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Prediction of Race Using Characteristics of Dental Morphology*

ABSTRACT: Historically, forensic anthropology has concentrated on race determination using skeletal morphological variation. Conversely, dental anthropology has been concerned with worldwide patterns of dental morphological variation. This paper represents a synthesis of the goals of forensic anthropology with the methods of dental anthropology. Dentitions of modern African Americans ($n = 110$) and European Americans ($n = 155$) were observed using methods based on the Arizona State University dental morphology standards. Of 136 characters observed, eight were found with frequencies that were very different between the groups. Based on these eight characteristics, probability tables were created for determining an individual's social race, using both Bayesian prediction and logistic regression. These tables are applicable for determining the probability that an unknown individual can be categorized as African American or European American. This method was tested on 40 individuals known to belong in one of these two ancestral groups. Correct assignment of race was made in 90% of cases.

KEYWORDS: forensic science, dental morphology, race identification, Bayesian prediction, logistic regression

The dentition is often preserved even when bony structures of the body are destroyed. For this reason, the use of dental morphology to determine group relationships is an established procedure in biological anthropological studies. However, past forensic application of dental morphological characteristics has been mainly limited to the using the presence of shovel-shaped incisors to indicate Asian or Native American ancestry or Carabelli's trait to indicate European ancestry. Identification of the race that would have been ascribed is an important factor in individualizing human remains, limiting the pool of missing persons to which a match could be made for unidentified human remains.

Toward this end, dental morphological data were compiled to create tables that can be used in the determination of ancestry for modern African American and European Americans. The traits that have the most different frequencies in the samples of modern African American and European Americans have been analyzed through logistic regression and Bayesian probability analysis to determine the probability of their co-occurrence in the general populations of these two groups. These probabilities have then been organized in tables according to the presence and absence of these traits. This kind of table allows forensic practitioners to quickly and easily compare a dentition from a single individual of unknown origin to a large databank of trait observations. These probability tables are a new presentation of traits used for determination of racial affiliation. Generally, traits that are considered markers of race are simply listed, without mathematical information about the probability of their being seen in a single individual of any particular race (1–3).

The study of dental morphology involves close observation of characteristics of tooth crowns and roots (4). Studies of dental morphology date to the first half of the 20th century, and include analysis of well-known traits such as shovel shaped incisors and Carabelli's trait, as well as many lesser known traits (5–6). Standardization of traits and techniques has continued to the present day, spearheaded by Albert. A. Dahlberg and Christy. G. Turner II (7–8).

Lasker and Lee (9) authored one of the first surveys in English of the use of dental characteristics to determine ancestry in a forensic setting. They noted that shovel-shaped incisors are most common in "Mongoloids" (persons of Asian descent), and that Carabelli's trait is most common in "Whites" (persons of European descent). They did not identify any traits that were more common in persons of African ancestry. Shovel-shaped incisors and Carabelli's trait remain the most common, if not the only, dental traits used in forensic analyses (1,3). However, recent research (10–11) has shown that Carabelli's trait frequencies are variable in all worldwide populations, and not usefully high or low in any particular population.

Carabelli's trait, apparently first described in 1842 by von Carabelli (12) may be the most studied of all dental morphological variables. The trait consists of a pit, Y-shaped fissure, bump, or cusp on the mesiolingual side of the maxillary deciduous posterior premolars and permanent molars. It has been studied in many worldwide populations, past and present, including Australopithecines (13,10). In a recent survey, Correia and Pina (11) surveyed 23 published reports of frequencies of first molar Carabelli's trait in populations ranging from Alaskan natives to Bantu speakers to American soldiers. They reported frequencies ranging from 13.5% (Portuguese) up to 85% (American Whites).

Shovel-shaped incisors are those with ridges on the mesial and distal margins of the lingual surfaces. Studies of shovel shaping date back to 1920, when Aleš Hrdlička described the characteristic in the collections at the National Museum of Natural History, which represent populations worldwide (14–15). Shoveling has usually been studied as a qualitative variable, but some researchers have studied it as a quantifiable metric trait by measuring the depth of the shoveling from the center of the lingual surface (16). As a qualitative variable, frequencies of shovel shaped incisors range from 0.0% up to 91.9% in samples from a wide range of geographic

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TABLE 1—*Dental casts used for this study.*

Institute	Collection	African American	European American	Total
Arizona State University	Univeristy of Washington	10		10
Case Western Reserve University	Bolton-Brush		54	54
Tennessee Memphis Health Center	Dental Casts	100	101	201
Total		110	155	265

areas (15). Western Eurasia, Africa, and Sahul-Pacific groups have the lowest frequencies, while the highest frequencies and greatest expression are generally found in Eastern Asian, Northern Asian, and Native American samples (15). In North America, the presence of shoveling is commonly used in making the determination that a skeleton is Native American or, in the Southwest, Hispanic.

Material and Methods

All observations from which the comparison tables were built were made on dental casts. However, the test of the method was performed on both casts and real teeth. Dental casts came from collections listed in Table 1. Further description of the collections can be found in Edgar (17).

Morphological Observations

Observations were made of 29 dental characteristics, each observation was made on all the teeth on which the character was potentially expressed. Both antimeres were scored when present, the higher or more complex of the two scores represents the maximum expression of the trait in the individual. Teeth with wear, caries, or calculus were observed to the extent that traits were not obscured. Permanent teeth in mixed dentitions were included to allow for a larger sample. This is a commonly used method of gathering the most observations per each individual (15). At maximum, 136 observations could be made per dentition. Table 2 lists the traits and the teeth for which they were observed. Only occlusal, buccal, or lingual surface traits were observed. The decision to leave out root traits was based on the fact that in most cases they would be unobservable, since the data came from casts, photographs, and museum skeletal collections, where teeth in the alveolar bone could not be removed. Other factors that limited observations of traits included preservation, cast quality, and dental wear.

All but two dental traits were scored according to the ASU Dental Anthropology System, described by Turner et al. (8). The two traits scored differently are midline diastema and "trigonid crest". Midline diastema, a gap of at least 1 mm between the two maxillary central incisors, is not included in the ASU system, but was recommended as a possible distinguishing characteristic for Africans and their descendants (Joel Irish, personal communication, 1998). Also, while some researchers use the ASU system's distal trigonid crest, others instead recognize a mesial and/or middle trigonid crest. For this analysis, it was found to be simplest to use a single observation that included distal, middle, or mesial crests, which I referred to as "trigonid crest."

In most cases the scores have the same meaning as in the ASU system. However, there are three traits, metacone, hypocone, and cusp seven size, where the ASU system includes a half grade, such as 3.5. During the development of the system, this grade was added

TABLE 2—*Dental morphology traits observed.*

Trait	Teeth Scored
Winging	UI1
Midline diastema	UI1
Shoveling	UI1, UI2, UC, LI1, LI2
Curvature of labial surface	UI1
Double shoveling	UI1, UI2
Peg shape	UI2, UM3
Interruption groove	UI1, UI2
Congenital absence	UI2, UM3, LI1, LM3
Tuberculum dentale	UI1, UI2, UC
Canine mesial ridge	UC
Canine distal accessory ridge	UC, LC
Premolar mesial and distal accessory cusps	UaP, UpP
Tri-cusped premolars	UaP, UpP
Disto-sagittal ridge	UaP
Metacone	UM1, UM2, UM3
Carabelli's trait	UM1, UM2
Hypocone	UM1, UM2, UM3
Maxillary molar cusp 5 (Hypocone)	UM1, UM2, UM3
Parastyle	UM1, UM2, UM3
Lower premolar cusp variation	LaP, LpP
Anterior fovea	LM1
Groove pattern	LM1, LM2, LM3
Cusp number	LM1, LM2, LM3
Deflecting wrinkle	LM1
Trigonid crest	LM1, LM2, LM3
Protostylid	LM1, LM2, LM3
Mandibular molar cusp 5 (Hypoconulid)	LM1, LM2, LM3
Mandibular molar cusp 6 (Entoconulid)	LM1, LM2, LM3
Mandibular molar cusp 7 (Metaconulid)	LM1, LM2, LM3

U = maxillary, L = mandibular, I = incisor, C = canine, P = premolar, M = molar, a = anterior, p = posterior.

to better represent the range of variation that has been found. It does not really indicate a half step in size change, rather a more complete description of the size variation that actually exists between the scores of three and four (8). For ease of computation, these half grades were elevated to full grade. In the case of metacone size, the choice of scores would not be 0, 1, 2, 3, 3.5, 4, 5, but 0, 1, 2, 3, 4, 5, 6 instead.

From these 136 observations, eight were found to have frequencies different enough between African Americans and European Americans to be of use in forensic situations. These characteristics are listed in Table 3, along with their breakpoints for trait presence and frequency in each sample. Using these traits, probability tables based on samples of modern African Americans and European Americans were created to determine an individual's social race affiliation.

Statistical Analysis

Results are presented as predictions based on logistic regression probability (RP) as well as a method based on Bayes' theorem (BP) (18–20). Logistic regression is similar to regular multiple regression except that the dependent variable is of a presence or absence nature, rather than continuous. It can be used to predict group affiliation based on two or more variables (19). Probability is defined as:

$$\mathrm{Prob}(Y \mid y_1) = 1/1 + \exp(1(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p))$$

and

$$\mathrm{Prob}(Y|y_2) = 1 - \mathrm{Prob}(Y = y_1)$$

TABLE 3—*Dental traits useful for determining African American of European American ancestry.*

Trait	Tooth	Code	Scores Considered		African Americans		European Americans	
			Absent	Present	Observed	Affected	Observed	Affected
Tuberculum dentale	UC	UCTD	0–1	2–6	99	83.8%	141	47.5%
Lower premolar cusp variation	LaP	LaPCV	0–3	4–9	101	89.1%	149	10.7%
Lower premolar cusp variation	LpP	LpPCV	0–2	3–9	106	95.3%	150	79.3%
Deflecting wrinkle	LM1	LM1DW	0	1–3	90	46.7%	138	22.5%
Trigonid crest	LM1	LM1TC	0	1	83	15.7%	125	0.8%
Mandibular molar cusp 5 (Hypoconulid)	LM2	LM2C5	0	1–5	81	59.3%	132	19.7%
Mandibular molar cusp 5 (Hypoconulid)	LM3	LM3C5	0	1–5	8	87.5%	4	25.0%
Mandibular molar cusp 7 (Metaconulid)	LM1	LM1C7	0	1–4	104	45.2%	146	14.4%

where Y is the dependent variable, in this case social race category, and β is the vector that corresponds with each dental characteristic in the analysis (19–20). Unfortunately, logistic regression cannot be used when the frequency of observation for any trait combination is zero. For this reason, in addition to probabilities based on logistic regression, a posterior probability method based on Bayes' theorem was used to compute a probability for each trait combination in the forensic probability tables.

Posterior probability is a means appropriate for categorical data of calculating the probability that an event will occur, based on the number of times it has not occurred in previous observations (18,21). The statistic as used here is defined as:

$$P(A_i \mid \{I_1, I_2, \dots, I_n\}) = \frac{P(\{I_1, I_2, \dots, I_n\} \mid A_i)P(A_i)}{\sum P(\{I_1, I_2, \dots, I_n\} \mid A_j)P(A_j)}$$

where $P(A_i \mid \{I_1, I_2, \dots, I_n\})$ is the posterior probability of an individual being of either African American or European American descent, $P(\{I_1, I_2, \dots, I_n\} \mid A_i)$ is the likelihood finding a particular trait combination in an individual of a particular race, and $P(A_i)$ is the proportion of individuals in which the trait combination under consideration is present (the prior probability) (21). This statistic is generalizable to any number of traits being considered at one time. It is used here for single traits, as well as for two, three, and four trait combinations.

Results

Probability analysis was done with dichotomized character states for two, three and four trait combinations. These probabilities, based on comparisons of two, three, and four traits, have been arranged in table sets available on the website www.unm.edu/∼osteolab. The table sets available on the website are exemplified here by Tables 4 through 7. A set of observations from an individual dentition can be compared to the tables to determine the probability that the observed characteristics would be found in either of the two groups.

To use these results, as many as possible of the eight traits considered should be observed in the dentition of an unknown individual. Observations should be scored using the ASU dental anthropology system (8), with the modification for trigonid crest described above, then dichotomized according to Table 3. Then, combinations of the traits should be compared to the tables to be found at the website. It is preferable to use probabilities computed through logistic regression, as these are intended to be generalized to the population from which the samples were drawn. However, if no logistic regression probability is provided, Bayesian probability may be substituted. An assessment of race should only be made if the probabilities for the particular unknown individual are consistently in agreement about the racial affiliation. The tables do not provide probabilities for some trait combinations. This is because those combinations did not exist in the sample data.

To use the tables:

1. Using ASU dental morphology plaques, record observations of the dental traits listed in Table 3 (above). The traits should be scored as present, absent, or unobservable, according to the breakpoints also listed in Table 3.
2. Compare the scores with the table sets A, B, C, and D on the website www.unm.edu/∼osteolab (exemplified by Tables 4–7). Table set A provides the frequency of each individual trait in the samples. Table sets B, C, and D provide probabilities of presence and absence combinations for two, three, and four trait combinations, respectively. In the tables and table sets, "0" refers to a trait observed to be absent, and "1" refers to a trait observed to be present. For each comparison that can be made, record the probability that the individual would be classified in each race, European American (EA) or African American (AA). Also, record whether the probability given is a Bayesian probability (BP) or a logistic regression probability (RP). Probabilities computed by logistic regression are preferable, but are not always computable.
3. Choose an acceptable level of probability (such as 85.0% or 90%) and note the race assigned by each combination of traits above that level. The determination of social race affiliation should be based on these probabilities.

TABLE 4—*Example of table showing dental trait frequencies.*

UCTD	0	1	Total
AA	16	83	99
EA	74	67	141
Total	90	150	240
AA BP	0.18	0.55	
EA BP	0.82	0.45	

TABLE 5—*Example of table showing two-trait combination probabilities.*

UCTD	0		1		
LaPCV	0	1	0	1	Total
AA	2	12	8	70	92
EA	67	5	54	11	137
Total	69	17	62	81	229
AA BP	0.03	0.71	0.13	0.86	
EA BP	0.97	0.29	0.87	0.14	
AA RP	0.03	0.75	0.14	0.86	
EA RP	0.97	0.25	0.87	0.14	

TABLE 6—*Example of three trait combination probabilities.*

UCTD	0				1				
LM1DW	0		1		0		1		
LM1C7	0	1	0	1	0	1	0	1	Total
AA	5	1	4	2	19	17	19	15	82
EA	47	3	10	4	35	7	10	4	120
Total	52	4	14	6	54	24	29	19	202
AA BP	0.1	0.25	0.29	0.33	0.35	0.71	0.66	0.79	
EA BP	0.9	0.75	0.71	0.67	0.65	0.29	0.34	0.21	
AA RP	0.09	0.28	0.31	0.41	0.3	0.6	0.63	0.82	
EA RP	0.91	0.72	0.69	0.59	0.6	0.4	0.37	0.18	

TABLE 7—*Example of four trait combination probabilites.*

UCTD	0								1								
LaPCV	0				1				0				1				
LpPCV	0		1		0		1		0		1		0		1		
LM2C5	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	Total
AA	1	0	0	1	0	0	5	4	1	0	2	3	1	1	16	32	67
EA	15	2	32	12	0	0	4	1	7	1	29	4	1	0	7	2	117
Total	16	2	32	13	0	0	9	5	8	1	31	7	2	1	23	34	184
AA BP	0.1	0	0	0.1			0.6	0.8	0.1	0	0.1	0.4	0.5	1	0.7	0.9	
EA BP	0.9	1	1	0.9			0.4	0.2	0.9	1	0.9	0.6	0.5	0	0.3	0.1	

Testing the Forensic Probability Method

The method of determining social race using dental morphology developed in the present study was tested using casts from the Ohio State University (OSU) dental cast collection. A colleague selected forty dentitions and casts without repetition, 20 African Americans and 20 European Americans, which were not included in the research to develop this method. Social race affiliation was documented either during these individual's lives or upon their death. Observations from these 40 individuals were then compared with the tables, and a determination of probable ancestry was made. These determinations accurately identified the ascribed social race category in 90% of the test dentitions.

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APPENDIX

Worked Example

This example refers to the table sets available on the website, http://www.unm.edu/~osteolab. The method that was used for this test is exemplified here by the description and analysis of OSU dental cast T138. Table 8 shows the presence (1) and absence (0) scores for the eight forensic traits for this dentition. Notice that three traits were unobservable (?) in the table. This is a likely situation in any forensic or historical archaeology case.

TABLE 8—*Observations for OSU dental cast T138.*

Code	Score
UCTD	1
LaPCV	0
LpPCV	0
LM1DW	?
LM1TC	?
LM2C5	0
LM3C5	?
LM1C7	0

The combination listed above of presence and absence scores for the observable traits was compared with each of the table sets B, C, and D so far as possible. First, the scores were compared with the four-trait probabilities in table set D. Four comparisons could be made, all based on Bayesian probabilities. All four comparisons indicated that the individual T136 is European American, with probabilities ranging from 0.78 to 0.91. Next, the individual was compared with the three-trait probabilities in table set C. Ten comparisons were possible, three based on logistic regression and seven based on Bayesian probabilities. The three logistic regression probabilities all indicated that the individual was likely European American, though with probabilities ranging from only 0.56 to 0.71. The seven Bayesian probabilities ranged from 0.80 to 0.95, all in favor of European American ancestry. Lastly, the individual's scores were compared with the two-trait probabilities listed in table set B. Nine comparisons could be made, seven are logistic regression probabilities and two are Bayesian probabilities. The logistic regression probabilities all indicate that the individual is European American, with probabilities ranging from 0.54 to 0.96. Of the two Bayesian probabilities, one indicates that the individual is likely

European American (0.90 probability), and the other indicates that the individual is likely African American (0.96 probability). As this is the only comparison indicating that the individual is African American, it is viewed as an anomalous result, one that could occur due to chance alone. The determination can be made, then, that the individual is most likely European American, a determination later found to be accurate. Using the method described above, 36 out of 40 of the test dentitions were correctly ascribed to the appropriate social race category.

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