TECHNICAL NOTE

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# Allocation of Crania to Groups Via the "New Morphometry"

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**ABSTRACT:** An investigation regarding the variation in cranial morphology between American blacks and whites was conducted using triangulation schemes of inter-landmark distances and converting these to three dimensional coordinate data. A least squares superimposition method and Euclidean distance analysis were utilized to obtain parameters for classifying individuals in our sample, consisting of 19 black and nineteen white crania from the William M. Bass, III Donated and Forensic collections curated at the University of Tennessee, Knoxville. Thirty-six caliper measurements were collected on each skull based on 14 homologous cranial landmarks (nasion, bregma, lambda, prosthion, subspinale, basion, frontomalare (left and right), zygoorbitale (left and right), zygotemporale (left and right), and left and right asterion). The results are compared to traditional discriminant analysis.

The classification results using the new morphometry are comparable to traditional discriminant analysis. However, the new morphometry can provide information as to the specific location of morphological variation that cannot be obtained with discriminant analysis.

**KEYWORDS:** forensic science, geometric morphology, traditional morphometry, forensic anthropology

Traditionally, studies in morphometrics have relied on the application of multivariate statistical methods to sets of caliper measurements (1). The measurements generally correspond to linear distances and sometimes to angles and ratios that are expressed numerically (1,2). However, much of the geometric or shape information is lost in these traditional analyses, which are limited to multivariate statistical space, rather than depicting a form in two or three dimensional morphological space (3). Newer morphometric methods that are based on coordinate data can provide considerably more information, but to date the "new morphometry" has seen little to no application in forensic anthropology.

One of the limitations with traditional morphometric methods is that they attempt to capture variation that may not be oriented along the span of the calipers. For example, biasterionic breadth may give an impression of the width of a cranium, but it cannot tell us whether the asterions are located more anteriorly or inferiorly in an individual skull. A second limitation with the traditional morphometry, is that it is impossible from a list of measurements or means to reconstruct a skull. Pictorial representations are easier to visualize and interpret than the numerical coefficients obtained from more traditional methods. Finally, the traditional morphometry provides no undisputed method for adjusting size, and can provide rather ambiguous descriptions of shape.

The purpose of this analysis is to present a study of between-sample variation of American Black and White crania and to demonstrate the advantages of using methods from the "new morphometry." The results are compared to traditional methods obtained by discriminant analysis.

## Materials and Methods

### *Sample*

The sample consists of 19 American Black males and 19 American White males from the William M. Bass III Donated and Forensic collections curated at the University of Tennessee, Knoxville.

### *Measurements*

Ideally, a 3-D digitzer should be used to obtain the x, y, z coordinates for each landmark. However, because 3-D digitizers are not currently readily available nor accesible in most departments, coordinate data can be easily obtained using the program pp3dd, which is available for downloading (written by L.W. Konigsberg), and traditional morphometric equipment (i.e., sliding and spreading calipers) (4). This approach is very similar to one described by Robert Benfer in a 1975 publication in the American Journal of Physical Anthropology (5).

Since geometric morphometry is landmark based, 14 homologous landmarks were chosen that reflect cranial variation. Table 1 lists the 14 (6 midline and 4 paired) landmarks selected. A total number of 36 measurements were taken $((3*14)-6))$, based on the fourteen homologous cranial landmarks. These were compared to the following eight traditional craniometrics: maximum cranial length (GOL), maximum cranial breadth (XCB), bizygomatic breadth (ZYB), basion-bregma (BBH), basion-nasion (BNH), nasion-prosthion (NPH), nasion-bregma (FRC), and bregma-lambda (PAC).

### *Method*

The caliper method consists of first selecting any three landmarks along the midline that form a triangle (e.g., nasion, bregma, and lambda). A minimum number of measurements equalling 3n-6 are required if all but the initial three landmarks are off the midline (6).

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From these inter-landmark distances (or ILDs), the x and y coordinates of the three landmarks can be trigonometrically or algebraically calculated. For landmarks that are off the midline, such as asterion, only the distances to each corner of the previous triangle need to be measured. Simple trigonometry or linear algebra can also be used to solve for the x, y, z coordinates of the new landmark.

After measuring all the crania used in the study, it is necessary to translate, scale, and rotate each configuration of points so that all skulls are of comparable size and in a similar orientation. To undertake these transformations a generalized least squares (GLS) superimposition approach was used that minimizes the sum of squared distances between the landmarks for a skull and the homologous landmarks for a consensus skull (or reference configuration) (7,8). This consensus is simply the average across the 38 skulls. The GLS superimposition was performed by using GRF-ND, a program written by Dennis Slice, which is available for downloading from the State University of New York at Stony Brook morphometrics homepage (9).

Briefly, GLS brings the individual forms into a common coordinate system and iteratively fits them to the estimated mean configuration (9). First, a specimen is arbitrarily chosen as the initial consensus form. Next the forms are brought into a common coordinate system by scaling, rotating, and translating the forms to the current consensus estimate. By calculating the average of each coordinate for each landmark across the entire group sample, a new consensus estimate is derived. The difference between the initial consensus estimate and the new consensus form is calculated, and if the difference is small enough the process will cease. However, if the differences are sufficiently large the procedure will return to the scaling, rotating and translating steps and a new consensus estimate will be derived. Generally the process iterates through several times before a consensus fit is reached representing the mean configuration for the sample (9).

The mean configurations can then be viewed with a wire frame program, which plots the mean Cartesian coordinates in three dimensional space. The shareware three dimensional viewer 3dv2.5 was used in this study (10). Additionally, the mean configurations for separate groups can be overlayed for visual comparison.

TABLE 1—*List of homologous cranial landmarks.*

| Cranial Landmarks | |
|---|---|
| 1. Nasion | 8. Left Zygotemporale |
| 2. Bregma | 9. Right Zygotemporale |
| 3. Lambda | 10. Basion |
| 4. Left Frontomalare | 11. Subspinale |
| 5. Right Frontomalare | 12. Prosthion |
| 6. Left Zygoorbitale | 13. Left Asterion |
| 7. Right Zygoorbitale | 14. Right Asterion |

*Statistics*

To classify the individual specimens, the squared Euclidean distance to the average Black and average White configurations were calculated, and then each case was assigned to the closest group. Euclidean distance is identical to Mahalanobis $D^2$ (or generalized distance) but assumes that all covariances are zero. For comparison a discriminant function was constructed using the eight traditional craniometrics and cross-validation method, which treats n-1 out of n observations. The statistical tests were conducted using the SAS package (11).

## Results

Figure 1 represents the consensus configurations for American Whites and Blacks from an anterior perspective. The overlay illustrates that the cranial breadth at the asterions is greater for the

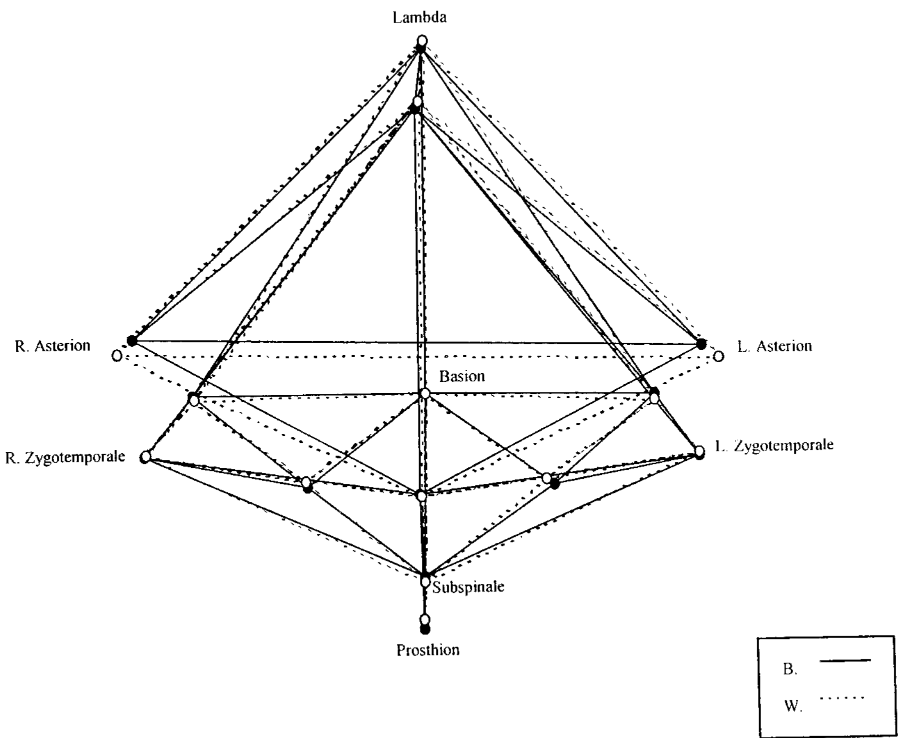


FIG. 1—*Anterior view of the consensus configurations for American Whites and Blacks.*

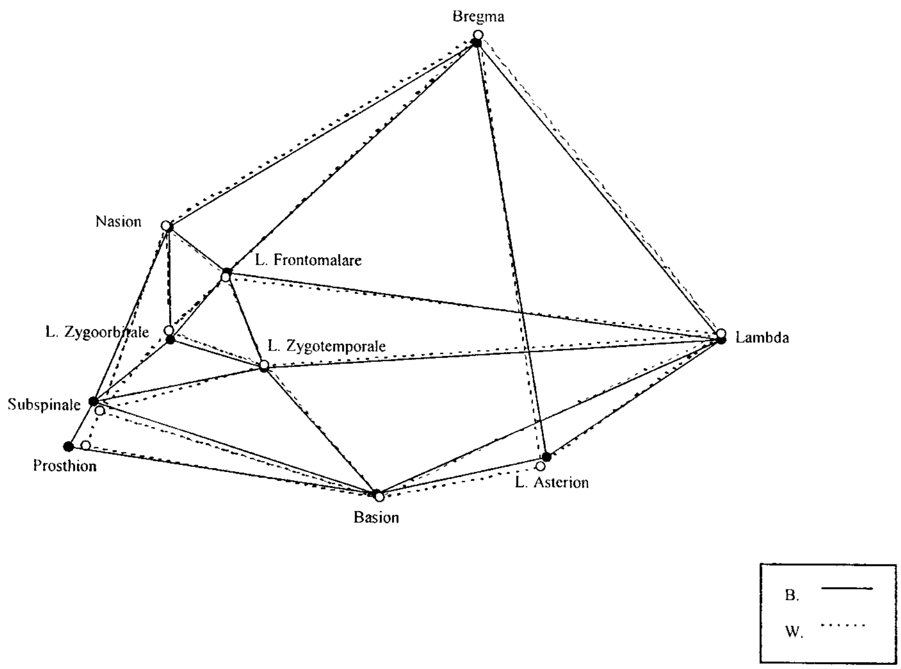


FIG. 2—*Lateral view of the consensus configurations for American Whites and Blacks.*

TABLE 2—*Allocation via superimposition versus traditional discriminant analysis.*

| | Correct Classification* | | |
|---|---|---|---|
| | Blacks | Whites | Overall |
| Superimposition | 78.9% | 88.9% | 84.2% |
| Trad. Discrim. Analysis | 84.2% | 73.7% | 78.9% |

*Using cross-validation.

White mean configuration than for the Black mean configuration. This is not surprising since it is generally noted that White crania are broader than Black crania. However, the more anteriorly placed asterions on the White mean form compared to the Black mean form (see Fig. 2) was an unexpected finding. Figure 2 is a lateral view of the same overlay and illustrates that bregma is higher on the White mean form than on the Black mean form, while the Black average configuration shows a more anteriorly projecting lower face at subspinale and prosthion.

Table 2 presents correct classification results for both traditional discriminant analysis and superimposition. Using the leave-one-out method, superimposition gives a correct classification for Blacks of 78.9%, and for Whites of 88.9%. This gives an overall correct classification rate of 84.2%. The discriminant analysis, based on traditional cranial measurements, gave similar results, correctly classifying Blacks 84.2% of the time and Whites 73.7% of the time. This gives an overall correct classification of 78.9%.

A discriminant analysis was also performed based on the locality of morphological variation observed with the three dimensional overlays. The following four measurements were used in the discriminant analysis that reflect the specific regions of variation observed: basion-bregma, lambda-midasterion, midasterion-prosthion, and biasterionic breadth. A correct classification of 79% was obtained for both Blacks and Whites.

## Discussion

For this project landmarks were chosen that best reflect the overall morphology of the crania. Since geometric morphometry captures information about the shape of most of the form, we were able to compare means for each group in a three dimensional graphic representation that permitted us to see where the morphological differences exist between the groups. Not only could we recognize the presence of cranial variation but we could more fully describe the quality of the difference. For example, the White mean form exhibited wider and more anteriorly placed asterions than the Black mean form. While the biasterionic breadth measurement of the traditional morphometry may have provided us with information regarding the greater breadth of White crania, it never would have indicated the variation in the placement of the asterions with respect to the coronal plane.

It is a simple matter to include classification of an unknown skull within the framework of the "new morphometry." For an unknown case its coordinate landmark data should be fit to the consensus configuration, where the consensus is the average across all crania (regardless of classification). The Mahalanobis squared distance can then be found between the unknown case and each of the averages within the classification (using pooled within-group variances to define the space). The unknown skull can then be classified to the nearest group, and posterior probabilities of membership, as well as "typicality" probabilities can be estimated.

While the new morphometry should not be viewed as a replacement for more traditional methods, it is a promising tool that can provide information that cannot be obtained with discriminant analysis. However, the classification results are only comparable, and not markedly better than discriminant analysis. The new morphometry would be useful in refining traditional measurement selection for more powerful statistical inquiries. Finally, geometric morphometry can be employed as a tool to locate specific regions of morphological variation as demonstrated by the three dimensional overlays. In this particular case, a discriminant function constructed from the coordinate data gave classification results which were as good as from a traditional craniometric analysis, even though the former method included only half as many measurements.

## References

1. Lynch JM, Wood CG, Luboga SA. Geometric morphometrics in primatology: craniofacial variation in *Homo sapiens* and *Pan troglodytes.* Folia Primatol 1996;67:15–39.
2. Rohlf FJ, Marcus LF. A revolution in morphometrics. TREE 1993; 8:129–32.
3. Bookstein FL. A brief history of the morphometric synthesis. In: Marcus LF, Bello E, Garcia-Vadecasas, A, editors. Contributions to morphometrics. Madrid: Museo Nacional de Ciencias Naturales, 1993;15–37.
4. Konigsberg LW. PP3DD: Poor person's 3D-Digitizer [computer program]. Knoxville: Department of Anthropology, the University of Tennessee, Knoxville, Tennessee, 1997. Web address: http://konig.la.utk.edu/pp3dd.html.
5. Benfer R. Morphometric analysis of cartesian coordinates of the human skull. Am J Phys Anthrop 1975;42:371–82.
6. Roth VL. On three-dimensional morphometrics, and on the identification of landmark points. In: Marcus LF, Bello E, Garcia-Vadecasas A, editors. Contributions to morphometrics. Madrid: Museo Nacional de Ciencias Naturales, 1993;41–59.
7. Bookstein FL. Combining the tools of geometric morphometrics. In: Marcus LF, Corti M, Loy A, Naylor GJP, Slice D, editors. Advances in morphometrics. New York: Plenum Press, 1996;131–51.
8. Rohlf FJ, Slice D. Methods for comparison of sets of landmarks. Systematic Zool 1990;39:40–59.
9. Slice D. GRF-ND: Generalized rotational fitting of N-dimensional data [computer program]. New York: Department of Ecology and Evolution. State University of New York at Stony Brook, 1993. Web address: http://life.bio.sunysb.edu/morph/main.html.
10. Garcia O. 3dv2.5. 3-D Viewer - Version 2.5 [shareware computer program], 1991.
11. Schlotzhauer SD, Littell RC. SAS systems for elementary statistical analysis, SAS Institute Inc., Cary, NC, 1987.

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