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Identification of Race and Sex from Palate Dimensions

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ABSTRACT: Measurements of the width and depth of the palate were used to predict the race (American black or white) or sex or both of an individual. The sample consisted of 332 living subjects with permanent dentitions, and measurements were made between cusp tips, so palate size includes bony and dental components. Blacks, with a more square palate, were distinguished from whites primarily by greater interpremolar widths and P1-to-M2 depths. Simultaneous prediction of race and sex had a correct classification of 48%, which is about twice that expected from chance. Pooling the two sex increases correct classification of race to 83%. Formulas also are provided for each variable separately to accommodate fragmentary remains. Resilience of palatal structures to traumatic and natural forces makes this method practical in several forensic situations.

KEYWORDS: forensic science, forensic anthropology, palate, arch form, osteometry, race, sex, discriminant functions

Bony and dental structures of the palate often are preserved even in the face of serious bodily damage at or following death. Coupled with the substantial statistical differences in palatal dimensions between sexes and races (1–3), there is the opportunity to establish criteria by which the forensic scientist can predict race and sex of an unknown individual from fragmentary craniofacial remains.

The purpose of this study was to generate canonical variates from stepwise discriminant function analyses that distinguish between American blacks and whites and between males and females using palatal dimensions. Formulas also were generated that can be applied to fragmentary remains of the palate.

Materials and Methods

Dental casts of the maxilla of 332 adolescents and young adults were studied. Half were American blacks, half were American whites, and the sample was divided proportionately between males and females. Cases were of routine dental patients and there were no selection criteria, though none had had orthodontic treatment. Of the 332 cases, 220 had complete data. Incomplete emergence of some late-forming teeth was the sole cause of missing data. None of the missing data was due to extracted teeth or caries. There is virtually no change in arch dimensions of arch size once teeth erupt, so age in adolescents and young adults is independent of arch size (4–6). As confirmation, each palatal dimension was regressed on age at examination, and none of the tests approached statistical significance (all with $p > 0.60$). Race was established by the person's self-assessment.

Buccal cusp tips and incisor line angles were marked on the casts to highlight them. Prints were made from the view orthogonal to the occlusal plane, and millimetric grids were included in the same plane to assure the absence of magnification and distortion. The 14 dental and palatal landmarks shown in Fig. 1 then were digitized as Cartesian coordinates. Landmarks on the incisors were the mesial line angles. A mesial and a distal point on the midpalatal raphe were digitized, and these two points defined the midline axis of the maxillary arch. Measurements were computer-generated trigonometrically from the Cartesian coordinates, but extensive testing shows that the same values can be obtained from a specimen using sliding calipers.

Five arch widths were calculated from each case (Fig. 1) as were eight depths (Fig. 2). Arch widths actually were calculated separately for left and right sides (perpendicular to the midpalatal raphe) then averaged and doubled to eliminate any left-right asymmetry. This also provides for the use of fragmentary remains since a width measured to the midline can be doubled to approximate width across both quadrants. Few of the variables used here depended on the incisors since these teeth are liable to trauma and their single, conical roots place them at risk of exfoliation. Moreover, the anterior segment of the arch is not as informative in terms of race-and-sex-discrimination as the buccal segments (3).

Two sets of arch depth dimensions were calculated. One measures arch depth from the second molar to other teeth in the buccal segment (Fig. 2*A*). The second set of four variables (Fig. 2B) measures depths from the canine distally to either a premolar or a molar.

Stepwise discriminant analysis was used to generate canonical functions from the subsets of the variables that maximally distinguished between blacks and whites, males and females, or both. Programs from both SAS (7) and BMDP (8) statistical packages were used. Various collections of variables were tested in anticipation of which regions of the palate are most likely to be preserved, if not the whole. The alpha level for variable entry and exit were set at 0.05.

Two steps were used to generate the discriminant functions. First, analysis was performed in the usual stepwise fashion using the whole set of variables. This limited analysis to the 220 cases without missing data. Stepwise analysis then was performed a second time based just on the variables retained in the first assessment. These two runs were concordant—which is a gross measure of the robustness of the model—but in some instances the second run omitted marginally-significant variables, which probably depended on unique features of this set of data, not biological differences. Importantly, this second step used incomplete cases

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where the few variables retained by the first analysis *were* measurable. This increased the usable sample sizes on the order of 15 to 20%.

Misclassification was assessed using both resubstitution (7) and the more common posterior probabilities using the jackknife option (8), though both have an optimistic bias. Given the large sample sizes and normality of the distributions, results of the two methods were highly concordant. Results of crossvalidation (jackknifing) are presented here as the apparent error rates (9).

Results

Two-way univariate analysis of variance was calculated for each variable to test for race, sex, and interaction effects (Table 1). F-ratios generally were quite large between races, and they were consistently larger for the black-white racial difference than between sexes, though both comparisons generally achieved statistical significance. None of the interaction effects approached significance.

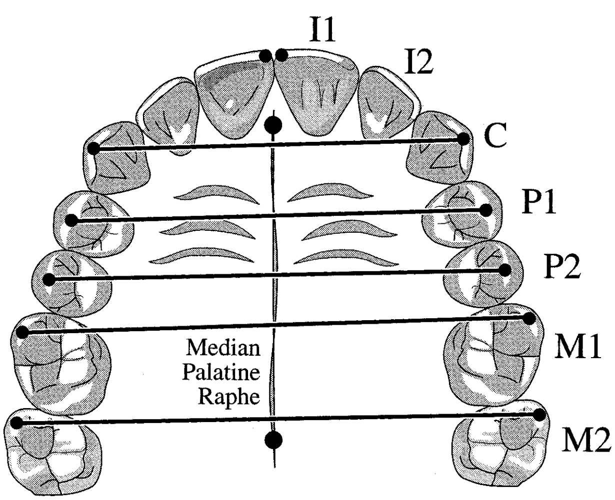

FIG. 1—*Illustration of the 14 landmarks on the teeth and palate. The mesiobuccal cusp tip was marked on each molar, as was the protocone (buccal cusp) on each premolar and canine. The mesial line angles of the central incisors were located, and the palatal midline was defined by a mesial and distal point on the median palatal raphe. Also shown are the five measures of arch width.*

Race Identification

Three approaches were pursued here, depending on whether sex of the individual can be determined. If sex is unknown, so both race and sex need to be predicted, the stepwise discriminant procedure uses two variables in the following canonical equations

$$\text{Variate 1: } 18.664 - 0.243(\text{4-4 Width}) - 0.363(\text{P1-M2 Depth})$$

TABLE 1—*Descriptive statistics and analyses of variance.*

		Blacks			Whites			F-Ratios		
Variable	Sex	n	$\bar{x}$	sd	n	$\bar{x}$	sd	Race	Sex	Interaction
3-3 Width	M	78	36.7	2.81	69	33.8	2.73	91.8*	10.9*	0.3
	F	82	35.8	2.69	67	32.6	2.39			
4-4 Width	M	83	43.4	2.27	75	39.3	3.23	165.1*	13.8*	1.3
	F	86	42.5	3.16	78	37.7	2.76			
5-5 Width	M	80	48.1	3.77	67	45.0	3.23	75.7*	17.0*	0.5
	F	80	46.7	3.56	75	43.1	2.78			
6-6 Width	M	85	53.4	3.24	79	50.1	2.87	126.6*	22.4*	2.9
	F	86	52.3	2.91	80	48.0	3.17			
7-7 Width	M	66	59.0	3.67	58	55.7	3.09	76.3*	21.1*	0.3
	F	71	57.4	3.30	72	53.7	2.69			
I1-C Depth	M	81	10.1	2.50	73	9.3	2.73	9.3*	0.1	0.1
	F	82	10.1	2.42	74	9.1	1.99			
C-P1 Depth	M	84	8.1	1.06	73	7.7	0.95	16.5*	2.6	0.4
	F	84	8.0	1.06	78	7.4	1.21			
C-P2 Depth	M	83	15.3	1.41	65	14.1	1.06	60.2*	7.8	0.0
	F	82	14.9	1.39	76	13.6	1.65			
C-M1 Depth	M	85	21.9	1.86	74	20.2	1.79	77.5*	8.7*	0.2
	F	85	21.4	1.68	78	19.5	1.85			
C-M2 Depth	M	68	33.6	2.15	61	31.1	1.74	96.7*	14.4*	0.0
	F	75	32.6	2.01	74	30.2	2.19			
M2-P1 Depth	M	68	25.4	1.75	65	23.4	1.39	98.3*	10.2*	0.0
	F	76	24.7	1.63	76	22.8	1.79			
M2-P2 Depth	M	67	18.3	1.22	64	16.9	1.01	70.3*	11.3*	1.0
	F	74	17.6	1.23	76	16.6	1.30			
M2-M1 Depth	M	68	11.7	0.92	66	10.9	0.81	48.2*	5.3	1.5
	F	77	11.4	0.87	76	10.8	0.94			

* $p < 0.01$.

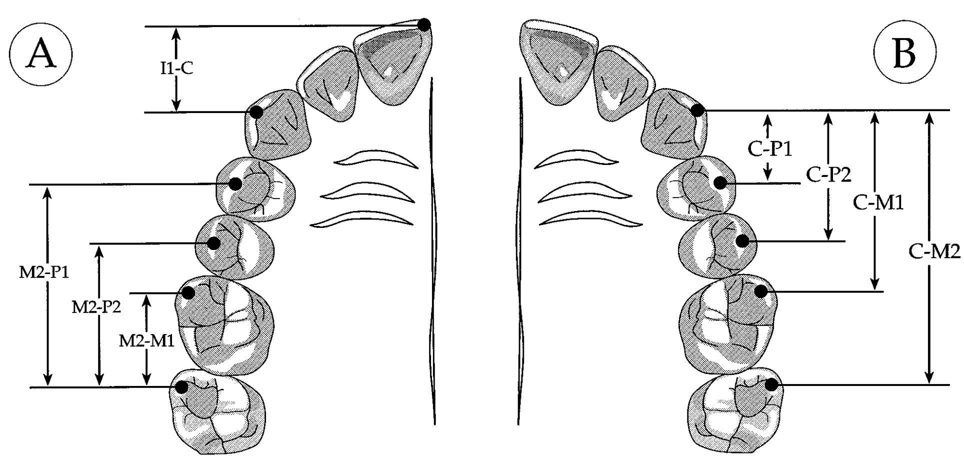

FIG. 2—*Eight arch depths were measured, though the anterior segment was purposely underrepresented because incisors often are broken or lost in forensic cases and because this region provided little race or sex discrimination. Measurements were made parallel to the midpalatal raphe. Most of the measurements in A used the second molar as a reference while those in B relied on the canine.*

Variate 2: 3.776 + 0.212(4-4 Width) − 0.516(P1-M2 Depth)

These variates (based on 281 cases) assigned individuals to the correct race and sex categories with 48% accuracy, which is about twice as good as expected from chance (i.e., assuming equal posterior probabilities). A positive value for variate 1 denotes whites; a negative value denotes blacks. Variate 2 further distinguishes between the four groups, primarily by separating males from females. Black males and white females have negative values for variate two; white males and black females have positive values. A worked example is provided in the Appendix for clarity.

If sex can be determined from other skeletal or cultural evidence, then race can be gaged using separate equations for blacks and whites (Table 2). Accounting for sex increased the correct allocation to race to 81% for males and 83% for females. It is noteworthy that the same variables (4–4 width and P1-M2 depth) entered the model for both sexes.

A third approach is to ignore sex determination (i.e., pool sexes) and predict racial affiliation. Stepwise discrimination function analysis (sexes pooled) produced a canonical variate with two variables (Table 3). The standardized canonical variates show that the equation is driven by 4–4 width (−0.75), followed by P1-M2 depth (−0.57). Using the jackknife procedure, 80% of the 281 usable cases were correctly classified by this function.

Forensic identification often involves fragmentary remains. Indeed, it is in cases with incomplete remains that metrical rather than observational methods are most helpful. Consequently, Table 4 provides a tact where the canonical function is provided for each variable, so the method can be applied to fragmentary remains. It should be noted that several of these univariate results have correct classifications approaching the percentages obtained from multiple variables. Best results were obtained from arch widths measured at the premolars—where blacks differ most in form from whites. Least accurate results were those that depended on arch depth in the region of the incisors, canine, and first premolar.

TABLE 2—*Canonical equations to estimate race given that sex is known.**

Males		Females	
Variable	Coefficients	Variable	Coefficients
4-4 Width	−0.221	4-4 Width	−0.283
P1-M2 Depth	−0.443	P1-M2 Depth	−0.271
Constant	19.584	Constant	17.797
Sample size	132	Sample size	149
Percent†	80%	Percent	83%

* Specimens predicted to be American blacks will have negative canonical variates from these equations; cases predicted to be American whites will have positive values.
† Percent correct classification using crossvalidation.

TABLE 3—*Prediction of race (sexes pooled).**

Variable	Coefficient
4-4 Width	−0.236
P1-M2 Depth	−0.350
Constant	18.056
Sample size	281
Percent†	80%

* Specimens predicted to be American blacks will have negative canonical variates from this equation.
† Percent correct classification using crossvalidation.

Sex Identification

There is appreciable sexual dimorphism in palate dimensions (Table 1), but prediction of sex in the absence of knowledge about race leads to little success because racial differences in size swamp out male-female size differences. If, however, race can be determined from ancillary information, then palatal dimensions can correctly classify two-thirds of the cases according to sex (Table 5). Two variables—a depth and a width—were entered into the canonical formula for each sex, so, again, it is arch *shape*—a depth-width ratio—that best discriminates between the sexes and between the races. Arch depth has a notably higher standardized coefficient in each formula than the width variable.

Discussion

Size of the palate is appreciably larger in males than females, and the average difference is significantly larger between American blacks and whites (ca. 8%) than between sexes within either race

TABLE 4—*Canonical variates for race determination.**

Variable	Sexes Pooled				Males Alone				Females Alone			
	n	Coefficient	Constant	Correct†	n	Coefficient	Constant	Correct	n	Coefficient	Constant	Correct
3-3 Width	296	−0.369	12.869	71%	147	−0.361	12.748	70%	149	−0.390	13.420	73%
4-4 Width	322	−0.315	12.863	76%	158	−0.308	12.761	73%	164	−0.336	13.517	81%
5-5 Width	302	−0.289	13.254	74%	147	−0.283	13.204	69%	155	−0.312	14.016	75%
6-6 Width	330	−0.317	16.162	74%	164	−0.326	16.887	70%	166	−0.329	16.539	78%
7-7 Width	267	−0.302	17.028	71%	124	−0.293	16.854	70%	143	−0.333	18.468	73%
I1-C Depth	310	−0.413	3.993	54%	154	...‡	...	...	156	−0.449	4.314	58%
C-P1 Depth	319	−0.926	7.249	61%	157	−0.987	7.826	59%	162	−0.878	6.792	59%
C-P2 Depth	306	−0.705	10.243	71%	148	−0.788	11.657	72%	158	−0.657	9.391	73%
C-M1 Depth	322	−0.551	11.453	71%	159	−0.547	11.540	70%	163	−0.566	11.610	77%
C-M2 Depth	278	−0.479	15.267	71%	129	−0.508	16.453	71%	149	−0.476	14.942	73%
P1-M2 Depth	285	−0.596	14.335	74%	133	−0.631	15.400	74%	152	−0.584	13.868	76%
P2-M2 Depth	281	−0.816	14.158	71%	131	−0.890	15.691	70%	150	−0.788	13.483	73%
M1-M2 Depth	287	−1.116	12.486	65%	134	−1.152	13.042	69%	153	−1.104	12.223	60%

* A negative value from these equations predicts the specimen is an American black; a positive value indicates the specimen is an American white.
† Percent correct classification using cross-validation with jackknifing.
‡ Variable did not meet entry criteria ($\propto = 0.05$); all others exhibited significant discrimination at $p < 0.05$.

TABLE 5—*Canonical equations to estimate sex given that race is known.**

Blacks		Whites	
Variable	Coefficients	Variable	Coefficients
7-7 Width	0.182	6-6 Width	0.283
P1-M2 Depth	0.372	C-P2 Depth	0.464
Constant	−19.918	Constant	−20.303
Sample size	136	Sample size	140
Percent†	65%	Percent	67%

* A specimen predicted to be male will have a positive canonical variate from these equations.

† Percent correct classification using crossvalidation.

(ca. 3%). As measured in this study, palatal dimensions incorporate both bony and dental structures. It is well known that tooth crown diameters are sexually dimorphic (10,11) as are palatal and other osteometric dimensions of the face (1,2,12), though the extent of dimorphism varies among groups.

Adult dimensions of the palate are effectively set once the full complement of permanent teeth has erupted into occlusion, ignoring the third molars (4,13) so the methods described here should be uniformly applicable for all ages with permanent dentitions. On the other hand, the intermaxillary and interpalatine sutures are patent at least until early adulthood (14) and since teeth may drift within the arches (15,16) there is the potential for age to confound the results. In fact, though, the exact chronological age was known for all cases, and in no instance did regression of trait size on age produce any discernible effect. The situation is that, while subtle changes do occur with aging in an individual, inter-individual variation is much too great to detect any age effect in cross-sectional data.

Major discriminators both between blacks and whites and between sexes were about equally driven by arch width and arch depth. Racial discriminators are, however, located in the midarch (e.g., 3-3 and 4-4 widths), while sex discriminators are in the molar region where the arch is widest.

Conventional osteometric dimensions of the palate are based on landmarks lingual to the tooth surfaces, so any race or sex difference in crown size is not included (17), but findings can be broadly compared to the present study. It is well established that the palate in blacks is broader in comparison to its depth than in whites (2,18,19). The present study shows that this racial difference is most apparent in the region of the canine and first premolar: palates of whites typically are convergent in this area, making palatal form elliptical (a catenary curve) while the greater breadth in the midarch of blacks results in a U-shape. Of course, width by itself gives no indication of shape (i.e., arch form), so it is perhaps, not surprising that the ''other'' variable entered into each discriminant function was a measure of mesiodistal arch depth (Tables 2 and 5). These discriminant depth measurements tend to be long spans in the buccal segment, such as P1-M2 depth.

Sex discrimination, on the other hand, depends largely on intermolar widths, both in blacks and whites. This may simply reflect the greater overall breadth of the male skull in any given ethnic group (20). It is of note, though, that percentage sex dimorphism increases in a mesial-to-distal gradient from intercanine width through 7-7 width. The discriminant function algorithm compares arch width against a depth variable, in both blacks and whites, to generate a ''shape'' function that better discriminates between sexes than size alone. Classification of a specimen's sex using palatal dimensions is not particularly effective; correct allocations were achieved just two-thirds of the time, and this presupposes that race, either black or white, is known. This discriminant method based on palatal dimensions is more effective in distinguishing between blacks and whites regardless of whether sex can be determined.

Thirteen variables (Figs. 1, 2) were entered into the stepwise discriminant function analyses, but, as is characteristic, few variables are retained since some are non-contributing and others are statistically redundant with those entered with higher F-ratios (21,22). At most, two variables were entered in any one equation; in each case it was some measure of arch width and some measure of arch depth. Data in the present study exhibit extensive multiple collinearity (i.e., statistical redundancy of information) that forced the stepwise procedure to stop after entrance of just a few variables. It is counterproductive to retain variables that are not statistically significant (cf. 3) because nonsignificant variables introduce noise in the discriminant function since, by definition, they do not differ systematically among groups. Instead they will exploit characteristics of the data structure unique to the sample being tested, so classification of new samples may be substantially poorer. More importantly, retention of nonsignificant variables often creates a situation where two or more predictor variables are more strongly correlated with one another than any is with the outcome variable (i.e., multiple collinearity), and this can bias the classification functions.

American whites and blacks constitute the largest ethnic groups in the United States. Their distinctive facial morphologies provide aids in forensic identification, and the present study shows that palate dimensions also are useful in discriminating between these two groups. Major racial differences are in the canine-premolar region where blacks are much broader in relation to their depth. Formulas are presented for optimal sets of discriminators as well as univariate results applicable to fragmentary remains.

APPENDIX

Worked Examples

Assume that a specimen has the following dimensions and the researcher wishes to predict both race and sex: 4-4 width = 37.9 mm and P1-M2 depth = 20.6 mm. There are two canonical variates here (Table 6) since two variables were retained in the stepwise discriminant function procedure and the number of groups exceeds the number of variables (21). For all other equations in this paper there is just one canonical variate since only two groups (males and females or blacks and whites) are being evaluated. The coefficients needed to compute in the two canonical equations are listed in Table 6.

The three calculation steps are, for each of the two canonical

TABLE 6—*Coefficients for computation of the two canonical variates discriminating between American blacks and whites and males and females.*

Coefficient	CV1	CV2
4-4 width	−0.243	+0.212
P1-M2 depth	−0.363	−0.516
Constant	18.664	3.776

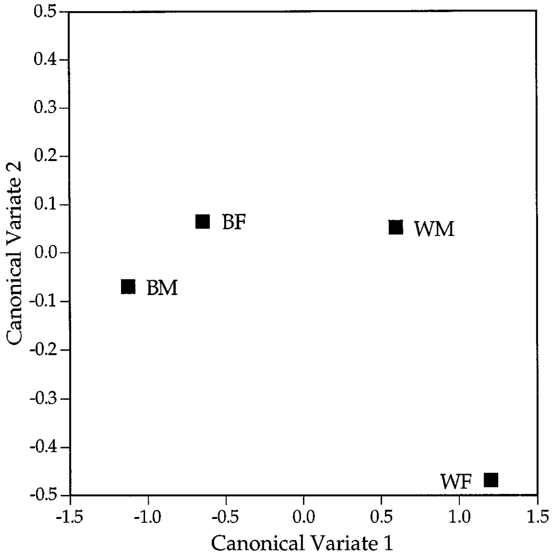

FIG. 3—*Plot of the group means on the two canonical axes based on discriminating both race and sex using 4-4 arch width and P1-M2 arch depth. Scale of the vertical axis is enlarged relative to the abscissa, but it still is obvious that there is far greater separation between blacks and whites by these two functions than between males and females of either race.*

variates: (1) multiply each of the specimen's dimensions by the corresponding coefficients, (2) add the products from the first step, and (3) add the sum from the second step to the constant. (Be careful about the signs of the numbers.) Sums of the products (step 2) are -16.687 for CV1 and -2.595 for CV2. Adding these to the constants (step 3) yields the solution: CV1 $=$ 1.98 and CV2 $=$ 1.18.

CV1 is found to discriminate primarily between blacks and whites. A positive value for CV1 indicates that the specimen is white and a negative result indicates that the specimen is black (i.e., the sectioning point between blacks and whites is set to zero). CV2 discriminates between males and females, but the sign is not consistent (Fig. 3): a positive covariate is associated with black females and white males. There is no confusion in diagnosis, though, because CV1—which is the driving force in this discrimination (since it contains most of the explained variation)—separates the races. Consequently, since values in this example are both positive (CV1 $=$ 1.98; CV2 $=$ 1.18), the specimen is predicted to be a white male.

With just two groups, such as discriminating between blacks and whites (but not trying to simultaneously predict sex of the specimen), there is just one canonical variate. Assume one wishes to determine the race of a palatal fragment where 4-4 width and P1-M2 depth are measurable on at least one quadrant (so width can be obtained by assuming left-right symmetry). Observed dimensions are 27.4 mm and 24.8 mm, respectively. We obtain the weighting coefficients from Table 3, and, using the same three steps as above, the sum of the products for the covariate is -17.506. Adding this to the constant yields $+0.55$ accounting for rounding. This positive value predicts the specimen is an American white (see footnote, Table 3).

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