Ancestry catches up to modern times: A new technique evaluating morphological traits using 3D technology

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ABSTRACT

In forensic anthropology, ancestry assessment describes population affinity using morphological and metric analyses (1). However, morphological analyses are particularly difficult to reproduce and standardize, since they strongly depend on an anthropologist's subjectivity, based on their experience with human variation (2).

The purpose of this research was to improve the rigour of morphological analyses of ancestry by using three-dimensional (3D) technology to quantify relevant features on the human skull. The sample consisted of 50 European-American, 24 Canadian Inuit and 13 African-American adult female crania, for a total sample size of 87 individuals. The samples were imaged using photogrammetry, the 3D models were constructed in 3DF Zephyr, and the shape analysis was performed in 3DS Max. The data were statistically analyzed using a non-parametric multivariate analysis of variance (PERMANOVA), a linear discriminant function analysis (DFA) and a principal component analysis (PCA). Results showed that major differences between groups were clearest when 3D measurements were combined. Overall, European-Americans were statistically different from the other two groups, while Canadian Inuit and African-American individuals were harder to distinguish statistically. The current method was satisfactory in presenting a classification rate of 87.36% (jackknifed: 80.46%) and an average repeatability of 97%. Nonetheless, this project had some limitations. Future research should evaluate the technique with a larger sample size, more diverse populations, other ancestry-related cranial traits (e.g., oval window), and other 3D measurements (e.g., volume). Despite its few limitations, this new and simple method of 3D shape analysis shows promise for the future of ancestry assessment via 3D technology.

INTRODUCTION

In forensic anthropology, "ancestry" refers to an individual's biogeographic region of origin (3). Ancestry assessment evaluates population affinity based on morphological analyses and metric analyses (1). Morphological analyses (Fig. 1) are difficult to reproduce and standardize, an issue strongly criticized in the Daubert court ruling of 1993 (4) and the 2009 U.S. National Academy of Sciences report (5).

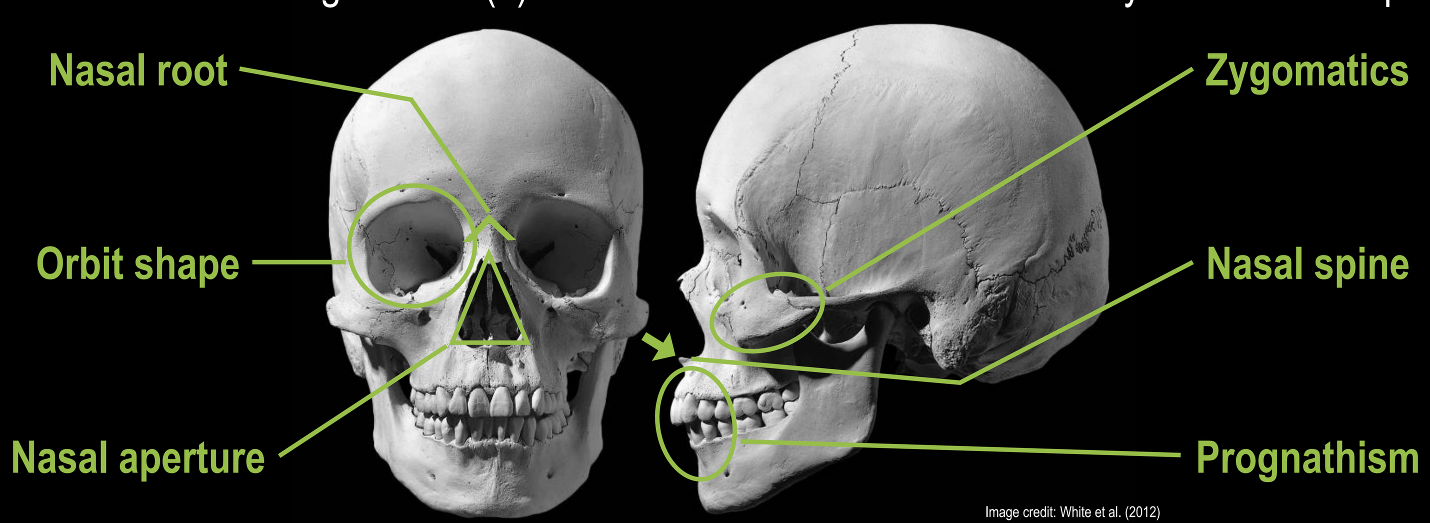

FIG. 1 – Examples of traits analyzed in morphological analyses.

- Purpose: to improve the rigour of morphological analyses by using 3D technology to quantify relevant cranial ancestry traits.
  - Circumference/perimeter, surface area of the defined perimeter and proportion ratios were used to characterize and quantify the 3D outline of the orbits, the nasal aperture and the palate, in lieu of the current subjective criteria (e.g., "round" versus "square" orbits).
- Research question: is it possible to distinguish Canadian Inuit, European- and African-American populations using 3D outline measurements?

MATERIALS

Samples (N = 87 individuals)

- Canadian Inuit (*n* = 24):
  - Derived from the Canadian Indigenous collection curated at the Canadian Museum of History (CMH) in Gatineau, Québec (Canada).
  - Individuals originate from four archaeological sites dated from the 20th century.
- European- (*n* = 50) and African-Americans (*n* = 13):
  - Derived from the William M. Bass Donated Skeletal Collection curated at the University of Tennessee's Forensic Anthropology Center in Knoxville, Tennessee (United States).
  - Individuals represent the United States' modern population, many of them originating from Tennessee and Southeastern U.S.

METHODS

Digital Imaging

FIG. 2 – Photogrammetry set-up.

3D Shape Analysis

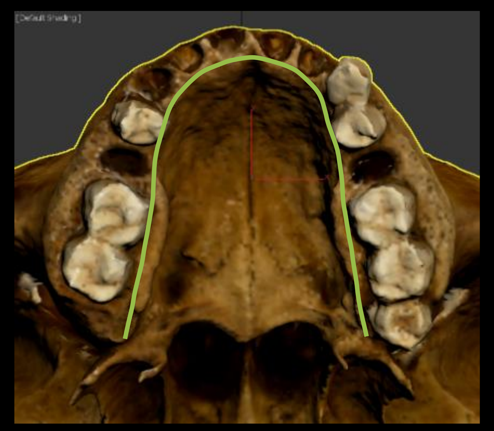

FIG. 3 – Example of circumference/ perimeter measurement.

FIG. 4 – Example of surface area measurement.

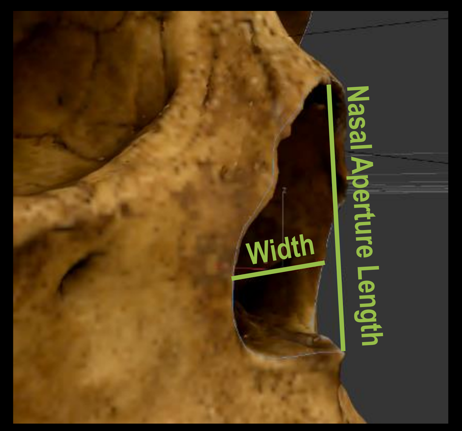

FIG. 5 – Example of proportion ratios measurement.

RESULTS

PERMANOVA

- Overall, there was a significant difference ($p < 0.05$) between populations, regardless of the category or combination of 3D measurements considered in the test (Table 1).
  - European-Americans were statistically different ($p < 0.05$) from African-Americans and Canadian Inuit for all tests (Table 2).
  - African-Americans were not statistically different ($p > 0.05$) from Canadian Inuit for all tests, except for proportion ratios (Table 2).

TABLE 1 – PERMANOVA results per measurement category.

Comparison	*F* value	*p* value
All Measurements	8.024	0.0003*
Circumference/Perimeter	4.799	0.0037*
Surface Area	8.028	0.0001*
Proportion Ratios	14.36	0.0001*

* Significant at α = 0.05.

TABLE 2 – Pairwise post-hoc results per measurement category.

Pairwise Post-Hoc Analyses	*p* value
All Measurements	
African-American * European-American	0.0009*
African-American * Canadian Inuit	1
European-American * Canadian Inuit	0.0015*
Circumference/Perimeter	
African-American * European-American	0.0075*
African-American * Canadian Inuit	0.8793
European-American * Canadian Inuit	0.0492*
Surface Area	
African-American * European-American	0.0012*
African-American * Canadian Inuit	1
European-American * Canadian Inuit	0.0009*
Proportion Ratios	
African-American * European-American	0.0003*
African-American * Canadian Inuit	0.0033*
European-American * Canadian Inuit	0.0003*

* Significant at α = 0.05 (following Bonferroni correction).

TABLE 3 – DFA classification rates per measurement category.

Comparison	Classification Rate (%)	Jackknifed (%)
All Measurements	87.36	80.46
Circumference/Perimeter	63.22	60.92
Surface Area	56.32	52.87
Proportion Ratios	73.56	64.37

PCA

- Most of the variation (more than 75%) was explained by the first two PCs for all measurement categories, the first describing size and the second describing shape.
  - These results were not very informative and were not analyzed further.

DFA

- The discriminant analysis providing the highest classification rate was the one containing all 3D measurements, rather than a single measurement category (Table 3).
  - Considering the small sample size of two of the three populations considered, this result was considered very satisfactory.
  - Even with the jackknifed confusion matrix, it fell within the ≥ 80% threshold generally recommended as a standard for accuracy (6).

Intra-Observer Error

- Except for the perimeter of the nasal aperture (91%), all measurements had a repeatability above 95%, providing an average repeatability of 97%.
  - All scores fell within the ≤ 10% threshold recommended for intra-observer concordance (6), making this method highly repeatable.

DISCUSSION

Significance in Forensic Anthropology

- The proposed technique will contribute to making ancestry assessments less dependent on an anthropologist's experience with human variation and more accessible to younger forensic anthropologists, through 3D technology and its numerous benefits over traditional methods:
  - Non-invasive and non-destructive, which maintains the integrity of the bones (7);
  - Provides a high-definition digital copy of the skeletal remains being imaged, which offers a permanent archival record (7,8); and
  - Allows for the accurate quantification of angles, surface areas and volumes through the extraction of coordinate data, which are most useful for the computation of precise statistical shape analyses (8).

Subjectivity

- Tracing of traits' shapes in 3DS Max is a subjective process, brought about by the observer's selective placement of vertices to create the 3D outline.
  - It cannot yet be argued that this method is better or worse than other techniques; an inter-observer test should be performed to settle this matter.

CONCLUSIONS

Future Research

- Increase in sample size, notably African-Americans and Canadian Inuit to offer more reliable results;
- Addition of populations to the analyses, such as other Asian groups, Hispanics (9) or Australian Aboriginals (10);
- Evaluation of other measurements obtained from the 3D models, such as surface area and volume; and
- Assessment of other traits known to vary between populations, such as the oval window (11).

The use of 3D technology is a promising avenue that can be beneficial to forensic anthropologists in many ways. This study has demonstrated how it can be successfully applied to ancestry assessment and opens the door to a more objective, innovative and accessible future in forensic anthropology.

Image credit: https://www.gtreview.com/earth-boy/

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Dawnie Steadman, at the University of Tennessee Knoxville, for providing assistance and access to the William M. Bass Donated Skeletal Collection, as well as Dr. Janet Young and Mrs. Stacey Girling-Christie, at the Canadian Museum of History, for providing assistance on exchanges with the Canadian Indigenous communities and for granting access to the Canadian Inuit individuals curated at the CMH.

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Research supported by:

SSHRC = CRSH
Social Sciences and Humanities Research Council of Canada
Conseil de recherches en sciences humaines du Canada
Canada