation observed in the measurements describing anterior sacral curvature. Other sources of variation may include mechanical factors, dietary deficiencies, skeletal disease, and age-related changes (20–22). Methods for sex determination using the sacrum should therefore be employed with caution.

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References

1. Warren E. An investigation on the variability of the human skeleton. Philos Trans R Soc Lond B 1897;189:398–401.
2. Bass WM. Human osteology: a laboratory and field manual, 4th edn. Columbia, MO: Missouri Archaeological Society, 1995.
3. Tague RG. Do big females have big pelves? Am J Phys Anthropol 2000;112:377–93.
4. Trotter M. The sacrum and sex. Am J Phys Anthropol 1926;9:445–50.
5. Flander LB. Univariate and multivariate methods for sexing the sacrum. Am J Phys Anthropol 1978;49:103–10.
6. Stradalova V. Determination of sex from metric characteristics of the sacrum. Folia Morphol 1974;22:408–12.
7. Benazzi S, Maestri C, Parisini S, Vecchi F, Gruppioni G. Sex assessment from the sacral base by means of image processing. J Forensic Sci 2009;54:249–54.
8. Dar G, Hershkovitz I. Sacroiliac joint bridging: simple and reliable criteria for sexing the skeleton. J Forensic Sci 2006;51:480–3.
9. Huffman M, Hunt DR. Sex identification in the pelvis: a re-evaluation of base-wing measurements, sacral anterior curvature, and *os Pubis* ventral arc. Am J Phys Anthropol 2006;129:106.
10. Albanese J. A metric method for sex determination using the hipbone and the femur. J Forensic Sci 2003;48(2):263–73.
11. Moore-Jansen PH, Ousely SD, Janz RL. Data collection procedures for forensic skeletal material, 3rd edn. Knoxville, TN: University of Tennessee Forensic Anthropology Series, 1994.
12. Moore-Jansen PH, Plochocki JH. Morphometric variation and sex determination in the human sacrum. Am J Phys Anthropol 1999;28(Suppl.):205–6.
13. Efron B. Estimating the error rate of a prediction rule: improvements in cross-validation. J Am Stat Assoc 1983;78:316–31.
14. McBride DG, Dietz MJ, Vennemeyer MT, Meadors SA, Benfer RA, Furbee NL. Bootstrap methods for sex determination from the os coxae using the ID3 algorithm. J Forensic Sci 2001;46:427–31.
15. Ponsting H, Henrick K, Thornton JM. Discriminating between homodimeric and monomeric proteins in the crystalline state. Proteins Struct Funct Genet 2001;41:47–57.
16. Fox CL, Martin AG, Civit SV. Cranial variation in the Iberian Peninsula and the Balearic Islands: inferences about the history of the population. Am J Phys Anthropol 1996;99:413–28.
17. Sokal RR, Rohlf FJ. Biometry: the principles and practice of statistics in biological research, 3rd edn. New York, NY: WH Freedman & Company, 1995.
18. Krogman WM, Iscan MY. The human skeleton in forensic medicine. Springfield, IL: Charles C. Thomas Publisher, 1986.
19. Flander LB, Corruccini RS. Shape differences in the sacral alae. Am J Phys Anthropol 1980;52:399–403.
20. Plochocki JH. Directional bilateral asymmetry in human sacral morphology. Int J Osteoarchaeol 2002;12:349–55.
21. Aufderheide AC, Rodriguez-Martin C. The Cambridge encyclopedia of human paleopathology. Cambridge, England: Cambridge University Press, 1998.
22. Plochocki JH. Morphometric age-related change in the adult human sacrum [thesis]. Wichita (KS): Wichita State Univ., 1999.

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