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Morphological Variation in Cervical Spinous Processes: Potential Applications in the Forensic Identification of Race from the Skeleton

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ABSTRACT: Determination of race (ancestry) is an important step in the identification of individuals in forensic cases. Race is most commonly assessed using cranial traits. Few reliable postcranial indicators are known. In this study, the frequency of bifidity of cervical spinous processes at different vertebral levels was examined in a sample of 359 Americans of African (black) and European (white) descent. The sample was selected from the Hamann-Todd collection, a large modern anatomical collection of known sex and race. Spinous processes were classified as "bifid," "partially bifid," or "nonbifid" based on previously defined criteria. Sex and race were kept entirely unknown to the classifier (S.M.D.) during data collection. Data were analyzed using Chi-square and logistic regression analysis. At C2, most individuals (91%) had bifid spinous processes. At C7, nearly all (98%) had nonbifid spinous processes. Significant differences between race/sex subgroups were found at C3–C6. At each of these levels, whites showed a higher frequency of bifidity than blacks and males a higher frequency of bifidity than females. Differences between races were greater than differences within races. Logistic regression analysis revealed C3 and C4 to be the most useful levels for identifying race. Based on these levels, 76.05% of a validation subsample was correctly classified by race (80.25% for whites, 72.09% for blacks). Pending further study, morphology of the cervical spinous processes may provide an additional method for the determination of race in skeletal forensic cases.

KEYWORDS: forensic science, forensic anthropology, cervical vertebrae, spinous processes, race, racial classification, ancestry, human variation, nonmetric traits

The determination of race (ancestry) from the skeleton is an issue of considerable importance to forensic anthropologists. Forensic identification is a two stage process. The first stage involves development of a biological profile of the individual, the second stage is an attempt at a positive match (1). The first step is necessary to narrow down the list of missing persons whose records may be searched in order to develop a positive match. Determination of race represents an essential step in the development of a biological profile, along with determination of sex, age, and stature. Of these four major aspects of biological profile development, race is the most difficult to determine for several reasons. First, all populations are subject to gene flow. There are no "pure" races, and therefore racial classification, by definition, imposes somewhat artificial boundaries on continuous variation. Current methodology employs cranial traits almost exclusively for the determination of race (2,3). While useful in the hands of an expert, such traits are continuously varying, often subtle, and highly influenced by sex. Another major problem has been the equating of racial classification with racism. Certainly, the concept of race has often been misused to promote racist ideologies. This has impeded the development of new techniques for forensic identification. Such techniques are needed, however, as the speedy and accurate identification of crime and mass disaster victims is of more than purely scholarly importance.

Much debate has taken place recently over whether races exist as biological entities (1,4,5). We, the authors, agree with the majority of physical anthropologists that racial classification is not a useful or biologically meaningful pursuit when addressing population based questions of adaptation or evolution. Race is not a biological entity but a sociocultural construct based on visually obvious biological characters. The aim of forensic anthropology, however, is not the study of populational processes but the identification of a single individual. The accurate assignment of an individual to an ethnic/racial group to which they would have been assigned during life within a specific society aids in narrowing the field of missing persons who could be potentially matched with the remains.

Racial variation in bifidity of the cervical spinous processes was first noted by Owen in 1851 (6) and first examined statistically by Cunningham in 1886 (7). In his study, Cunningham found that bifid cervical spinous processes were more common in Europeans than in other racial groups. The sample employed by Cunningham was very small ($n = 38$), and sex differences were not taken into account. Later studies by Shore in 1931 (8) and Lanier in 1939 (9) also found a much higher frequency of bifid spinous processes in populations of European (white) descent than in those of African (black) descent. Shore's sample was drawn from museum collections in South Africa, and included Europeans, Bantus, and Bushmen. Lanier's study was a general survey of vertebral variations from American museum collections. Neither study included females.

In the present study, the frequency of bifidity of cervical spinous processes at different vertebral levels is examined in a large sample of known sex and race, to determine: 1) If differences exist be-

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tween races, and 2) If those differences can be used effectively for forensic identification.

Materials and Methods

The sample consisted of 359 Americans of African (black) and European (white) descent, including equal numbers of males and females of each race. The sample was selected from the Hamann-Todd collection, a modern anatomical collection of known sex and race, housed at the Cleveland Museum of Natural History in Cleveland, Ohio. Data were collected in 1995. Selection of the sample was random, and sex and race were kept entirely unknown to the classifier (S.M.D.) during data collection.

Spinous processes were classified as bifid, partially bifid, or nonbifid based on the following criteria: 1) Bifid (B): the spinous process includes a clearly distinct cleft resulting in two elongate projections. The bifurcation must separate both the tubercles and part of the spinous process itself (Fig. 1). 2) Partially Bifid (P): two distinct tubercles at the end of the spinous process are present. The spinous process itself is not bifurcated and no cleft is present (Fig. 2). 3) Nonbifid (N): the end of the spinous process is rounded or flattened. A median groove may be present but two distinct tubercles are not present (Fig. 3).

Statistical methods included Chi-square and logistic regression analysis. For the logistic regression phase of the analysis the data were randomly divided into two subsamples. One of the subsamples was used to develop a model for predicting race from bifidity. Bifidity at cervical levels 2 through 7, as well as gender and interactions were considered for inclusion in the final model. Stepwise regression techniques were used and variables which significantly improved the model fit at the .05 level of significance, based on the likelihood ratio test, were kept in the final model. The final model contained variables that, in combination, best predicted race. The second subsample was used for model validation, that is, to assess the fit of the model developed with the first subsample (10). All analyses were performed using the SPSS statistical package.

Results

The frequency of bifid, partially bifid, and nonbifid cervical spinous processes by race and sex is shown in Table 1 and illustrated graphically in Figures 4 through 9. Chi-square analyses and lambda statistics for each vertebral level are shown in Table 2. The asymmetric version of the lambda statistic was used with race as the dependent variable.

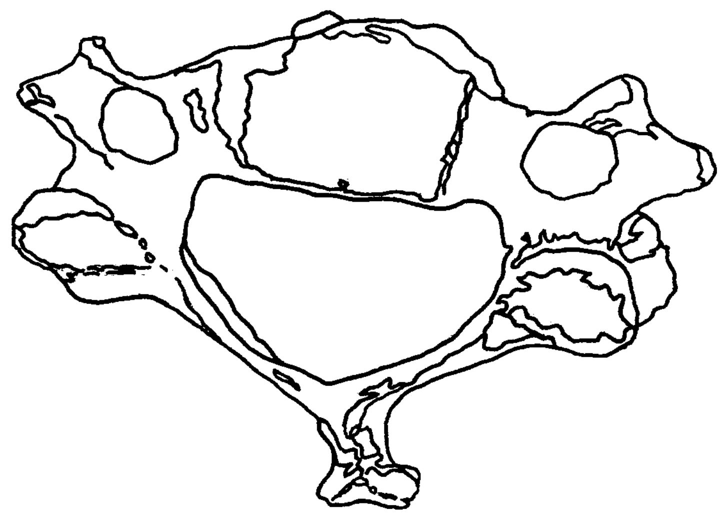

FIG. 2—*Partially bifid spinous process (3rd cervical vertebra).*

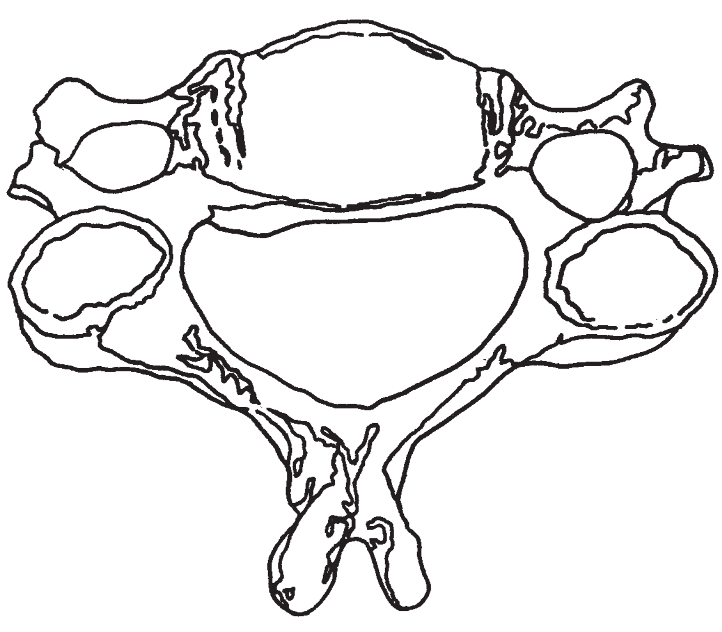

FIG. 1—*Bifid spinous process (3rd cervical vertebra).*

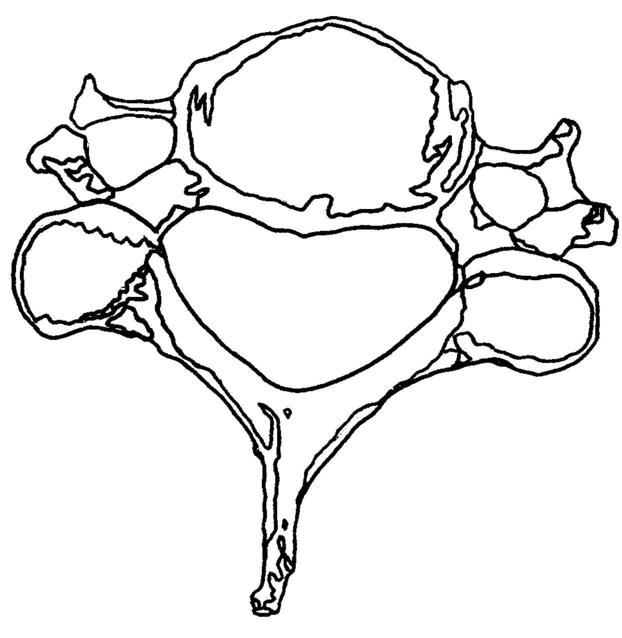

FIG. 3—*Nonbifid spinous process (3rd cervical vertebra).*

At Cervical Vertebra 2, most individuals (91%) had bifid spinous processes. Little variation was present by race or sex, and Chi-square tests were not significant. At Cervical Vertebra 7, nearly all individuals (98%) had nonbifid spinous processes. Chi-square results were also not significant. Significant differences in race/sex subgroups were found at Cervical Vertebrae 3 through 6.

At each of these levels, whites showed a dramatically higher frequency of bifid spinous processes than blacks. Results of Chi-square tests were very highly significant at each of these levels, reaching a p-value of .000001 for cervical vertebrae 3 through 5 in black versus white females, and the same value for C3 through C4 in black versus white males. The C5 level in males was significant at .00003, while C6 was significant at .001 for both sexes.

Lambda values suggest a strong association between race and bifidity at each of these levels. Differences by sex were also found. Within each race, males consistently showed a higher frequency of bifidity than females. Differences between sexes were much

TABLE 1—*Frequency of bifid, partially bifid, and nonbifid cervical spinous processes by race and sex.*

		C2			C3			C4		
Group		B	P	N	B	P	N	B	P	N
Black Males	N	83	4	2	16	21	52	29	23	38
	%	93.3	4.5	2.2	18.0	23.6	58.4	32.2	25.6	42.2
Black Females	N	74	6	5	9	11	66	13	23	50
	%	87.1	7.1	5.9	10.5	12.8	76.7	15.1	26.7	58.1
White Males	N	83	6	1	63	15	13	74	10	7
	%	92.2	6.7	1.1	69.2	16.5	14.3	81.3	11.0	7.7
White Females	N	83	7	1	41	22	29	67	13	11
	%	91.2	7.7	1.1	44.6	23.9	31.5	73.6	14.3	12.1

		C5			C6			C7		
Group		B	P	N	B	P	N	B	P	N
Black Males	N	49	18	23	30	14	46	0	0	90
	%	54.4	20.0	25.6	33.3	15.6	51.1	0	0	100.0
Black Females	N	37	16	33	22	16	48	3	1	82
	%	43.0	18.6	38.4	25.6	18.6	55.8	3.5	1.2	95.3
White Males	N	77	6	7	54	7	28	0	1	90
	%	85.6	6.7	7.8	60.7	7.3	31.5	0	1.1	98.9
White Females	N	74	10	8	46	6	39	0	2	88
	%	80.4	10.9	8.7	50.5	6.6	42.9	0	2.2	97.8

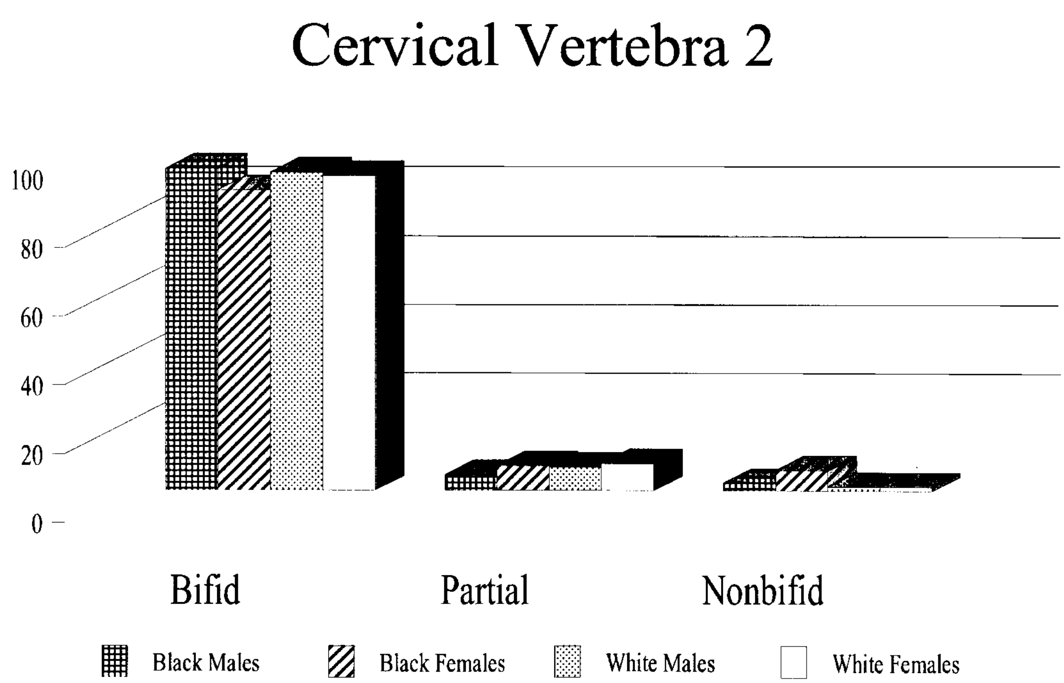

FIG. 4—*Frequency of spinous process types by race and sex: cervical vertebra 2.*

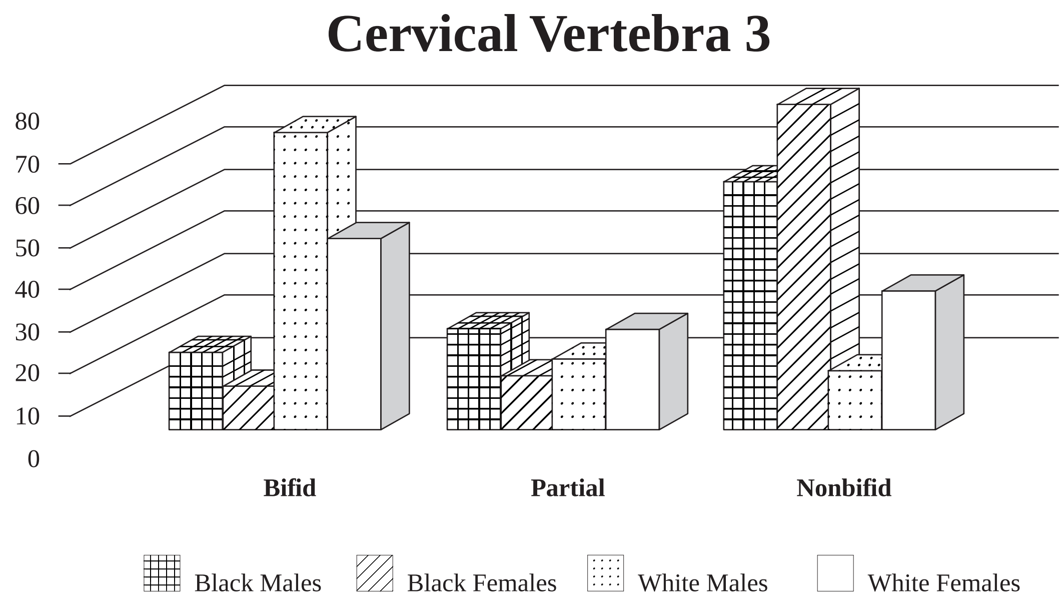

FIG. 5—*Frequency of spinous process types by race and sex: cervical vertebra 3.*

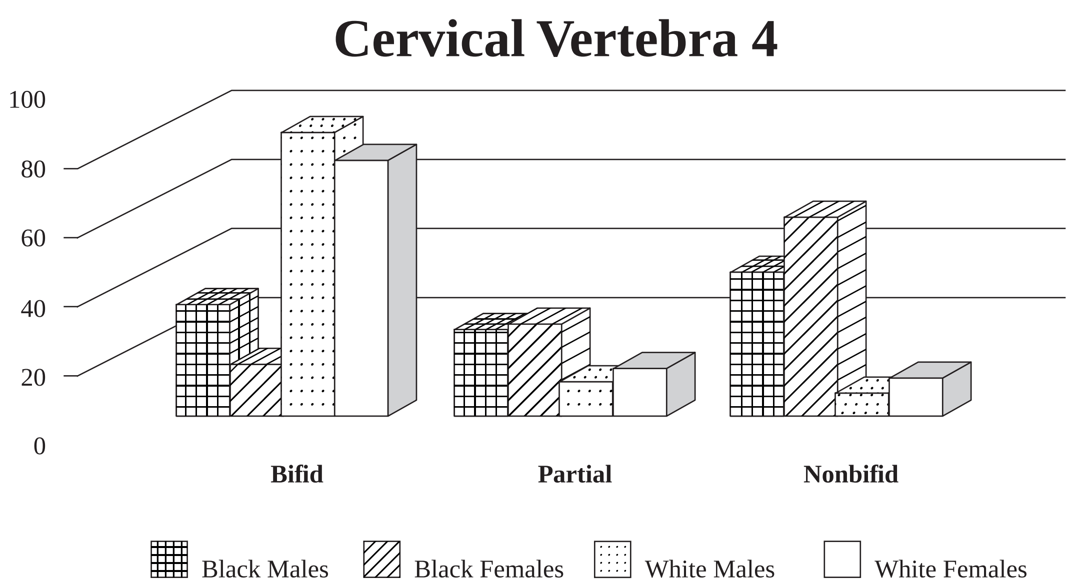

FIG. 6—*Frequency of spinous process types by race and sex: cervical vertebra 4.*

TABLE 2—*Chi-square analysis and lambda statistics*.

		C2	C3	C4	C5	C6	C7
Black/White	Chi-square	.73	52.35	46.13	20.76	13.56	.99
Males	P-value	n.s.	.000001	.000001	.00003	.001	n.s.
	Lambda	.011	.506	.489	.311	.270	.000
Black/White	Chi-square	3.06	38.40	64.07	28.79	13.81	3.46
Females	P-value	n.s.	.000001	.000001	.000001	.001	n.s.
	Lambda	.047	.430	.570	.360	.221	.035

* Chi-square analyses were also performed for males versus females within races. Results were not significant except at C3 in the white subsample (p = .002) and at C3 and C4 in the black subsample (p = .04 and p = .02, respectively).

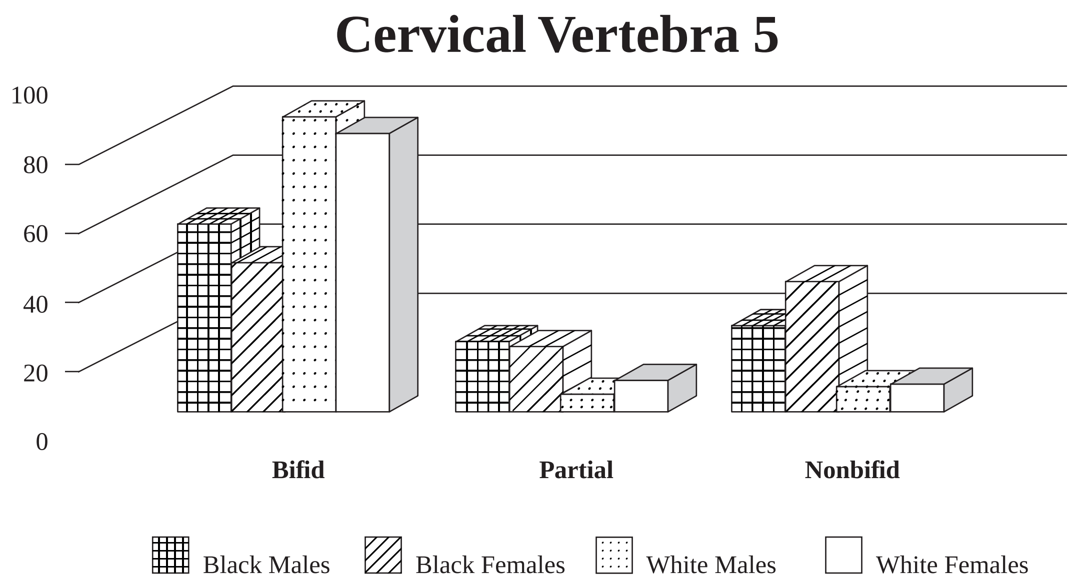

FIG. 7—*Frequency of spinous process types by race and sex: cervical vertebra 5.*

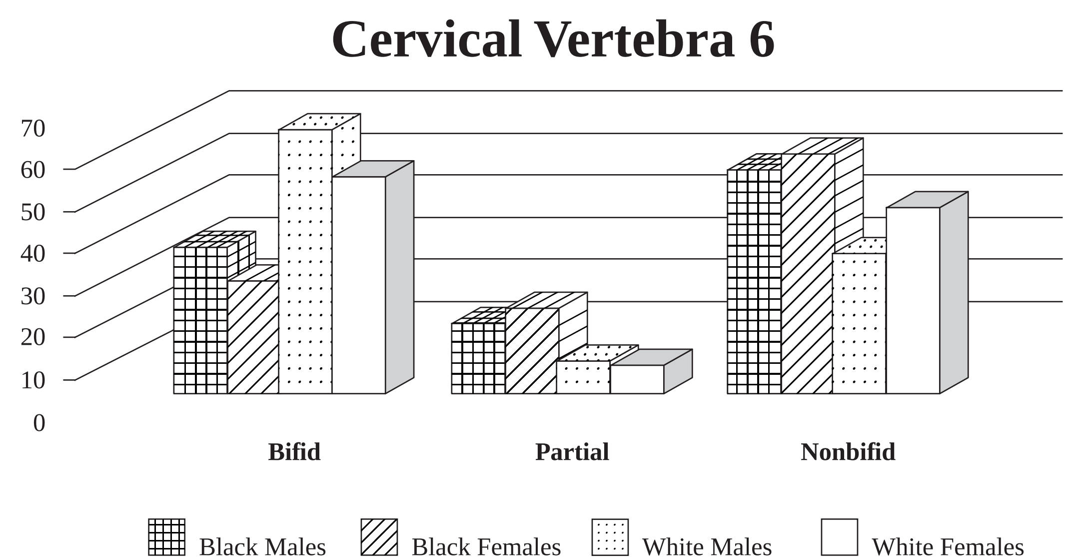

FIG. 8—*Frequency of spinous process types by race and sex: cervical vertebra 6.*

smaller than differences between races. The magnitude of difference between blacks and whites in the frequency of bifidity generally decreased between C3 and C6.

A randomly selected subsample consisting of 190 individuals was used for the model building phase of the logistic regression analysis. C3 and C4 were determined to be the significant variables in predicting race. No interactions were detected among the vertebral levels or with sex. Odds ratios and respective p-values are shown in Table 3. P-values were significant for each of the variables, based on the Wald statistic, reaching .02 for C3 and .0001 for C4. At each of these levels, the bifid versus nonbifid classification was the significant one for the prediction of race. Odds ratios indicate that an individual with a bifid C4 is 6.23 times more likely to be white than one with a nonbifid C4, while one with a bifid C3 is 3.44 times more likely to be white. The partially bifid category was not significant in its contribution to the model based on the Wald statistic.

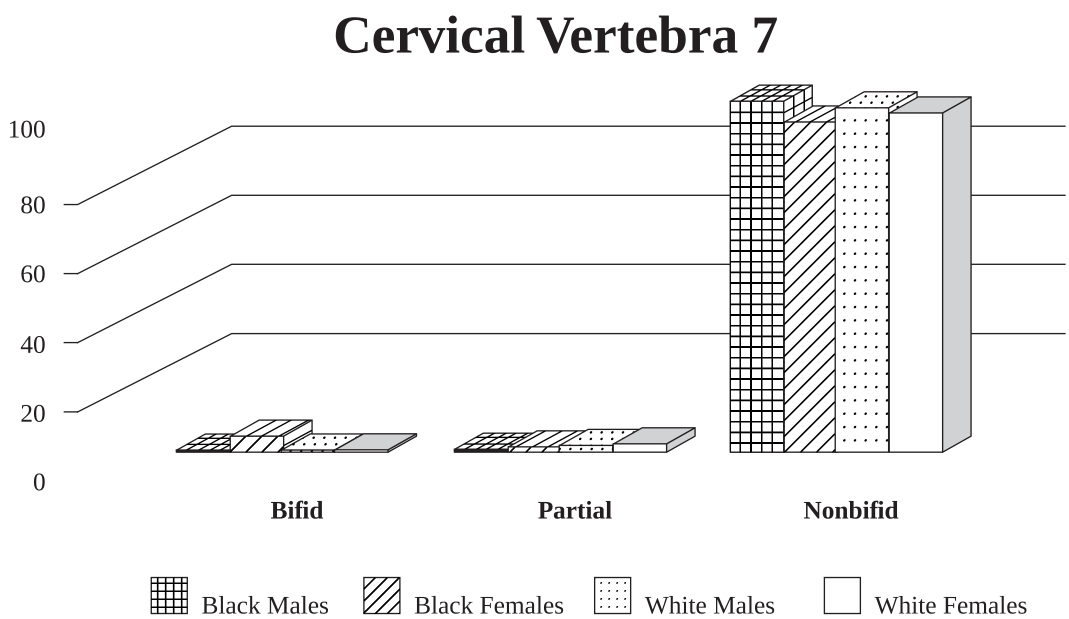

FIG. 9—*Frequency of spinous process types by race and sex: cervical vertebra 7.*

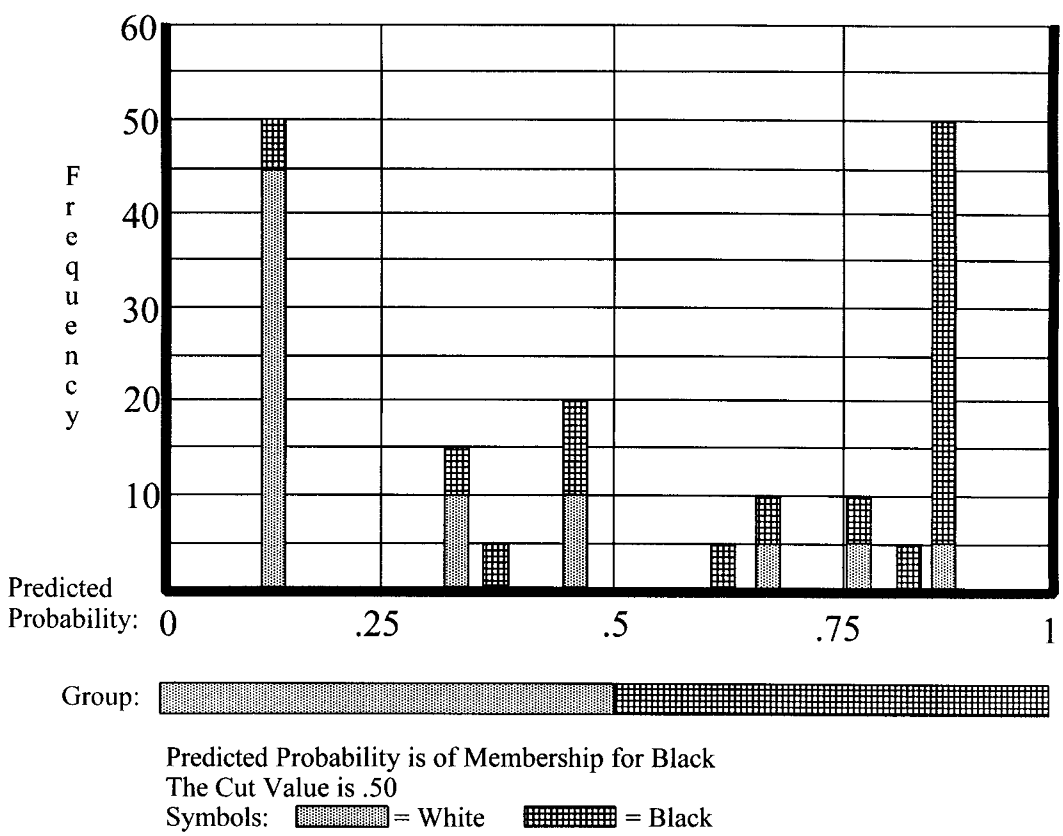

FIG. 10—*Observed groups and predicted probabilities based on logistic regression analysis using the validation subsample.*

TABLE 3—*The relationship between bifidity and race at C3 and C4, estimated from an unconditional logistic regression model based on the model-building subsample (*n *= 190).*

Variable	Odds Ratio	P-value*
C3	—	.0182
Bifid vs. Nonbifid	3.44	.0065
Partial vs. Nonbifid	2.32	.0723
C4	—	.0001
Bifid vs. Nonbifid	6.23	.0001
Partial vs. Nonbifid	1.39	.5238

* Significance based on the Wald statistic.

TABLE 4—*Classification table by race, based on an unconditional logistic regression model with C3 and C4, using the validation subsample (*n *= 169).*

		Predicted		
		White	Black	Percent Correct
Observed	White	65	16	80.25%
	Black	24	62	72.09%
			Overall:	76.05%

For the validation phase of the logistic regression analysis, based on the second subsample of $n = 169$, C3 and C4 were used to construct the model. Table 4 shows observed versus predicted classification by race, based on the model. Overall, 76.05% of individuals were correctly classified: whites were correctly classified 80.25% of the time while blacks were correctly classified 72.09% of the time. Figure 10 is a histogram showing observed groups and predicted probabilities based on the model.

Discussion

Clear and consistent differences in the frequency of bifidity of cervical spinous processes have been identified in a large sample of American blacks and whites. Significant differences have been found at Cervical Vertebrae 3 through 6. At each of these levels, whites showed a higher frequency of bifidity than blacks, and males a higher frequency of bifidity than females. Differences between races were greater than differences within races. Logistic regression analysis demonstrated that C3 and C4 were the most useful variables for obtaining correct classification by race. As shown in the histogram of observed groups and predicted probabilities (Fig. 10), dramatic separation between races was obtained in the majority of cases.

In regard to practical forensic applications, these data suggest that an individual with bifid spinous processes at both C3 and C4 would have a high probability of being white rather than black, and an individual with nonbifid spinous processes at both C3 and C4 would have a high probability of being black rather than white. However, because no interactions were detected among vertebral levels in the logistic regression analysis, a decision rule cannot be proposed for individuals with a bifid C3/nonbifid C4 or nonbifid C3/bifid C4 combination, based on these data.

Among those individuals who were misclassified, more blacks were misclassified than whites. This is most likely related to the fact that race is a social construct and the ethnic group classified as "American Blacks" is a genetically heterogeneous population composed of mixed West African, Northern European, and in some cases, Native American ancestry.

The C2–C7 cervical spinous processes serve as attachment points for a number of muscles, including trapezius, splenius capitis, spinalis cervicis, semispinalis cervicis, semispinalis thoracis, multifidus, rotatores, and interspinalis. In addition, the C2 segment gives specific attachment to rectus capitis posterior major and to obliquus capitis inferior, while the C6 segment may sometimes give attachment to rhomboid minor. The interspinous ligaments and ligamentum nuchae also attach to the spinous processes of C2–C7 (11–13). Bifid spinous processes result from the development of two secondary ossification centers (13).

The functional significance (if any) of differences in cervical spinous process morphology is unknown. Differences in bifidity may represent population specific (epigenetic) traits of little or no functional importance. Shore (8) found the frequency of nonbifid spinous processes in Europeans, Bantus, and Bushmen to be 28.3%, 78.8%, and 92.8% respectively. The greater similarity in frequency between Bantus, Bushmen, and American Blacks than between any of these populations and Europeans suggests that a high frequency of nonbifid spinous processes is a characteristic of African ancestry rather than a function of body size. In a more recent radiographic case study of an African Pygmy woman standing 140 cm in height, nonbifid spinous processes were found at all cervical levels except for C2 (14). Shore (8) reports that bifid spinous processes can be recognized during fetal development and are found at a higher frequency in fetuses than adults of both European and Native African (Bantu) populations. Future gross anatomical and histological studies may shed further light on this subject.

Regardless of functional considerations, the implications of these data for forensic identification are clear. Pending further study of other groups (Native Americans, Asians, individuals of mixed ancestry), bifidity of cervical spinous processes should provide a useful adjunct to cranial traits in the determination of race from the skeleton.

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References

1. Sauer NJ. Forensic anthropology and the concept of race: if races don't exist, why are forensic anthropologists so good at identifying them? Social Science and Medicine 1992;34(2):107–11.
2. Rathbun TA, Buikstra JE. Human identification: case studies in forensic anthropology. Springfield, Illinois: Charles C Thomas 1984.
3. White TD. Human osteology. New York: Academic Press 1991.
4. Brace CL. Region does not mean "race"-reality versus convention in forensic anthropology. J Forensic Sci 1995;40(2):171–5.
5. Kennedy KAR. But professor, why teach race identification if races don't exist? J Forensic Sci 1995;40(5):797–800.
6. Owen R. Comparison of the lower jaw and vertebral column of the Troglodytes gorilla, Troglodytes niger, and Pithecus satyrus and different varieties of the human race. Trans Zool Soc Lond 1851;101:98.

7. Cunningham DJ. The neural spines of the cervical vertebrae as a race-character. J Anat 1886;20:637–40.
8. Shore LR. A report on the spinous processes of the cervical vertebrae in the native races of South Africa. J Anat 1931;65:482–505.
9. Lanier RR. The presacral vertebrae of American white and negro males. Am J Phys Anthropol 1939;25:341–420.
10. Hosmer DW, Lemeshow S. Applied logistic regression. New York: John Wiley and Sons 1989.
11. Cramer GD, Darby SA. Basic and clinical anatomy of the spine, spinal cord, and ANS. St. Louis: Mosby 1995.
12. Lang J. Clinical anatomy of the cervical spine. New York: Thieme Medical Publishers 1993.
13. Williams PL, Warwick R, Dyson M, Bannister LH. Gray's anatomy. 37th edition. London: Churchill Livingstone 1989.
14. Von Neiss A. Sind ungespaltene Dornfortsätze der Halswirbelsäule ein Rassenmerkmal der Pygmäen des tropischen Afrikas? Fortschr Roentgenstr 1964;101:322–3.

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