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# Palate shape and depth : a shape matching and machine learning method for assessment of ancestry from skeletal remains

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PALATE SHAPE AND DEPTH: A SHAPE MATCHING AND MACHINE LEARNING METHOD  
FOR ASSESSMENT OF ANCESTRY FROM SKELETAL REMAINS

A Thesis

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Master of Arts

in

The Department of Geography and Anthropology

by

Christopher Maier

B.A., University of North Carolina Wilmington, 2011

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## **Abstract**

The assessment of ancestry from skeletal remains is a vital aspect of forensic anthropology. As such, a myriad of techniques exists for estimating this particular component of the biological profile. The most traditional of these methods utilizes the naked eye and the observer's experience. As replicability has become more important, objective, metric techniques have been developed. This study attempts to merge these two subfields: by taking a traditionally non-metric feature, palate shape, and using a computer, evaluating it quantitatively. Using 3D digitizer technology in conjunction with shape matching and machine learning methods common in computer science, palate shape curves were collected from 376 individuals of varying backgrounds from mixed historic and modern contexts. Additionally, measurements were taken to capture palate depth, which is a novel measurement in this study. Results of the computer analysis indicated palate shape was an accurate indicator of ancestry 58% of the time. This number improved slightly when the historic sample was examined on its own (61%), but not to such a degree as to indicate a significant difference. This result may indicate that secular change in the human skeleton is not affecting this region, or at least that secular change does not affect the shape of the palate as it relates to ancestry. Cluster analysis of the curves revealed that the parabolic, hyperbolic, and elliptical shapes are relatively discrete from one another, with the only major overlap in shape being between white and Hispanic individuals. The results regarding depth are rudimentary at this stage; however, results indicate that the depth of the palate in Hispanic individuals is significantly deeper than in other ancestry groups.

## **Chapter 1** **Introduction**

The question of assessing ancestry from the skeleton is a central focus of the practice of forensic anthropology, inasmuch as it aids with the identification of unknown individuals. A myriad of techniques exist, both metric and non-metric, but each has limitations. The metric techniques are objective because they are rooted in statistical analysis, but they rely heavily on a large set of data points. Metric techniques also require mostly intact skeletal material, so that the data points necessary to run the analysis are present. These analyses are dependent on the availability of the technology needed to analyze the data (Gill 1995), and, consequently, may have limited use. Conversely, non-metric, or morphological, methods of ancestry determination can be easier and faster to use since they do not require specialized equipment or analysis; however, they are subjective, relying heavily on the observer's experience. This can make these methods more of an art than a science (Hefner 2009).

Since passage of the Daubert standard in 1993, a greater effort has been made in forensic anthropology to establish methods that are more objective, reliable, and replicable (Daubert v. Merrell Dow Pharmaceuticals Inc. 1993). This is especially true of those methods used to assess ancestry. Methods, such as that of Giles and Elliot (1962), were early innovations with regard to objective assessment, but have proved to be inaccurate in some cases (Gill 1995). Newer methods, such as FORDISC, Forensic Discriminant Function Software, developed at the University of Tennessee, Knoxville, have achieved a higher degree of accuracy, but they, too, have limitations (Ousley and Jantz 2006).

This study is an attempt to quantify and make more objective one of the indicators commonly used to assess ancestry: palate shape. Traditional non-metric analyses of the



palate shape, or as it is sometimes called, the dental arcade, have established three variously named categories (Gill 1995, Krogman and Işcan 1986, Rhine 1990). The parabolic (triangular), the hyperbolic (rectangular), and the elliptical (rounded), palate shapes are indicative of white, black, and Asian/Native American ancestry, respectively. As three geometrically discrete shapes, it stands to reason that a parabola, hyperbola, and ellipse would lend themselves easily to metric assessment; thus, a more objective method for assessing ancestry from the palate could be formulated. However, non-metric analysis of ancestry is becoming increasingly complicated as populations continue to undergo increased admixing, that is, the combination of genetic material from once distinctive population groups. Therefore, this research will help in assessing ancestry objectively, as well as illustrate to what degree secular change, possibly as a result of admixture, has affected these ancestry traits.

## **Chapter 2** **Literature Review**

### Non-metric Ancestry Estimation

The use of non-metric, or morphoscopic, traits to assess the ancestry of an individual has been one of the longest running practices for forensic anthropologists. Determinations of ancestry are important to the biological profile of the decedent. Many of the ancestry traits examined by practitioners today were originated by Harvard professor E.A. Hooton, as discussed in his 1931 book *Up from the Ape* (Hefner 2009, Hooton 1931). Although Hooton was not looking explicitly at ancestry estimation when he developed the list of traits, he was able to recognize their usefulness in broadly classifying skeletal material (Hooton 1931). Hooton understood the potential in applying these traits to a forensic context and, thus, developed the first standardized set of descriptions and illustrations, the “Harvard List.” That list is the basis for much of what is practiced today (Hefner 2009).

Since Hooton’s work in the 1940s, more refined lists of traits have been established (Gill 1995, Krogman and Işcan 1986, Rhine 1990). These lists, particularly the trait list developed by Rhine (1990), comprise the body of work on which most forensic anthropologists are trained. The features on these lists are completely qualitative and represent a highly subjective means of assessing ancestry (Hefner 2009). However, this method of ancestry estimation is fast and relatively straightforward; therefore, it continues to be used. The continued and necessary use of non-metric methods to assess ancestry has led to research into standardizing these traits in order to eliminate as much subjectivity from the process as possible (Hefner 2009, Hughes 2011).

These standardized methods utilize an ordinal scale, typically from 1-5, to describe varying degrees of expression of non-metric ancestry features (Hefner 2009, Hughes 2011). Yet, even this method has problems with subjectivity, as it requires observers to make assessments as to degree of expression.

### Metric Methods of Ancestry Estimation

Metric methods of ancestry estimation were also developed concurrently with the non-metric methods; however, after the advent of the Daubert standard in 1993, which required that methods used in forensic cases be relevant, reliable, and replicable (Daubert v. Merrell Dow Pharmaceuticals Inc. 1993), methods already used in forensic anthropology were subject to revision. In a similar vein of thinking as that which inspired this project, research was conducted to describe the morphology of the skull mathematically. Some early work, even before the Daubert standard, employed discriminant function analysis to extrapolate which ancestral group the remains in question most closely resembled (Giles and Elliot 1962). This method is still occasionally used in labs today because it is based on calculations that can be done by hand. While accurate in assessing sex, some researchers have suggested that its efficacy in assessing ancestry can be inaccurate (Gill 1995). More comprehensive metric methods have been developed, such as FORDISC, which assess ancestry with greater accuracy (Guyomarc'h and Bruzek 2011, Ousley and Jantz 2006, Ramsthaler et al. 2007).

While the metric methods available to forensic anthropologists are popular and widely practiced, they, too, have their limitations. In the case of Giles and Elliot's method, all of the cranial measurements prescribed are required for the method to be effective, and the examiner can only determine ancestry once sex has been assigned (Giles and Elliot

1962). Sex and ancestry are inexorably linked; therefore, this is a common limitation of ancestry estimation methods (Konigsberg et al. 2009). FORDISC is better, in that it is able to make assessments without every measurement, but it is subject to the same limitations because it is based on essentially the same math (Ousley and Jantz 2006). The large sample from which FORDISC is working allows for probable sex and ancestry to be generated, even if some cranial measurements are absent (Ousley and Jantz 2006). Yet, with each missing measurement, the accuracy of these assessments decreases (Ousley and Jantz 2006).

### Ancestry Estimation in the Digital Age

Currently, an interest in using computer technology to reconcile metric and non-metric methods for ancestry estimation exists. A major emphasis has been toward the use of geometric morphometrics, a practice that uses landmarks to represent the morphology of bone as a set of points in space, which can be analyzed mathematically (Bytheway 2010). This type of analysis is typically conducted using a digitizer. More recently, the use of 3D laser scanners has allowed practitioners to create computer representations of bones, such as the skull and the pelvis, on which metric and non-metric analysis can be performed (Decker et al. 2011, Sholts et al. 2010, 2011). This may enhance the ability of forensic anthropologists to analyze fragile or fragmentary remains, as it will reduce the need to physically handle the remains to analyze ancestry.

### Secular Change in the Human Skeleton

One other aspect involved in this research requires an assessment of secular change to the shape of the palate. This change is thought to be related to increased admixture in modern times, plus a variety of additional environmental factors. Secular change in the human skeleton is a subject that has been of interest to a number of researchers (Jantz and

Jantz 2000, Jonke et al. 2007, Lavelle 1973, Smith et al. 1986). Such change has been a noted phenomenon in regard to the stature of individuals for well over a century, generally as an increase in stature (Boas 1912, Bowditch 1877, Bowles 1932, Quetelet 1835). More recently, investigations of secular change in the cranial skeleton have been undertaken, revealing a trend of increasing height (measured superior to inferior), increasing depth (measured anterior to posterior), but decreasing breadth (measured lateral to opposite lateral) (Angel 1976, 1982, Jantz and Jantz 2000, Jonke 2007, Smith 1986, Wescott and Jantz 2005).

Other research into secular trends in the human skeleton has focused on specific regions of the skull. For example, Lavelle (1973) focuses on secular changes in the teeth and maxillary dental arch. His research suggests that there are two primary and inverse changes occurring in this region: 1) the overall size of the teeth is increasing and 2) the size of the dental arch is decreasing (Lavelle 1973). Interestingly, the regions of prosthion and nasion appear to have very little change, suggesting that secular change is not a significant factor in the facial skeleton (Wescott and Jantz 2005). Although Lavelle does explore size changes in the maxillary dental arcade, no research has been conducted on the effect of secular change on palate shape.

#### The Evolution of Palate Shape as an Ancestry Indicator

The use of palate shape to determine ancestry is a long-standing practice in the field of forensic anthropology. Since the shape of the palate was discovered to be an ancestry indicator, qualifying that shape has been difficult and has yielded a multitude of descriptions over the years. Hooton was one of the earliest to notice the differences in palate shape and describe them, calling white palates “pinched”, black palates “narrow and

long”, and Asian/Native American palates “wide and short” (Hooton 1931). Years later, W.M. Krogman developed his own classification system for the palate. He described white palates as narrow, black palates as wide, and Asian/ Native American palates as intermediate between the two extremes (Krogman and Işcan 1986). Later still, Gill redefined the classification of the palate into the basic categories of parabolic, hyperbolic, and elliptical, which are commonly used today (Gill 1986, 1995). He delineated white and East Asian palates as triangular or parabolic, black palates as hyperbolic, and North American Indian and Mesoamerican Indian palates as elliptical, or occasionally parabolic (Gill 1986, 1995).

In spite of the variety of classification systems, the shape of the palate has been an enduring and well-received indicator of ancestry. This indicator has been used to assess ancestral differences within relatively isolated populations, such as the continent of Australia (Dalidjan et al. 1995). Also, it has been used, with some success, to distinguish distinct population groups within the pre-established ancestral groups, such as the Asian/Native American classification (Miyazaki 1993).

As with most other aspects of forensic analysis, the use of palate shape should be subject to standardization and quantification under the Daubert standard (Daubert v. Merrell Dow Pharmaceuticals Inc. 1993). The variety of classification systems used to assess ancestry from the palate (Gill 1986, 1995, Hooton 1931, Krogman and Işcan 1986) has made it difficult to standardize a non-metric description of palate shape, and it is not included in such research (Hefner 2009). However, an effort has been made to define palate shape metrically and reify the process (Burris and Harris 1998, Byers et al. 1997). Byers et al. (1997) conducted a study on a sample of 414 individuals of black, white, and

Amerindian ancestral groups. In order to best describe the palate, palate width and length were recorded through a series of measurements. These included the distance between the midpoints of the lingual borders of the central incisors, canines, second premolars, and second molars, as well as the distance between the central incisor and the canine, second premolar, and second molar, respectively (Byers et al. 1997). Palate length was a calculated measure using the Pythagorean theorem to find the straight-line distance between the level of a certain tooth and the front of the mouth (Byers et al. 1997). Overall, it was found that certain measures were not useful for assessing ancestry in the different sexes (i.e. palate width at the incisors was not useful in males, and palate width at the second molar was not useful in females). Yet, the measurements altogether were somewhat helpful in assessing ancestry (Byers et al. 1997). For an individual of unknown sex, ancestry was correctly assessed 66% of the time; however, if sex was known, that percentage improved only for females, showing 65.7% accuracy for males and 72% accuracy for females (Byers et al. 1997).

Burris and Harris (1998) conducted a similar study to that of Byers (1997). In their study, 332 dental casts were used to assess ancestry metrically from the palate by taking five measurements of width and four measurements of length (Burris and Harris 1998). Widths were measured at the canines, first and second premolars, and first and second molars; the width at the central incisors was considered to be negligible (Burris and Harris 1998). Length was calculated using two methods, first by calculating the distance from the canine to both premolars and the first two molars (Burris and Harris 1998). The second method calculated length by measuring the straight-line distance from the central incisor to the canine and the distance from the second molar to the first and second premolar and

from the first molar to the second molar (Burriss and Harris 1998). Using these measurements, Burriss and Harris (1998) were able to say that for individuals of unknown sex, the method is able to estimate ancestry with 48% accuracy; however, when sex was known, the method was able to achieve 81% accuracy for males and 83% accuracy for females (Burriss and Harris 1998).

While Byers' and Burriss' methodologies were successful at distinguishing both sex and ancestry using metric analysis of the palate, neither has gained popularity within the forensic anthropology community. This may be due in part to the complex mathematical and statistical analysis required to achieve results, in conjunction with the lack of a computer program, such as FORDISC, with which to run this analysis. While the calculations themselves are not an insurmountable obstacle, ease of use may be a highly influential factor in regard to the use, or disuse, of these methodologies.

It can be seen from the literature that ancestry estimation is an ever-present concern for physical anthropologists. New methods are continually developed to address that concern. By building upon previously conducted research, new ideas are formulated and gaps in knowledge can be filled.



### **Chapter 3** **Materials and Methods**

#### **Sample**

The sample for this study was comprised of 376 individuals, including 101 white males, 100 white females, 72 black males, 53 black females, 40 Hispanic males, 6 Hispanic females, 3 Asian males, and 1 Native American female (Table 1). The Asian/Native American ancestral group was not well represented in North American modern forensic skeletal collections, which explained the limited representation of that population. This sample came from the William M. Bass Skeletal Collection, a modern sample, housed at the University of Tennessee, the Hispanic Collection housed at the Pima County Office of the Medical Examiner (PCOME) in Tucson, Arizona which was also a modern collection comprised primarily of undocumented Mexican immigrants, and the Robert J. Terry Skeletal Collection, a more historic sample, housed at the Smithsonian Institution's Museum Support Center. Both modern and historic samples were used in order to address the question of secular change occurring in skeletal representations of ancestry.

Table 1: Composition of sample used

	<b>Male</b>	<b>Female</b>	<b>Total</b>
<b>White</b>	83	85	168
<b>Black</b>	65	51	116
<b>Asian/Native American</b>	3	1	4
<b>Hispanic</b>	20	2	22
<b>Total</b>	171	139	310

#### **Data Collection**

A *Microscribe™* digitizer, which uses a stylus to record points in three-dimensional space, was used to record data for each palate. This was accomplished by recording the

point on the bone that represented the approximate center of each tooth at its junction with the alveolar bone (Figures 1 and 2). In the event that all sixteen teeth were not present, a point was recorded if a reasonable assumption could be made as to the location of that tooth. If no assumption could be made, the point was not recorded. Five points were also taken on the “roof” of the mouth to capture data on palate depth (Figure 2), a



Figure 1: Photograph of how the points are recorded using the digitizer.

previously unrecorded measurement that may prove useful in ancestry estimation. These points were located posterior to the incisal foramen, at the intersection of the transverse palatine suture and the posterior median palatine suture, at the most posterior point on the palate, and at two points at the level of the mesial first molar in the “middle” of each side of the palate. This protocol allowed for a topographic view of the palate (Figure 2).

## Processing

The sixteen discrete points collected as coordinates by the digitizer for palate shape were converted into continuous smooth curves. This was accomplished using a B-spline curve, which is a smooth, continuous type of curve that lends itself easily to the calculations

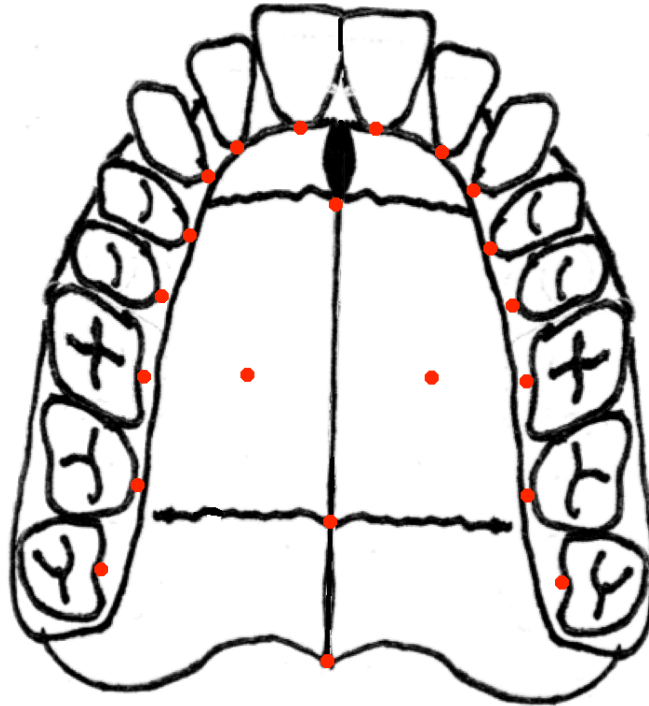


Figure 2: Diagram of the palate depicting the points that are recorded

required. The intrinsic variability of dental configurations, as well as variability in data collection, required a curve smoothing procedure to be implemented. Rather than producing a curve that crossed every point that was recorded, a “best fit” version of the curve was produced. These smooth curves intercepted the first and last points recorded and minimized the least square distance between the remaining points and the curve

(Figure 3); this allowed the curve, and calculations performed using it, to be resistant to the variability discussed above.

In order to standardize the analysis of these curves, they were transformed to a normalized scale and position, such that the arc length, of the curve was equal to 1, the line of reflection, or midline of the palate, for each curve rested on the y-axis, and the anterior portion of the curve (the front of the mouth) was in the positive y direction (Figure 3). Once the curves had been processed, they were inspected visually by the author and designated as “ideal”, “general”, or “bad”. The designation of “ideal” indicated that the curve was a good representation of the expected shape for the ancestry group to which it belonged. The designation of “general” meant that the curve was not the best representative of the expected palate shape, but rather a representation of normal human variation. The designation of “bad” was reserved for those curves that upon visual inspection were deemed unusable due to recording error, since the shape produced did not resemble a curve of any type. There were only three curves receiving the “bad” designation; they were excluded from the sample. Additionally, 63 other curves were excluded because of unknown ancestry (probable Hispanic, but unknown) or the curves had fewer than 16 data points. These curves were excluded to simplify the shape matching procedure for this initial study.

### Curve Fitting

Since the traditional shape categories for palate shape are parabolic, hyperbolic, and elliptical, each curve was fit with a parabola, a pair of hyperbolas, and an ellipse. To fit an processed curve to a parabola, the formula for a “best fit” parabola was generated, and the curve was overlain for comparison. The hyperbolic fitting process required an additional

step. Since a hyperbola is not symmetric about the y-axis, in order to best approximate a palate curve, two hyperbolas were generated, one for each side of the curve.

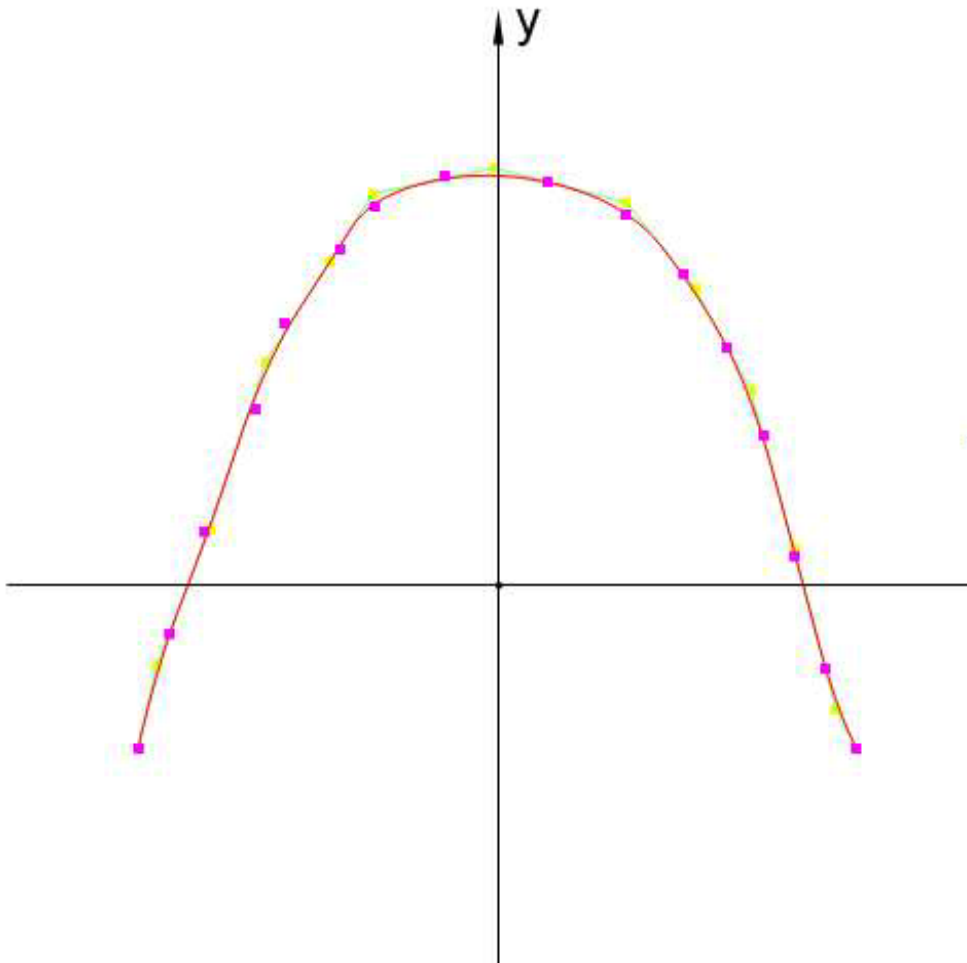


Figure 3: Example of a standardized best-fit curve. Pink dots are collected points, yellow points are best fit points. The curve is centered on the y-axis with the anterior in the positive y direction.

In regard to the ellipse, special considerations had to be made, since the apex of an ellipse resembles a parabola (Figure 4). To solve this problem, the curves were fitted with ellipses that best fit at least 50% of the curve as opposed to the ellipse which was the overall best fit (Figure 5). Once the curve had been fitted to each of these three quadratic shapes, it was

assigned to an ancestry group based on which shape exhibited the least error as calculated by the computer (Figure 6).

In conjunction with the shape matching method described above, each curve was also fit using more specific pieces of the shapes to help improve classification accuracy.

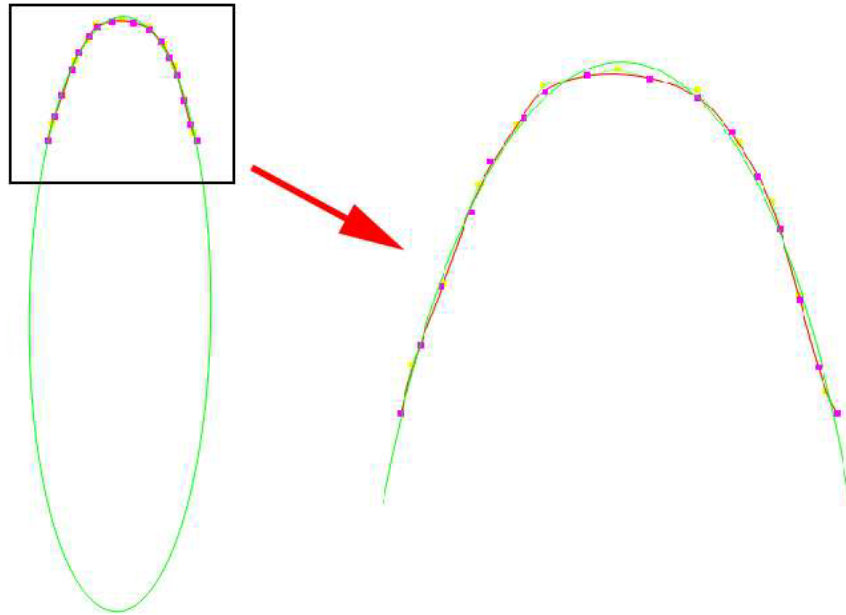


Figure 4: The parabola problem in fitting an ellipse

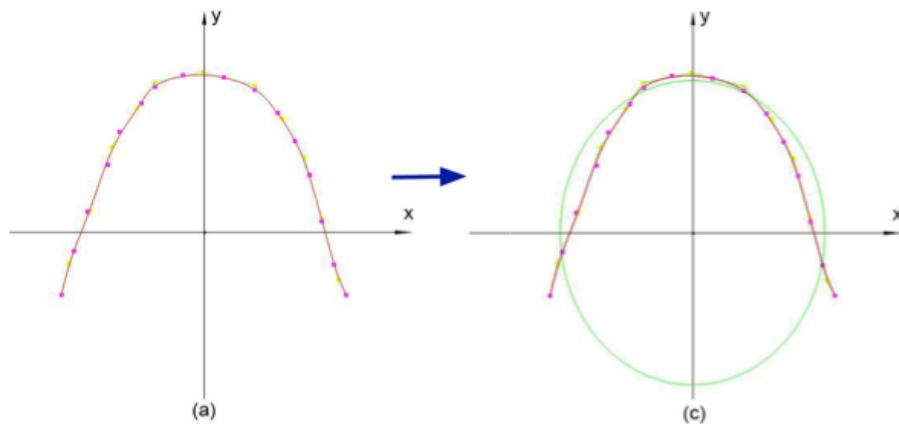


Figure 5: Method ultimately used to fit an ellipse

The angulation of the sides was considered a defining feature, in that the parabolic shape will have highly angled sides and the sides of the hyperbolic shape approach parallel(Figure 7).

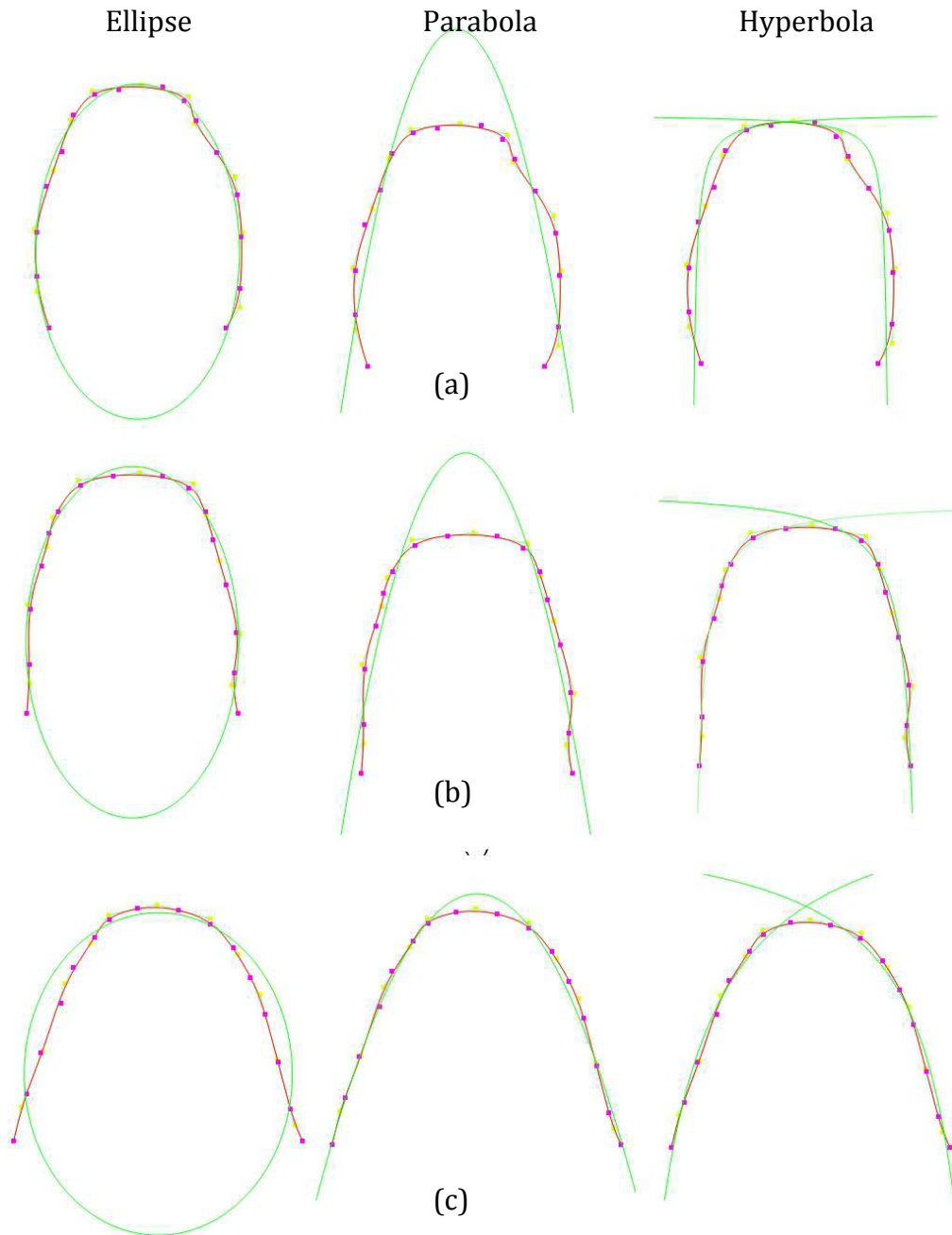


Figure 6: Curve fitting for a) an Asian/Native American individual b) a Black individual c) a White individual.

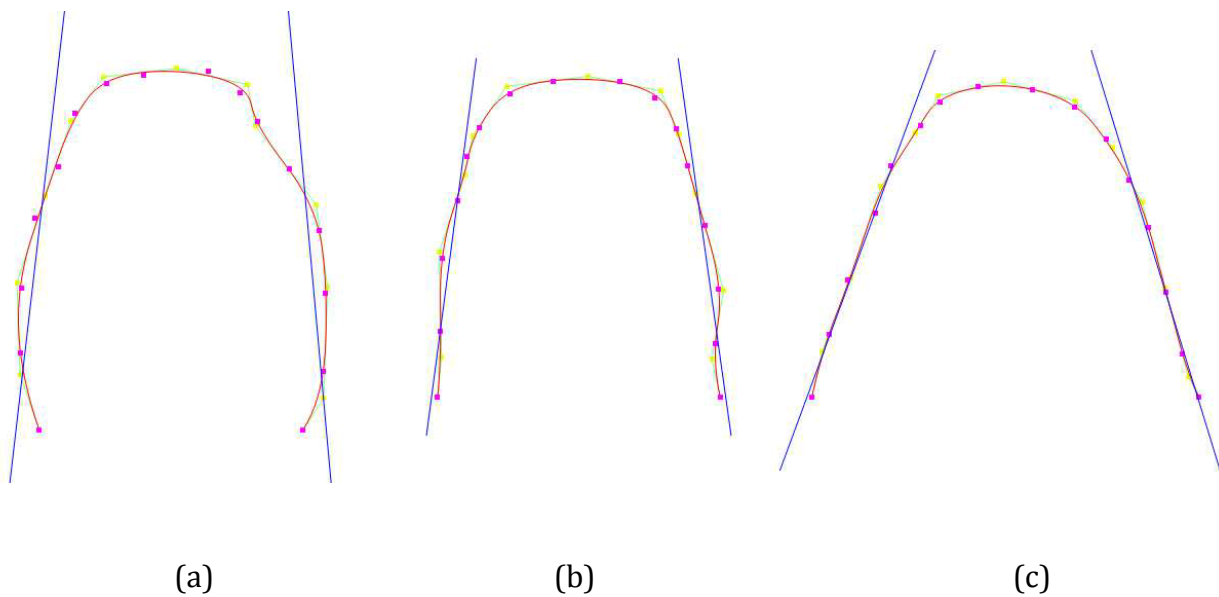


Figure 7: Measure of the angle of the sides of the palate in a) elliptical, b) hyperbolic and c) parabolic shapes.

The sides of the elliptical shape were classified based on the size of the error between the curve and the set of lines that define its sides (Figure 7). Additionally, the curvature of the anterior of the palate was examined as a classification variable. In a parabolic palate, the anterior portion should appear pointed; in a hyperbolic palate, it should appear flatter; and in an elliptical palate, the anterior palate should be very rounded (Figure 8).

### Analyses

#### Accuracy

The program was tested for consistency and accuracy by using a ten-fold testing procedure. The dataset was partitioned into ten groups. For every iteration of testing, nine of the ten groups were used as the data pool, and the tenth group was tested against it. Two types of tests were performed to assess different measures of accuracy. In the first,



the test group as a whole was compared to the data pool, and the percent of that test group that was correctly classified was recorded. This was repeated until all groups had been tested against all others, and an average accuracy was obtained. In the second type of test, the test group was partitioned into those curves that had been marked as “ideal” and those that had been marked “general”. The “ideal” curves were compared to the data pool, and the percent of those ideal curves that were correctly classified was recorded. Again, an average accuracy was calculated from the results of all the tests, using the ten-fold testing procedure discussed above.

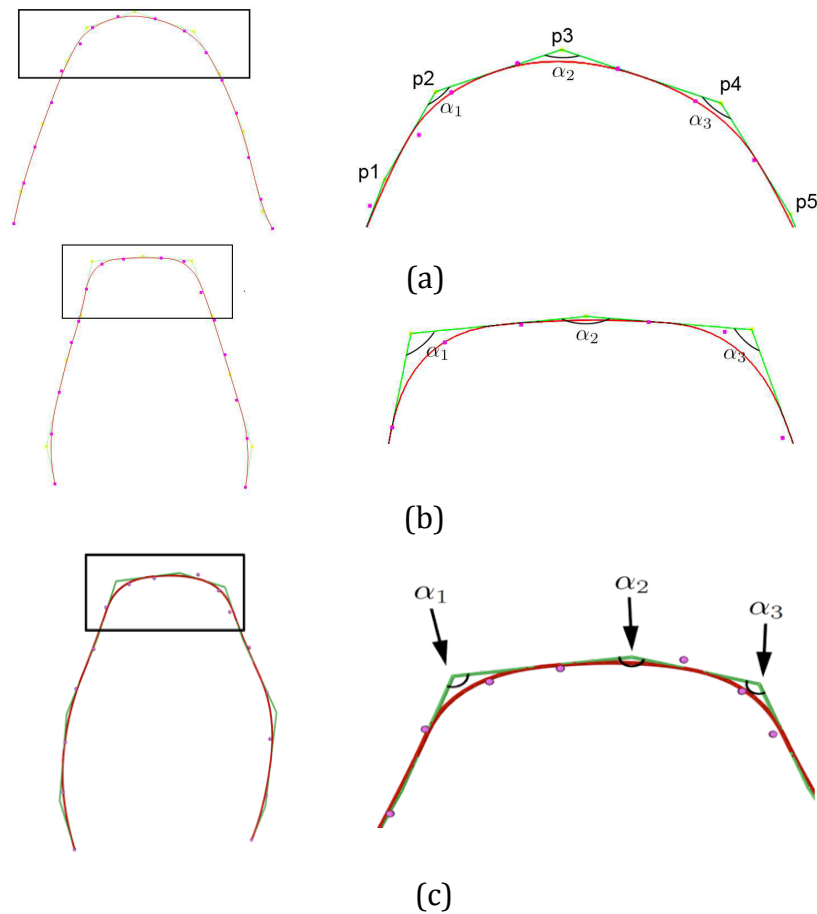


Figure 8: Curvature of the anterior palate in a) parabolic, b) hyperbolic, and c) elliptical shapes

Additionally, a test of 20 randomly selected curves from the sample was used to assess the accuracy of the human practitioner using palate shape to estimate ancestry. Five graduate students, all first or second year master's degree students with backgrounds in forensic anthropology, were asked to assign ancestry based solely on the digital representation of a palate curve. Each observer was asked to assign each curve to the "white", "black", or "Asian" category. This was done three times to obtain the average accuracy for each observer. The mean of those averages was used as a baseline accuracy for human practitioners to which the computer-generated assessments were compared. Finally, the accuracy of data collection, through measurement of intraobserver error, was calculated by examining a set of duplicate measurements, obtained by collecting 17 curves twice, and measuring the difference between the curves.

#### Secular Change

Secular change was assessed by examining the data to see if the palates from the historic Terry Collection were more closely matched to the appropriate "ideal shape" than their modern counterparts. This was achieved using the second testing procedure described above. In this instance, rather than separating the test group by "ideal" or "general", the data were separated into "historic" (Terry Collection) "modern" specimens. These data were then compared to the data pool, and the percent correctly classified was recorded.

#### Clustering

Clustering of palate shape data was measured using a Davies-Bouldin (DB) Index. The DB Index examines the ratio of the cluster density, or how much variation exists within each cluster, to the distance between the clusters, or how distinct from one another they

are. As such, a smaller number for the DB Index is indicative of better clustering and more distinct ancestry groups.

### Hispanic Ancestry

For this study, the Hispanic individuals, as identified by PCOME records, were treated as somewhat of an experimental group. Since the expected palate shape for the Hispanic group is not known, they were not included in creating the program. The curves collected were analyzed to determine where the cluster would be located, and what, if anything, could be suggested about palate shape from that location.

### Depth

The measure of palate depth was novel in this study and yielded rudimentary results at this stage. Although five points were collected, only three were deemed useful for describing depth. Three points were not enough to generate a depth curve, so depth was measured as a simple linear distance from the “plane” of the curve, the level on which the sixteen point of the curve were collected, to the intersection of the median and transverses palatine sutures, which was a consistent point taken on all individuals (Figure 9). Analyses of Variance were performed using SAS version 9.3 to detect if depth differed significantly due to either ancestry or sex. The Tukey HSD (honestly significant difference) and Fischer LSD (least significant difference) procedures were also used via SAS to detect where the significant differences exist.

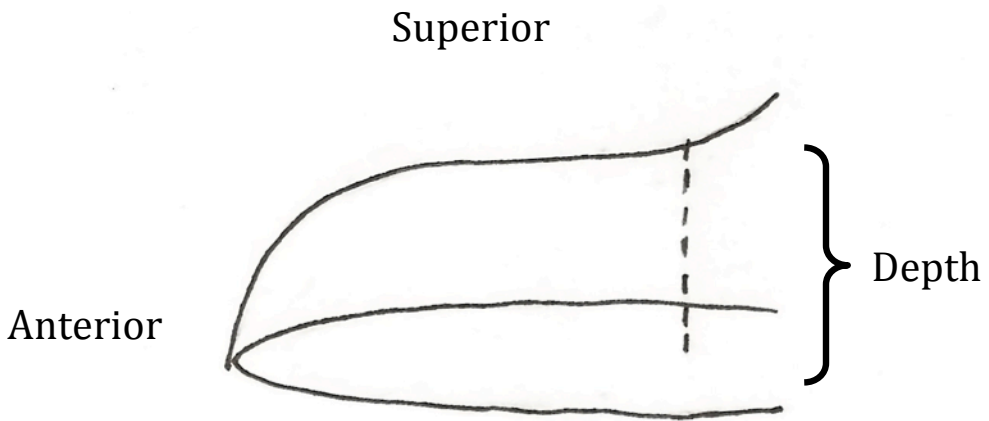


Figure 9: The measure of palate depth, taken between the plane of the palate curve, and the intersection of the transverse and median palatine sutures (lateral view)

## Chapter 4 Results

### Accuracy and Secular Change

The sample of ideal data classified correctly 89% of the time, which is much higher than the 58% accuracy achieved by the sample as a whole. Comparison of the accuracy rates between the historic and the modern samples yielded a difference of 3%. The historic sample yielded an average accuracy of 61%, and the modern sample yielded 58% accuracy, a difference that is not statistically significant as determined by a z-test comparison of proportions ( $\alpha=0.05$ ;  $p=0.1423$ ). The accuracy test performed on human practitioners yielded an overall average accuracy of 40% over 15 trials (Table 2). The accuracy of the human observer was not statistically significantly less than the accuracy of the program ( $\alpha=0.05$ ;  $p=0.08$ ), again utilizing a z-test. Intraobserver error in data collection was low, in that only 4% of the time were inconsistent curves generated. Additionally accuracy for the individuals ancestry groups were calculated to determine if one group was correctly classified than the others (Table 3). The white ancestry was both the most often correctly classified, and the group into which most curves were incorrectly placed.

Table 2: Accuracy for a human observer

<b>Observer</b>	<b>Trial 1</b>	<b>Trial 2</b>	<b>Trial 3</b>	<b>Average</b>
1	0.5 (10/20)	0.55 (11/20)	0.55 (11/20)	0.533
2	0.15 (3/20)	0.55 (11/20)	0.6 (12/20)	0.433
3	0.35 (7/20)	0.35 (7/20)	0.3 (6/20)	0.333
4	0.2 (4/20)	0.2 (4/20)	0.4 (8/20)	0.267
5	0.45 (9/20)	0.55 (11/20)	0.3 (6/20)	0.433
<b>Average</b>	0.33	0.44	0.43	0.399

Table 3: Sample accuracy by ancestry group

Actual Ancestry		Classified Ancestry		
		White	Black	Asian
White	168	111 (66%)	56 (33%)	1 (1%)
Black	116	60 (52%)	56 (48%)	0 (0%)
Asian	4	2 (50%)	2 (50%)	0 (0%)
Total	288	173 (60%)	114 (40%)	1 (0%)

### Clustering

For these data, the DB Index, which measures the discreteness of a cluster, between white and black individuals is 7.486; between white and Asian individuals it is 5.69; and between blacks and Asians it is 3.77. However, when calculated among the three major ancestry groups simultaneously, the DB Index is equal to 6.88 (Table 4). The DB Index between Hispanics and whites was 13.65, between Hispanics and blacks it was 6.46, and between Hispanics and Asians it equaled 2.85 (Table 4).

Table 4: Davies-Bouldin Indices calculated for Ancestry Group Clustering

Davies-Bouldin Indices	
<i>Comparison</i>	<i>Index</i>
White-Black	7.486
White-Asian	5.69
White-Hispanic	13.65
Black-Asian	3.77
Black-Hispanic	6.46
Asian-Hispanic	2.85
White-Black-Asian	6.88

### Depth

The depths of the palates were analyzed for significant differences among the ancestry groups. Results of a one-way ANOVA indicated that significant differences exist

among depth measurements for various ancestry groups ( $F=4.65$ ;  $\alpha=0.05$ ;  $p=0.0034$ )(Table 5). The Tukey HSD procedure indicated that significant differences exist between whites

Table 5: Results of One-Way ANOVA between Ancestry and Depth.

Analysis of Variance							
Source	df	SS	MS	Error	Error df	F	Pr>F
Ancestry	3	138.67588	46.225294	MS (Residual)	306	4.65	0.0034
Residual	306	3039.368429	9.932577				

and blacks, and that no other significant differences exist (Table 6). The Fischer LSD procedure was also used. The LSD is more powerful, but less conservative than the HSD,

Table 6: Pair-wise comparison adjusted using Tukey HSD for significant differences in depth

Tukey HSD comparisons (***=significant at the 0.05 level)				
Ancestry Comparison	Differences between Means	Simultaneous 95% CL		
Hispanic-Black	0.3998	-1.4933	2.2930	
Hispanic-White	1.6375	-0.2084	3.4833	
Hispanic-Asian	2.4199	-2.0053	6.8452	
Black-Hispanic	-0.3998	-2.2930	1.4933	
Black-White	1.2376	0.2548	2.2204	***
Black-Asian	2.0201	-2.1201	6.1603	
White-Hispanic	-1.6375	-3.4833	0.2084	
White-Black	-1.2376	-2.2204	-0.2548	***
White-Asian	0.7825	-3.3363	4.9012	
Asian-Hispanic	-2.4199	-6.8452	2.0053	
Asian-Black	-2.0201	-6.1603	2.1201	
Asian-White	-0.7825	-4.9012	3.3363	

which means that differences are more likely to be found to be significant, but there is also a greater chance of finding a false significant difference. These results indicated that

significant differences exist in depth between both whites and blacks, and whites and Hispanics (Table 7). Although few statistically significant differences were found, the signs (+/-) of the differences between the means indicate some general trends in regard to palate

Table 7: Results of the Fischer LSD test for significant differences in depth

<b>Fischer LSD comparisons (**=significant at the 0.05 level)</b>				
<b>Ancestry Comparison</b>	<b>Differences between Means</b>	<b>Simultaneous 95% CL</b>		
<b>Hispanic-Black</b>	0.3998	-1.0423	1.8420	
<b>Hispanic-White</b>	1.6375	0.2314	3.0436	***
<b>Hispanic-Asian</b>	2.4199	-0.9510	5.7908	
<b>Black-Hispanic</b>	-0.3998	-1.8420	1.0423	
<b>Black-White</b>	1.2376	0.4890	1.9863	***
<b>Black-Asian</b>	2.0201	-1.1337	5.1739	
<b>White-Hispanic</b>	-1.6375	-3.0436	-0.2314	***
<b>White-Black</b>	-1.2376	-1.9863	-0.4890	***
<b>White-Asian</b>	0.7825	-2.3550	3.9199	
<b>Asian-Hispanic</b>	-2.4199	-5.7908	0.9510	
<b>Asian-Black</b>	-2.0201	-5.1739	1.1337	
<b>Asian-White</b>	-0.7825	-3.9199	2.3550	

depth (Table 6). Namely, that Hispanic individuals appear to have the deepest palates, and white individuals have the shallowest of the adequately represented populations (Table 8) (Asians have shallower palates but are not on the table due to a negligible sample).

Table 8: General ordering of ancestry groups by depth from deepest to shallowest

<b>Rank</b>	<b>Ancestry</b>	<b>Mean Depth</b>	<b>Sample Size</b>
1	Hispanic	11.365	22
2	Black	10.965	116
3	White	9.728	168

Sex of the individual may be a possible confounding variable in regard to depth. A one-way ANOVA of this variable indicated that significant differences exist in palate depth



between males and females ( $F=46.79$ ;  $\alpha=0.05$ ;  $p<0.0001$ ) (Table 9). The means indicate that males have deeper palates than females, as would be expected (Table 10). This

Table 9: One-way ANOVA for differences in palate depth due to sex

Analysis of Variance							
Source	df	SS	MS	Error Term	Error df	F Value	Pr>F
Sex	1	419.135455	419.13545	MS(Residual)	308	46.79	<0.0001
Residual	308	2758.908855	8.957496				

Table 10: Mean palate depth by sex

Sex	Mean	Sample Size
Male	11.3454	171
Female	9.0074	139

becomes an important factor because males are over-represented in the sample (Table 11).

Table 11: Percentage of each sex in each ancestry group.

Ancestry	Percent Male	Percent Female
White	49.4%	50.6%
Black	56.0%	44.0%
Asian	75.0%	25.0%
Hispanic	90.9%	0.1%

## **Chapter 5** **Discussion**

### Accuracy

Several interesting findings arose out of the accuracy results for this study. First, a program accuracy of 58% indicates that the shape of the palate may be a useful feature in assessing ancestry, and that a computer can be used to examine this feature. This is an important finding, in that it may eliminate some of the subjectivity currently associated with the prediction of ancestry from skeletal remains.

Additionally, the difference in accuracy between the more historic and the modern samples may be evidence of secular change. Results indicated that the Terry Collection was classified more accurately than the rest of the sample. Although this difference was not a statistically significant one, future research involving more temporally distinct populations may reveal a greater difference, yielding more conclusive evidence of increasing homogeneity.

That the accuracy of human practitioners was 40% suggests several interesting facts regarding the efficacy of palate shape in assessing ancestry. First, it affirms that the shape of the palate is indicative of ancestry, regardless of experience of the observer, since the accuracy is different from what would be expected due to random chance (33%). Second, it may suggest that a computer program may be able to discern differences more effectively than the human eye. Although the accuracy difference between the practitioner and the computer is not statistically significant, it may have practical significance, and be indicative of the need for more trials to establish statistical significance.

## Clustering

The results of the cluster analysis demonstrate how useful palate shape alone is in distinguishing different ancestry groups. The Davies-Bouldin indices for these data indicate that there is clustering, but that it is not extremely strong (Table 4). The smallest indices are between white and Asian (5.69), black and Asian (3.77), and Hispanic and Asian (2.85) while the largest indices are between white and Hispanic (13.65) and white and black (7.486). These results can be interpreted in one of two ways. First, it may indicate that the Asian elliptical palate shape is more distinctive than either the parabolic or the hyperbolic, and certainly more distinctive than they are from each other. Second, these results may simply be due to error related to insufficient sample size. The limited availability of Asian or Native American modern samples in the United States allowed for only four individuals to be represented in this study. This may make the indices calculated using the Asian group inaccurate. In spite of this problem, the DB Index between white, black, and Asian ancestry groups indicated that the clusters are distinct but not discrete, which accounts for expected intrapopulational idiosyncratic variation.

## Hispanic Ancestry

The results for the Hispanic sample were particularly revealing, especially in regard to understanding palate shape. The Davies-Bouldin Index indicated that the shape of the Hispanic palate is more similar to the parabola seen in white individuals (13.65) than it is to either the shape seen in black (6.46) or Asian (2.85) individuals. The Hispanic sample in this study consisted of Southwest Hispanics, who typically would be considered a genetic admixture of European and Native American traits. As such, one would expect palate shape to be expressed as either the white shape, or the Asian shape, or as some blending of these

two traits. Therefore, it is not surprising that, in this study it was found that Hispanic palates were most similar to white palates, nor was it surprising that they were delineated from black palates to about the same degree as the other ancestries. However, what may be surprising is how far removed the Hispanic palates appear to be from the Asian palate shape. This is likely due in large part to the small Asian sample in this study, but it may be indicative of something more. For example, it may indicate that the white palate shape is the dominant genetic feature, as compared to the elliptical shape, or that in cases of European and Asian/Native American admixture, the white traits will be dominant and persist.

#### Palate Depth

The results of this preliminary analysis of palate depth indicate that differences among ancestral groups do exist. Different analyses indicate that differences exist between white individuals and both black and Hispanic individuals. These results may prove to be useful in determining ancestry, especially in regard to discerning Hispanic individuals from white individuals. As noted earlier, in regard to palate shape there do not appear to be any difference between individuals of white ancestry and individuals of Hispanic ancestry. The difference that appears to exist in palate depth may be used to distinguish these populations from skeletal remains.

The result that the palate depths of males and females differed significantly is not surprising. This may have influenced the significant differences that exist in palate depth due to ancestry, since the white sample is the only balanced sample; the other samples are unbalanced in the direction of males (Table 11). Since males have, on average, deeper palates than females (Table 10), the over-representation of males in the black and Hispanic

samples may have skewed the data, producing significant differences where in fact there is none.

### Future Research

While useful in and of itself, this study has opened the door to a wide variety of fascinating questions still to be explored. First, the use of a larger sample, particularly of Asians and Native Americans, may improve accuracy and offer more conclusive results.

The question of the use of the computer versus the ability of a human observer to discern palate shape is one that can be further explored. In this study, the human observers were limited to graduate students all with fewer than five years of experience working with skeletal remains, but with basic knowledge in regard to assessing ancestry from the skeleton. A similar test could be performed using professionals with more experience, which would elucidate how great a role experience plays in assessing these palate shapes. Additionally, further testing could discern whether or not a computer program would be useful for all practitioners, or only those with little experience.

Further, the use of the computer to assess palate shape may become useful in cases involving fragmentary remains. With a sufficiently large sample, it is conceivable that a computer program will be able to classify partial curves into ancestry groups, by predicting the missing part of the curve based on the samples in its data pool. This would allow anthropologists to speak to ancestry in cases of fires or explosions where it may be more difficult to ascertain.

One of the richest areas for future research would be on the ancestry traits of Hispanic individuals. This study indicated that palate shape of Hispanic individuals is closest to that of white individuals; however, the Hispanics in the sample were all of the

same presumed genetic background (white and Native American admixture). Further research could collect a broader sample of Hispanic individuals from various geographic regions, including those in which the Hispanic individuals are of black and Native American ancestry, to determine how these different backgrounds affect palate shape. An expansion of this research could move beyond simply the palate and look at the expression of multiple traits used in the assessment of ancestry. From there, we could begin to understand how different features express themselves in cases of admixture, and may even be able to define new features specific to the Hispanic ancestry group.

The most promising avenue of future research is in regard to palate depth. In this study only a simple depth, measured at the intersection of the transverse and median palatine sutures, could be analyzed. Results of this study indicated that ancestry differences do exist to some degree, but not for all ancestry groups. However, depth can be better assessed digitally if more data points are recorded; therefore, future studies may be able to distinguish stronger differences in this feature. Capturing the curvature of the palate in the sagittal plane would allow for an understanding not only of how depth itself varies among ancestry groups, but also how the rate of depth change varies. This information would add to the body of knowledge that already exists and enrich our understanding of skeletal ancestry differences. Additionally, further research should be conducted that eliminates sex as a possible confounding variable, therefore, allowing a better understanding of the role ancestry plays in determining palate depth.

## **Chapter 6** **Conclusions**

In conclusion, palate shape appears to be a useful indicator of ancestry from the human skull, and potentially more useful when assessed by a computer as opposed to a human practitioner. This finding may indicate that non-metric ancestry estimation as it stands now is vulnerable to a certain degree of subjectivity. Additionally, these results indicate that some environmental factor, possibly admixture, is causing secular change in the shape of the palate. As these shapes become more difficult to discern morphoscopically, the ability to discern these features more precisely with the aid of digital equipment will become more important.

The results of this study also provide insight in regard to two other sparsely explored topics in ancestry estimation: non-metric Hispanic ancestry and palate depth. Since this study focused only on the shape of the palate as it relates to ancestry, conclusions can only be drawn about this one feature. These data suggest that palate shape in Hispanics does not undergo trait blending, as one might expect in an admixed population, but rather that the white parabolic palate shape is predominant. Therefore, it appears that palate shape alone does not adequately distinguish Hispanic individuals.

Palate depth offers potentially more promising results. The data collected for this study were insufficient to fully test the differences that exist in palate depth due to ancestry. However, the analyses performed indicated that depth might be useful in determining ancestry. Differences appear to be present between the two ancestry groups with the deepest palates (Hispanic and black), and the group with one of the shallowest (white). However, further analyses must be done to more completely describe palate depth, and divorce the effects of ancestry on palate depth from those effects due to sex.

Finally, it is important to recognize that, like all features indicative of human ancestry, palate shape (or depth, for that matter) should not be used in isolation. Although patterns exist that allow ancestry to be determined from these features with some confidence, the use of multiple features is always recommended where possible, and is more reliable.



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## Vita

Christopher Maier was born in Cheverly, Maryland and grew up primarily in the city of Bowie, Maryland. An attendee of DeMatha Catholic High School, he went on to receive a Bachelor of Arts degree in Anthropology from the University of North Carolina Wilmington in 2011. While there, he completed an undergraduate thesis entitled *Cervical Vertebral Centra Epiphyseal Union as an Age Estimation Method in Teenage and Young Adult Skeletons* in partial fulfillment of the requirements for University Honors. That research was funded in part by the Paul E. Hosier Undergraduate Research Fellowship, and has been transformed into a paper, coauthored with Dr. Midori Albert, in the *Journal of Forensic Sciences* titled “Epiphyseal union of the cervical vertebral centra: Its relationship to skeletal age and maturation of the thoracic vertebral centra.” He attended Louisiana State University from 2011 until 2013 to earn a Master’s Degree for which the current paper was his thesis. While at Louisiana State University, Christopher was provided an assistantship through the FACES Lab under the direction of Ms. Mary H. Manhein.