TECHNICAL NOTE

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A Pilot Study Using the First Cervical Vertebra as an Indicator of Race

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ABSTRACT: The articular surfaces and vertebral foramen of the first cervical vertebra can be used to estimate race from complete and fragmentary specimens. Eight measurements taken from 200 vertebrae from the Terry and Hamann-Todd collections (Smithsonian Institution and Cleveland Museum of Natural History, respectively) were used to construct 13 discriminant functions that predict race with 76–60% accuracy.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, articular regions, racial classification

For years forensic anthropologists have sought to expand the arsenal of statistical techniques that estimate race to include not only complete bones, but also fragmentary elements. For example, successful tests have been developed that effectively estimate gender using only certain portions of long bones (5). Similarly, in 1985, the usefulness of the skull as an estimator of race was expanded by the development of a technique (4) that could be applied to fragmented skulls. Multiple regression equations were created using measurements on the basicranium that could be obtained from complete and incomplete specimens. Given the fragmentary nature of the remains with which forensic anthropologists deal, such techniques are necessary and increase the chances of making an accurate determination by allowing for more reliable and quantifiable estimations (8). This pilot study follows work on the basicranium (4) but uses discriminant function equations to examine the first cervical vertebra and determine its usefulness as an indicator of race.

Samples and Measurements

Two hundred first cervical vertebrae were drawn from the Cleveland Museum of Natural History, Hamann-Todd collection (n = 100) and the Smithsonian Institution's Terry collection (n = 100). All vertebrae are from individuals aged 20 to 75 years and show no extraordinary pathological condition.

The measurements used in this study are closely related to those defined for the basicranium (4) because of the functional relation between the first cervical vertebra and the cranial base and are the same as those devised by the author for a previous study (7). The measurements used are those that proved easiest to obtain and that provided the best discrimination.

Eight measurements were taken from the superior and inferior articular surfaces and vertebral foramen area of Terry and Hamann-Todd vertebrae. All measurements were obtained using a sliding caliper graduated to 0.05 mm and were taken to the nearest 0.1 mm. Measurements are expressed in centimeters. A 20% sample of vertebrae drawn from both samples was measured twice for replicability and observer error purposes. An average error rate of 3% was noted and is within acceptable ranges (2). 1. Length of Superior Facet—Maximum length of (right) superior facet (LSF). Maximum length as measured between the distal/proximal edges of the facet. 2. Width of Superior Facet—Maximum width of (right) superior facet (WSF). Maximum width as measured between the medial/lateral edges of the facet. 3. Length of Inferior Facet—Maximum length of (right) inferior facet (LIF). Maximum length as measured between the distal/proximal edges of the facet. 4. Width of Inferior Facet—Maximum width of (right) inferior facet (WIF). Maximum width as measured between the medial/lateral edges of the facet. 5. Maximum Distance between Superior Facets—Maximum distance between the lateral edges of the superior facets (MxDS). 6. Maximum Distance between Inferior Facets—Maximum distance between the lateral edges of the inferior facets (MxDI). 7. Length of Vertebral Foramen—Maximum length of the vertebral foramen (LVF). Maximum length as measured from fovea (anterior) to posterior arch. 8. Width of Fovea—Maximum width of fovea (WFV). Maximum width as measured along the long axis of the fovea (right to left).

Statistical Equations

Discriminant functions derived from 200 vertebrae were constructed using the SYSTAT statistical package version 6.0 on an IBM PS/2. To use the discriminant functions (Table 1) multiply the value of the required measurement (cm) by the designated coefficient, sum the products, and apply the constant. The sectioning point is 0; whites have scores > 0, blacks < 0.

Table 1 lists 13 discriminant functions that were selected because they resulted in the fewest number of misclassified individuals. The top row of the table lists the equation number, the next row shows the number of measurements used in that equation, the third row lists the groups used to create the equation, the bottom two

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TABLE 1—*Discriminant function equations for predicting race from the first cervical vertebra.*

Equation Number	1	2	3	4	5	6	7	8	8	9	10	11	12	13
Number of Measurements	8	5	2	2	1	8	5	2	2	1	8	5	2	1
Group	Males & Females	Males & Females	Males & Females	Males & Females	Males & Females	Males	Males	Males	Males	Males	Females	Females	Females	Females
LSF	1.398	2.332	3.973	—	—	2.482	3.477	4.239	—	—	0.332	0.193	—	—
WSF	1.237	1.195	1.100	—	—	1.422	1.114	0.979	—	—	0.518	−0.757	—	—
LIF	−3.653	−2.723	—	1.796	—	−0.534	0.060	—	2.069	—	−4.785	3.553	3.357	—
WIF	1.089	5.268	—	−7.430	7.099	3.808	5.356	—	8.023	8.740	4.345	−9.665	−9.605	9.563
MxDS	0.140	—	—	—	—	0.994	—	—	—	—	−0.776	—	—	—
MxDI	3.009	—	—	—	—	0.930	—	—	—	—	3.711	—	—	—
LVF	−1.094	—	—	—	—	−1.361	—	—	—	—	1.213	—	—	—
WFV	−1.703	−1.027	—	—	—	−2.074	−1.019	—	—	—	0.260	−0.733	—	—
Constant	−9.821	−9.218	−9.953	8.393	−10.999	−16.266	−17.263	−10.716	−16.812	−14.316	−15.795	9.370	8.325	−13.968
Percent Accuracy	69.0	60.0	60.0	62.0	60.0	72.0	75.0	67.0	67.0	64.0	76.0	72.0	68.0	67.0
Percent Accuracy (Jackknifed)	66.0	58.0	59.0	62.0	60.0	68.0	71.0	67.0	66.0	64.0	72.0	67.0	67.0	67.0
F ratio (Wilks Lambda)*	5.507	5.276	6.23	9.011	16.984	4.99	6.207	9.779	5.763	10.685	5.243	4.620	11.452	18.272

*$p = 0.001$.

TABLE 2—*Canonical structure coefficients* for males and females.*

	Males	Females
LSF	0.708	0.143
WSF	0.093	0.125
LIF	0.257	−0.195
WIF	0.568	0.706
MxDS	0.702	0.274
MxDI	0.685	0.747
LVF	−0.092	0.109
WFV	0.029	−0.063

*Canonical structure coefficients calculated for each sex using all variables.

rows list accuracy ratings for the classification matrix and the jackknifed classification matrix, respectively, and the bottom most row lists Wilks Lambda F ratios for each equation.

Discussion

Measurements from Terry and Hamann-Todd blacks and whites differ in their contribution to each function. This is apparent by examining the canonical structure coefficients for each measurement and observing the patterns that emerge (Table 2). Measurements WIF and MxDI are consistently different for blacks and whites in both sexes, while LSF and MxDS show racial differences in males, but not in females. Measurements WSF, LIF, LVF, and WFV show a lack of racial difference in both sexes. The positive signs associated with the structure coefficients indicate that whites have larger values than blacks.

Similarly, examination of sample statistics from both Terry and Hamann-Todd specimens (Table 3) shows that measurement values for white males are slightly higher than values for black males. It is these size differences that account for the usefulness of the atlas to estimate race. For example, biomechanical forces, which are most likely connected to weight-bearing activities, that are discernible in portions of the cranial base and that allow it to be used to estimate race are also evident in similar portions of the atlas. Because these equations use measurements of those portions of the atlas that support a load, it seems likely that the usefulness of this element as an indicator of race lies in the manner in which load-bearing differs among blacks and whites.

Finally, a comparison of accuracy results from this examination to those generated using the basicranium (4) suggests that racial dimorphism decreases as one proceeds from the occipital region of the skull to the upper spine. Equations using measurements from the basicranium (4) produce overall accuracy ranges of 90–70%, whereas equations from this study produce overall accuracy ranges of 76–60%.

One explanation for the decrease in accuracy is the presence of a dimorphism gradient that is a result of differences between the skull and the atlas, especially in the way that biomechanical forces that are responsible for racial characteristics act upon the two elements. According to Giles and Elliot (3), the skull "provides more indication of race than any other skeletal part." This statement concerns anatomical indicators of race, but perhaps the statement can be extended to statistical examinations as well. The basicranium technique (4) focuses on the skull—an element that is already an excellent visual indicator of race—and produces equations that estimate race with a high rate of accuracy. The present study, focusing on the first cervical vertebra—an element that has never been considered useful as a visual estimator of race—produces results that are lower than those associated with the skull. Though the basicranium study uses an area of the skull that is not anatomically, or visually, diagnostic for race, its results are still higher than those derived from the atlas. The skull is simply a better overall indicator of race, both anatomically and when examined statistically, than the atlas. The reasons for this require further study, but it follows that the same biomechanical forces responsible for racial differences that are discernible on both elements may in some way also serve to make the cranial base a better race estimator than the atlas. Further study with these two elements in general and these two sets of variates in particular is necessary to more fully explain this issue. Study should not however, be limited to only these two bones. Creation and examination of similar variates applied to the second cervical vertebra might also serve to more fully elucidate the presence or absence of a dimorphism gradient. For example, if the supposition stated here is valid then one would expect even lower estimation when using equations developed from the second cervical vertebra.

Conclusion

Developmental differences between the basicranium and the first cervical vertebra suggest that the atlas may not be as robust an indicator of race as the base of the skull, though accuracy ranges from discriminant function equations (Table 1) do suggest that it is somewhat effective. For example, these ranges are equal to and, in some instances, higher than other current tests used to estimate race (1,6). In addition, this technique is not limited to complete elements, but can be applied to fragmentary specimens as well. However, before any reliance is placed on this technique within forensic applications, more work with larger and more geographically and temporally diverse populations should be conducted.

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TABLE 3—*Sample statistics (cm) and standard deviations for Terry and Hamann-Todd vertebrae.*

Group	LSF	WSF	LIF	WIF	MxDS	MxDI	LVF	WFV
Means (Terry)								
White females	1.98	1.52	1.68	1.48	4.71	4.45	2.84	0.890
White males	2.19	1.67	1.78	1.69	5.07	4.75	3.07	0.916
Black females	1.95	1.48	1.68	1.39	4.51	4.20	2.75	0.876
Black males	2.04	1.59	1.71	1.60	4.75	4.57	3.00	0.888
Standard deviations (Terry)								
White females	0.197	0.179	0.149	0.090	0.297	0.232	0.211	0.144
White male	0.226	0.259	0.141	0.122	0.311	0.246	0.264	0.152
Black female	0.162	0.219	0.130	0.112	0.336	0.208	0.138	0.098
Black male	0.204	0.211	0.119	0.110	0.378	0.213	0.314	0.120
Means (Hamann-Todd)								
White females	2.09	1.40	1.69	1.53	4.61	4.47	2.65	0.692
White males	2.39	1.08	1.81	1.67	5.04	4.80	2.84	0.726
Black females	2.05	1.43	1.71	1.44	4.65	4.31	2.71	0.727
Black males	2.18	1.10	1.80	1.60	4.81	4.57	2.39	0.735
Standard deviations (Hamann-Todd)								
White females	0.212	0.194	0.135	0.110	0.243	0.240	0.178	0.114
White males	0.294	0.153	0.155	0.131	0.364	0.356	0.234	0.124
Black females	0.224	0.251	0.265	0.096	0.398	0.286	0.297	0.102
Black males	0.201	0.130	0.133	0.097	0.275	0.190	0.644	0.150

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