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Identification of Euro-Americans, Afro-Americans, and Amerindians from Palatal Dimensions

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ABSTRACT: Seven measurements were taken on 414 Euro-American, Afro-American, and Amerindian palates in an attempt to evaluate differences in dental arcade shape among these three groups. Width measurements across the palate at the first incisor, canine, second premolar, and second molar were taken directly on the dental arcade. The distances along the sagittal plane from the front of the palate to the level of these teeth were calculated from measurements taken between the right central incisor and the canine, second premolar and second molar. Discriminant functions computed from the measurements properly classified palates by group 66.0% of the time if sex is unknown. If sex is known to be male, other functions properly classified 65.7% of the sample; for sex known to be female 72.0% correct classification was achieved. Because these percentage are more than twice that expected from probability theory alone, it is concluded that the seven measurements are useful in determining ethnic group.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, ethnic groups, palatal dimensions, discriminant functions

When evaluating human skeletal remains in a forensic context, the anthropologist is usually requested to provide an estimation of ethnic group as an aid to personal identification. Although postcranial features can be utilized (1–9), it generally is accepted that the skull presents the greatest number of useful anthroposcopic and craniometric landmarks in this regard (10–17). Among the variety of cranial features asserted to vary with group is the shape of the dental arcade and hard palate. If this assertion is true, it is reasonable that measurements of the palate that reflect these variations of configuration should be useful in determining group affiliation. Therefore, it is the purpose of this article to evaluate the use of palatal dimensions for ethnic group identification.

Previous research on ethnic group and palatal shape has been limited to qualitative observations about differences among the three main races (i.e., Caucasoid, Mongoloid, and Negroid). Hooton (10) indicates that Whites have small jaws and pinched palates whereas the palates of Negroids are long and narrow, and those of Mongoloids short and wide. Krogman (12) attributes narrow to moderately wide palates to different Caucasoid groups with Negroid arcades described as wide, and those of Mongoloids as moderately wide. Olivier (13) presents two indexes of the palate and maxillae whose values reflect shape and states that Negroes have long narrow palates whereas Xanthoderm (Mongoloid) and White palates are short and wide. However, he does not relate these observations to index values. Finally, Gill (16,18) states that North American and Mesoamerican Indians have elliptical and parabolic palates, whereas Negroids have long, parallel sided (hyperbolic) arcades. He also claims that Caucasoids and (surprisingly) East Asian Mongoloids have triangular and/or parabolic arches with the latter groups sometimes showing the elliptical shape of Amerindians.

The above information from the literature indicates there is relative agreement that each of the three main races is characterized by a typical palatal configuration; Figs. 1a, 1b, and 1c illustrate these archetypes. Because most authors describe the palate of Caucasoids as pinched, parabolic, or narrow, Fig. 1a represents the typical dental arcade of this race. Similarly, Fig. 1b represents the typical configuration for Negroids because there is general agreement that their palates are long, narrow, and parallel sided. Finally, because the palate of Mongoloids usually is described only as short and wide, the smoothly rounded arcade in Fig. 1c is attributed to this race.

Examination of these archetypes reveal differences among the three groups in the relationship between the width of the palate at the level of a given tooth and the distance of that tooth, along the sagittal plane, from the front of the palate. For example, the long, parallel-sided palate of Fig. 1b (i.e., the Negroid dental arcade) would cause the distance between the second molars to be smaller than the distance from the front of the palate to the level of this tooth. However, these two measurements would approach each other more closely in Fig. 1a (Caucasoids) and more closely still in Fig. 1c (Mongoloids). From this information, it is reasonable to assume that, if a graph were constructed with the distance from the front of the palate plotted on the vertical axis and width across the dental arcade on the horizontal axis, Negroids would cluster in the lower right-hand corner, with Mongoloids in the upper left-hand corner and Caucasoids in between. Similar relationships occur when other teeth (i.e., canine, second premolar) are examined in a analogous manner. This information suggests that discriminant function analysis, which uses many measurements in multivariate space to differentiate groups, is an appropriate method for discriminating race or ethnic group on the basis of palatal measurements.

Materials and Methods

To determine if the shapes described by earlier researchers apply to the major ethnic groups of people in the United States, a sample

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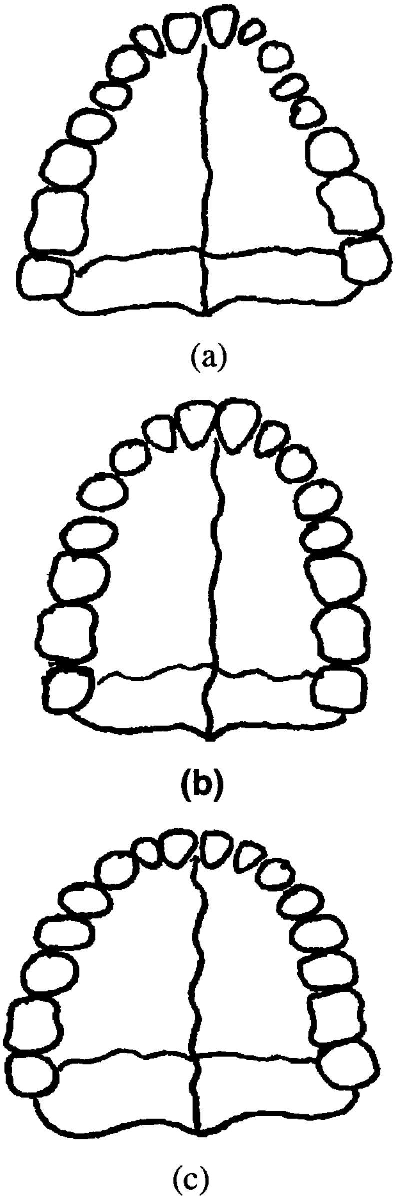

FIG. 1—*Three archetypes of palatal shape:* (a) *triangular (parabolic) of Caucasoids,* (b) *parallel sided of Negroids, and* (c) *rounded of Mongoloids.*

of 414 palates of Euro-Americans, Afro-Americans, and Amerindians was drawn. The palates originate from four sources: The Smithsonian Institution (Terry Collection), the University of New Mexico's Maxwell Museum, the Anthropology Department of the University of Tennessee at Knoxville (UTK), and the private collection of Michael Charney. The Euro-American and Afro-American specimens are documented autopsies; therefore, demographics (i.e., sex, age, and ethnic group) are firmly known. The samples from these ethnic groups originate from individuals both born in the 1800s (Terry) as well as this century (Charney, Maxwell, and UTK). The Amerindian palates are from three prehistoric United States populations: Southwestern, Northern Plains, and Southeastern Woodlands. The Southwestern series (n = 98) are derived from collections of the Maxwell Museum of Anthropology at the University of New Mexico. These specimens vary in age from A.D. 1200 to early historic times and originate from all areas of New Mexico. The Northern Plains series (n = 56) originate from four sites: Larson, Mobridge, Sully, and Leavenworth, dating from A.D. 1600 to 1830. Lastly, the Southeastern Woodlands group (n = 25) derive from the Averbuch site, a Late Mississippian Period village in central Tennessee and dated approximately A.D. 1150 to 1550. An Amerindian specimen was used in this sample only if the pelvis was so typically male or female as to render sex determination relatively unequivocal. From all series, only palates that did not exhibit damaged, misaligned, congenitally absent or supernumerary dentition were used. In cases in which teeth were missing, a palate entered the sample if the tooth socket was sufficiently intact such that accurate measurements could be taken.

Table 1 presents a breakdown of the sample by ethnic group, sex, and source. As can be seen, Afro-Americans are under-represented being only 25.1% of all palates from the four collections whereas Euro-Americans comprise 31.6% and Amerindians 43.2%. Also, it can be seen that 57.7% of the sample is male and the remaining 42.3% is female. The small number of Euro-American females is due to the difficulty in securing usable palates of individuals of that sex among all of the collections. In addition, several small samples were included in the study despite their possible biasing effects (e.g., Euro- and Afro-Americans from the Charney collection, Afro-Americans from UTK). This was done because usable palates were so difficult to obtain that it was deemed necessary to include all available specimens.

To quantify arcade shape, dimensions were needed that described both palatal width at the level of various teeth and distance of those levels from the front of the palate along the sagittal plane. Although widths between antimeric teeth are easily taken, straight distances from the front of the dental arcade to lines drawn between antimeres (across the palate) are difficult to obtain because the floor of the palate is higher than the teeth. Also, with 16 teeth in the maxilla, there are 16 length and width measurements possible (more if greater acuity is desired). Further, for forensic applications, techniques are most useful if measurements are simple to take and few in number. After considering these factors, seven chords were chosen which promised to provide the most amount of information on palatal shape without the burden of excessive mensuration. These measurements, which are illustrated in Fig. 2, are defined

TABLE 1—*Study sample by race, sex, and collection.*

	Sex		
Race	Male	Female	Total
Euro-American			
Charney	1	2	3
Maxwell	27	13	40
Terry	47	13	60
UTK	23	5	28
Total	98	33	131
Afro-American			
Charney	2	1	3
Maxwell	0	0	0
Terry	42	53	95
UTK	3	3	6
Total	47	57	104
Amerindian			
Charney	0	0	0
Maxwell	51	47	98
Terry	0	0	0
UTK			
Plains	30	23	53
Woodlands	13	15	28
Total	94	85	179
Total	239	175	414

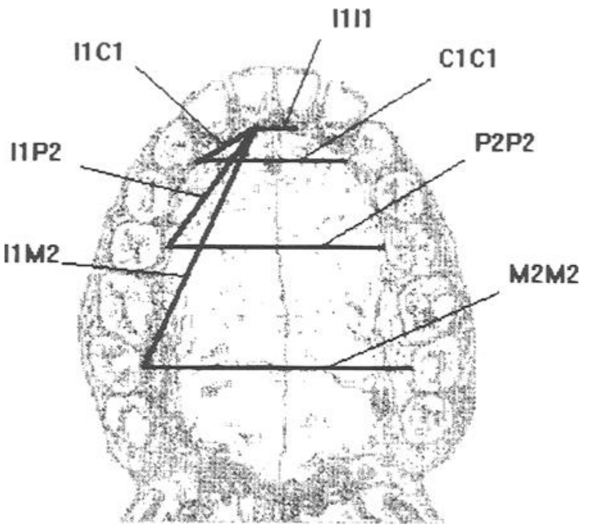

FIG. 2—*Illustration of measurements.*

as follows: Distance between the central incisors (I1I1), distance between the canines (C1C1), distance between the second premolars (P2P2), distance between the second molars (M2M2), distance from the central incisor to the canine (I1C1), distance from the central incisor to the second premolar (I1P2), and distance from the central incisor to the second molar (I1M2). These last three measurements were taken on the right side of the palate, unless the left teeth or their sockets were in better condition. Also, all dimensions were taken to the nearest 0.1 mm with a sliding caliper whose tips were placed on the midpoint of the lingual borders of the tooth sockets. Thus, I1I1 is the straight distance between the middle of the lingual borders of the upper central incisor tooth sockets. Similarly, I1C1 is the distance from the middle of the lingual border of the right central incisor to the middle of the lingual border of the right canine.

To obtain the straight distances from the front of the palate to the level of the three teeth, the theorem of Pythagoras was applied in the following manner. First, by subtracting I1I1 from C1C1, P2P2, and M2M2 and dividing by two, the distance of the canine, premolar, and molar, respectively, to a point directly behind the first incisor was obtained; the numbers resulting from this operation correspond to the base of the triangle in the Pythagorean theorem. Second, because I1C1, I1P2, and I1M2 represent the hypotenuses of their respective triangles, these distances were squared and the squared results of the first operation were subtracted from them; this operation obtained the squared "height" of the triangle. Last, by taking the square roots of the last operation, the distances from the front of the palate to the level of the canine (CanLen), premolar (PreLen), and molar (MolLen) were obtained. These computations are illustrated in Formulae (1), (2) and (3):

$$\text{CanLen} = \sqrt{\text{I1C1}^2 - \left(\frac{(\text{C1C1} - \text{I1I1})}{2}\right)^2} \tag{1}$$

$$\text{PreLen} = \sqrt{\text{I1P2}^2 - \left(\frac{(\text{P2P2} - \text{I1I1})}{2}\right)^2} \tag{2}$$

$$\text{MolLen} = \sqrt{\text{I1M2}^2 - \left(\frac{(\text{M2M2} - \text{I1I1})}{2}\right)^2} \tag{3}$$

The palatal measurements were analyzed in the following manner. First, since non normal distributions can indicate invalid data in a sample, descriptive statistics of the measurements were calculated as a way of determining deviations from the normal distribution. For this and subsequent analyses, all data were separated by group and then by sex and group (i.e., Euro-American males, Euro-American females; Afro-American males, Afro-American females; Amerindian males and Amerindian females). Measurements that fell suspiciously far from their mean were reexamined, if possible, and corrected. Questionable palates whose measurements could not be retaken (i.e., those that would have required a revisit to the Smithsonian) were eliminated from study. One individual had palatal measurements within the norms for his group; however, in multivariate space, the shape of this palate was such that there was a less than 1 in 10,000 chance that a similar individual would ever be encountered again. Thus, he was eliminated because of his potential biasing effect.

After data validation, the SAS PROCedure STEPDISC was used to calculate stepwise discriminant functions for all data, as well as for each sex, to determine which distances contributed significantly to the determination of group. Two sets of dimensions were submitted to this analysis: The original seven measurements, and the four widths combined with the three lengths derived from formulae (1), (2), and (3). This was done so that, if the original measurements discriminated as well as the widths and derived lengths, their functions (which would be simpler to calculate) could be used in a forensic context. During these calculations, a measurement did not enter into, or was later removed from, the computations if its F was less than .15 as calculated from analysis of variance. After this, PROC DISCRIM in SAS was used to calculate Fisher's linear discriminant functions and to verify the efficacy of the discrimination process; cross-validation was used to determine how well the three main groups could be classified. Only those distances shown by STEPDISC to contribute significantly to discrimination were entered into these computations. Again, both the original measurements and the four width measurements with the three calculated length measurements were submitted to this analysis, and computations were performed on all data combined as well as data separated by sex.

Results

The stepwise discriminant procedure indicated that all seven original measurements added discriminating value to the functions calculated on combined sex data; however, M2M2 was not valuable in the calculations using the widths and calculated lengths. Among males, all original measurements except I1I1 helped to discriminate ethnic group; but in the second computations, only the P2P2 width helped to discriminate group in conjunction with the three calculated lengths. Finally, among females, all original distances except M2M2 and I1P2 added discriminating value whereas only two widths (C1C1 and P2P2) and two lengths (CanLen and MolLen) were useful in the second function calculations. This information indicates high correlation between some of the values used in the calculation of functions within sex, resulting in their exclusion from further analyses. Concomitantly, this simplified the calculation of the linear discriminant functions as well as the cross-validation of the data.

Table 2 presents the accuracy by which discriminant functions predicted ethnic group during cross-validation with the sexes combined as well as separated. These results are presented for those functions that used the four antimeric widths and three calculated

TABLE 2—*Percent correct classification using cross-validation.*

Sex	Source of Lengths	Euro-American	Afro-American	Amer-Indian	Overall
Both Sexes	Formulae	60.3%	43.3%	84.3%	66.3%
	Original	58.0	44.2	84.4	66.0
	Charney	100.0	0.0	N/A	
	Maxwell	57.5	N/A	81.6	
	Terry	58.3	43.2	N/A	
	UTK	53.6	83.3	N/A	
	Plains	N/A	N/A	83.0	
	Woodlands	N/A	N/A	96.4	
Males	Formulae	73.5	36.2	80.9	69.0
	Original	71.4	25.5	79.8	65.7
	Charney	100.0	0.0	N/A	
	Maxwell	77.8	N/A	76.5	
	Terry	74.5	28.6	N/A	
	UTK	56.5	0.0	N/A	
	Plains	N/A	N/A	76.7	
	Woodlands	N/A	N/A	100.0	
Females	Formulae	51.5	64.9	83.3	71.3
	Original	54.6	63.2	91.3	72.0
	Charney	100.0	0.0	N/A	
	Maxwell	53.9	N/A	78.7	
	Terry	46.2	62.3	N/A	
	UTK	60.0	100.0	N/A	
	Plains	N/A	N/A	91.3	
	Woodlands	N/A	N/A	93.3	

lengths as well as those that used the original seven measurements. In addition, the percent properly classified from each sample is presented for the latter functions. Notice that the probabilities of correct classification from the antimeric widths and calculated lengths are approximately equal to those obtained from the original measurements. In the former functions, correct ethnic group prediction with sex unknown is 66.3%, although it is 66.0% for the other computations. For sex known to be male, these rates are 69.0 and 65.7%, respectively, whereas they are 71.3 and 72.0% for females.

Table 3 presents Fisher's linear discriminant functions that can be used to determine the group of an unknown palate. Functions

TABLE 3—*Fisher's linear discriminant functions for sexes combined.*

Sex	Measurement	Euro-American	Afro-American	Amer-Indian
Both Sexes	Constant	−180.00	−193.47	−195.67
	C1C1	0.9385	0.8872	1.5736
	P2P2	3.6077	3.7221	3.9178
	M2M2	0.4457	0.3448	0.5675
	I1C1	−3.3867	−3.1138	−4.3720
	I1P2	−0.0223	0.1220	0.5825
	I1M2	6.3041	6.5077	5.8727
	I1I1	−0.0968	0.0208	−0.3847
Males Only	Constant	−179.38	−195.84	−194.08
	C1C1	−0.2088	−0.4457	0.1438
	P2P2	4.4321	4.7877	4.6946
	M2M2	−0.0024	−0.1435	0.2331
	I1C1	−2.1896	−1.8992	−3.0490
	I1P2	−1.1201	−1.0441	−0.4799
	I1M2	6.8997	7.1659	6.4176
Females Only	Constant	−233.63	−261.56	−266.07
	C1C1	2.1948	2.3043	3.2560
	P2P2	5.4183	5.3433	5.9432
	I1I1	−0.4901	0.0701	−0.8806
	I1C1	−5.6724	−5.2834	−6.6919
	I1M2	8.3656	8.9104	8.4469

are presented for cases when sex is unknown as well as when it is known. Notice that these functions use the original seven measurements because Table 2 indicates that they perform as well as those calculated from the antimeric widths and calculated lengths.

Discussion

As can be seen, the discriminant functions are useful in ethnic group differentiation. Probability theory predicts that 33.3% of palates would be correctly classified into one of the three groups in this study by random assignment. Use of the functions given in Table 3 doubles that probability. Although this result is not as good as other discriminant functions using other skeletal features (e.g., the Giles and Elliot (11) formulae have 81 to 89% probabilities of proper racial classification using measurements of the skull), it is respectable enough to warrant their use in the absence of additional characteristics or as a supplemental method.

The finding that the functions calculated from antimeric widths and computed lengths do not perform better than those calculated from the original seven measurements is not too surprising. Although it is easier to envision the shapes of the palates and their clustering on two dimensional graphs using these first distances, the nature of length measurements is irrelevant in multivariate space. Although I1C1, I1P2, and I1M2 contain both width and length components, palates of similar shape still will cluster together in a hyperplane, thus allowing discrimination.

Although it seems reasonable to assume that the greater accuracy with which the Amerindians were classified is due to the greater genotypic homogeneity of their sample, there is no evidence for this. Table 4 presents the means and standard deviations of the widths and calculated lengths for the three ethnic groups broken out by sample (male and female measurements are weighted equally) and Table 5 presents the correlation coefficients between the six measurements for the combined samples. As can be seen, the Amerindian all samples standard deviations for each measurement are not appreciably smaller (which would indicate less variance due to greater homogeneity) than those of the Euro- or Afro-Americans. Also, the Amerindian correlation coefficients are not appreciably greater than those of the other two groups (in many cases they were smaller indicating greater heterogeneity). However, the Amerindian all samples means usually fall above or below those of the Euro- and Afro-Americans; and, the differences between that group's mean widths and those of the other two groups usually are greater than those seen between the Euro-Americans and Afro-Americans. Thus, it appears that the greater accuracy of discriminating the Amerindians is due to their having the most distinctive palatal configuration of the three ethnic groups.

The lesser reliability of the functions to discriminate Afro-American palates calls into question the qualitative observations described above. This study indicates that the shapes of the palates in this group are not as clear cut as reported by earlier workers. Although this could be due to sample bias, it also might be due to admixture with other groups. Reed (19), Roberts (20), and Workman et al. (21) have presented evidence that the Afro-American genome contains anywhere from 10 to 20% alleles that can be traced to Euro-American ancestors. Because this would lessen the disparity between these two groups for many phenotypic characters, it is reasonable to assume that differences in the palate also would be mitigated. In addition, while observing the palates and nasal areas of a number of Afro-Americans, the senior author

TABLE 4—*Means and standard deviations of ethnic groups and samples (sexes combined and weighted equally).*

Measurement	Source	Euro-American Mean	Euro-American StdDev	Afro-American Mean	Afro-American StdDev	Amerindian Mean	Amerindian StdDev
I1I1	All Samples	7.9	1.1	8.3	1.3	8.9	1.1
	Charney	7.1	0.3	8.3	1.1	N/A	N/A
	Maxwell	7.9	1.1	N/A	N/A	9.1	1.2
	Terry	8.0	1.1	8.3	1.2	N/A	N/A
	UTK	7.6	1.1	9.0	1.6	N/A	N/A
	Plains	N/A	N/A	N/A	N/A	8.8	1.1
	Woodlands	N/A	N/A	N/A	N/A	8.5	1.0
C1C1	All Samples	23.2	2.2	24.3	1.9	25.9	1.8
	Charney	21.1	2.4	26.3	3.0	N/A	N/A
	Maxwell	23.3	1.9	N/A	N/A	26.0	1.9
	Terry	23.1	2.1	24.1	1.7	N/A	N/A
	UTK	23.5	2.7	26.0	2.6	N/A	N/A
	Plains	N/A	N/A	N/A	N/A	25.6	1.8
	Woodlands	N/A	N/A	N/A	N/A	26.3	1.5
P2P2	All Samples	32.9	2.7	34.2	2.4	36.6	2.1
	Charney	31.6	2.0	37.1	1.8	N/A	N/A
	Maxwell	32.6	2.7	N/A	N/A	36.3	2.1
	Terry	33.4	2.5	34.0	2.3	N/A	N/A
	UTK	32.2	3.0	34.8	2.1	N/A	N/A
	Plains	N/A	N/A	N/A	N/A	36.4	2.1
	Woodlands	N/A	N/A	N/A	N/A	37.7	1.8
M2M2	All Samples	38.4	3.4	39.6	2.8	41.8	2.7
	Charney	36.9	3.1	42.2	2.0	N/A	N/A
	Maxwell	37.5	3.1	N/A	N/A	40.8	2.3
	Terry	39.1	3.4	39.4	2.8	N/A	N/A
	UTK	38.2	3.6	41.0	3.8	N/A	N/A
	Plains	N/A	N/A	N/A	N/A	42.5	2.4
	Woodlands	N/A	N/A	N/A	N/A	44.2	3.1
CanLen	All Samples	6.0	1.4	6.9	1.5	5.2	1.4
	Charney	5.5	1.3	6.8	1.2	N/A	N/A
	Maxwell	5.8	1.2	N/A	N/A	5.2	1.5
	Terry	5.8	1.5	6.9	1.5	N/A	N/A
	UTK	6.5	1.1	6.9	1.3	N/A	N/A
	Plains	N/A	N/A	N/A	N/A	5.1	1.4
	Woodlands	N/A	N/A	N/A	N/A	5.1	1.4
PreLen	All Samples	16.4	1.6	17.7	1.9	16.4	1.6
	Charney	15.7	0.7	18.9	2.2	N/A	N/A
	Maxwell	16.5	1.6	N/A	N/A	16.8	1.7
	Terry	16.0	1.6	17.7	1.9	N/A	N/A
	UTK	17.3	1.5	17.8	1.3	N/A	N/A
	Plains	N/A	N/A	N/A	N/A	15.6	1.5
	Woodlands	N/A	N/A	N/A	N/A	16.5	1.3
MolLen	All Samples	33.2	2.5	35.4	2.5	33.0	2.1
	Charney	31.8	1.3	34.8	3.4	N/A	N/A
	Maxwell	33.6	2.6	N/A	N/A	33.2	2.0
	Terry	32.6	2.2	35.4	2.5	N/A	N/A
	UTK	34.0	2.6	36.8	3.1	N/A	N/A
	Plains	N/A	N/A	N/A	N/A	32.5	2.2
	Woodlands	N/A	N/A	N/A	N/A	33.1	1.9

TABLE 5—*Pearson's product moment correlation coefficients by ethnic group for all samples with sexes combined.*

Euro-Americans	I1I1	C1C1	P2P2	M2M2	CanLen	PreLen	MolLen
I1I1	1.00	.56†	.58†	.35†	−.03	.00	.15
C1C1		1.00	.77†	.51†	−.02	.21*	.33†
P2P2			1.00	.72†	.01	.07	.24†
M2M2				1.00	.07	.21*	.29†
CanLen					1.00	.54†	.39†
PreLen						1.00	.71†
MolLen							1.00
Afro-Americans							
I1I1	1.00	.53†	.47†	.32†	.11	.22*	.24*
C1C1		1.00	.68†	.61†	.27†	.32†	.36†
P2P2			1.00	.75†	.21*	.19	.24*
M2M2				1.00	.14	.20*	.16
CanLen					1.00	.69†	.63†
PreLen						1.00	.76†
MolLen							1.00
Amerindians							
I1I1	1.00	.48†	.37†	.07	.05	.13	.15*
C1C1		1.00	.67†	.37†	.01	.19*	.23†
P2P2			1.00	.68†	.03	.00	.06
M2M2				1.00	.05	.03	.06
CanLen					1.00	.44†	.36†
PreLen						1.00	.77†
MolLen							1.00

*significance less than, or equal to, .05.
†significance less than, or equal to, .01.

found considerable overlap with characteristics thought to be Euro-American and Amerindian. For example, strictly U-shaped palates were rarely seen in this group; however, a great percentage of parabolic and/or curved dental arcades were observed. Similarly, although most of the Afro-Americans exhibited wide nasal apertures, the low bridge and thin nasal bones described by some authors for Negroids (10,14) were rare, with high tent-like nasal bones more the norm. Given this, the sample appears to have non African influences, with concomitant problems in classification.

Another issue of importance to this work is the applicability of the sample to modern populations. Because the skeletons from the Terry Collection date from the latter part of 1800s, objections can be raised against using information from them to predict characteristics in populations of the present time. Similarly, the applicability of prehistoric Amerindians to present populations in the United States can be questioned. In addition, there has been some indication of temporal changes in the skeletons of human populations over the last century (22,23). Finally, the effect of orthodontic work on palatal shape is difficult to detect and assess; because it has risen in popularity over the last decades, it is not impossible that some of the sample members have been so treated.

Unfortunately, these issues cannot be resolved at this time; however, there is some indication that they do not affect the findings of this study to any significant degree. Because the samples came from a number of collections possibly reflecting secular and geographic differences, two-way multivariate Analyses of Variance (Anova) were performed with sample source and sex as factors to determine if differences exist between the collections within each ethnic group. Thus, for Euro-Americans, there were four categories within the main factor of source: Charney, Maxwell, Terry, and UTK. Similarly, for Afro-Americans, there were three such categories, because the Maxwell collection did not contain any usable individuals of this group. However, for Amerindians, two of the three samples came from the same collection; thus, the Maxwell contributed Amerindians from the Southwest whereas UTK contributed both Plains and Woodlands peoples. Computation of these multivariate Anovas showed Wilk's Λ to be significant beyond the .05 level in all calculations, demonstrating that at least some of the centroids from the various samples are significantly different from each other. However, further analysis using one-way Anovas revealed that only a few measurements within each ethnic group reached the .05-level of probability. Among Euro-Americans, the significant Wilk's Λ was caused by differences in PreLen and MolLen whereas C1C1, P2P2, and M2M2 caused the significance seen in the Afro-Americans; in Amerindians I1I1, P2P2, M2M2, and PreLen reached the .05 level. To help determine if these findings are due to geographic variation or secular effects, the means and standard deviations of the separate samples in Table 4 are useful. As can be seen, among Euro-Americans, the greatest differences for PreLen and MolLen are between the contemporary, but geographically separated, Charney and UTK specimens. In addition, the means for all measurements within this ethnic group from those specimens not born in this century (i.e., the Terry Collection) do not consistently fall above or below those the other three samples. Thus, it appears that geography not secularism causes the differences uncovered. Among Afro-Americans, there is a possible secular effect in that the greatest discrepancies for the three measurements are between the Charney and Terry specimens; and, the means from the latter sample are always smaller than those from the other two collections. However, removal of one unusually large male from the Charney sample, causes the F value from the one-way Anovas for P2P2 and M2M2 to fall above the .05 level. Thus, it would be premature to hypothesize secular variation as causing the significant differences because these could be due to small sample bias. Finally, among the Amerindians, the Woodlands group means are most divergent from the other two series for P2P2 and M2M2 whereas the Plains sample is most divergent for PreLen and the Southwest for I1I1. These results and the concomitant size of the differences seem to indicate that the Plains Amerindians are the most dissimilar of the three groups, again indicating that geography has a greater affect than secularism.

Although the above information indicates possible variation in shape between the samples within ethnic group, there is evidence that it does not adversely affect the classification rates of the discriminant functions. Table 2 shows the percentage of individuals from each sample properly classified during cross-validation. As can be seen, the only samples that have discernable classification rate patterns are the Charney and Woodlands specimens. In the former, proper classifications is 100% among the Euro-Americans and 0% among the Afro-Americans, whereas the Woodlands specimens have a slight tendency to be classified at a greater rate than the other two Amerindian samples. To determine if any of these rates are statistically significant, chi-square tests of independence were performed on the data within each ethnic group with sexes combined and separated. In these tests, the columns were the sources while the rows were number correctly, and number incorrectly, classified. Two of the chi-square values calculated by the log-likelihood ratio method reached the .05 level of significance, that for Afro-Americans with the sexes combined ($P = .024$) and for Amerindian males ($P = .041$). In the first test, the deviations of the UTK sample provides the largest contribution to the value of chi-square whereas in the second test, the Woodlands group furnishes the greatest contribution. Because these results do not closely follow the observations on correct classification and because chi-square calculated by any method is inexact when expected cell sizes are small (although the likelihood ratio method is less affected than the normal chi-square), there appears to be little reason to hypothesize a relationship between source and rate of proper categorization. Thus, the variations in group centroids and measurements discussed above, whether due to secular or geographic differences, do not appear to affect classification rates.

In addition to the above tests, the private collection of Michael Charney contained two persons of eastern Asian origin, a Chinese male and a female from Thailand (represented by a cast). When the appropriate functions from Table 3 were applied to their measurements, both cases calculated highest on the Amerindian function; because there is general agreement that eastern Asia is the source of the native American populations, this finding is not unexpected. Similarly, an Eskimo palate and one from a Flathead skull in the same collection both calculated to be Amerindians. Thus, there is some evidence that the samples used here have at least partial validity. However, because this supporting data is scanty, the forensic anthropologist must exercise the usual caution when applying the techniques provided here.

To use the discriminant functions, calculate the values for a given palate and assign ethnic group from that function giving the highest result. For example, if a palate of unknown sex has a C1C1 of 31.7 mm, a P2P2 of 42.2 mm, a M2M2 of 46.5 mm, a I1C1 of 13.4 mm, a I1P2 of 25.7 mm, a I1M2 of 42.5 mm, and a I1I1 of 12.4 mm, the discriminant functions from Table 3 would be calculated as:

Euro-Am $= -180.00 + 0.9385\,(31.7) + 3.6077\,(42.2) + 0.4457\,(46.5) - 3.3867\,(13.4) - 0.0223\,(25.7) + 6.3041\,(42.5) - 0.0968\,(12.4) = 243.5$

Afro-Am $= -193.47 + 0.8872\,(31.7) + 3.7221\,(42.2) + 0.3448\,(46.5) - 3.1138\,(13.4) + 0.1220\,(25.7) + 6.5077\,(42.5) + 0.0208\,(12.4) = 246.0$

Amerind $= -195.67 + 1.5736\,(31.7) + 3.9178\,(42.2) + 0.5675\,(46.5) - 4.3720\,(13.4) + 0.5825\,(25.7) + 5.8727\,(42.5) - 0.3847\,(12.4) = 247.1$

Because the last function has the highest value, this person would be considered to be Amerindian. (Use of other "racial" terms for this individual such as Asian-American or Mongoloid is at the discretion of the researcher.)

In sum, the results of the study indicate that palatal measurements can be used to predict the major ethnic groups in the United States. The linear discriminant functions properly classified group 66.0% of the time with sex unknown, and 65.7% of males, and 72.0% of females. These functions best classify Amerindians (over 80% correct classification) whereas Euro-Americans and Afro-Americans are classified less well (54.6 to 71.4, and 25.5 to 63.2%, respectively). Therefore, it appears that use of palatal metrics is warranted in cases in which the upper jaw is the only diagnostic element available or the forensic anthropologist seeks to supplement evidence for ethnic group affinity based on other skeletal elements.

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