ANCESTRAL DETERMINATION OF AFRICAN AMERICAN AND EUROPEAN AMERICAN DECIDUOUS DENTITION USING METRIC AND NON-METRIC ANALYSIS

DISSERTATION

Presented in partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By
Loren Rosemond Lease, M.A.

****

The Ohio State University

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Dissertation Committee:

Professor Paul Sciulli, Advisor

Associate Professor Jeffrey McKee

Assistant Professor Debra Guatelli-Steinberg

Approved by:

______________________________
Advisor

______________________________
Anthropology Graduate Program
ABSTRACT

This study examines the use of deciduous tooth morphology and metrics in discriminating modern European Americans and African Americans in a forensic context. To test the deciduous dentition for its use in discrimination and allocation analyses, morphological and metric data were collected from six samples representing the major ancestral groups in question, European/European-derived and African/African-derived. The analysis of morphological data describes the frequency of the morphological traits within each sample, determines the biological distance among the samples and, employs logistic discriminant analysis for allocation. The analysis of the metric data considers the descriptive statistics, univariate and multivariate normality, determines the biological distance among the six groups, and employs discriminant analysis for allocation. The findings of this study support previous investigations which have shown that significant size and morphological variation among populations can form the basis of discrimination and allocation.

A total of 785 logistic discriminant functions were created from the morphological data and examined for allocation rates. Of the 785 functions, 250 functions had an accuracy rate of 70% or greater. Of these 250, 12 were two trait
logistic discriminant, 66 were three trait crosses, and 172 functions were four trait crosses.

The metric data were used to create four different linear discriminant functions. Two of the discriminant functions have accuracy rates greater than 70%. The European/European derived and the African/African derived function had an accuracy rate of 88.5%. A discriminant function for the modern American samples had an accuracy rate of 88%.
Dedicated to my grandparents
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VITA

June 2, 1972........................................... Born- Englewood, New Jersey, USA

1994 .....................................................B.A. Anthropology, Kenyon College

1996.....................................................M.A. Anthropology, The Ohio State University

1992 - 1994 ............................................ Laboratory Assistant, Kenyon College

1994.....................................................Research Assistant, The Ohio State University

1997 - 2003................................. Graduate Teaching Associate,

The Ohio State University

2001- present................................. Visiting Instructor, Kenyon College, Gambier Ohio

PUBLICATIONS


FIELD OF STUDY

Major Field: Anthropology
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CHAPTER 1

INTRODUCTION

1.1 Goals of Present Research

The primary goal of this study is to examine the use of the deciduous dentition’s morphology and size in the discrimination between modern European Americans and African Americans in a forensic context. As discussed below, the majority of studies have been performed on the permanent dentition. These studies have been of a comparative nature. Most comparative studies center around the concept of using either the morphology or the metrics for the purpose of discrimination between groups or populations. Discrimination primarily examines the ways groups (populations) differ with respect one or more traits. But discrimination analysis also examines how well populations are separated and what characters are the most powerful discriminators (Kieser 1990). In addition to discrimination, several studies have examined the possibility of allocation of unknown individuals into population categories. Allocation classifies an unknown individual into one of a number of populations based on the measurements or dental traits derived from a predetermined set of characteristics (Kieser 1990).
In order to test the deciduous dentition for its use in both discrimination and allocation analysis, morphological and metric data were collected from six samples representing two of the major human ancestral groups, European/European-derived and African/African-derived. The morphological data were analyzed to describe the frequency of the morphological traits within each sample, to determine the biological distance among the samples, and to determine if the traits can be used to allocate an unknown individual into the proper ancestral group. The metric data were analyzed first to determine the pattern of variation (descriptive statistics), second to determine the biological distance among the six groups and, third to determine if a linear discriminant function could be created to allocate an unknown individual into the proper ancestral group.

1.2 Literature Review

The human dentition has become a primary source of information in studies of biological anthropology (Turner 1969, Kieser 1990, Dalhberg 1991, Scott and Turner 1997). Data collected from the dentition have been used to conduct studies on macroevolutionary and microevolutionary trends in morphological variants, causes of variation in normal growth and development, the genetic and the environmental influences on dental development and, models of inheritance of dental features (Kieser 1990). Examination of the microevolutionary trends within the human dentition specifically important for this study includes investigations describing the patterned geographic variations for both size and morphological variation among modern
populations (Scott and Turner 1997). There are several reasons why the dentition is a
good source of information for these studies.

The dentition, consisting of several tissues, is the most durable element of the
body. The hardness of enamel has been compared to that of mild steel (Eisenmann 1994).
The enamel of a tooth consists of 96% mineral, and 4% organic material and water
(Eisenmann 1994). The mineral content of enamel consists of crystalline calcium
phosphate knowns as hydroxyapatite (Eisemann 1994). The hydroxyapatite crystals are
densely packed between strands of the organic material which primarily consists of TRAP
(tryrosine-rich amelogenin protein) peptide sequences as well as nonamelogenin proteins
(Eisemann 1994). Due to the high mineral content the enamel can withstand not only the
mechanical forces of function, but also postmortem forces (e.g., soil pressure, water
movement). But this hardness also gives enamel its brittleness as a layer, which is
countered by the underlying layer of dentin. Due to its stability as a unit, a tooth survives
in postmortem situations more often than any other element of the skeletal system.
Consequently, the dentition makes up an significant amount of material in fossil,
archaeological, as well as, forensic situations (Kieser 1990, Larsen and Kelley 1991, Scott
and Turner 1997).

It is presumed that the dentition has a high genetic component in regard to the
determination of size, morphology and number of teeth present (Larsen and Kelly 1991).
Heritability estimates are population specific, thus, difficult to generalize for humans.
Osborne (1967) states that any heritability estimates apply only to one particular set of
genotypes in one particular environment, a different set of genotypes in the same
environment or the same set of genotypes in a different environment, may produce a
different estimate. Multiple studies have examined the genetic component of inheritance
in regard to both the size and the morphology of the teeth. A sample of the studies
conducted on the inheritance of tooth size includes, Garn and Kerewsky 1963a, Garn et
al. 1963a; 1967b, Garn et al. 1964; 1968b, Garn et al. 1966a, Goose 1967; 1971, Garn et
Similarly, there have been several studies conducted on the heritability of morphological
traits, these studies include the following, Garn et al.1963a; 1966d, Garn et al.1966e,
1971. While previous studies show that there is a degree of heritability in regards to tooth
size and morphology, the information from these studies are, at times, contradictory. In
recent years, the impact of environmental influences, both in utero and post utero,
highlight the fact that size and morphology of the dentition are not just genetically
controlled (Moller 1967, Garn et al1979b, Garn et al1980, Fearne and Brook 1993,
Heikkinen et al 1996). What can be concluded from these studies is that heritability
estimates are the result of three factors, the property of the character(s) and the
population(s) examined and the environment in which these two develop (Falconer 1967).
Therefore, a change in one or more of the factors will result in a change in the heritability
estimate. However all studies agree that in all populations studied there is a degree of
genetic variation underlying the expression of both morphological and size variants of the
human dentition.
Once a tooth completes development, it provides a permanent record of its development and the dentition’s previous evolution (Larsen and Kelley 1991). Unlike osseous tissue, the enamel does not have a plastic response to the environment. Except for attrition or destruction through caries, a tooth does not change shape after mineralization early in development. It is ideally suited, in this manner, for diachronic studies within and among populations (Turner 1969). In addition, a significant advantage in the use of the dentition over other skeletal elements, is that the dentition can be examined without using intrusive methods. A researcher can either examine the teeth in situ while in an individual’s mouth or casts can be made for later study (Larsen and Kelly 1991).

Until recently, the majority of dental anthropology studies have concentrated on the permanent dentition (e.g. Grine 1981, Haeussler et al 1989, Turner 1990, etc). There are few studies which focus on the deciduous dentition alone. When the deciduous dentition is examined, it is usually as part of a larger study (e.g. Seipel 1946, Selmer-Olson 1949, Lunt 1969, Jacobson 1982). Rarely has the deciduous dentition been examined as the primary source of information for a population. A few examples of populational studies on the deciduous dentition are Jørgensen (1956), Hanihara (1968), Sciulli (1977, 1990, 1998), Harris (2001), Harris and Lease (nd) and Grine (1986).

There are several reasons why the deciduous dentition has not been studied as intensively as the permanent dentition. A major difficulty is that the deciduous dentition is shed early in life and is less likely to survive in the archaeological record (Sciulli 1998). Juvenile skeletons (2-5 years in age) can be described as less mineralized than the
adult and the teeth have less enamel than in the adult dentition. Therefore, juvenile skeletons are more fragile leading to smaller samples surviving in the archaeological record. In comparison to the enamel of the adult dentition, the enamel of the deciduous teeth is thinner (Kramer and Ivesland 1959) and is also more porous (a greater density of microcanals) which makes it less resistant to wear (Sumikama et al. 1999). This is a problem when examining the deciduous dentition in the archaeological record but is less of a problem in modern populations due to the refined nature of the diet. Another reason may be differential treatment of the dead by different cultures. Infants and children may not be buried in the same manner or location as adult members of the society, reducing the number of juveniles that can be examined for those populations. An assumption prevalent in dental anthropology is that the deciduous dentition is conservative in nature and thus microevolutionary changes would expected to be small (Jørgensen 1956). In the examination of Ohio Valley Native American lineages, Sciulli (2001) reports that there is a relative stasis in deciduous tooth size. A fairly constant environment combined with the relatively short period an individual’s deciduous dentition is exposed to the external environment, suggests that stabilizing selection caused the relative stasis in deciduous tooth size for the Ohio Native American lineages (Sciulli 2001). However, this may not be the case in all populations. Significant changes may occur if environmental conditions which affect tooth size or morphology change in a consistent manner (Luckacs et al. 1983). Along with the assumption of conservative dentition, it has also been assumed that the deciduous dentition reflects similar size and morphological variations as the permanent dentition since the two sets of dentitions have similar genetic
components (Scott and Turner 1997). All of these factors have influenced the direction of study in regard to the deciduous dentition.

This study focuses on the metrics and morphology of the deciduous dentition in European American, African American, European, and African children. Before discussing the deciduous morphology and metrics, it is necessary to review the morphology and metrics of the permanent dentition since the majority of studies have been performed on the permanent dentition. The results of these prior studies on the permanent dentition reveal that both the metrics and morphology of the permanent dentitions have variations and patterns that are characteristic of populations located in certain geographic areas and their descendant populations (Kieser 1990, Scott and Turner 1997).

1.3 Permanent Dentition Morphology

Scott and Turner (1997) provide an overview regarding geographic variation in the permanent dentition among populations. When reviewing the most common dental traits used in population analyses, it can be seen that there are significant similarities and differences between the populations of Europe and Africa.

In general, the European morphological dental complex is characterized by trait absence rather than elaboration or mass additive features (Hanihara 1966; 1968, Mayhall and Saunders 1982). Scott and Turner (1997) state that there are three traits that are most common in European populations, the four cusped mandibular first and second molars and the presence of two rooted canines. Two other traits could be added to the complex due to high frequencies, Carabelli’s trait and three cusped maxillary second
molar, but the frequencies within European populations are almost equal to the presence in other populations around the globe. Turner and Hawkey (1998) state that Carabelli’s trait is not just a European feature. When comparing 35 European groups and 6 African groups, Turner and Hawkey (1998) found that the European and African groups demonstrated the presence of Carabelli’s trait equally (42.6% vs 52.3%, respectively). The frequency range for the Europeans was 19.8% - 78.9%, while the range was 47.9% - 58.3% in African groups (Turner and Hawkey 1998). When examining the cusp expression, the European group (n=43) had lower frequencies, from 0.0% to 36%, and a mean percent of 13.9%, in comparison to the African groups (n=5) frequencies of 11.6% - 29.9% and mean of 20.4% (Turner and Hawkey 1998). Therefore, this trait may not be an ancestral trait for the European geographic area, but rather it may be a primitive trait for humans and should be examined at the local or intraregional level.

Other traits, such as the maxillary lateral incisor interruption groove, mandibular second molar Y pattern, two rooted maxillary anterior premolar, three rooted maxillary second molar, and the single rooted mandibular second molar, have intermediate frequencies (20- 40%) within the populations of Europe (Scott and Turner 1997).

The following traits are generally at low frequencies or are not present in European populations: winging of the maxillary central incisors, shovel shaped anterior dentition, double shovel shape of the anterior dentition, canine mesial ridge, cusp 5 on the maxillary second molar, cusp 6 on the mandibular first molar, cusp 7 on the mandibular first molar, the deflecting wrinkle on the mandibular first molar, Tome’s root on mandibular premolars, and three rooted mandibular first molars (Scott and Turner 1997).
Mayhall et al. (1982) have proposed the following traits as the Caucasoid Dental Complex: absence, or at most trace expression, of shovel-shaped incisors, the maxillary central incisors are either straight or counterwinged, the absence of premolar occlusal tubercles, and low frequencies for the protostylid, cusp 6, and cusp 7 on the mandibular first molar. The Carabelli’s trait was also included in the Caucasoid Dental Complex, prior to Turner and Hawkey’s (1998) study.

The African dentition is characterized by high frequencies of mass additive traits and the retention of several generalized features (Hanihara 1998). When compared to other populations there are high frequencies of cusp 7 on the mandibular first molar, canine mesial ridge, the mandibular second molar Y pattern, two rooted maxillary anterior premolar, three rooted maxillary second molars, Tome’s root on the mandibular premolars, and a high frequency of double rooted mandibular second molars (Irish 1993;1997, Scott and Turner 1997).

In comparison to Europeans, African populations show low frequencies of three cusped maxillary second molars, and four cusped mandibular first and second molars. Similar to Europeans, Africans also have low frequencies of maxillary central incisor winging, shovel shaped anterior dentition, double shovel shape, and interruption grooves of the anterior maxillary incisors. Carabelli’s trait presence on the maxillary first molar, cusp 5 on the maxillary first molar, cusp 6 and the deflecting wrinkle on the mandibular first molar are all present at an intermediate frequency in comparison to other global populations (Scott and Turner 1997).
There have been a few studies conducted focusing on African American and European American populations. These two populations are important to study separately from their ancestral groups, as admixture among the ancestral groups in North America has influenced variation in morphology and metrics of the teeth. For this review, American does not strictly refer to individuals from the United States but has been expanded to include Canadian populations as well. The demographics of the United States and Canada are similar enough to do so (Mayhall et al 1982).

A few “interrace variable characteristic(s)” (Hanihara 1967: 923) frequencies, such as the shovel shape trait of the anterior dentition, have been examined in the African American and European American populations. Hrdlička (1920) reported that the shovel shape trait was present at 12.5% in African Americans and 8.4% in European Americans. This is consistent with the very low frequencies (0-15%) reported in both African and European populations by Scott and Turner (1997).

A trait common to Sub-Saharan African populations is the maxillary canine mesial ridge (Bushman canine). This trait frequency is reported as 12 to 35% in African populations and 4-7% in European populations (Scott and Turner 1997). Morris (1975) reported that there is a complete absence of the canine mesial ridge for European Americans.

Additional cusps (cusp 5 present on the maxillary first molar, cusp 6, and cusp 7 both found on the mandibular first molar) can also be used to compare African Americans, European Americans, and their ancestral populations. Scott (1973) reported the cusp 5 on the maxillary first molar at a frequency of 10.5% in European Americans.
This is comparable to the European frequencies of 10-25% (Scott and Turner 1997). The presence of cusp 6 on the permanent mandibular first molar is also very low for both African Americans (2%) and European Americans (0%) (Hellerman 1928). The European American frequency is in line with the 0-10% summarized in Scott and Turner but the African American frequency is much lower than the reported African frequencies of 10-20% (Scott and Turner 1997). The Y groove pattern on the mandibular molars is another trait in which there are reported frequencies for both African American, European American and their ancestral populations. Hellerman (1928) states that African Americans have a frequency of 98% for the Y groove pattern, while “Ancient” European Americans have between an 83-87% frequency. These are much higher than the summary frequencies reported for the African and European populations of 60-70% (San) and 5-20% respectively (Scott and Turner 1997). See Table 1.1 for an synopsis of the permanent dentition trait frequencies and a comparison with the deciduous dentition trait frequencies.

1.4 Permanent Dentition Metrics

African and African-derived populations are generally described as having larger tooth sizes in comparison to other population groups (Irish 1994, 1995, Hanihara 1998). In comparison, European populations are characterized by general size reduction (Harris and Rathbun 1991, Turner 1992, Hanihara 1998). When the populations from these two geographic areas and derived populations are examined, a great deal of variation can be identified within each. Several studies have been performed to examine the variation among various samples representing different populations.
Some of the earliest examinations of European populations were Selmer - Olsen (1949) of Norwegian Lapps and Seipel (1946) of Swedish children and adults. These two studies emphasize the variation among populations described as “European”. The “European” population is not a homogeneous population for genetic, dental, or other phenotypic traits. Although both the Lapps and Swedes samples are located in geographic proximity to each other in Europe and are considered “European”, the two populations are not homogeneous genetically (Crawford 1973). Thus, when examining the metrics and morphology of the “European” population, it can be seen that there is a great deal of variation with respect to both tooth size and dental morphology.

The range of variation in the dental dimensions among Europeans is seen when two European populations (the Lapps and Swedes) and European Americans are compared. When the means of mesiodistal measurements are compared for the Lapps and the Swedes, it was found that the Swedes are larger in all dimensions. The exception is the maxillary lateral incisor which has equal means for both the Lapps and the Swedes (Hanihara 1976). The same holds true when comparing the means of mesiodistal measurements between the Swedish sample and a European American sample (Hanihara 1976). The Swedish population has larger dimensions than the European Americans. This is true for all measurements when comparing the females of the two groups. When the males of the two groups are compared, the Swedes have larger dimensions for all teeth except the maxillary anterior molar where the European American males have a larger mean and the mandibular central incisors where the two samples have similar means.
Lapps, when are compared to European Americans samples, exhibit smaller teeth (Hanihara 1976). The European American males have greater mesiodistal measurements for all teeth except the maxillary lateral incisors, canine, and the molars. In the female samples, the only teeth in which the Lapps had a greater mesiodistal dimension were the maxillary lateral incisor and canine, and the mandibular anterior molars.

Lunt (1967) supports the idea that there is a great deal of variability among different populations of Europe in her examination of Mediaeval Danes. Lunt (1967) compared her Danish sample to several other samples in Europe. When comparing the Mediaeval Danes to samples from the Neolithic, Bronze, and Mediaeval time periods of Scotland, it was seen that both the Neolithic and Bronze Age Scots had larger dimensions than the Mediaeval Danes (Lunt 1967). The Mediaeval Scots had dimensions smaller or equal to those of the Danes. When the Mediaeval Dane sample was compared to other Mediaeval samples from France, Belgium, and England, it was seen that these other groups had larger dimensions (Lunt 1967). When a sample of contemporary Mediaeval Swedes from Västerhus were compared to the Danes, the Swedish sample had smaller teeth (Lunt 1967). Lunt (1967) also compared the Mediaeval Danish sample to modern European samples. All of the modern samples, especially Seipel’s Swedes (1946), had larger teeth than the Mediaeval Danes (Lunt 1967). According to Lunt (1967) this variation among Europeans is found primarily in the buccolingual dimensions but is also present in the mesiodistal dimensions.

One of the few studies which compare an African population to both European and European derived samples is Jacobson’s 1982 study of South African Blacks. In his
study, Jacobson examined ten teeth in South African black males: the maxillary and mandibular anterior teeth and the first molars. The means of the teeth examined in the study were compared to the means of the dentition for the Lapps (Selmer - Olsen 1949), Swedes (Seipel 1946), and European Americans (Moorrees 1957). Sample comparison results do not support the generalization that Africans have larger teeth than Europeans. The South African blacks had larger dimensions for the maxillary lateral incisor, mandibular canine and mandibular first molar (Jacobson 1982). The Swedish sample had the largest dimensions for the maxillary central incisor, maxillary canine, mandibular central and lateral incisors. Interestingly, the European American sample had the largest dimensions for the maxillary first molar (Jacobson 1982).

Hanihara (1976) examined the relationship between African American and European American mesiodistal dimensions. For both males and females, the African American samples had larger tooth sizes than European Americans for all teeth examined (the third molars were not studied) (Hanihara 1976). The only deviation from this was the mandibular central incisor in males in which the mean for the African American samples is greater or equal to that of the European American sample (Hanihara 1976).

Harris and Rathbun (1991) used Principal Component Analysis (PCA) to examine the differences in apportionment of tooth sizes among European and African-derived populations. They found that African and African-derived populations can be described as having disproportionately small anterior teeth and large posterior teeth relative to summed crown diameters in the mesiodistal dimensions. European and European-derived populations have larger anterior mesiodistal dimensions in comparison to the
posterior dimensions. When the buccolingual dimensions were examined, there was an opposite relationship between the anterior and posterior dimension. European populations had smaller than expected buccolingual dimensions in the anterior teeth when compared to the posterior dentition. Africans, on the other hand, have larger buccolingual dimensions than expected in the anterior dimensions.

Two studies recently examined the difference in the dimensions of the dentition for forensic application. Carrico (1997) studied the permanent dentition of European Americans and African Americans. Chiu and Donlon (2000) examined the differences between Caucasian Australians and Asian Australians.

Carrico (1997) used the permanent dentition to determine sex and ancestry of European Americans and African Americans. Using the mesiodistal and buccolingual dimensions of the entire dentition (excluding the third molars), the correct classification by ancestry ranged from 66% to 85% (Carrico 1997). The most accurate combination was of eight dimensions. Carrico (1997) found that the buccolingual dimensions of the maxillary lateral incisor, maxillary anterior premolar, maxillary molar, mandibular central incisor, mandibular anterior premolar, the mesiodistal dimension of the mandibular lateral incisor, and both the mesiodistal and buccolingual dimensions of the mandibular first molar gave the highest accuracy in the discrimination between European Americans and African Americans using the permanent dentition.

Chiu and Donlon (2000) examined the use of discriminant function analysis to separate Asian Australians and European Australians from Sydney, Australia. Using both the mesiodistal and buccolingual dimensions, they achieved a 93.9% accuracy rate
for separation (Chiu and Donlon 2000). The most apparent separations between the two samples are the mesiodistal and buccolingual dimensions of the maxillary anterior premolar and the mesiodistal measurement of the maxillary and mandibular posterior premolars. The majority of misclassifications were found to be of European Australians as Asian Australians.

1.5 Deciduous Dentition Morphology

Within the past 50 years, several reports regarding the morphology of the deciduous morphology have been produced. One of the earliest was Jørgensen’s (1956) comprehensive review of Danish children’s morphology. Szlachetko (1959) has also added to the description of the European deciduous morphology and metrics with his description of historical and modern children in Poland. The two studies which describe the traits and provided standardization for the expressions of the traits are Hanihara’s 1960 article on the criteria for the expressions of deciduous dentition morphological variants and Sciulli’s (1998) work on the evolution of Ohio Valley Native American deciduous dentition which integrates additional traits identified in other works.

Hanihara (1960, 1961, 1965, 1967) has contributed a great deal to the description of not only the deciduous morphology in general, but also of African American and European American dental morphology. While Hanihara’s work (1960, 1961, 1965, 1967) on Japanese children and the Mongoloid deciduous dentition complex are major contributions to the field of dental anthropology, the discussion will be limited to his work on regarding European Americans and African Americans. Hanihara (1963) examines the frequencies of several traits in the European American and African American
American populations. In his analysis of morphological and metric traits of South African black children, Grine (1986) states that South African morphological trait frequencies are very similar to the frequencies in African American and European American populations.

As with the permanent dentition in these two populations shovel shaped anterior dentition is not well developed or in high frequencies. European Americans generally express only a trace of the trait at a frequency of 10% and the true shovel shape trait is absent (Hanihara 1963, 1967). On the other hand, African Americans exhibit the trace expression at a 10% frequency and the true shovel shape expression at a 15% frequency (Hanihara 1963, 1967). In general for both populations, the maxillary lateral incisors are more likely to express the trait than the central incisors (Hrdlička 1920, Hanihara 1960). When Grine (1986) examined shovelling in the maxillary incisors, he found that both South African blacks and African Americans have higher frequencies than European Americans. But for the mandibular canines, all three groups have similar frequencies.

Also in the anterior dentition, Grine (1986) found that South African black children had a frequency less than 20% for maxillary canine tuberculum dentale. On the other hand, both European American and African American children have higher than 28% frequency for this trait (Grine 1986).

In the description of the deciduous posterior dentition, the use of the term “deciduous molar” reflects the historic or traditional usage in dental anthropology and the scoring procedures. Ontogenetically these teeth are premolars (Sciulli 1998). The morphology of the two maxillary molars is of particular interest for examination, as these
two teeth seem to exhibit basic differences between the populations. When the morphology of the maxillary anterior molar is compared between African Americans and European Americans, it can be seen that the European Americans have a more simplified morphology of the tooth than African Americans. The most common expression of the molar was two cusps for the European Americans (60%), while African Americans exhibited two cusp morphology only 28% of the time (Hanihara 1963). African Americans also had a higher frequency of hypocone development 36% (expressions 3 and 4 combined) versus the 16.4% (expression 3 only, 0% in expression 4) of the European Americans (Hanihara 1963). The maxillary posterior molar shows similar trends with the highest frequencies for a well developed hypocone found in the African American population. Expression 4, large hypocone, has a frequency of 90.2% in African Americans while European Americans have a frequency of 73.7% (Hanihara 1963). The expressions for three cusps or small hypocones have a frequency of 9.8% in African Americans, in contrast, the European Americans have a frequency of 26.4% for these expressions (Hanihara 1963).

Carabelli’s trait is also expressed on the maxillary posterior molar in the same range of expressions as the permanent dentition. For ease of discussion, the range of variation has been combined into three expressions: absence, pit and cusp. In deciduous teeth, European Americans have a low frequency of absence (5.4%), while the African Americans have an intermediate absence frequency of 19.6% (Hanihara 1963). The expression of a pit (shallow or deep) has similar frequencies in the two populations: 58.9% and 68.6% in the European American and African American populations.
respectively (Hanihara 1960, 1963). The European American population is more likely to have cusps as the expression of the Carabelli’s trait (35.7%) as opposed to the African Americans who express this trait at a 11.8% frequency (Hanihara 1960, 1963, 1967).

The protostylid on the mandibular posterior molar was also examined by Hanihara (1960, 1963, 1967). Although Hanihara has a reported several different frequencies of this trait in the two populations, the African American population expresses this trait at a higher frequency than the European Americans. The frequency for the deflecting wrinkle has been reported between 17% to 20% for African Americans (Hanihara 1960, 1963, 1967), while the European population expressed the trait at frequencies between 11% and 13% (Hanihara 1960, 1963, 1967). Jørgensen (1956) reported that the frequency of the protostylid was extremely low in the Danish population he examined. Hanihara (1960) suspected that this is the result of Jørgensen having different criteria for scoring the trait. Hanihara (1960) believed if his scoring criteria were used to re-examine the Danish sample, the frequency of the would be similar to the European American population one. The same problem occurs when Grine compares the deflecting wrinkle frequency in the South African population to other populations. If only the “true” deflecting wrinkle frequency is reported, then there is only a 8% frequency, a much lower frequency than the African American frequency or frequencies in the permanent dentition. Grine (1986) defined a “true” deflecting wrinkle as a metaconid ridge which takes a sharp turn distally. If the milder expressions of the deflecting wrinkle are included, the frequency of the trait increases to 84.6%, much higher than the African American or European American frequencies (Grine 1986). The mild expression but not a “true” deflecting wrinkle,
according to Grine (1986), is a strongly developed metaconid crest without the distal turn.

The frequency for cusp 6 on the mandibular posterior molar in the South African blacks and African Americans is very similar. Both are approximately 18% (Hanihara 1966, 1976, Grine 1986). The frequency for European Americans is much lower at 7.3% (Hanihara 1966, Grine 1986).

Interestingly, in comparison to the permanent dentition, the deciduous dentition is more likely to express cusp 7 on the mandibular posterior molar. Also of note, is the fact that the cusp 7 frequencies are very similar between African Americans and European Americans. In comparison to the 0-10% reported for the permanent dentition in European populations (Scott and Turner 1997), European American children have at 41.8% frequency for the trait (Hanihara 1967). Cusp 7's frequency in the African American population is similar to that of the frequencies of the permanent African dentition. Scott and Turner (1997) report that cusp 7 is expressed at a rate between 25-40% in the African dentition. African American deciduous dentition expressed the trait at an 46.8% frequency (Hanihara 1967). Grine (1986) found that the frequencies for cusp 7 in South African blacks was very similar to African American frequencies.
<table>
<thead>
<tr>
<th>Incidence</th>
<th>u1 uc</th>
<th>uc tuberculum</th>
<th>uc mesial</th>
<th>m1 hypocone</th>
<th>m2 hypocone</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% Absent</td>
<td>A AA E EA</td>
<td>A AA E EA</td>
<td>A AA E EA</td>
<td>A AA E EA</td>
<td>A AA E EA</td>
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<tr>
<td>0.1-4.99% Unusual</td>
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<td>5-9.99% Rarg</td>
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<tr>
<td>10-24.9% Low</td>
<td>P1 D2 P1</td>
<td>D7</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>25-49.9% Intermediate</td>
<td>D7</td>
<td>D7</td>
<td>P1</td>
<td>D3</td>
<td></td>
</tr>
<tr>
<td>50-74.9% Common</td>
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<tr>
<td>75-84.9% Frequent</td>
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<tr>
<td>85-94.9% Prevalent</td>
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<tr>
<td>95-99.9% Characteristic</td>
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<tr>
<td>100% Fixed</td>
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A- African populations
AA- African American populations
E- European populations
EA - European American populations


Table 1.1 Trait Frequencies in the Permanent and Deciduous dentition - continued
Table 1.1 continued

<table>
<thead>
<tr>
<th>Incidence</th>
<th>m2 Carabelli’s cusp</th>
<th>m2 c6</th>
<th>m2 c7</th>
<th>m2 Y-groove</th>
<th>m2 deflecting wrinkle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% Absent</td>
<td>A AA E EA</td>
<td></td>
<td></td>
<td>A AA E EA</td>
<td>A AA E EA</td>
</tr>
<tr>
<td>0.1-4.99% Unusual</td>
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<td>D5</td>
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<td></td>
<td></td>
<td>P1</td>
<td>D7</td>
</tr>
<tr>
<td>10-24.9% Low</td>
<td>P6 D2 P6</td>
<td></td>
<td></td>
<td></td>
<td>D3 D2</td>
</tr>
<tr>
<td>25-49.9% Intermediate</td>
<td>D2</td>
<td></td>
<td></td>
<td>D7/P1 D2</td>
<td>D7/P1 D2 D2</td>
</tr>
<tr>
<td>50-74.9% Common</td>
<td></td>
<td></td>
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<td></td>
<td>P1 D7</td>
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<tr>
<td>75-84.9% Frequent</td>
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<td>D7</td>
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<tr>
<td>85-94.9% Prevalent</td>
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<tr>
<td>95-99.9% Characteristic</td>
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<tr>
<td>100% Fixed</td>
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</tbody>
</table>

A- African populations
AA- African American populations
E- European populations
EA - European American populations

Grine (1986) found that the most common groove pattern on the mandibular posterior molar was the Y pattern (89.7%), with the + pattern the next most common. Szlachetko (1959) reports a 57.1% frequency for the trait in the Polish Whites.

Table 1.1 presents a synopsis of the deciduous dental trait frequencies discussed above and a comparison with the permanent dental trait frequencies.

1.6 Deciduous Dentition Metrics

Although there are differences among populations in regard to the size of the deciduous dentition, some similarities are found in all populations. Gantt et al. (2001) found a similar pattern in the mesiodistal dimensions of the molars for both African Americans and European Americans. In both populations, the mandibular posterior molar had the largest dimension, the maxillary posterior molar has the next largest dimension, then the mandibular first molar, and finally, the maxillary anterior molar has the smallest dimension. This is consistent with the literature (e.g. Seipel 1946, Moorrees 1957). The buccolingual dimensions show a different relationship with the maxillary posterior molar and the mandibular posterior molar having the largest measurements, followed by the maxillary and mandibular anterior molars. Jørgensen (1956) states the mandibular molars are narrower due to the mesial lateral compression of the buccal and lingual cusps.

In regard to the size relationships among the total dentition, the deciduous dentition displays relationships similar to the permanent dentition. Harris (2001) states that in an examination of a world wide survey of the mesiodistal dimensions of deciduous teeth Europeans have smaller teeth in general but have relatively larger anterior
dimensions. This is similar to the finding relating the sizes of the permanent teeth. Using PCA, once again the Europeans are the only samples to have a generally small tooth size but the anterior dimensions are larger than expected and the posterior dimensions are smaller than expected. African and Asian samples demonstrate an intermediate tooth size between the small toothed Europeans and the megadont Australian Aborigines (Harris 2001). While the African and Asian samples have an intermediate overall tooth size, they have larger than expected molar mesiodistal dimensions. Harris and Lease (nd) expanded the number of population samples examined and found that Europeans consistently displayed the smallest teeth in general, but no consistent patterning in size. In other words, some samples are extremely small (e.g. Cleveland European Americans) and others are much larger (e.g. Swedes). Moorrees (1957) supports this result with his comparison of European Americans from Ohio to Seipal’s (1946) Swedish sample. Moorrees (1957) found that for all deciduous teeth, except the maxillary posterior molar, the European Americans had smaller means than the Swedish sample. For both sexes, the differences between the means per tooth were statistically significant, except for the maxillary central incisor and both posterior molars (Moorrees 1957).

As with the permanent dentition, Africans and African-derived populations have disproportionately large mesiodistal dimensions of the molars (Harris and Lease nd). This world wide survey of mesial-distal dimensions is supported in the literature by other studies comparing Europeans and Africans in regards to molar size (Moss and Chase 1966, Hanihara 1976, Harris 2001, Harris and Rathbun 1991).
The relationship of larger anterior mesiodistal dimensions in European Americans in comparison to African Americans was discussed by Hanihara (1976) as well. For males, the European Americans had larger anterior mesiodistal means in comparison to the African Americans but smaller posterior dimensions. Interestingly, for the females the European American sample had larger means than the African American sample for all teeth except the lateral incisors and maxillary anterior molar (Hanihara 1976). In comparison to the Swedish sample (Seipal 1946), the Swedes had larger mesiodistal dimensions for the anterior teeth in comparison to both the African American and European American samples. The African American samples had the largest means for the posterior dentition in comparison to the European and European-derived samples (Hanihara 1976). Again, the females exhibit a different relationship than the males. The Swedish sample has the largest dimensions for the maxillary central incisor, canine and posterior molar, and the mandibular anterior teeth and the anterior molar. The African American sample has the largest dimension for maxillary anterior molar and the mandibular posterior molar. All three samples have equal means for the maxillary laterally incisor (Hanihara 1976).

Lavelle (1970) compared a sample of British Caucasian children to Black West African children and found that the African children had larger dimensions for both the mesiodistal and buccolingual dimensions. The exceptions were the buccolingual dimension of the mandibular canine in which the two samples had almost equal means and, the mandibular posterior molar buccolingual dimension where the European sample
was larger than the African sample. With the buccolinguall dimension of the mandibular central incisor the European males were the largest, then the African samples and, finally, the European females. The maxillary anterior molar buccolinguinal dimension also displayed a difference between the sexes. The African females had the largest dimension, then the European sample, and finally, the black males with the smallest dimension. When examining the dentition as a whole, the Africans are approximately 9.4% larger than the European sample, with a 10.5% difference between the two samples in the anterior dentition and 7.9% difference in the posterior dentition (Lavelle 1970).

Moss and Chase (1966) compared the means of the 21 Liberian black African children to published means of several other populations. (These Liberian children are the same children used in the present study. See Materials and Methods). When compared to European American children studied by Sillman (1964), the African children had larger means for all dimensions except the mesiodistal measurement of the maxillary canine, mandibular lateral incisor, and mandibular canine. In comparison to the European American children studied by Moorrees (1959), the only measurement which the Liberian children had a smaller mean was the mesiodistal length of the mandibular canine. When comparing the Liberian children means to Polish, Belgian, and European American samples studied by Szlecheko (1959), Mydlarz (1964), and Black (1902) respectively, again the African children generally had larger dimensions. The exception in the Polish/African comparison is the mesiodistal measurement of the maxillary canine (Moss and Chase 1966). There are five measurements in the Belgian/African comparison in which the Africans have smaller means. These measurements are the buccolinguial
measurement of the maxillary central and lateral incisors, mandibular lateral incisor and mandibular canine, and the mesiodistal diameter of the mandibular canine (Moss and Chase 1966). Three measurements were larger in the American Europeans in comparison to the African sample. These measurements are the buccolingual measurements of the maxillary lateral incisor, anterior molar and posterior molar (Moss and Chase 1966).

Some variation both within and between populations may also be the result of different amounts of sexual dimorphism in the populations. Seipel (1946) examined sex differences based on measurement means of both the deciduous and permanent dentition of a Swedish sample. He found that there was a 1.4% difference between the sexes in the deciduous dentition, but a 3.7% difference in the permanent dentition (Seipel 1946). The only tooth in the deciduous dentition to be significantly different was the canine (1.2-2%) (Seipel 1946). On the other hand, all of the teeth of the permanent dentition were significantly different (2.6 - 6.5%), although the mandibular central incisor had the least amount of difference and the maxillary canines the most.

Black (1978) examined the sexual dimorphism in the deciduous dentition of European Americans and found the percentage to be very low (approximately 2%). Only five of 20 measurements were found to be significantly different between the sexes, the greatest the mesiodistal dimension of the mandibular anterior molar (3.15%) (Black 1978). Moss and Chase (1966) also compared the sexual dimorphism found for each measurement of the two European American samples studied by Sillman (1964) and Moorrees (1959). In the sample Moorrees (1959) studied, the males have the larger
means for all the mesiodistal measurements. Six measurements were statistically significantly different at the 0.05 level. Males were significantly larger for the mesiodistal measurements of the maxillary canines, anterior and posterior molars, and the mandibular canine (Moss and Chase 1966). The other two measurements were significant at the 0.01 level, the mesiodistal measurements of the mandibular anterior and posterior molars (Moss and Chase 1966). The Sillman (1964) sample did not show the same pattern though. In this sample, the females had the larger means for all of the mesiodistal measurements, with the exception of the maxillary central incisor and the maxillary anterior molar. None of the means were significantly different between the sexes (Moss and Chase 1966).

In contrast, De Vito and Saunders (1990) found the sexual dimorphism within a European Canadian sample to be within the range of permanent dentition. In their sample, all 40 measurements (20 buccolingual and 20 mesiodistal) of the deciduous teeth were significantly different between the sexes (DeVito and Saunders 1990). Using three to five measurements, discriminant functions were created which achieved between 76-90% accuracy rates (DeVito and Saunders 1990). The five measurements which resulted in the highest accuracy were the buccolingual dimensions of the right maxillary lateral incisor, the right maxillary central incisor, the left maxillary posterior molar, the left maxillary canine, and the mesiodistal dimension of the right mandibular canine (DeVito and Saunders 1990).

Previous studies have shown that there is a great deal of variation present in both the morphology and size of the permanent dentition. From the results of the few studies
focusing on the deciduous dentition, the deciduous dentition seems to display a similar range of morphological and size variation. The present study’s goal is to examine the utility of both the morphological traits and the measurements of the deciduous dentition as a means for discrimination between European Americans and African Americans. Until now these data were lacking and there has been limited comparison of European American and African American differences in deciduous teeth in modern North American children. The second purpose of the study is to ascertain the accuracy of using these data as a basis of allocation of children.
CHAPTER 2

MATERIALS AND METHODS

2.1 The Samples

2.2 Sample Sizes

Metric data were collected from a total of 515 individuals from six samples representing three ancestral groups: European, African, and (East) Indian. European-American children are represented by 100 individuals collected from Cleveland, Ohio. African American children are represented by 110 individuals from Memphis, Tennessee and 101 individuals from Dallas, Texas. Europeans are represented by 86 individuals from London, England. West Africans are represented by 18 individuals and 100 individuals represent India (Lukacs et al. 1983, Lukacs personal communication).

Non-metric morphological data were collected from 422 individuals; there are no non-metric data for the individuals in the India sample and 117 individuals were scored in the Memphis sample.

Data were collected from three sources: dental casts, actual dentitions, and photographs. Metric data were collected from dental casts and actual dentitions, while morphological data were collected from all sources. Dental casts were included in this study if they met the following criteria: morphological features were clearly visible, there
were clear separations between teeth, and at least one member of the antimere was present. Casts were excluded if there was chipping of the casting material, dental wear, or stretching of the casts after removal from the mouth. Actual teeth (dentitions) were excluded if there was wear obscuring the morphological traits, caries destroyed part of the tooth, or there were less than fifteen teeth present. Finally, photographs were used if the morphology was clearly visible and if there were no caries present on the occlusal surface.

The viability of using these three sources was tested by Edgar (2002). While, fewer morphological traits are visible from photographs in comparison to actual dentitions, the difference was no greater than observing the same dentitions twice (Edgar 2002). Previous studies have shown that there is minimal difference between observations are made from dental casts and the actual dentition (PW Sciulli, personal communication 2003).

2.3 European American and European Samples

The sample representing modern European-Americans was collected at the School of Dentistry, Case Western Reserve University from the Bolton-Brush Longitudinal Growth Study. Ancestry was based on parental determination. Both metric and morphological data were collected from one hundred casts (50 male and 50 female), randomly chosen from the Bolton - Brush Collection (N = 4309) (Bailey 1992).

Subjects of the study were born between 1920 and 1945 in Cuyahoga County, Ohio. The subjects of the Bolton - Brush Collection resided in the urban areas of Cleveland, Ohio. Those who took part in the study were specifically chosen to study the
“growth of normal, healthy children” (B. Holly Broadbent, personal communication 1999, 2003) and were described as having access to good health care, education and nutrition (Bailey 1992:3).

The European sample consists of 86 individuals from five different time periods in England. These collections are housed at the British Natural History Museum, London, England. Thirty individuals are from Poundbury Camp, Dorchester (Dorset) excavated during the 1970s (Green 1987). The cemetery spans from the Neolithic to late Middle Ages (Farwell and Molleson 1993). A total of 1200 skeletons were excavated from 1400 identifiable graves (Green 1987, Farwell and Molleson 1993). The Late Roman Era, 3rd century - 4th century, was the best represented time period. In general, the individuals (including the children) can be described as undersized and in fair health (Molleson 1989, Molleson 1992a, Molleson 1992b, Farwell and Molleson 1993). Farwell and Molleson (1993) use the presence of *cribra orbitalia* in 41% of the total children as an indicator of health.

A total of 16 individuals (eight from the 12th century and eight from the 16th century) is from Abingdon Cemetery located, at the time, in a rural hamlet of Oxfordshire. Health of the individuals cannot be ascertained due to the small sample size.

A total of 30 individuals represent the 215 juveniles excavated from vaults of Christ Church, Spitalfields located in East London. In the first half of the 18th century, Spitalfields was a small hamlet which increased in size by the second half of the century to 20,000 individuals (Molleson and Cox 1993). The inhabitants of Spitalfields can be described as upper lower class to professional (Walker 1982). The vaults were family
vaults located in the crypt below the floor of the church (Reeve and Adams 1993). Only two of the three vaults were excavated. The vaults were in active use from 1729 to 1859 (Cox 1996). The individuals are termed the “named sample” because of coffin plates associated with the burials. A total of 1042 of the 1062 (98.12%) of the skeletons were identifiable as individuals. Of the 1042 individuals, 215 were juveniles under the age of 16 and only 36 of the individuals are between the ages of 1 and 5 (Molleson and Cox 1993). In general, the children can be said to be in good health (Molleson and Cox 1993) The adolescent males tend have reduced stature (Floud and Wachter 1982) but do not have linear enamel hypoplasia (LEH) an indicator of severe stress (Molleson and Cox 1993). In regard to other pathologies, cribra orbitalia is common but not sever, only four children have cribra parietalia, and 20 juvenile skeletons show active cases of rickets at the time of death (Molleson and Cox 1993, Cox 1996).

The final ten individuals were born during 1970's -1980's and were children of Museum employees (Robert Kruszynski, personal communication, 1999). In general, these ten individuals represent the urban, upper middle class, modern English population. The sex of the individuals is known only for the modern English samples (five males and five females) and therefore all were pooled into an unknown sex category. Both metric and non-metric data in the European sample were collected from actual dentitions. Due to the small samples size in the English collections, a Monte Carlo statistical comparison was employed and it was concluded that the samples from the five time periods could be pooled (See Results).
2.4 African American and African Samples

The modern African American sample was collected from children who were routine dental patients of the Pediatric Dentistry Department at the University of Tennessee, Memphis during the 1990s (Lease and Harris 2001). The children’s economic background is described as middle class. The children primarily came from the “greater metropolitan area of Memphis” which includes the urban and suburban areas of Memphis. Some of the members of the study resided in the surrounding states: Arkansas, Mississippi, Kentucky, and Missouri. In addition, these children had access to health care at the University of Tennessee Medical Center (EF Harris, personal communication 2003). Ancestry was based on parental determination. Casts were made of dental stone. A total of 110 individuals were studied for metric analysis and 117 were examined for non-metric analysis. Fifty-four females and 56 males comprised the sample size for the metric analysis. Fifty-seven females and 60 males comprised the sample size for the morphological data.

The second sample of African American children (N=101) was from the Freedman’s Cemetery of Dallas, Texas. Individuals buried at the Freedman’s Cemetery resided in the urban areas of Dallas, but some may have been recent arrivals from more rural areas. All economic classes open to African Americans at the time are represented, i.e. paupers to professionals. Some of the adult individuals buried in the earlier graves may have spent time in slavery. The cemetery was active from 1867 to 1907, with the majority of the excavated burials dating from 1900-1907 (Condon et al. 1998). Therefore, the juveniles of the sample did not spend time in slavery (HJH Edgar, personal
communication, 2003). The sex of the individuals is not known. The metric data was kindly provided by Keith Condon. The morphological data was observed from 5"x7" photographs taken in professional laboratory setting (Condon et. al 1998). The metric and morphological data are from the same 101 individuals. The remains have been reinterred.

The West African sample (N=18) consists of dental casts collected in pediatric wards of the Firestone Medical Center, Liberia in 1963 (Moss and Chase 1966). The parents of the children were employees of the Firestone Rubber Company (Moss and Chase 1966). Tribal affiliations and sex designations were not available. Moss had possession of the dental casts and the School of Dentistry, Columbia University in New York City until 1999 when he transferred possession to the Department of Anthropology at The Ohio State University, Columbus, Ohio. Both metric and morphological data were collected from the 18 individuals.

2.5 India Sample

The Indian sample consists of 100 (50 males and 50 females) modern Ahmedabad, Gujarati Hindu children. Stone plaster dental casts were made of children, with normal occlusion, between the ages of three and six and half years (Lukacs et al. 1983). The left side of the dental arcade was measured according to the method of Moorrees (Moorrees 1957) using a vernier caliper (Lukacs et al.1983). Each measurement was rounded to the nearest 0.1 mm and is an average of three repeated measurements (Lukacs et al 1983; Lukacs, personal communication). John Lukacs kindly made these metric data available.
2.6 Test Samples

Additional samples were obtained to test both the logistic regression analysis of the nonmetric data and the discriminant functions produced from the mesial distal metric analysis (See Results). All test samples are dental casts. Metric and non-metric data were collected from an additional fifteen European American children (eight males and seven females) at the Bolton Brush Collection and fifteen children, of unknown sex, were randomly sampled from the Gullah Collection housed at The Ohio State University, Columbus Ohio, donated by Renee Menegaz-Bock. The casts of the Gullah people, an African American population located on the Outer Banks, South Carolina, were collected in the 1950s as part of a study examining the ancestry and biology of the population. This population is characterized by limited admixture with other populations (races) (Menegaz-Bock 1968).

2.7 Morphological Traits

The morphological data consist of the scores of 25 traits and were collected from all samples excluding the sample from India. The traits and their descriptions are listed in Appendix A. These traits represent the most commonly used traits in population microevolution studies and have been used to create Dental Morphology Complexes, describing various ancestral groups (Jorgenson 1953, Hanihara 1963, Hanihara 1966, Irish 1993, Scott 1980, Grine 1986, Turner 1990, Turner et al. 1991, Turner and Hawkey 1995, Irish and Morris 1996, Sciulli 1997; 1998 ).

Morphological (non-metric) data were collected from 417 individuals following Sciulli (1998). Both the right and left teeth of each individual were scored if present. If
the expression of the feature was the same for each tooth, that score was used as the expression for that tooth. If the expression of a trait for the antimere was different, the more complex expression was used. When only one tooth of a pair was present, that score was used to represent the individual. All frequencies are based on counts per individual.

Unlike other population studies done (e.g. Sciulli 1998, Turner 1981), root traits were not collected here as casts (Bolton Brush, Memphis and West Africa) and photographs (Freedman) were the principal sources of information.

In the description of the morphological traits, the use of the term “deciduous molar” reflects the historic or traditional usage in dental anthropology and the scoring procedures. Ontogenetically these teeth are premolars (Sciulli 1998).

2.8 Metric Traits

The measurements for all samples were obtained to the nearest 0.01 mm with a Mitutoyo digital caliper. Metric data from the Freedman’s sample were collected by Keith Condon (Condon et al. 1998) and the India sample data was collected by John Lukacs (Lukacs et al 1983; Lukacs personal communication). All measurements in the remaining samples were collected by the author and downloaded directly into SAS v8 (2000). A total of 30 measurements was taken of the dental arcade by the author. The mesial distal measurement (MD) was taken with the calipers held in the occlusal plane. Each measurement was taken at the contact point between two teeth, resulting in a measurement near the occlusal surface on the incisors and molars but closer to mid-tooth on the canines. Care was taken to replicate the placement of the calipers on both the casts
and real teeth. The buccolingual measurement (BL) was taken parallel to the MD measurement. Each deciduous molar was measured for an anterior buccolingual (ABL) measurement and a posterior buccolingual measurement (PBL). These measurements were taken at the widest points of the anterior and posterior halves of the molar. In addition to the standard measurements, six chords (c1 - 6) of the occlusal surface were also recorded. The chord measurements were taken in order to examine differences in cusp sizes among the samples. Later analyses showed that there is little variation among the samples for these measurements. The chord data are discussed, briefly, for the univariate and multivariate analyses but is not included in later analyses.

Chord 1 was measured with one point of the caliper on the terminal edge of the central groove on the mesial occusal edge and the other point the occlusal surface of the buccal groove between the eoconid and the hypoconid. C2 represent the measurement between the buccal groove and the groove between the hypoconid and hypoconulid. C3 is the chord measurement from the C2's ending point and the terminal edge of the central groove on the distal occlusal surface (between the hypoconulid and the entoconid). C4 begins at the terminal edge of the central groove on the distal occlusal surface and ends at the beginning of the lingual groove on the occlusal surface, between the entoconid and the metaconid. Chord 5 measured the distance between the ending point of C4 and the terminal edge of the central groove on the mesial occusal edge. The final chord (C6) was taken with one point of the calipers on the terminal edge of the buccal groove on the occlusal surface and the other point on the terminal edge of the lingual groove on the occlusal surface.
Both the right and left sides of the dentition were measured. The measurements were then averaged and this represents the measurement of that tooth for an individual. If one member of the pair was missing, the other measurement was used to represent the individual. Therefore, all counts (N) represent individuals, not teeth. The measurements taken, and their abbreviations, are listed in Appendix B.

2.9 Intra-observer tests

Twenty-five individuals, 15 from the Bolton Brush and 10 from the Memphis samples, were re-examined to test the intra-observer error for the metric and morphological data.

The intra-observer tests were performed on the mesiodistal and buccolingual dimensions of twelve teeth. The twelve teeth were the right and left antimeres of the maxillary central incisors, maxillary canines, maxillary anterior molars, mandibular lateral incisors, mandibular anterior molars, and the mandibular posterior molars.

Intra-observer error for the metric data was calculated by computing the absolute difference between repeated measurements. The absolute difference (d) for each measurement was calculated by using the following formula: $|M_1-M_2| = d$. The means were then calculated for the total sample (25) for that measurement. The total absolute difference was calculated by summing the previously calculated absolute differences and dividing by the total number of variables examined: $(\sum d/25)$.

The author’s mean absolute difference for this study was 0.18 mm for the 24 measurements examined. The absolute difference for all of the measurements ranged
from 0.11 mm (mesiodistal dimension of the right maxillary central incisor) to 0.30 mm (mesiodistal dimension of the mandibular posterior molars).

The intra-observer test for the morphological data was calculated in a similar manner. The test was performed on nine morphological traits: the shovel shape trait of the maxillary lateral incisor, the maxillary canine tuberculum dentale, the maxillary anterior molar morphology, Carabelli’s trait on the maxillary posterior molar, the groove pattern on the mandibular posterior molar, the deflecting wrinkle on the mandibular posterior molar, the protostylid on the mandibular posterior molar, and the development of cusp 6 and the mesial trigonid crest on the mandibular posterior molar. The expressions for each trait was re-scored for both antimeres.

The absolute difference means for each trait were calculated in the same manner as for the metric data. The mean absolute difference was calculated by summing the differences for each trait and then divided by 18. The author’s mean absolute difference between the original sample and re-scored sample was 0.03. The range of absolute differences was 0.0 (12 teeth) and 0.17 for the groove pattern of the left mandibular posterior molar. For this trait, there are three possible expressions and for one individual, the author scored the individual a different pattern than originally determined. 2.10

**Statistical Analysis**

Statistical analyses were done to test the primary hypothesis that deciduous teeth can be used to discriminate between European American and African American children. The analyses of both the morphological traits and the measurements were performed, first, to describe the deciduous dental morphology and size variation of modern European
American and African Americans in the United States. Until now these data were lacking and there has been limited comparisons of European American and African American differences in deciduous teeth in modern North American children. The second purpose of the analyses was to ascertain the accuracy of using these data as a basis of allocation of children to European American or African American (sub)populations. Unlike skeletons of adults, there are very few agreed upon methods for estimating the ancestry of subadult skeletons. Deciduous dental metrics and morphology may provide the data needed for ancestry determination. Therefore, both types of data were analyzed to determine the biological distance among the samples and to allocate a deciduous dentition with respect to a group with which it shares recent ancestry.

### 2.11 Morphological Statistical Analysis

The statistical analysis of the morphological data was performed in SAS version 8.02. A total of 25 morphological traits were observed for each sample. Morphological data were collected by the author on five samples: Bolton Brush, Memphis, Freedman, and West Africa. The sample from India was not included in the morphological analysis.

Prior to biological distance and ancestral group classification analyses, several preliminary analyses were performed. First was the calculation of the expression frequencies, in order to examine the total variation within the samples. The weighted average expression, $W$, was then calculated for each feature: $W = \left(\frac{\sum c_i x_i}{\sum x_i}\right)$, where $C_i$ is the expression value and $x_i$ is the number of individuals with that expression. The weighted average is one method that captures where in the range of variation the sample
lies. The range of expression of traits and weighted average for each sample can be found in Appendix C.

The next analysis was the calculation of the dichotomized frequencies of the morphological traits (absence and presence). Dichotomization should, in theory, reflect the weighted average for each trait. For example, the morphological trait of shovel shape for the maxillary central incisor has four expressions: 0, 1, 2, 3. The weighted average for this trait in the Bolton Brush sample is 1.15.

\[ W= \left( \frac{\sum c_i x_i}{\sum x_i} \right) = \frac{(0*28)+(1*40)+(2*21)+(3*11)}{100} = 1.15. \]

Therefore, the division between absence and presence (dichotomization) should be between the expression class 1 and expression class 2.

Separation into presence and absence frequencies was also necessary for performing biological distance analysis (mean measure of divergence). The presence-absence frequency of a trait was calculated as in the following example using the shovel shape of the deciduous maxillary central incisor:

**Shovel shape :** ul1

0 Absent: lingual surface smooth
1 Semishovel: slight
2 Shovel: marginal ridges present
3 Strong shovel: marginal ridges broad and wide

Expressions 0 and 1 were designated as the absence of the shovel shape trait and expressions 2 and 3 were designated as the presence of the trait in the individuals. The frequency of the trait (presence) in the population can then be expressed at \( p = \frac{2-3}{0-3} \), with 2-3 as the number of individuals having the expression 2 or 3 and 0 to 3 the total
number of individuals scored (Sciulli 1998). All other traits will follow similar
procedures which are presented in Appendix A along with descriptions of the breakpoint
criteria and thus the threshold at which a trait was determined to be present.

C.A.B. Smith’s Mean Measure of Divergence (MMD), a biodistance statistic
using morphological data, examines the degree of phenetic similarity or dissimilarity
between populations (Irish 1997). It is only appropriate when traits have frequencies
between 5% and 95% within a sample as this the range within which the arcsin
transformation is valid (de Souza and Houghton 1977). The use of the MMD statistic
also assumes uncorrelated traits. When the traits are independant, the variance of the
total mean of divergence is the sum of variances of the individual means of divergence
(de Souza and Houghton 1997). The MMD of was calculated using the following
formula:

$$\sum_{i=1}^{C} \left[ (\Theta_{ui} - \Theta_{zi})^2 - \left[ 1 / \left( n_{ui} + \frac{1}{2} \right) + 1 / \left( n_{zi} + \frac{1}{2} \right) \right] / C \right]$$

where $\Theta = \sin^{-1} \left( \sqrt{r/n + 1} \right) + \sin^{-1} \left( \sqrt{r+1/n+1} \right)$

$C$ is the number of traits examined

$r$ is the number of occurrences of ‘present’

$n$ is the sample size for each sample

(Freedman and Tukey 1950, de Souza and Houghton 1977)
In other words, MMD examines the square of the difference in frequency minus the variation of the traits in the samples.

Logistic discrimination was performed on the morphological data. Logistic discrimination is method of creating the probabilities of class membership (parameters) and a discriminant function which allocates unknown individuals (Everitt and Dunn 1991). The logistic discriminant functions were created using the total range of expressions of each morphological trait.

The probabilities of class membership parameters for any sample \((D_1)\) were calculated using the following formula:

\[
P(D_1|x) = \frac{\exp(\alpha_0 + x)}{1 + \exp(\alpha_0 + \sum_{i=1}^{p} \alpha x_i)}
\]

While the probability of class membership parameters for a comparative sample \((D_2)\) can be calculated as:

\[
P(D_2|x) = \frac{1}{1 + \exp(\alpha_0 + \sum_{i=1}^{p} \alpha x_i)}
\]

Where

\[
\alpha_0 = \text{constant for the logistic discriminant function}
\]

\[
\sum_{i=1}^{p} \alpha x_i = \text{summed trait expressions multiplied by the coefficient for the trait}
\]
The allocation method is calculated by the following formula:

\[ \hat{\alpha}_0 + \sum_{i=1}^{p} \hat{\alpha}_i x_i \]

(Everitt and Dunn 1991)

Where

\[ \hat{\alpha}_0 \] = is the constant of the discriminant function

If the score of the allocation procedure is positive the individual is allocated to D1

(P(D1) > P(D2)) (Everett and Dunn 1991).

2.12 Metric Analysis

Univariate descriptive statistics were collected for each sample separately, and when possible, by sex. The descriptive statistics for each measurement consisted of the total number of individuals (N) in each sample, the mean, the standard deviation, and the 95% lower and upper confidence intervals of the means. In addition, measures of skewness, kurtosis, and an omnibus test for normality were collected. These statistics were obtained to provide a description of the samples, and to identify outliers, asymmetry of distribution, or data point extremes which may have affected normality.

Before multivariate analyses could be performed, normality and equality of the variance - covariance matrices had to be determined. Multivariate analyses used here rest on the assumption that the samples are both normal and have equal variance-covariance matrices.
Multivariate normality testing consisted of the graphical method developed by du Toit (1986). The graphs are plots of the Mahalanobis distance of the data points from the mean raised to the 1/3 power against the probability levels of a chi square distribution (DF= number of degrees of freedom) (NCSS 1999). If the data points for a sample have a multivariate normal distribution, the points should fall along a straight line. Outliers can be identified by placement outside of the 95% confidence interval (CI) lines. The CI lines will also indicate a lack of symmetry of the data or if there are either long or short distribution tails (NCSS 1999).

Homogeneity of covariance matrices was examined using Box’s M test on the log transformed data for the six samples. For a proper linear discriminant function to be calculated, the samples must be multivariate normal and have equal variance-covariance matrices. If these assumptions hold, the only way the samples differ is the means of the measurements.

Principal Component Analysis (PCA) was performed in NCSS on the pooled MD data, BL data for each sample, and the combined MD/BL data for four samples (European-American, Memphis and Freedman African American, and India). PCA summarizes the total variation of a sample and allows the characterization of the interrelationships of measurements within the samples. PCA transforms possibly correlated variables into uncorrelated data (principal components). PCA analysis often reveals relationships not previously observed, allowing for a new interpretation of the data. The ultimate goal of the present PCA analysis was to determine if there were similar isometric or allometric relationship among the teeth of the different samples.
Several studies for the growth rates of the dentition (e.g. Stack 1967) have shown that various dimensions grow faster in comparison to other dimensions (anterior vs. posterior) in different populations. Therefore, if there are significant differences between the isometric or allometric results, PCA could be used as another measure of distance to explain similarities or dissimilarities among the samples.

The hypothesis of an isometric relationship among the teeth, using the first observed eigenvector, was tested using Anderson’s test (1961). If the sample failed the isometric test, an allometric test was then performed to determine the growth relationship among the teeth. Anderson’s test is as follows:

\[
n (\lambda_1 V_1 S^{-1} V_1' + 1/\lambda_1 V_1 S V_1' - 2)
\]

where

- \( S^{-1} \) is the inverse of the sample covariance matrix;
- \( n \) is the number of degrees of freedom associated with \( S \);
- \( \lambda_1 \) is the eigenvalue associated with the observed eigenvector;
- \( V_1 \) is the hypothetical row vector of direction cosines of the major axis;
- \( V_1' \) is the column vector obtained by transposing \( V_1 \).

(Jolicoeur 1963)

A hypothetical isometric eigenvector is calculated as \( 1/\sqrt{p} \) for the isometry tests (\( p = \) numbers of variables). Therefore, all elements in the hypothetical isometric eigenvector are equal; reflecting equal growth in all dimensions. The hypothetical isometric eigenvector variable for both the MD and BL analyses was \( 1/\sqrt{10} = .31623 \). The hypothetical isometric eigenvector for the combined MD and BL analyses was .2236 (\( p=20 \)).
Hypothetical allometric eigenvectors were constructed based on the hypothesis the deciduous anterior dentition grows faster than the posterior dentition (Stack 1967, Sciulli 2001). The hypothetical allometric eigenvectors were calculated by first identifying any differences among the elements of the eigenvector between the tooth classes in the first observed eigenvector. Using the PCA of the Bolton-Brush and Memphis BL data (Table 2.1) as an example, there is a clear separation between the anterior teeth and the posterior teeth in these two samples.
# PRINCIPAL COMPONENT ANALYSIS

**EUROPEAN AMERICAN AND MEMPHIS AFRICAN AMERICAN SAMPLES**

**BUCCAL LINGUAL LOG DATA**

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<thead>
<tr>
<th>VARIABLES</th>
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<th>MEMPHIS OBSERVED</th>
<th>ALLOMETRIC HYPOTHETICAL</th>
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## BOLTON BRUSH

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## EIGENVALUES

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<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
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<td>80.51%</td>
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</table>

Table 2.1: Bolton Brush and Memphis Allometric Principal Component Analysis
The allometric constant was estimated by dividing the mean of the elements of one tooth class into the mean of the elements of the other tooth class. If \( x \) represents the elements of the eigenvector the hypothetical allometric elements can be found by: \( 4x^2 + 6(1.83x)^2 = 1 \); where \( 4x^2 \) represents the four posterior teeth and \( 6(1.83x)^2 \) represents the six anterior teeth. It was observed in this case that the elements of the anterior teeth were about \( \frac{5}{6} \) larger than the elements of the posterior teeth. The hypothetical eigenvector would consist of four elements equal to 0.2037 corresponding to the posterior teeth and six elements equal to 0.3730 corresponding to the anterior teeth. Similar methods were used to find the allometric constants for the following allometric relations: \( 1 \frac{1}{3} \) or (1.33), \( 1 \frac{1}{2} \) or (1.5), \( 1 \frac{2}{3} \) or (1.66). These ratios were calculated since different allometric relationships have been reported in various populations (Stack 1967, Liversidge et al. 1993, Sciulli 2001).

Mahalahobis distance \((D^2)\) is a method of calculating mathematically the biological distance between groups using the means and the variance-covariance matrix of the measurements of each sample. \( D^2 \) was performed to determine if there is a significant biological difference among the six samples. If there is no significant difference among the samples, there would be no purpose to doing the discriminant analysis.
For the metric data, the pairwise generalized squared distance between samples \( (D^2) \), was calculated using the following formula:

\[
D^2(i\mid j) = (\bar{x}_i - \bar{x}_j)'COV^{-1}(\bar{x}_i - \bar{x}_j)
\]

Where \( \bar{x}_i \) and \( \bar{x}_j \) represent the means of the two samples compared weighted by the pooled variance-covariance matrix.

Discriminant analysis is a method which uses the metric data of the samples to create a classification method to allocate new individuals, through the measurements of their teeth, into the predefined ancestral groups (Johnson and Wichern 1988). Two types of discriminant functions are commonly created: linear discriminant functions and quadratic discriminant functions. The linear discriminant function was calculated for the MD measurements only. This is due to the fact that linear discriminant functions are valid only when the covariances matrices are homogeneous and can be pooled. For the BL measurements, a quadratic linear function was calculated and was based on the within-class covariance matrices.

The constants for the MD linear discriminant function was calculated using the following formula:

\[
-0.5 \bar{x}_j'COV^{-1}\bar{x}_j
\]

Where \( \bar{x}_j \) is the mean of the sample tested and \( COV^{-1} \) is the inverse of the pooled covariance matrix.
The coefficient vector for each sample was calculated using the following formula:

\[
\text{COV}^{-1} \vec{X}_j
\]

Where \( \vec{X}_j \) is the mean of the sample tested and \( \text{COV}^{-1} \) is the inverse of the pooled covariance matrix.

The quadratic linear function was calculated using the following formula:

\[
-0.5X_0' (S_1^{-1} - S_2^{-1})X_0 + (\vec{X}_1' S_1^{-1} - \vec{X}_2' S_2^{-1})X_0 - K
\]

Where:

\( X_0 \) is the unknown measurement
\( S_1^{-1} \) is the inverse of the within covariance matrix of the first sample
\( S_2^{-1} \) is the inverse of the within covariance matrix of the second sample
\( \vec{X}_1 \) is the mean of the measurements the first sample
\( \vec{X}_2 \) is the mean of the measurements of the second sample
\( K \) is the constant for the discriminant function

\( K \) is calculated as follows:

\[
0.5\ln \left( \frac{|S_1|}{|S_2|} \right) + 0.5 (\mu_1' S_1^{-1} \mu_1 - \mu_2' S_2^{-1} \mu_2)
\]
Where:

$\ln$ is the log transformation of

$|s_1|$ is the log determinant of the within covariance matrix of first sample

$|s_2|$ is the log determinant of the within covariance matrix of the second sample

$\mu_1$ is the total samples mean for the measurements of the first sample

$\mu_2$ is the total samples mean for the measurements of the second sample

$S_1^{-1}$ is the inverse of the within covariance matrix of the first sample

$S_2^{-1}$ is the inverse of the within covariance matrix of the second sample

All statistical analyses were performed in the Number Crunching Statical System (2000) or SAS or SAS/IML v 8.02 (2001) programs.
CHAPTER 3

RESULTS

3.1 Monte Carlo Analysis of England samples

The Monte Carlo test is a sample randomization test (Cooley and Lohnes 1971). Randomization tests are necessary in a number of analytical situations. In the present case, the sample sizes for each time period in the English data are too small for traditional statistical analysis.

Monte Carlo analysis considers the observed outcome of a set of variables (measurement for each individual) as only one of many possible outcomes that could have arisen due to chance. In this application, the Monte Carlo analysis first determines the differences between the means of the measurement for each sample (observed outcome = x), the samples are then combined together. The measurements for each individual (variables) are then randomly separated into two new samples of the same size as the original samples. The means (outcomes) are then recalculated and the differences calculated. For each measurement, the differences were calculated 2999 times. The results of the 2999 tests were then compared to the original outcome to determine how many of the differences were greater or equal to the original difference. If the proportion
(x/3000) was greater than 5%, the means were considered equal and the samples could be combined for that measurement.

The Monte Carlo analysis on the English metric data was divided into four comparisons of the pre-Industrial Age samples and the post-Industrial Age samples. The pre-Industrial Age samples consisted of: Poundbury, 12th Century Abington, and 16th Century Abington. The post-Industrial Age samples consisted of: Spitalfields and the modern children samples. The full results of the analyses are found in Appendix D.

The first comparison was performed on the 16 individuals representing the two time periods (12th and 16th Centuries) from Abington. In this comparison, only one measurement (lclbl) could be considered significantly different between the two samples. Since it would be expected, by chance, that approximately one measurement out of 20 would be significantly different if all measurements were independant, the samples can be considered to be from the same population and can be combined. The combined sample from Abington was referred to as Abington total in the following analysis. The second analysis compared the Abington total sample to the next closest era, third century Poundbury. Although, there is a large temporal separation between Poundbury and Abington, the data still can be combined. No measurements were significantly different between the two samples, resulting in the new combined sample of Abington/Poundbury.

The third step was the examination of the post-industrial samples, Spitalfields and the London children. These measurements were analyzed and six were found to be significantly different. Three measurements were close to the 5% value necessary to be considered not significantly different. The other three measurements were significantly
different, but this is only two more than is expected due to chance. The author chose to 
combine the samples because of the small sample size of modern children and the less 
than overwhelming evidence of differences between the groups. The final analysis was 
the comparison of the two combined samples, the pre-Industrial Age English children 
(Abington/Poundbury) versus the post-Industrial Age English children 
(Spitalfields/modern). No measurements were significantly different between the two 
samples, they were combined as one sample (England).

The Monte Carlo analyses of the morphological data were performed on the 
absence and presence frequencies of 14 of the 25 traits. The construction of the analysis 
was similar to that described for the metric Monte Carlo analyses but instead of the 
sample mean of individuals’ measurements for each variable, the morphological Monte 
Carlo analyses compared the frequency of presence of a trait in two samples. 
The absence and presence of a trait in a sample was used to create a sample mean 
frequency which was then compared to the second sample’s mean frequency. The 
analyses were performed in the same method as the metric analyses with 2999 tests with a 
critical value of .05. The Monte Carlo analyses were performed to determine if there 
were any differences in the frequencies of the 14 morphological traits. Eleven 
morphological traits were eliminated from the analyses (double shovel on the maxillary 
incisors and canines, maxillary incisor interruption grooves, maxillary canine double 
shovel, maxillary canine mesial ridge, mandibular canine distal ridge, maxillary molar 
hypocone development, cusp 5 presence on the maxillary second molar, mandibular
second molar cusp number, and the mesial trigonid crest) as they exhibited no variation among the five time periods. The full results of the analyses are found in Appendix D.

The first analysis performed was the comparison of the 12th Century Abington sample to the 16th Century Abington sample. There were no traits in this comparison which were significantly different from each other. The two samples were combined, and referred to as the combined Abington sample. The combined Abington sample was then compared to the Poundbury sample. Two traits, the maxillary central incisor tuberculum dentale and the maxillary canine distal ridge, were found to be significantly different. Once again, it would be expected that a few traits would be significantly different due to chance, therefore; the samples can be combined to created the pre-Industrial Age English sample.

The next comparison in the Monte Carlo analysis was to compare the Spitalfield and the modern samples. Four traits were found to be significantly different, Carabelli’s trait, mandibular first molar cusp number, mandibular second molar entoconulid, and the mandibular second molar protostylid. Of the four traits, two were significantly different (p< 0.001), the other two traits were close to the 5% critical value. Again, the author chose to combine the samples due to the small sample size of the modern children. The two samples, pre-Industrial Age and post-Industrial Age, were then compared. Only one trait, mandibular second molar deflecting wrinkle, was found to be significantly different. The five time periods were combined into one sample, England, for the morphological data.
3.2 Results of Morphology Analysis

3.3 Morphological expression

The full description of expressions for the morphological traits can be found in Appendix A. The traits discussed in the following analysis are ones researchers use most often for ancestral determination. Some traits (e.g. interruption grooves) had no or minimal variation, and are not discussed in the text but can be found in Appendix C. West Africa does not show a wide range of variation in the morphological traits, most likely due to its small sample size. Therefore, the West Africa sample is not discussed (see Appendix C for expression counts).

Shovel shape trait

The expression of 0 and 1 were combined as absence for the expression of shovel shape. In all the samples, there is not a wide variation in the expression of shovel shape for both the maxillary and mandibular anterior dentition. The following table contains the absence percentages (%) for shovel shape in the samples.
<table>
<thead>
<tr>
<th></th>
<th>Bolton Brush</th>
<th>England</th>
<th>Memphis</th>
<th>Freedman</th>
</tr>
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<tbody>
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<td>%</td>
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<td>78</td>
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Table 3.1: Anterior Dentition Absence Percentage of Shovel Shape

From the table, it can be seen that anterior teeth of the maxillary dentition are more likely to have the shovel shape trait than those of the mandibular teeth and the lateral incisors are more likely to express the trait than the central incisors. The canines are more likely to express the trait than either incisor. An exception to this observation is the maxillary lateral incisors in the Memphis samples. In the Memphis sample, the maxillary lateral incisors have a higher frequency of presence (68.7%) than the maxillary canines (45%).

**Tuberculum dentale**

The two most common expressions of the tuberculum dentale in the maxillary anterior incisors were absence (0) and pits or grooves (1). For the maxillary canines, the
second most common expression was a ridge (2). The following table is the frequencies for the expressions in the samples.

<table>
<thead>
<tr>
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<th>Bolton Brush</th>
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<th>Memphis</th>
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</table>

Table 3.2: Maxillary Anterior Dentition Tuberculum Dentale

The presence of a ridge (or ridges) on the maxillary canine is the most common expression of this trait. Bolton Brush and Memphis express the trait at approximately the same percentage. The English sample expressed the trait the most often at 36%, while Freedman is the lowest at 12.7%.

All of the samples have similar percentages for absence and ridge(s) in the incisors, except for the Bolton Brush sample. This sample has the lowest absence frequencies for both the central and lateral incisors (79.3% and 83% respectively), when compared to the
other samples. The highest expression for pits on these two teeth (17% and 15% respectively) is also found in this sample.

Maxillary Canine Mesial Ridge

The expressions of this feature were divided into absence (0) and all the other expressions combined into present (1) for this analysis. All of the samples showed low frequencies for the presence this trait. The trait was expressed at a frequency of 1% and 0% in Bolton Brush and England respectively. Memphis expressed the trait at 2.6% percentage, while Freedman had the highest frequency at 6.8%.

Maxillary Canine Distal Ridge

The same division of the expressions was used for the distal ridge as the mesial ridge. Bolton Brush had the highest presence frequency at 11% for the trait. The next highest was 6% found in the Memphis sample. England had a 3.9% frequency of expression for the trait. While Freedman sample had a 1.9% frequency.

Manibular Canine Distal Ridge

The same division of the expressions was used for the mandibular canine distal ridge as for the maxillary canine distal ridge. The highest frequencies were found in the English sample (6.4%) and the Memphis sample (4.3%). The Bolton Brush and Freedman samples had extremely low frequencies at 1% and approximately 0% respectively.

Development of the Maxillary anterior molar hypocone

The expressions of the anterior molar were combined for ease of analysis. Expression 2 remains 2. While 3M1 and 3M2 were combined into 3, 3H1 and 3H2 were
combined into 4, and 5 consists of expressions 4- and 4. The following table is the percentages for each expression in the four samples:

<table>
<thead>
<tr>
<th></th>
<th>Bolton Brush</th>
<th>England</th>
<th>Memphis</th>
<th>Freedman</th>
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</thead>
<tbody>
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<td>%</td>
<td>N</td>
<td>%</td>
</tr>
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<td>5</td>
<td>5</td>
<td>3</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Table 3.3: Expression Percentages of the Anterior Maxillary Molar

Bolton Brush has the simplest anterior molar morphology with the primary expression of 2 cusps (61%). England has most well development morphology of the anterior dentition with 94.9% of the sample expressing some development of the hypocone. Memphis and Freedman are intermediate with 66.% and 78.4% frequencies for the more complex morphology.

**Development of the Maxillary posterior molar hypocone**

The expressions for the maxillary posterior molar are as follows: 3A is 3, 3B is 4, 4- is 5, and 4 is 6. (See Appendix A).
<table>
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<th>Bolton Brush</th>
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<th>Memphis</th>
<th>Freedman</th>
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</thead>
<tbody>
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<td></td>
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<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
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<td>12</td>
<td>64</td>
<td>75.2</td>
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Table 3.4: Maxillary Posterior Molar Morphology Frequencies

The results for the expression of the hypocone in the posterior molar are similar to the result for the anterior molar, in that Bolton Brush exhibits more frequently the most simple expressions (3 and 4), while the other three samples more frequently express the more complex morphologies (5 and 6) of the molar form.

**Cusp 5 on the maxillary posterior molar**

The presence of this trait is highest in Bolton Brush at 12%. England and Memphis express this trait at similar frequencies (3% and 3.5% respectively), and the trait is rare, about 1%, in the Freedman sample.

**Carabelli’s trait on the maxillary posterior molar**

The expression of Carabelli’s trait is the most complex of the dentition. For ease of analysis the expressions were subdivided into three categories: absence (0), pit (expression 1-3), and cusp (expression 4-6). The following is the table of the expression frequencies in the samples.
<table>
<thead>
<tr>
<th></th>
<th>Bolton Brush</th>
<th>England</th>
<th>Memphis</th>
<th>Freedman</th>
</tr>
</thead>
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<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>absent</td>
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<td>12</td>
<td>13.9</td>
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<tr>
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<td>35</td>
<td>39</td>
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<tr>
<td>cusp</td>
<td>39</td>
<td>39.4</td>
<td>36</td>
<td>40.4</td>
</tr>
</tbody>
</table>

Table 3.5: Carabelli’s Trait expressions

The European American (Bolton Brush) sample has the highest absence frequency while the other three have similar absence frequencies. The Bolton Brush and English samples exhibit almost equal percentages for the expression of a pit or a cusp. The Bolton Brush (European American) sample has an expression of 39.4% for a pit and a 39.4% frequency for the cusp. The England sample has a frequency of 39% for the pit expression and a frequency of 40.4% for the cusp. The Memphis and Freedman samples have higher expressions for a pit than a cusp. The Memphis sample has a 57.9% verses 30.7% frequency and Freedman has a 51.5% verses 35.6% frequency for the two different types of expression of this trait.

**Cusp Number of Mandibular anterior molar**

The author divided the number of cusps found on the mandibular anterior molar into two categories. The count of 3 or 4 cusps is expression 1. Cusp numbers of 5 or greater is expression 2. The following table is the frequencies for the expressions.
Table 3.6: Cusp Number of the Mandibular anterior molar

All four samples have similar frequencies for the two expression.

Groove Pattern on the mandibular posterior molar

The following is the table for the three different groove patterns associated with the mandibular posterior molar.

Table 3.7: Groove pattern frequencies

The least frequently expressed pattern the four samples is the X pattern. Bolton Brush has the highest frequency of the + pattern at 66% and the lowest Y pattern.
frequency at 32%. The England and Memphis samples have similar frequencies for both patterns with 39% for the + pattern and 57% or 56% for the Y pattern. Freedman sample has the highest expression of the Y pattern at 69.4% and the lowest of the + pattern at 23.5%.

**Deflecting wrinkle on the mandibular posterior molar**

The expression for this trait was subdivided into absent (0-1) and present (2-3) for this analysis. England and Bolton Brush have the lowest frequencies for the expression of this trait with 15% and 24.7% respectively. Freedman has the highest frequency at 43.4%. Memphis is intermediate at 38.2%

**Protostylid on the mandibular posterior molar**

The protostylid, similar to the Carabelli’s cusp, has very complex expressions. For ease of analysis, the expressions were subdivided into absence (0), pit/groove (1-2), an cusp (3-4). The most common expression for all of the samples, except England, is absence (Bolton Brush = 90%, Memphis =78.9%, Freedman=59%). England had the lowest percentage for absence at 26.2%. England also has the highest frequency for the pit/groove morphology at 73%. Freedman expresses this morphology at 38%. Memphis had a 19.2% percentage. Bolton Brush has the lowest rate at 5%. Bolton Brush, though, has the highest percentage for the cusp morphology at 5%. The other three samples, England, Memphis, Freedman, have similar percentages at 1%, 1.7%, and 3% respectively.

**Cusp 6 on the mandibular posterior molar**

The expression for the development of cusp 6 were divided into absent (0) and present (1-5). Bolton Brush and England have the lowest frequency for cusp 6 at 1% and
14.4% respectively. Memphis and Freedman have frequencies of 24% and 33% respectively.

Cusp 7 on the mandibular posterior molar

The expression of a true cusp (expression 3-5) was considered present for this trait. England and Bolton Brush have similar frequencies at 17.5% and 16% respectively. Memphis and Freedman have similar frequencies at 21% and 25% respectively.

Mesial Trigonid Crest

This trait was scored as absent or present, the presence frequency is reported here. England and Memphis have similar rates at 6% and 5.4% respectively. Bolton Brush has a 10% frequency, while Freedman has the highest frequency at 14%.

3.4 Absence/ Presence Frequencies

The results of the dichotomization of the expressions of the traits (absence and presence frequencies) can be found in Appendix E. The following is a brief description of the percentages of traits in the four samples (Bolton Brush, Memphis, Freedman, England). Due to the small sample size of West Africa, the absence and presence frequencies will not be described here.

It was observed that several traits are present in the samples at a level of 50% or above. In the Bolton Brush sample the traits at 50% or above are: maxillary lateral incisor shovel shape, maxillary canine tuberculum dentale, Carabelli’s trait, the complexity of the mandibular anterior molar, and the development of cusp 7 on the mandibular posterior molar. The traits at a 50% plus level in the Memphis sample are: the development of mandibular posterior molar hypocone, Carabelli’s trait, the
complexity of the mandibular anterior molar, the Y groove pattern and development of cusp 7 on the mandibular posterior molar. The traits present at a 50% plus level in the Freedman are: the development of mandibular posterior molar hypocone, complexity of the mandibular anterior molar, the groove pattern and development of cusp 7 on the mandibular posterior molar. The English sample has Carabelli’s trait, the development of the hypocone of the maxillary posterior molar, the complexity of the mandibular anterior molar, the groove pattern of the mandibular posterior molar, the development of the protostylid and cusp 7 on the mandibular posterior molar at a 50% or higher percentage.

At a 5% or below frequency within the Bolton Brush sample are the following traits: double shovel shape on the maxillary canine, interruption grooves on the maxillary incisors, the maxillary canine mesial ridge, the mandibular canine distal ridge, and the development of the hypocone of the maxillary anterior molar. Within the Memphis sample the traits are: shovel shape on the mandibular incisors, double shovel shape on the maxillary canine, interruption grooves of the maxillary incisors, the maxillary lateral incisor and canine tuberculum dentale, the maxillary canine mesial ridge, cusp 5, and the mandibular canine distal ridge. In the Freedman sample, the double shovel shape on the maxillary canine, the interruption grooves, the maxillary lateral incisor tuberculum dentale, cusp 5, the maxillary canines mesial and distal ridges, and the mandibular canine distal ridge are all 5% or below. In the England sample, the mandibular central incisor shovel shape, maxillary canine double shovel shape, interruption grooves, maxillary central incisor tuberculum dentale, maxillary canine mesial and distal ridges, the
development of the maxillary anterior molar hypocone, cusp 5 are 5% or below. The rest of the traits for the samples vary in frequency between 6% and 49%.

3.5 Weighted Average (W)

The weighted average (W) of the expressions were calculated for each trait in the samples. All the samples tend to have similar traits with high averages. The exception is West Africa which maybe biased due to the small sample size. The weighted averages (W) are important to examine separately, since they should reflect the variation examined in the MMD analysis. The author chose 1.00 as a high weighted average for the trait, since traits with weighted averages less than 1.00 had slight variation of the expressions within the samples. Traits with a weighted average of 1.00 or higher express more variation of expressions within the samples examined. (See Appendix C)

Of the 25 morphological traits originally observed, eight traits had high W values. These traits are: the presence of the shovel shape on the maxillary dentition, the development of the maxillary posterior molar hypocone, Carabelli’s trait, the complexity of the mandibular anterior cusp number, the groove pattern on the mandibular posterior molar, and the development of a cusp 7 on the mandibular posterior molar. The nine uncorrelated traits used in the MMD analysis are: maxillary central incisor shovel shape, maxillary canine tuberculum dentale, Carabelli’s trait on the maxillary posterior molar, mandibular anterior molar cusp number, mandibular posterior molar groove pattern, mandibular posterior molar deflecting wrinkle, mandibular posterior molar protostylid, mandibular posterior molar entoconulid or cusp 6, and mandibular posterior molar mesial trigonid crest. Of the nine uncorrelated traits used in the MMD analysis and the eight
traits with high Ws, only four traits had both a high W and were uncorrelated: the
maxillary incisor shovel shape, Carabelli’s trait, the complexity of the mandibular
anterior molar, and the groove pattern of the mandibular posterior molar.

In addition to the eight traits previously listed, Bolton Brush has a high W value
for the development of a deflecting wrinkle on the mandibular posterior molar for a total
of nine traits. Neither the Memphis nor England samples have a high value for the
deflecting wrinkle, but unlike Bolton Brush, they both have a high value for the
development of the maxillary anterior molar hypocone for a total of nine traits as well.
Dallas had high values for 10 traits, the eight previously listed, as well as, the deflecting
wrinkle trait and the maxillary anterior molar hypocone development.

There are only four traits which had both high weighted averages and were
uncorrelated. Three traits with high Ws, the shovel shape morphology of the lateral
maxillary incisor and canine and cusp 7, were eliminated from the MMD analysis because
of correlation with other traits. The following traits are included into the MMD analysis
but have low Ws: the deflecting wrinkle, which has a low W in both England and
Memphis; the maxillary canine tuberculum dentale, development of a protostylid on the
mandibular posterior molar, cusp six, and the presence of a mesial trigonid crest on the
mandibular posterior molar.

It cannot be determined if the Ws for West Africa would reflect similar patterns to
the other samples or to the uncorrelated traits in the MMD analysis. The majority of the
traits in West Africa are present at a zero (0%) frequency, therefore the sample was not
included in the MMD analysis. Appendix C contains the complete results for the expression, associated W, and the absence/presence frequency for each trait by sample.

3.6 Mean Measure of Divergence

The Mean Measure of Divergence was calculated for four (Bolton Brush, Memphis, Freedman, and England) out of the original six samples after dichotomization. India was not examined due to the lack of morphological data from this sample. West Africa was not examined due to the small sample size and lack of variation.

Only 15 traits, of the 25 observed traits, were between 5% and 95% for each of the four samples. Using a likelihood ratio statistic, it was determined that nine of these traits were uncorrelated in each sample. The nine uncorrelated traits used for the MMD statistic are as follows: maxillary central incisor shovel shape, maxillary canine tuberculum dentale, Carabelli’s trait on the maxillary posterior molar, mandibular anterior molar cusp number, mandibular posterior molar groove pattern, mandibular posterior molar deflecting wrinkle, mandibular posterior molar protostylid, mandibular posterior molar entoconulid or cusp 6, and mandibular posterior molar mesial trigonid crest. The likelihood ratios for each trait comparison are found in Appendix F.

An MMD comparison was done for each pairing of the four samples. The following table contains the MMD’s. The critical value of the chi-square distribution for a two sample comparison is $\chi^2_{(0.05,9)} = 16.91$. Numbers greater than 16.19 indicated the two samples are statistically different from each other. The $\chi^2_{(0.05,9)}$ are located in the
upper right portion of the matrix, the MMD values are located in the bottom left of the
matrix. An asterisk (*) indicates which are MMDs significantly different.

<table>
<thead>
<tr>
<th></th>
<th>Bolton Brush</th>
<th>Memphis</th>
<th>Freedman</th>
<th>England</th>
</tr>
</thead>
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<td>.1807717*</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3.8: MMDs of Four Samples

All samples are significantly different from each other statistically. Figure 3.1 is
the Principal Coordinate plot of the samples using the MMDs values. A total of 93.8% of
the variation in the MMD matrix is accounted for by these two axes. Axis I accounts for
60.4% of the total variation and Axis II accounts for 33.4%. This figure indicates
that the four samples can be separated into the two ancestral groups, so the
discrimination analysis may be successful. If a line is drawn at the 0.0 point on Axis 2,
the two African American samples (Memphis and Dallas/Freedman) are located above
this line. The two European/European-derived samples (England and Bolton Brush) are
located below this division.
In addition to the MMDs, the total sample chi-square value, total sample variance, and the standard deviation of the MMD were calculated (Appendix G). The morphological traits which are significantly different between the two samples are reported in Appendix G as well.

### 3.7 Logistic Discrimination Analysis

Since the four samples were statistically and by inference biologically different, a logistic discrimination analysis was considered appropriate. The goal of this analysis was
to determine if the differences among the modern European and African American samples were consistent enough to create logistic functions to accurately allocate individuals into the appropriate ancestry category. The modern European American (Bolton Brush) and modern African African (Memphis) study samples were used to create the logistic discriminant functions. Fifteen morphological traits were used to create the logistic discriminant functions. These fifteen traits were chosen because there was a high degree of variation in the expressions, either within or between the two samples. The traits consisted of the shovel shape trait on the maxillary lateral incisor and maxillary canine, the tuberculum dentale on both maxillary incisors and the maxillary canine, the mandibular canine distal ridge, the development of the maxillary anterior molar, cusp 5 on the maxillary posterior molar, Carabelli’s trait on the maxillary posterior molar, cusp 6 and 7 on the mandibular posterior molar, and the deflecting wrinkle and mesial trigonid crest on the mandibular posterior molar. Three types of discriminant functions were created, two trait crosses, three trait crosses, and four trait crosses. Since both the modern European American and modern African American samples are assumed to have equal posterior probabilities (Everitt and Dunn 1991), the European American sample was randomly chosen as the sample to test the classification accuracy of the crossvalidation analysis. The logistic discriminant functions are considered to have a high accuracy of proper classification for the European American individuals if the frequency was 70% or greater, since this frequency represents a better than average frequency for allocation. Of the total 785 functions created, 250 which have an accuracy rate of 70% or greater when classifying European American individuals. From the 15
morphological trait comparisons, a total of 77 two trait logistic discriminant functions were created. Of the 77 two trait crosses, 12 discriminant functions accurately classified the modern European American (Bolton Brush) individuals at a frequency of 70% or greater. For the three trait logistic discriminant functions, a total of 262 were created, of which, 66 classify the European American individuals at an accuracy rate of 70% or greater. The final logistic discriminant functions created were 446 four trait logistic discriminant functions. Of the 446 four trait functions, 172 function classified the European American individuals at accuracy frequency of 70% or greater.

The low percentage of the logistic discriminant functions (250/785 or 31.8%) correctly allocating individuals at a frequency of 70% or greater is due to two factors. The proximate factor is, while there is variation of trait frequencies between the two groups, the variation is not very high. For example, the frequency for shovel shaped maxillary central incisor is 32% for the Bolton Brush sample and is 35% for the Memphis sample. This lack of marked variation is due to the ultimate factor, gene flow between European Americans and African Americans which is causing the African Americans to become more similar to the European Americans. Since only 12 out of the 77 (15.6%) two trait crosses and 66 out of the 262 (25.2%) of the three trait crosses have a frequency of 70% or greater, it is suggested that a four trait cross (162/446 or 38.6%) be used because allocation accuracy increases as more traits are included in the analysis.

To use the logistic discriminant functions, the expressions of a trait must be multiplied against the coefficient for the trait and summed with the constant. See Appendix A for the numerical values and descriptions of the expression. An unknown
individual is allocated into $D_1$ if positive and $D_2$ if negative. Individual 1 is a Bolton Brush test subject and Individual 2 is a Gullah test subject. Both Individual 1 and Individual 2 were properly allocated into their class memberships. $D_1 = $ European Americans (Bolton Brush) and $D_2 = $ African American (Memphis). See Appendix H for a summary of the logistic discriminant functions which have an class membership probability accuracy over 70%, their discriminant functions, and their membership probability tables. The following are two examples of using the logistic discriminant functions from a three trait cross and a four cross trait.
### Three trait cross

Individual 1 = 3.8743 + 2.0119 (0) + -1.2667 (2) + -.9284 (0) = 1.3409

Individual 2 = 3.8743 + 2.0119 (0) + -1.2667 (5) + -.9284 (0) = -2.4592

### Four trait cross

Individual 1 = 4.1218 + 3.0150 (0) + -2.4145 (0) + -1.3422 (2) + -.9951 (0) = 1.4374

Individual 2 = 4.1218 + 3.0150 (0) + -2.4145 (0) + -1.3422 (5) + -.9951 (0) = -7.9507

Table 3.9: Example of Logistic Discrimination

### 3.8 METRIC ANALYSIS

#### 3.9 Normality Results:

#### 3.10 Univariate Normality

Univariate normality for each of the 30 measurements was tested in each group. In the Memphis, Bolton Brush, and India samples, each sex was tested for normality separately (Appendix I). For 30 measurements, if all the variables were independent from each other, it would be expected one to two measurements would display non-normality due to chance. England, Dallas and Memphis each had four non-normal
variables, Bolton Brush and India had only two non-normal variables, and West Africa had none. Two of the non-normal variables in the Memphis sample are chords and not included in the following analyses, therefore there are only two non-normal measurements to be considered. The Dallas sample has three variables which are not normal but one variable is close to the critical value of .05, which leaves only one variable more than expected by chance. The non-normal variables in the English sample, two are positively skewed and one is a chord. Both the European American and India samples had two non-normal variables. The samples can be considered to be univariate normal. Since the molar chords were measured for only four samples one of which is West Africa (an extremely small sample size) and there was little variation among the samples for these measurements, the chords were excluded from the later multivariate analyses.

See Appendix I for a more complete description of the differences in the means among the samples. Briefly, the samples can be described as follows. The samples with the largest means to smallest are: India, Freedman, England, Memphis, Bolton Brush, and West Africa. Three samples can be separated by sex for comparison, Bolton Brush, Memphis and India. In both the Memphis and the India samples, the males have larger means for all measurements. The European American (Bolton Brush) sample cannot be easily classified as one sex having larger measurements than the other. In general, males have smaller BL means than the females, but the males have larger MD means than the females.
The degree of sexual dimorphism was calculated (Table 3.10) to determine if the sexes could be pooled. For all measurements in the Memphis and the India samples, the males were larger than the females. In the European American sample (Bolton Brush), the females were larger than the males for six out of 40 measurements. These measurements are indicated by the negative (-) sexual dimorphism percentage. The six measurements are the buccolingual dimension for the maxillary lateral incisor, maxillary canine, mandibular lateral incisor, mandibular canine, mandibular anterior molar, and the mandibular posterior molar. The total sexual dimorphism for the European American (Bolton Brush) sample was the lowest at 1.15%. The Memphis African American sample has total sexual dimorphism value of 3% for the dentition. The India sample has the largest degree of sexual dimorphism (3.44%). For all samples the sexual dimorphism, both total and per measurement, was below 3.5%. Since the degree of sexual dimorphism is low for all samples, the sexes were pooled. The following table summarizes the degree of sexual dimorphism for each measurement in the three samples.
<table>
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<tr>
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<th>Bolton Brush</th>
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<th>India</th>
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<td>3.5%</td>
</tr>
</tbody>
</table>

Total | 1.15% | 3.00% | 3.44% |

Table 3.10: Degree of Sexual Dimorphism of the teeth

\[
((\text{male} \bar{X} / \text{female} \bar{X}) - 1) \times 100
\]

(Garn et al. 1967d)

### 3.11 Multivariate Normality

Multivariate normality graphs were created for each sample separately (Appendix J). The data, itself, was separated into four different categories. First, the total buccal-lingual/mesial-distal data was tested. Other tests were performed on the buccal-lingual data alone and the mesial-distal data alone. All tests indicated the data were multivariate
normal. Thus, the test of the homogeneity of the covariance matrices could be performed on all samples. All multivariate normality graphs are found in Appendix J.

3.12 Homogeneity of Covariance Matrices:

Due to incomplete data for some measurements, the number of individuals in some samples is less than the total number of individuals examined. The within group covariance matrices for the Bolton Brush European American (N = 86), Memphis African American (N = 60), India (N = 100), and Freedmen African American (N = 72) samples were first compared, using all twenty buccal-lingual and mesial-distal measurements. England and West Africa were eliminated in this test due to small sample sizes, N = 26 and N = 17 respectively. The F value associated with the Box’s M test indicated that the variance - covariance matrices of the four groups were too different for the samples to be pooled (Appendix K). An F of 0.01 was used due to the large degree of freedom. For each group, the within covariance matrices were calculated separately for these data (Appendix K).

The within group covariance matrices of the MD measurements and the BL measurements for the six groups were then examined separately. The Box test showed that the covariance matrices for the MD measurements were homogeneous in the six groups, so the six samples can be pooled (Appendix K). However, the BL matrices were not homogeneous (Appendix K). The BL measurements were rechecked for univariate and multivariate normality and were found to have a normal distributions in both cases. The data were reexamined for outliers and those found were eliminated. Following this, the Box test again reported the covariance matrices being unequal. The covariance
matrices for each group were then calculated separately for the BL measurements (Appendix K).

3.13 Principal Component Analysis

The principal component analysis (PCA) was conducted to see if the samples has similar relationships among the teeth, and if not, to see where the differences were apparent. PCA was performed to isolate the presumed underlying size and shape sources of variation from the total variation of the samples. PCA extracts the eigenvectors commonly associated with these dimensions from the data (Hanihara 1998). This analysis is used to determine the relative contribution of size and shape to the distance analyses (Hanihara 1998).

The first two observed eigenvectors were analyzed for the six samples. The directional cosines of the first observed eigenvector are all in one direction, indicating either simultaneous increase or decrease of all measurements (Jolicoeur 1963, Sciulli 2001, Harris 1998). The first observed eigenvector explains variation within a sample due to size.

Studies of growth rates of the deciduous dentition show that various dimensions grow faster than than others (Sciulli 2001). Stack (1967) and Liversidge et al. (1993) have examined crown height and, in general, found that anterior dentition grows almost twice as fast as the posterior premolar. The maxillary incisors increase in size roughly in a 3/2 ratio to the anterior premolar (Stack 1967). Sciulli (2001) found a similar relationship in the Native American populations of the Ohio River Valley. All of the first observed eigenvectors were tested for an isometric or allometric relationship to discover
what was the growth rate relationship among the teeth. For the MD measurements, the
total sample covariance matrix (N = 370) was used in the calculation of the PCA
(Appendix L).

The majority of the variation, 60.96%, within the MD measurements is found on
the first eigenvector (size variation). The second observed eigenvector had both positive
and negative directional cosines, indicating shape variation. The second eigenvector
accounts for an additional 11.08% of the variation attributed to shape. The third
eigenvector, also attributed to shape variation, accounts for a further 5.90% of variation.
A total of 77.94% of variation can be accounted for by the first three eigenvectors.

Even though the angle between the hypothetical eigenvector \(1/\sqrt{3} = .31623\) and the observed eigenvector is only 5.22°, the two are significantly different \(\chi^2 =
34.83, p<0.005\). Therefore, the relationship between the measurements is not completely
isometric. The allometric tests performed using, for example a constant of 1.33x for the
anterior dentition, did not fit the growth patterns in the size of the teeth. Other constants,
1.5, 1.33, 1.66, 1.83, were also unsuccessful in fitting the allometric relationship among
the teeth. The mesiodistal data for all six samples were able to be pooled due to equal
variance-covariance matrices, and have close to an isometric relationship among the
teeth. All the samples have a similar shape relationship between the mesiodistal
dimensionships, therefore, any differences among the groups is based on size differences
of the mesiodistal dimensions.
Since the covariance matrices for the five samples could not be pooled for the BL data, PCA was done separately. West Africa was not analyzed due to the small sample size, making analysis statistically unsound.

Both the Memphis and the European American samples were found to have a non-isometric relationship for the buccolinguual dimensions. The angle between the observed first eigenvector and the hypothetical first eigenvector (isometric) for the Memphis sample was 19.76° with \( \chi^2 = 39.96, p<0.005 \). The Bolton Brush sample had an angle of 17.69° with \( \chi^2 = 31.40, p<0.005 \). A second hypothetical eigenvector was calculated for the European American and the Memphis African American sample to test the allometric relationship. The anterior dentition eigenvector constant was calculated as 0.3730 and the posterior dentition as 0.2034, a described in the previous chapter. The allometric hypothetical eigenvector indicates that in both samples, the anterior teeth are growing 1.83 times faster, in the mesiodistal dimension, than the posterior teeth (Appendix L). The angle between the allometric hypothetical eigenvector and observed eigenvector was 10.07° with \( \chi^2 = 21.28, p \sim 0.01 \) for the European American sample. The Memphis sample had an angle of 8.11° between the allometric hypothetical eigenvector and the first observed eigenvector with a \( \chi^2 = 16.94, p \sim 0.05 \).

For the buccolinguual dimensions of the European American sample, 77.48% of the variation was contained on the first three eigenvectors. Approximately half of the variation, 49.09%, within the European American sample can be attributed to size.
differences in the BL dimension. Shape variation, the second and third eigenvectors, accounts for 28.39% of the total variation within the sample. A total of 77.48% of the sample variation is explained by the first three eigenvectors. The size variation in the Memphis sample is 58.64% and the shape eigenvectors explain 21.87% of additional variation. Total variation, 80.51%, is contained on the first three eigenvectors.

The samples from India, Freedman African American, and England all have an isometric relationship among the BL dimensions of the teeth on the first eigenvector (Appendix L). The first three observed eigenvectors account for 82.93% of the total sample variation for India, with size explaining 64.04% of the variation. 78.77% of the total sample variation is contained on the first three eigenvectors for the Freedman sample. Size accounts for 60.70% of the variation within the sample. The England sample total variation consists of 80.44% on the first three observed eigenvectors and 59.62% of that variation can be attributed to size differences.

The PCA tests of the BL/MD measurements of the four samples (European American, Memphis African American, Freedman African American and India) revealed that all but India had an allometric relationship between the measurements (Appendix L). The test of the isometric eigenvector (1/√p  p = 20) on the Bolton Brush sample produced an angle of 25° and a $\chi^2_{19} = 85.86$ p<0.005, the Memphis sample has an angle of 16.82° and a $\chi^2_{19} = 42.98$ p<0.005, and the Freedman sample’s angle is 9.49° and a $\chi^2_{19} = 53.72$, p<0.005. Again, due to no obvious pattern of the measurements, growth patterns could not be determined for these three samples.
In the European Americans, a total of 66.10% of the variation was found in the first three eigenvectors. The size variation accounting for 43.07% of variation and shape accounting for 23.03% of the sample variation. The first eigenvector contains 48.86% of total sample variation in the Memphis sample, with an additional 20.74% of the variation found along the second and third eigenvectors. The first three eigenvectors explain 70.5% of the total sample variation in the Freedman sample, 55.51% attributed to size variation and 14.99% of the variation to shape. India was the only sample to have an isometric relationship between all the dimensions of the teeth. Size variation accounts for 56.40% of the sample variation and the shape variation of the second and third eigenvectors are 14.52%.

In summary, it can be observed from the approximately isometric relationship of the mesiodistal dimensions of all six samples, differences among the samples are due to size differences not shape differences. The buccolingual data of the six samples could not be pooled due to unequal variance-covariance matrices, therefore PCA was performed on the six samples separately. It can be observed that there are two different relationships in regards to the buccolingual dimensions. Both the modern African American (Memphis) and European American (Bolton Brush) samples have the same allometric relationship with the anterior buccolingual dimensions being 1.83 times greater than the posterior dimensions. The India, Freedman (African American), and England samples have an isometric relationship among the buccolingual dimensions. Therefore, this differences among the samples are both size and shape differences. Finally, in regards to the combined mesiodistal and buccolingual PCA results, only India has an isometric
relationship the other four samples have no distinguishable pattern of the relationships among the dimensions of the teeth. The differences among the groups in regard to all of the dimensions together are most likely both size and shape differences.

3.14 Mahalanobis’ D²

Mahalanobis’ D² distance was performed on the MD measurements of six samples to determine the degree of similarity among the samples. If the samples are not significantly different from each other, it would not be worth while for the discriminant analysis to be performed. The D² values indicated that the means of the six samples are statistically different from each other. The following matrix table consists of the D² values for each pairwise comparison found on the lower left side and the associated F_{(0.05)} value on the upper right. Appendix M contains the full listing of F values with degrees of freedom. An asterisk (*) indicates significant differences.
<table>
<thead>
<tr>
<th>Bolton Brush</th>
<th>Memphis</th>
<th>India</th>
<th>Freedman</th>
<th>England</th>
<th>West Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolton Brush</td>
<td>0</td>
<td>21.42</td>
<td>18.48</td>
<td>13.50</td>
<td>6.86</td>
</tr>
<tr>
<td>Memphis</td>
<td>6.10141*</td>
<td>0</td>
<td>9.21</td>
<td>8.50</td>
<td>7.48</td>
</tr>
<tr>
<td>India</td>
<td>4.411*</td>
<td>2.41277*</td>
<td>0</td>
<td>14.52</td>
<td>3.02</td>
</tr>
<tr>
<td>Freedman</td>
<td>10.30787*</td>
<td>2.58204*</td>
<td>2.58361*</td>
<td>0</td>
<td>10.01</td>
</tr>
<tr>
<td>England</td>
<td>3.66057*</td>
<td>4.35844*</td>
<td>1.55542*</td>
<td>5.61553*</td>
<td>0</td>
</tr>
<tr>
<td>West Africa</td>
<td>5.78811*</td>
<td>1.05275</td>
<td>1.853301*</td>
<td>0.26945</td>
<td>4.21807*</td>
</tr>
</tbody>
</table>

Table 3.11: $D^2$ Values of the Six Samples

The F tests for each pair comparison, indicate that the samples are significantly different from each other. The exceptions are the West Africa - Memphis ($D = 1.05275$, $F_{10.75} = 1.35$) and West Africa-Freedman ($D = 0.26945$, $F_{10.46} = 0.358$) comparisons. The similarities between the West Africa-Freedman samples and the West Africa-Memphis samples may be the result of ancestry. Both statistically and biologically, West Africa may be more similar to the Freedman African Americans and the Memphis African Americans than the latter two samples are to each other. Another explanation for the insignificant difference between West African and Freedman and West Africa and Memphis may be the result of the small sample size of West Africa ($N = 18$) and, therefore, it may not be a true reflection of biological distance. The F test results can be found in Appendix M.
Figure 3.2 is the Principal Coordinate Analysis of the $D^2$ values. The first and second axes account for 75% of the total variation among the groups with Axis 1 accounting for 48% of the variation and Axis 2 for 27% of the variation.

It can be observed from the $D^2$ analysis that the six samples are statistically different, reflecting the biological differences among the samples. Two slopes can be drawn on Figure 3.2 to illustrate this point. The first line is located at the 0.0 point on Axis 1. This line separates the Freedman (Dallas), West Africa, and Memphis samples from the European/European-derived samples, England and Bolton Brush. India is located directly on this line. The second line is a diagonal drawn from 6.0 on Axis 2 to 8.0 on Axis 1. This line again separates England, India and Bolton Brush from the African/African-derived samples of West Africa, Freedman, and Memphis. Since the samples are both statistically and biologically dissimilar from each other, it is worthwhile to perform the discriminant analysis.
3.15 Discriminant Analysis

Four discriminant analyses were conducted on the six samples using the MD measurements (Appendix N). The goal of these analyses is to determine which discriminant function has the highest accuracy for allocation. For each function there is a constant and a coefficient vector for each measurement. When performing a
classification of an individual of unknown ancestry, an investigator multiples the log data of each measurement from the unknown individual with the coefficient of that measurement. Finally, the results of the multiplication of each measurement and coefficient should be summed together, along with the constant. The function which produces the greatest number is the ancestral group of the individual.

The number of observations and percent classified correctly can be calculated using the posterior probabilities. When the six sample discriminant function was calculated, a total of 57.7% (213/369) of the individuals were classified correctly. It was observed that individuals from the Bolton Brush sample were classified correctly 89.5% (69/76) of the time. Individuals from the Memphis sample were classified correctly 74.2% (33/66) of the time. The Indian sample was correctly classified 40% (40/100) of the time. The Freedman sample was classified correctly at a rate of 84% (45/73). Individuals from the England sample were properly classified at a rate of 69% (18/26). West Africans were properly classified at a rate of 83% (8/18).

The discriminant function supports the D² results. The samples represent biologically different populations and can be separated by measurements of the deciduous teeth. The one exception to this is India. In the Principal Coordinate Analysis (Figure 3.2) the sample is located in the center of the graph between the European/European-derived and African/African-derived samples. Statistically (and biologically due to admixture among the populations of Eurasia), it is intermediate between these two large groups. This may explain why only 40% of the Indian sample were properly classified.
The author observed that most of the misclassifications occurred by placing of individuals into the India sample. A second discriminant function was created using just the Bolton Brush, Memphis, Freedman, England, and West African samples. The total accuracy rate of membership in a group classification improved to 66.9% (180/269) when using only five of the samples. The Bolton Brush individuals were properly classified at 81.3% (70/86). The Memphis and Freedman samples were classified correctly at 48.5% (32/66) and 68.5% (50/73) respectively. Individuals from the English sample were classified correctly at a rate of 80.7% (21/26) and West African individuals were classified correctly 38.9% (7/18) of the times. The majority of the misclassifications were the result of an individual being misclassified into other samples of the same ancestral group. For example, eight individuals from the Bolton Brush sample were misclassified into the England sample, while five were misclassified into Memphis, one into Dallas, and two into West Africa.

The five samples were then pooled into two samples: an European/European-derived sample (England and Bolton Brush) and an African/African-derived sample (Memphis, Freedman, and West Africa). The total accuracy rate of classification into a group improved to 88.5% (238/269). The accuracy rate of individuals of European or European-derived ancestry was 90.2% (101/112). Individuals of African and African-derived ancestry were correctly classified at a rate of 87.3% (137/157).

A discriminant function for just the modern American samples (Bolton Brush and Memphis) was then generated since these are the modern samples most likely to be used in a forensic situation. The total accuracy rate for group classification was 88%
(134/152). The Bolton Brush sample was properly classified at 90.7% (78/86), while the Memphis sample was properly classified 84.8% (56/66).

The following is an example of a test of an individual of unknown ancestry using the six functions. The log transformed measurement of Individual 1 were multiplied with each of the coefficients of the discriminant function and summed with the constant for that function (Table 3.12). Table 3.12 reports the results of the calculations. The largest number is the result of the Bolton Brush discriminant function, therefore, it can be assumed that Individual 1 is an European American child. The data of Individual 1 was, in fact, collected from a European American.
<table>
<thead>
<tr>
<th>Bolton Brush Function</th>
<th>Memphis Function</th>
<th>India Function</th>
<th>Freedman Function</th>
<th>England Function</th>
<th>West Africa Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-1053</td>
<td>-1136</td>
<td>-1132</td>
<td>-1164</td>
<td>-1116</td>
</tr>
<tr>
<td>Ui1md</td>
<td>59.41678</td>
<td>53.87010</td>
<td>56.51088</td>
<td>55.85950</td>
<td>44.93917</td>
</tr>
<tr>
<td>Ucmd</td>
<td>200.77270</td>
<td>196.63774</td>
<td>185.36222</td>
<td>190.41192</td>
<td>200.83281</td>
</tr>
<tr>
<td>Um1md</td>
<td>51.05396</td>
<td>67.97343</td>
<td>47.58228</td>
<td>54.44105</td>
<td>37.56365</td>
</tr>
<tr>
<td>Um2md</td>
<td>232.22008</td>
<td>234.89493</td>
<td>253.43505</td>
<td>231.75719</td>
<td>242.78794</td>
</tr>
<tr>
<td>Li1md</td>
<td>-65.55446</td>
<td>-50.15418</td>
<td>-61.97350</td>
<td>-48.75994</td>
<td>-57.55882</td>
</tr>
<tr>
<td>Li2md</td>
<td>-76.66015</td>
<td>-107.22253</td>
<td>-84.86835</td>
<td>-104.84741</td>
<td>-74.84286</td>
</tr>
<tr>
<td>Lm2md</td>
<td>589.42994</td>
<td>627.95831</td>
<td>617.16251</td>
<td>627.75527</td>
<td>625.82392</td>
</tr>
</tbody>
</table>

**Individual 1 data**

- Ui1md: 1.7749524
- Ui2md: 1.6389967
- Ucmd: 1.8269657
- Um1md: 1.8832746
- Um2md: 2.144761
- Li1md: 1.258461
- Li2md: 1.4516138
- Lcmd: 1.6389967
- Lm1md: 2.1423897
- Lm2md: 2.2278615

Table 3.12: 6 Sample Discriminant Functions
**Individual 1**

<table>
<thead>
<tr>
<th>Region</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolton Brush</td>
<td>973.27 *</td>
</tr>
<tr>
<td>Memphis</td>
<td>965.88</td>
</tr>
<tr>
<td>India</td>
<td>967.47</td>
</tr>
<tr>
<td>Freedman</td>
<td>964.87</td>
</tr>
<tr>
<td>England</td>
<td>967.50</td>
</tr>
<tr>
<td>West Africa</td>
<td>969.67</td>
</tr>
</tbody>
</table>

Table 3.13: Results of 6 Sample Discriminant Functions

The following is an example of using the Bolton Brush/ Memphis discriminant function using the data of Individual 1. As before, the discriminant function which results in the largest number is the sample (or ancestral group) into which the individual should be allocated.
<table>
<thead>
<tr>
<th></th>
<th>Bolton Brush</th>
<th>Memphis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-1182</td>
<td>-1269</td>
</tr>
<tr>
<td>Ui1md</td>
<td>69.70490</td>
<td>64.16253</td>
</tr>
<tr>
<td>Ui2md</td>
<td>-45.63869</td>
<td>-43.62830</td>
</tr>
<tr>
<td>Ucmd</td>
<td>322.64755</td>
<td>324.45992</td>
</tr>
<tr>
<td>Um1md</td>
<td>179.53526</td>
<td>198.66162</td>
</tr>
<tr>
<td>Um2md</td>
<td>246.30751</td>
<td>245.12390</td>
</tr>
<tr>
<td>Li1md</td>
<td>-111.76200</td>
<td>-93.96321</td>
</tr>
<tr>
<td>Li2md</td>
<td>-5.40711</td>
<td>-39.41384</td>
</tr>
<tr>
<td>Lcmd</td>
<td>-118.59371</td>
<td>-127.08939</td>
</tr>
<tr>
<td>Lm1md</td>
<td>-12.69987</td>
<td>-10.66680</td>
</tr>
<tr>
<td>Lm2md</td>
<td>550.42020</td>
<td>591.43169</td>
</tr>
</tbody>
</table>

**Individual 1 Data**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ui1md</td>
<td>1.7749524</td>
</tr>
<tr>
<td>Ui2md</td>
<td>1.6389967</td>
</tr>
<tr>
<td>Ucmd</td>
<td>1.8269657</td>
</tr>
<tr>
<td>Um1md</td>
<td>1.8832746</td>
</tr>
<tr>
<td>Um2md</td>
<td>2.144761</td>
</tr>
<tr>
<td>Li1md</td>
<td>1.258461</td>
</tr>
<tr>
<td>Li2md</td>
<td>1.4516138</td>
</tr>
<tr>
<td>Lcmd</td>
<td>1.6389967</td>
</tr>
<tr>
<td>Lm1md</td>
<td>2.1423897</td>
</tr>
<tr>
<td>Lm2md</td>
<td>2.2278615</td>
</tr>
</tbody>
</table>

**Individual 1**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolton Brush</td>
<td>1117.87*</td>
</tr>
<tr>
<td>Memphis</td>
<td>1110.77</td>
</tr>
</tbody>
</table>

Table 3.14: Bolton Brush/ Memphis Discriminant Functions and Results

The discriminant functions for all six samples, the five samples (Bolton Brush, Memphis, Freedman, England, and West Africa), the European/European-derived and
the African/African-derived samples, and the modern American samples (Bolton Brush and Memphis) are presented in full in Appendix XIV.

Since the BL measurements had unequal covariance matrices, a quadratic discriminant function was calculated (See Material and Methods). The quadratic function was calculated using only the modern European American (Bolton Brush) and modern African American (Memphis) samples, since the linear discriminant function created from these two samples had the greatest allocation accuracy rates. The posterior probabilities were examined for the number of observations and percentage classified correctly. A total of 86.3% (139/161) of the individuals was properly classified in the correct ancestry category. The European American (Bolton Brush) individuals were properly classified 83.7% (82/98) of the time. The African American (Memphis) individuals were properly classified 90.5% (57/63) of the time.

The formula,

$$H = -0.5X_0'(S_1^{-1} - S_2^{-1})X_0 + (\bar{X}_1'S_1^{-1} - \bar{X}_2'S_2^{-1})X_0 - K$$

can be used to determine the ancestral group of an unknown individual ($X_0$) by multiplying the log transformed BL measurements within the formula and subtracting $K$. $K$ was determined to be -233.3112 using the six samples of this study (See Materials and Methods). The test individual will be allocated to $P_1$ if $H$ is less than or equal to zero. The test individual will be allocated to $P_2$ if $H$ is greater than zero. The following is an example using the BL measurements of an individual from the Gullah collection.
The test individual logarithmic transformed data is presented in the order of $Ui^{bl}$, $Uu^{bl}$, $Uu^{abl}$, $Uu^{abl}$, $Li^{bl}$, $Li^{bl}$, $Lc^{bl}$, $Lm^{abl}$, and $Lm^{abl}$. The full formula, matrices included, can be found in Appendix O.

$$X_0 = 1.7491999, 1.7155981, 1.893112, 2.2066247, 2.3326292, 1.3837912, 1.5390154, 1.6311994, 1.9516082, 2.2539199$$

$$H = -4753.661$$

$P_1 = $ Bolton Brush (European American)

$P_2 = $ Memphis (African American)

Therefore, the $X_0$ is allocated into $P_1$, a misclassification; see Appendix O for the complete results of the quadratic discriminant function test.

### 3.16 Results of Analysis of Test Samples

### 3.17 Morphological Analysis

The logistic discriminant functions were created to determine if individuals of unknown ancestry could be allocated as either as an European American or African American. The study samples used to create these functions were the modern European Americans (Bolton Brush) and the modern African American (Memphis) samples. A total of 30 individuals, fifteen additional individuals from the Bolton Brush Collection (European American) and 15 from the Gullah Collection (African American), were used to test three of the logistic discriminant functions. The complete results can be found in Appendix P. The two trait cross tested was $m^1cn/c6$ with a classification accuracy of 77.8%, the three trait cross tested was $i^2td/m^1cn/c6$ (79.4%), and the four trait cross tested was $i^2td/ldr/m^1cn/c6$ (80.4%).

98
When the two trait cross was used to test the 30 individuals, the 1/15 (6.67%) of the Bolton Brush test subjects were allocated correctly as European American. Of the Gullah test subjects, 13/15 (86.67%) were allocated correctly as African American. The three trait cross results for the Bolton Brush test subjects were 1/15 (6.67%) correctly allocated as European American while 80% (12/15) of the Gullah were properly allocated as African American. The four trait cross results were the same at the three trait crosses with 1/15 (6.67%) of the Bolton Brush and 12/15 (80%) of Gullah test subjects properly allocated. When the total sample of 30 individuals is examined the two trait cross allocated 14/30 (46.67%) individuals properly and both the three trait cross and the four trait cross allocated 13/30 (43.33%) correctly.

3.18 Metric Analysis

A total of 30 individuals, fifteen additional individuals from the Bolton Brush Collection and 15 from the Gullah Collection, were used to test the discriminant functions generated from the data of the six samples. The complete results for each discriminant function analysis on the 30 test subjects can be found in Appendix P. When the six sample discriminant function was used, at total of 26.7% (4/15) of the Bolton Brush test subjects were correctly allocated into the Bolton Brush sample and one individual (6.67%) was allocated into the England sample. When the 15 individuals were from the Gullah collection was tested, 6.67% (1/15) were classified at Memphis (the closest sample temporally) but the other 14 individuals were allocated into either the Freedman (10/15, 66.67%) or the West Africa (4/15, 26.67%) samples.
Testing the same 15 tests subjects from the Bolton Brush Collection using the five sample (Bolton Brush, Memphis, Freedman, England, and West Africa) discriminant function, 26.7% (4/15) were once again allocated correctly. The use of the five sample discriminant functions produced similar results to the six sample results. One individual (6.67%) was allocated into the Memphis sample, while the other 14 individuals were allocated into the Freedman (10/15, 66.7%) and the West Africa sample (4/15, 26.67%). The allocation accuracy percentage increased to 40% (6/15) when the European/European-derived and the African/ African derived discriminant function was used on the Bolton Brush test subjects. When the Gullah test sample was analyzed using the same discriminant function all of the individuals (15/15, 100%) were allocated into the African/African-derived sample.

Using only the Bolton Brush/Memphis discriminant function, the allocated accuracy increased to 53% (8/15) for the Bolton Brush test subjects. When the Gullah test subjects were analyzed with the Bolton Brush/Memphis discriminant function, 14 out of the 15 individuals were allocated into the Memphis sample (93%).

When examining the accuracy of the four different types of discriminant function for the 30 individuals total, the most accurate in allocating individuals was the Bolton Brush/Memphis discriminant function. This discriminant function allocated 22 out of 30 individuals correctly for an accuracy rate of 73%. The next accurate was the European/European-derived versus the African/African-derived discriminant function with a 70% (21/30) accuracy rate. Both the multi-sample functions performed poorly,
with the six sample function correctly allocating only 13% (4/30) of the individuals and the five sample function allocating 10% (3/30) correctly.

The quadratic discriminant function was only tested on the Gullah test subjects. All 15 individuals were misallocated as European Americans and not as African Americans. Classification with quadratic functions is rather awkward when using more than two dimensions, often leading to strange results unless the samples are very different (Johnson and Wichern 1988). In the present case, the difficulty in applying this function and the poor results suggests this approach is not useful. See Appendix O for results.
CHAPTER 4

CONCLUSIONS

4.1 Morphological Analysis

4.2 Trait Variation

As more information is added to the literature regarding the variation of deciduous dental morphology, it becomes clear that there is a great deal of variability both among and within populations. The four samples Bolton Brush (European American), Memphis (African American), Dallas (African American), and England, analyzed for this study both support and contradict the literature on dental variation. Table 4.1 is a synopsis table presenting an overview of the dental frequencies for the permanent and deciduous dental frequencies from the literature. Table 4.2 presents a synopsis of the results from this study.
<table>
<thead>
<tr>
<th>Incidence</th>
<th>ui¹-uc shovel shape</th>
<th>uc tuberculum dentale</th>
<th>uc mesial ridge</th>
<th>m¹ hypocone presence</th>
<th>m² hypocone presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% Absent</td>
<td>A AA E EA</td>
<td>A AA E EA</td>
<td>D²</td>
<td>P³</td>
<td>A AA E EA</td>
</tr>
<tr>
<td>0.1-4.99% Unusual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-9.99% Rare</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-24.9% Low</td>
<td>P¹ D² P¹ D⁸</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-49.9% Intermediate</td>
<td>D⁷ D⁷</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-74.9% Common</td>
<td></td>
<td></td>
<td></td>
<td>P¹ D²</td>
<td></td>
</tr>
<tr>
<td>75-84.9% Frequent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D²</td>
</tr>
<tr>
<td>85-94.9% Prevalent</td>
<td></td>
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<td>100% Fixed</td>
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A- African populations
AA- African American populations
E- European populations
EA - European American populations


Table 4.1 Trait Frequencies in the Permanent and Deciduous dentition - continued
Table 4.1 continued

<table>
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<tr>
<th>Incidence</th>
<th>m2 Carabelli’s cusp</th>
<th>m2 c6</th>
<th>m2 c7</th>
<th>m2 Y-groove</th>
<th>m2 deflecting wrinkle</th>
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<tr>
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<td>P^6 D^2 P^6</td>
<td>D^2</td>
<td>D^7/P^1 D^2</td>
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<tr>
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<td>75-84.9% Frequent</td>
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</table>

A- African populations
AA- African American populations
E- European populations
EA - European American populations

Sources: 1. Scott and Turner 1997  
2. Hanihara 1967  
3. Morris 1975  
4. Scott 1973  
5. Helleman 1928  
6. Turner and Hawkey 1998  
7. Grine 1986  
8. Szlachetko 1959
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<tr>
<th>Incidence</th>
<th>ui′-uc shovel shape</th>
<th>uc tuberculum dentale</th>
<th>uc mesial ridge</th>
<th>m1 hypocone presence</th>
<th>m2 hypocone presence</th>
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BB- Bolton Brush 1. except ui′ - 11.4%
E - England 2. except ui′ - 68.7%
M - Memphis
F - Freedman

Table 4.2 Trait Frequencies of Present Study’s Samples - continued
Table 4.2 Continued

<table>
<thead>
<tr>
<th>Incidence</th>
<th>m2 Carabelli’s cusp</th>
<th>m2 c6</th>
<th>m2 c7</th>
<th>m2 Y-groove</th>
<th>m2 deflecting wrinkle</th>
</tr>
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<tbody>
<tr>
<td>0% Absent</td>
<td>BB E M F</td>
<td>BB E M F</td>
<td>BB E M F</td>
<td>BB E M F</td>
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BB- Bolton Brush
E - England
M - Memphis
F - Freedman
The frequencies of the shovel shape of the incisors among the four samples supports the generalization that the shovel shape will be found in higher frequencies on the maxillary anterior teeth as opposed to the mandibular teeth. The lateral incisors and canines are more likely to express the trait than the central incisors. For the central maxillary incisors, the European American (Bolton Brush) sample had a presence of 32%, England 11.4%, and the two African American samples (Memphis and Freedman) had frequencies of 34.4% and 38% respectively. For the lateral maxillary incisors, the frequencies were 51%, 33%, 68.7%, and 46% for the European American, England, Memphis and Freedman, respectively. Grine (1986) found comparative frequencies in African Americans (35%) and European Americans (52%) for the maxillary incisors. The canine shovel shape frequencies were 48% for the European American sample, 39% for the England sample, 45% for the Memphis sample, and 37.3% for the Freedman sample. Hanihara (1967) reports the presence of shovel shape incisors for European American and African American samples as 0% and 10% for the maxillary central incisors and 0% and 15% for the maxillary central incisors, respectively. But, Hanihara (1976) also reports frequencies in Caucasians and African and their derived populations as 0% and 20%, respectively, as well. Interestingly, Grine (1986) found the shovel shape trait on the maxillary canines to be greater in the South African black and African American sample than in the European American sample.

The European American sample had the greatest frequency for the presence of the tuberculum dentale on the maxillary central incisor with 20.4%, England was extremely low with 4.7%, Memphis had a frequency of 6%, and Freedman a frequency of 8%. The
frequency of the tuberculum dentale on the maxillary lateral incisor showed similar percentages with the European American sample having the greatest frequency at 16%, the England sample 7.7%, Memphis 3.5%, and Freedman 3%. The presence of the tuberculum dentale on the maxillary canine was much greater for all four samples. The European American frequency was 56%, the England sample was the next highest with 48%, Memphis was similar with 40%, and Freedman was the lowest frequency with 22.5%. Grine (1986) found a similar pattern when comparing South African blacks and European American and African American samples. South African blacks have the lowest frequency at under 20%, while the both American samples were above 28% (Grine 1986). Hanihara (1961) reports that 50% of European American deciduous maxillary canines exhibited double tuberculum dentale ridges.

A trait generally associated with African and African derived populations, the maxillary canine mesial ridge (Bushman’s canine), is found in higher frequency in the African American samples. The Memphis sample has a frequency of 2.6% and the Freedman sample 6.8%. The European American and England sample had frequencies of approximately 0%. It is not possible to compare the frequencies of this trait to other samples described in the literature, since the trait has not been reported for the deciduous dentition in most studies.

The maxillary canine distal ridge had the highest frequency in the European American sample at 11%, the Memphis sample had a frequency of 6%, the England sample 3.9%, and the Freedman sample had the lowest frequency at 1.9%. As with the maxillary canine mesial ridge, the distal ridge is not generally reported for studies
examining the deciduous dentition of African and European and their derived populations.

The findings of this study, in regard to the development of the hypocone of both the maxillary anterior and posterior molars, supports the findings of previous studies (Hanihara 1963, 1967, 1978, Grine 1986). Africans and African derived samples have a more well developed hypocones than European and European Americans. The exception being the frequency of the development of the hypocone on the posterior molar in the England sample which is comparable to the African American frequencies for the trait. The highest frequencies for the maxillary anterior molar hypocone were found in the Memphis and Freedman (African American) samples, at 17.8% and 19.6% respectively. The Bolton Brush (European American) and England samples had 5% and 3.7% respectively. The maxillary posterior hypocone development frequencies for Memphis and Freedman were 76% and 92% respectively. The Bolton Brush and England samples had higher frequencies than found in the development of the anterior molar hypocone, with 36.7% and 96% respectively. Jørgensen (1956) states that the four cusped maxillary posterior molar is the ancestral condition, 97-98% of his Danish sample expressed the hypocones.

It is commonly assumed that the cusp expression of the Carabelli’s trait on the maxillary posterior molar is most commonly found in European and European derived populations (Hanihara 1961, 1963, 1967). In the present study, the four samples had similar frequencies for the cusp expression of the trait. The European American (Bolton Brush) sample, has a frequency of 39.4% and the England sample had a frequency of
40.4%. The African American (Memphis and Freedman) had frequencies of 30.7% and 35.6%, respectively. In comparison, the pit expression was more common in the African American samples than the European or European American samples. The frequencies for the European American and England samples were both approximately 39% while both African American samples had frequencies about 50% (Memphis 57.9% and Freedman 51.%). This is similar to what Grine (1986) reports for South African blacks, where the pit or fissure expression was the most common expression of the trait in the sample. Hanihara (1968, 1976) found the cusp expression to by highest for European Americans at 35.7% (comparable to 39% found for this study) and African Americans at 11.8%. On the other hand, the pit expression was reported at 60% for European Americans and 68.6% for African Americans (Hanihara 1961, 1967). Jørgensen (1956) reports that the cusp expression was seen 12-13% in modern Danish children, while the fissure or pit expression had a frequency of 9-10.5%. The final expression welt (undefined by Jørgensen), cannot be compared to any of the present studies expressions, was the most common expression at 77.5% (Jørgensen 1956).

Another trait examined in the literature is the groove pattern of the mandibular posterior molar. The three most common types of groove pattern identified are the X, +, and Y patterns. In general, the + and the X pattern are associated with dental reduction and fewer cusps on the posterior molar (Jørgensen 1956) and the Y pattern is considered the ancestral pattern (Hanihara 1976). The Bolton Brush (European American) has the lowest frequency of the Y pattern with a 33% frequency. The Memphis (African American) sample has the next lowest frequency with 56.1%. Both the England and
Freedman (African American) samples have relatively high frequencies with a 63.1% and 69%, respectively. The most common groove pattern in the European American sample is the + plus pattern. The X pattern is low for all four samples. This is comparable to Grine’s (1986) findings in which the Y pattern was most common (89.7%) for South African blacks. While Szachetko (1959) reports a frequency of 57.1% for a sample of Polish Caucasians.

The deflecting wrinkle of the mandibular posterior molar also displays variation in presence among the samples. The England sample has the lowest frequency at 15% while the Freedman (African American) sample has the highest at 43.4%. The Memphis (African American) and the Bolton Brush (European American) have intermediate frequencies of 38.2% and 24.7%, respectively. These frequencies are much higher than Hanihara’s (1961, 1968) reported frequencies of 20% in African American and 11% in European Americans. Hanihara (1967, 1976) reported even lower frequencies of 13% and 19.1%, respectively. Grine (1986) reports that confusion may arise from difference among researchers in regard to what is the morphology of a deflecting wrinkle. If the swelling on cusp two is included into the definition of a deflecting wrinkle, South African blacks have the highest frequency at 84.6% (Grine 1986). If, what Grine (1986) terms as “true” deflecting wrinkle (the crest turning sharply to the distal margin), then the frequency for South African blacks is only 8%. The differences between the frequencies reported in this sample and the frequencies in the literature maybe due the inclusion of a “weak” deflecting wrinkle expression as a part of the presence of a
deflecting wrinkle on the posterior molar. Grine (1986) speculates that other researchers may have included this expression into the “swelling on cusp 2” category.

The extra cusps on the mandibular posterior molar, cusp 6 and cusp 7, also display differences among the samples. The European American and English samples have the lowest frequencies of cusp 6 with 7.3% and 14.4%, respectively. The African American samples have higher frequencies of 24.1% in the Memphis sample and 33% in the Freedman sample. Jørgensen (1956) reports a 2.5-2.9% frequency for modern Danish children. Hanihara (1976) reports the same frequency (7.3%) for his European American sample as is reported in this study for the Bolton Brush (European American) sample. The frequency for the African American sample was 12% (Hanihara 1976). Grine (1986) reports an 18.4% frequency for the South African black sample. The cusp 7 frequencies for the four samples in this study were all very high with the exception of the Freedman (African American) sample. The Bolton Brush sample (European American) had a frequency of 61%, while the England and Memphis (African American) samples had frequencies of 65% and 67.8%, respectively. The Freedman sample had the lowest frequency of 49%. Jørgensen (1956) reports a low frequency of 26.9% for modern Danish children, but Hanihara (1976) suspects this low frequency is due to differences in expression descriptions. Hanihara (1976) reports slightly lower frequencies of 40.7% and 46.8% for European American and African American samples, respectively. Grine (1986) reports that South African blacks have equal frequencies to African American samples for the presence of cusp 7, both of which are greater than the frequencies found in European American samples.
4.3 Mean Measure of Divergence (MMD)

Nine traits were used for the MMD analysis, the maxillary central incisor shovel shape, masillary canine tuberculum dentale, Carabelli’s trait on the maxillary posterior molar, mandibular anterior molar cusp number, mandibular posterior molar groove pattern, mandibular posterior molar deflecting wrinkle, mandibular posterior protostylid, mandibular posterior molar cusp 6, and mandibular posterior molar mesial trigonid crest. The MMD analysis reveals that the four samples, European American (Bolton Brush), Memphis (African American), Freedman (African American, and England, are significantly different from each other statistically. The four samples can be separated into European and European American and African American groupings. This statistical difference appears to reflect the biological dissimilarities due to the different ancestries among the samples.

The examination of the biological distance among the European, African, European American, and African American populations is complicated by admixture. Historically, the first Africans were brought to the United States from a variety of locations in West Africa and west-central Africa as slaves in the early 1600's but Africans were not a large population until after 1700 with the increased importation of slaves which continued at a high level through the 1800s (Reed 1969). Prior to the Civil War Era, admixture between European Americans (specifically male European Americans) and Africans slaves (specifically African females) was at a higher level than the post-Civil War time (Davis 1991). Also complicating admixture studies, is the fact that the degree of admixture between the populations differ from one area of the country to
another (Reed 1969, Pollitzer and Elston 1973) and also within a geographic area, such as the High South versus the Low South (Morgan 1970, Pollitzer and Elston 1973, Edgar 2002).

Therefore, the degree of admixture, which is presumed to be primarily from Europeans or European Americans into the African/African American population, is variable throughout time and geographic residency of the populations studied (Morgan 1970, Pollitzer and Elston 1973, Reed 1969, Edgar 2002). Admixture has occurred between Europeans and Africans during the early parts of the slave period (Davis 1991) and further admixture has occurred (and continues to occur) between the descendant populations of European Americans and African Americans (Reed 1969, Davis 1991) throughout the last 400 years of history. This has resulted in African Americans becoming more similar to European Americans genetically (Reed 1969, Morgan 1970, Edgar 2002). However, the biological differences among Europeans, Africans, European American and African Americans remain at levels sufficient to detect. Thus, dental traits can still be used for discrimination and allocation analyses. As time (and admixture) proceeds, the differences between European Americans and African Americans may (and probably) will continue to decrease, making it difficult to use statistical analyses based on biological distance (such as the MMD) or discriminant analysis to identify the ancestry of an individual. For this study, the separation of the samples into two different ancestral groupings implies that logistic discriminantion analysis would result in a high accuracy rate for allocation of new individuals.
4.4 Logistic Discrimination

In the logistic regression analysis, fifteen morphological traits were analyzed in order to determine the percentage of accuracy in ancestry identification of modern European Americans and African Americans in a forensic situation. The logistic discriminant functions posterior probability percentage identifies the likelihood that an individual is European American. High accuracy was defined as 70% or greater for the posterior probabilities of the logistic discriminant function. A total of 250 trait crosses out 785 discriminant functions created (31.85%), fit this criterion. The other logistic discriminant functions which did not meet this criterion of 70% or great accuracy, imply that the combination of those traits are not sufficient for discrimination between the two samples. Of the 250 trait crosses examined, 15.58% (12/77) two trait crosses were identified as being over 70% accurate at allocating an individual. Of the three traits logistic discriminant functions, 25.19% (66/262) were identified as being over 70% for allocation. Of the four trait discriminant functions created, 38.56% (172/446) were identified as being over 70% accurate at allocation. Two of the 172 four trait crosses have over an 80% accuracy rate.

As discussed previously, admixture between European Americans and African Americans is both a historical and ongoing biological process, which is resulting in African Americans becoming more similar to European Americans over time (Reed 1969, Morgan 1970, Pollitzer and Elston 1973, Davis 1991, Edgar 2002). Several admixture studies have given differing admixture percentages depending on the samples studied and the genetic trait examined (Morgan 1970). Reed (1969) states than an African American
individual has between 2% and 50% European American genetic material as part of his/her genome. A conservative estimate of admixture based on the Gm locus examined in African Americans in Oakland, California places the admixture percentage in the African American population at 22% (Reed 1969). Therefore, it is not surprising that only 250 out of 785 (31.85%) logistic discriminant functions have accuracy rates of 70% or higher.

While it is not possible to determine a generalized heritability estimate for dental morphology or crown size (see Introduction), the dentition is genetically controlled and is influenced by both evolutionary forces (e.g. selection, gene flow, genetic drift) and cultural/historical event. This does not mean, though, that the statistic is fatally flawed. Since uncorrelated traits were used for the MMD analysis, biological distance is being estimated by the analysis (Pollitzer and Elston 1973). Since there is significant biological distance between the modern European American and modern African American samples, the statistical assumptions hold for the logistic discriminant analysis.

4.5 Metric Analysis

4.6 Univariate Statistics

When examining the means of the each measurement, the six samples analyzed for this study conform to the generalization that African and African derived populations have larger dimensions than European and European derived populations (Harris and Lease nd., Harris 2001, Hanihara 1976). When the means of the measurements are compared for the three sex combined samples (Freedman, West Africa, and England), the Freedman African American sample has the largest dimensions in comparison to the
West African and the England samples. The exceptions are four buccolingual dimensions and one mesiodistal measurement. Only one measurement, the buccolingual measurement of the maxillary lateral incisor, was the England sample has a greater mean than the West African sample. For two of the buccolingual measurements, the mandibular central incisor and the mandibular posterior molar, the West African sample had the largest mean in comparison to the Freedman and England samples, respectively. The three samples had approximately equal means for the buccolingual means of the mandibular lateral incisor. The only mesiodistal dimension to vary from the African/African derived samples having the largest means was the mandibular canine in which the West African and England samples had approximately equal means.

When examining the means of the sex divided samples (Bolton Brush, Memphis, and India), the samples do not conform to this generalization. For the males, the India sample has the larger means that both the African American (Memphis) or the European American (Bolton Brush) samples. For six mesiodistal measurements the India and Memphis samples have approximately equal means, the maxillary central and lateral incisors, the mandibular anterior molar, and the maxillary and mandibular posterior molars. India and Memphis have approximately equal means for the buccolingual dimension of the maxillary canine. The Memphis sample has larger means than both the India and European American sample for the buccolingual dimension of the maxillary central incisor and the mesiodistal dimension of the mandibular central incisor. There is only one measurement in which the European American males (Bolton Brush) have the largest dimension, the buccolingual dimension of the maxillary canine. The European
American sample has a larger mean than the African American sample (Memphis) for the buccolingual measurement of the mandibular lateral incisor but is still smaller than the India mean.

As with the males in the European American (Bolton Brush), African American (Memphis), and India samples, the India females generally have the greatest means when comparing tooth dimensions. The Memphis females have greater or equal means of the mesiodistal measurement of the maxillary lateral incisor and the mesiodistal dimension of the mandibular anterior molar. The African American sample has a larger mean than both the India and European American samples for the mesiodistal measurement of the maxillary anterior molar. The females of the three samples have approximately equal means for the mesiodistal measurement of the maxillary canine. The European American females have only one dimension larger than the African American sample, the mesiodistal dimension of the lateral incisors, but are still smaller than the India mean for this tooth.

In comparison to results from previous studies (Harris and Lease nd, Harris 2001, Hanihara 1976, Lavelle 1970), the univariate results support the conclusion that European and European derived populations have smaller means than African and African derived populations. The fact that the India sample has, in general, larger means that the other sample is unusual. This may be explained by regional variation or admixture from the Asian populations. Too much emphasis should not be placed on the disparity between the results of the present study and other works regarding the dimensions of the deciduous dentition. A comparison performed by Grine (1986) among South African
blacks, African Americans, and European Americans shows that even without assumed admixture between European Americans and African Americans, overlap of the means can occur. For the mesiodistal measurements, the South African blacks were larger than the European American sample except for both the maxillary and mandibular canines and anterior molars, and the mandibular posterior molar (Grine 1986). The South African blacks have equal mesiodistal measurements to the African American sample examined by Hanihara (1976) except for the maxillary canine in which the South African black females have a larger dimension. Harris (2001) and Harris and Lease (nd) report that while there are differences among different populations worldwide, there is a great deal of similarity among populations with respect to the mesiodistal dimensions. European and European derived populations have been examined the most often in regard to dimensions, and it has been noted that there is a great deal of variation among various samples from this area (Harris 2001, Harris and Lease nd). Seipal’s (1946) Swedish sample has greater mesiodistal dimensions than either there the Lapps (Selmer-Olsen 1949) or modern European Americans from Cleveland, Ohio (Harris and Lease nd).

The low percentage of sexual dimorphism of the three samples that can be separated by sex also supports previous findings (Black 1978, Lavelle 1970, Sillman 1964, Moorrees 1959). The total amount of sexual dimorphism in the European American (Bolton Brush) sample was 1.15%, similar to the 2% found by Black (1978) and roughly half of the sexual dimorphism reported by Lavelle (1970) for British Caucasian children (3%). The 3% and 3.44% of sexual dimorphism found in the African American (Memphis) and India samples respectively, are still comparative to the amount
in the European American sample and other reported percentages. Lavelle (1970) reports a percentage of 1.2% for his West African sample.

Interestingly, Lavelle (1970) found that there was a greater amount of sexual dimorphism for the anterior teeth than the posterior teeth (4.6% versus 0.6% for Caucasians, and 1.7% versus 0.5% for West Africans). No such pattern can be discerned in the India sample in which all the measurements have high levels of sexual dimorphism (2% or greater), except for the buccolingual and mesiodistal measurements of mandibular central incisor (1.6% and 1.7%), the mesiodistal measurement of the mandibular lateral incisor (1.9%). The African American (Memphis) sample does display more sexual dimorphism in the maxillary dentition than the mandibular dentition. The anterior teeth has sexual dimorphism values of 3.5% or higher versus the mandibular teeth (2.8% or lower). The mandibular dentition has relatively low values except for the mesiodistal measurement of the central incisor (4.5%) and the mesiodistal diameters of the anterior and posterior molars (3.7% and 4.2% respectively). The European American (Bolton Brush) sample is unusual in that the females have larger dimensions for the buccolingual dimensions of the maxillary lateral incisor, canine, and the mandibular lateral incisor, canine and both molars (-0.46%, -0.52%, -2.3%, -0.82%, -0.86%, and -0.48% respectively). The other dimensions have relatively low sexual dimorphism values (below 2%), except for the buccolingual measurement of maxillary central incisor (4.5%), the maxillary anterior molar (2.1% buccolingual, 2.8% mesiodistal), and the mesiodistal dimension of the mandibular canine (2.6%).

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This variation in which teeth have greater sexual dimorphism and also variation among populations has also been reported in the literature. Black (1978) reports that females have larger mesiodistal dimensions for all of the incisors and the buccolingual dimension of the central incisor. Sillman’s (1964) study found that females had greater dimensions for all measurements except the maxillary central incisor and anterior molar. In contrast, Moorrees (1959), found that males were greater than females for all dimensions. Finally, the present study contradicts the finding of DeVito and Saunders (1990), in which they reported that the sexual dimorphism of a European American (Canadian) sample was similar to that found in permanent dentition (1.9-6.44%). It was also found that the sexual dimorphism was greater in the mesiodistal measurements of the maxillary dentition in contrast to the mandibular arcade. The teeth which displayed the greatest amount of sexual dimorphism were the right buccolingual measurement of the central incisor, both dimensions of the right and left maxillary lateral incisor, and the mesiodistal measurement of the right mandibular canine (DeVito and Saunders 1990).

4.7 Mahalanobis’s $D^2$

Mahalanobis’s $D^2$ was performed to determine if the six samples were significantly different statistically. The F tests indicate that all of the samples are statistically different from each other except the West Africa and the Freedman samples and the West Africa and Memphis samples. One possible explanation is that the populations form which the samples were taken, Freedman and Memphis, are more similar biologically to West Africans but differential gene flow with European Americans has caused the Memphis and Freedman samples to be dissimilar to each other. Another
explanation is that the disparities are due to the small sample size (N=18) of West Africa.
Analysis of the biological distance among the six samples indicates that there is a clear separation between the European (England) and the European American (Bolton Brush) samples and the African (West Africa) and the African American (Memphis and Freedman/Dallas) samples. The India sample is located in between the two other groupings which is reflected in both the univariate statistics and the discriminant analysis.
The statistical difference among the samples, more specifically the separation of European and European derived and African and African derived samples, reflects the biological dissimilarities among these groups.

While the history of the admixture between European Americans and African Americans has increased the genetic similarities between the two populations, other factors have influenced the genetic composition of African Americans. A cultural factor which has influenced admixture rates is assortative and negative mating patterns within the African American population (Morgan 1970, Pollitzer and Elston 1973). In some urban, nonsouthern African American populations such phenotypic traits such as darkness of skin pigmentation, lip thickness and nose width have played a part in mate choice (Morgan 1970). Pollitzer and Elston (1973) report that the Melungeons, which were descendants from ‘free persons of colour’ located in the Appalachian mountains, are rapidly disappearing due to out-marriage and out-migration.

Another factor that may have influenced the genetic material contributed to the modern African American population is from which European group the mates originated. Prior to the latter half of the 19th century, the majority of Europeans settling in
the United States were from western Europe. From the latter half of the 19th century to
the first part of the 20th century, the majority of the European immigrants were from
eastern and southern European (Edgar 2002). As Harris (2001) and Harris and Lease
(nd) have demonstrated, there is a wide variety in the mesiodistal dimensions of the teeth
among the different groups of Europe. This would impact crown size variation
depending on which European group was contributing to the African Americans genetic
material. Since most of the admixture between the two groups is one-directional, from
European Americans into the African American gene pool, this would cause African
Americans to become more similar to European Americans overtime (Reed 1969). It
should be also kept in mind that the variation in tooth size among African and African
derived populations has not been examined as fully as European and European derived
populations. While it has been documented that African and African derived populations
have larger tooth dimensions than Europeans and European derived populations (e.g.
and Rathbun 1991), the range of variation among groups has not been ascertained. For
example, Harris and Rathbun (1989) report on a South Carolina Planation slave sample,
which stands out for having small crown diameters when compared to other African
African samples. Therefore, while the samples are statistically significantly different,
indicating biological dissimilarities, there are several cultural and biological events that
have influenced the biology of the modern European Americans and modern African
Americans, which probably has acted to make the groups more similar and, thus decrease
the accuracy of the discrimination and allocation analyses.
4.8 Discriminant Analysis

The discriminant analysis was performed since the Mahalanobis’s $D^2$ values indicated that the samples were statistically significantly different from each other. This indicated that the populations the samples are drawn from are at least to some degree biologically different from each other. Of the four different discriminant analyses performed on the six samples, the discriminant function created from the modern European American (Bolton Brush) and African American (Memphis) samples produced the greatest accuracy for allocation when testing modern children. The total accuracy for ancestry allocation from this discriminant function was 88% with 90.7% of the European Americans and 84.8% of the African Americans being properly allocated during the analysis. Even though discriminant analysis is the most accurate for the samples the function is created from, this discriminant function can be of use in forensic situations in the United States. The discriminant function should be used in conjunction with other methods, such as other elements of the biological profile, time of disappearance, state of decomposition, associated evidence, and logistic analysis of the morphological dental traits, when determining the ancestry of a subadult skeleton/remains.

4.9 Comparison between the Analyses of the Morphology and Metric Data

4.10 MMD versus $D^2$

Both analyses separated the samples in the same manner with the European and European American samples clearly separated from the African and African American samples. The Principal Coordinate Analysis shows that 75% of the total variation of the metric data is contained on the first two axes. The first axis accounts for 48% of the
variation among the six samples in regards to the metric data, while the second axis accounts for 27% of the variation.

In comparison, the Principal Coordinate Analysis of the morphological data accounts for 93.8% of the total variation among the four samples, European American (Bolton Brush), African American (Memphis and Freedman), and English. Both India and West Africa were not included due to the lack of morphological data. The first axis accounts for 60.4% and the second axis accounts for 33.4% of the total variation.

4.11 Logistic versus Linear Discriminant Analyses

Both the logistic and the linear discriminant analyses show that the modern European (Bolton Brush) and Memphis (African American) samples can be used to created functions to allocate individuals with respect to ancestry. Two logistic discriminant functions have an accuracy over 80% using four traits to allocate an individual. This is similar to the 88% accuracy rate of the linear discriminant function for the allocation of European Americans and African Americans. Therefore, either procedure can be used for ancestry identification in a forensic situation but it is suggested to use both methods for greater precision.

4.12 Results of test samples

A total of 30 individuals, fifteen additional individuals from the Bolton Brush Collection (not included in the original sample) and 15 from the Gullah Collection, were used to test both the logistic discrimination and linear discriminant analyses. Three of the logistic discriminant functions were chosen to be tested, a two trait cross, a three trait cross, and a four trait cross. The two trait cross tested was m'cn/c6 with a classification
accuracy of 77.8%, the three trait cross tested was i\textsuperscript{1}td/m\textsuperscript{1}cn/c6 (79.4%), and the four trait cross tested was i\textsuperscript{1}td/lcdr/m\textsuperscript{1}cn/c6 (80.4%).

When the two trait cross was used to test the 30 individuals, the 1/15 (6.7%) of the Bolton Brush test subjects were allocated correctly. Of the Gullah test subjects, 13/15 (80%) were allocated correctly. The three trait cross results for the Bolton Brush test subjects were 1/15 (6.7%) correctly allocated while 80% (12/15) of the Gullah were properly allocated. The four trait cross results were the same at the three trait crosses with 1/15 (6.7%) of the Bolton Brush and 12/15 (80%) of Gullah test subjects properly allocated. When the total sample of 30 individuals was examined, the two trait cross allocated 14/30 (46.7%) individuals properly and both the three trait cross and the four trait cross allocated 13/30 (43.3%) correctly.

There are several sources that could be a contributing factor in the low allocation rates of the test subjects. Since the logistic discriminant functions were chosen randomly based on accuracy rate, it is possible that the trait crosses chosen for these tests did not accurately represent the traits which display the most variation between the groups. Other trait crosses which contain traits which due reflect a greater degree of variation between the two groups may yield higher allocation accuracy rates. Another possible explanation is that there is more variation in the expressions of the European American sample that can be accounted for in the logistic discriminant functions. The majority of the misallocations in the European American test subjects is due to a greater than expected complexity of the maxillary anterior morphology. Hanihara (1967) states the most common expression for European Americans is a two cusped maxillary anterior
molar (60%). Analysis of the Bolton Brush (European American) study sample supports Hanihara’s (1967) findings with a 61% frequency of a two cusped maxillary anterior molar. The test subjects from the Bolton Brush Collection, while randomly chosen, display a greater than expected range in the complexity of this trait.

It should also be kept in mind for both logistic discrimination and linear discriminant analysis, that discriminant functions are most accurate for the samples (populations) that the functions were created from. Therefore, since the Gullah sample was not part of the study samples used for the analysis, this sample may not be an appropriate test of these functions. Finally, as mentioned that since the Gullah (African American) sample was not part of the original six study samples, it is not know if the expressions of the morphological traits in the Gullah sample are more similar to the other African and African American samples or to the European and European American samples. Since the Gullah population was (and is) relatively small and genetically isolated, genetic drift may have acted upon the population and, by chance, the frequencies of the traits are more similar to modern European American frequencies than modern African American frequencies.

A test was made of the modern European American (Bolton Brush) and African American (Memphis) discriminant function using the previous 30 tests subjects (15 European American and 15 African American). The function correctly allocated 73% of subjects to their ancestral category. The accuracy of allocation of the European American test subjects was 53% (8/15). When the African American test subjects were analyzed with the discriminant function, 14 out of the 15 individuals (93%) were allocated into the
African American category. The difference between the allocation accuracy percentages may be due to the documented variation in the size of the teeth in European populations from which the European American sample is derived (Harris, 2001, Harris and Lease, n.d.). The Gullah test subjects are from a sample which has been documented to have little admixture with other populations (Menegaz-Bock 1968). At this time, the variation among African and African derived populations is unknown. Another possible contributing factor is sexual dimorphism. For the mesiodistal dimensions, the European American study sample as a 1.9% sexual dimorphism value while the African American test sample has a 3% value.

4.13 Applicability of Present Study and Future Directions for Research

The goal of the present study was to determine if the deciduous dentition’s morphology and metrics could be used as features to determine ancestry in modern European Americans and African Americans. The results of this study have shown that sufficient variation between group variation exists in deciduous dentition for its use in discrimination between European Americans and African Americans.

The analysis of the morphological data reveals that there is variation among the samples, which can be used to distinguish between modern European Americans and African Americans. These differences in trait frequencies are significant, reflecting the biological differences among the samples. Due to this biological difference among the samples, logistic discriminant analysis can be used to discriminate between the modern European American and African American samples. These logistic discriminant
functions have an allocation accuracy rate of 70% or greater and can then be used to allocate new individuals into ancestral categories.

The analysis of the metric data reveals that there are also differences among mesiodistal dimensions of the samples. The linear discriminant functions, using the mesiodistal dimensions, have allocation rates of 80% or greater and can be used for allocation of new individuals into ancestral categories.

This study is limited in scope as just six samples were analyzed and are therefore, not completely representative of the ancestral groups studied. To strengthen these methods, data must be collected from a number of European samples, not just England. Ideally, all populations found in Europe should be represented. In addition, there should also be a temporal range to these samples. A similar collection of samples should represent Africa, both geographically and temporally. In the United States, multiple samples are needed to represent different geographic areas. For example, samples should represent European Americans and African Americans in both the North and South, as well as the West and East coast. These samples should also represent populations at different times as well. This expanded collection should reflect better the variation found within the ancestral groups better and will decrease errors in discrimination and allocation analyses.
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APPENDIX A

DESCRIPTION OF MORPHOLOGICAL TRAITS
The abbreviations in the morphological analysis are as follows: u = maxillary teeth, l = mandibular teeth, i = incisors, 1 = central, 2= lateral, c = canine, m1 = anterior molar, m2 = posterior molar. These traits represent the most commonly observed traits for populational studies using deciduous dentitions. The following descriptions should aid in inter-study comparisons, since variations in the descriptions have occurred from one study to another.

**Shovel shape**

All anterior teeth (u1-uc and l1-lc) were scored for the development of lingual ridges following Hanihara’s (1963) criteria.

- 0 Absent: lingual surface smooth
- 1 Semishovel: slight
- 2 Shovel: marginal ridges present
- 3 Strong shovel: marginal ridges broad and wide

Expressions 0 and 1 were designated as the absence of the shovel shape trait, expressions 2 and 3 where designated at the presence of the trait in the individual. The frequency of the trait in the population can then be expressed at p = 2-3 / 0-3. With 2-3 as the number of individuals having the expression 2 or 3 and 0 and 1 being the individuals, who are not expressing this feature (Sciulli 1998). All other traits will follow a similar format.

**Double-shovel**

All anterior teeth (u1-uc and l1-lc) were scored for the presence of labial marginal ridges.

- 0 Absent
- 1 Mesial ridge present
- 2 Distal ridge present
- 3 Both Mesial and Distal ridges present

p = 1-3 / 0-3
**Incisor interruption groove**

The maxillary incisors (ui1-ui2) were scored for the presence of grooves extending from the root over the cemento-enamel junction following Turner *et al.* 1991 criteria

- 0 Absent
- 1 groove on the mesiolingual surface
- 2 groove on the distolingual surface
- 3 one groove centrally located
- 4 two grooves, one mesiolingual and the other distolingual

\[ p = 1.4 / 0.4 \]

**Tuberculum dentale**

The maxillary anterior teeth (ui1-uc) were examined for the degree of development of the elaborations in the area of the lingual cingulum and lingual fossa using Grine (1986) criterial

- 0 Absent
- 1 pit(s) or groove(s) present
- 2 one ridge
- 3 two ridges
- 4 free tubercle

\[ p = 1.4 / 0.4 \]

**Canine Mesial ridge**

The maxillary canine (uc) were scored for the presence or absence of a distal deflection of the mesial marginal ridge (Irish and Morris 1996).

- 0 Absent
- 1 tuberculum dentale and mesial lingual ridge weakly joined
- 2 tuberculum dentale and mesial lingual ridge joined - medium
- 3 tuberculum dentale and mesial lingual ridge joined - strong

\[ p = 1.3 / 0.3 \]
Canine distal ridge
Using Turner et al (1991) criteria, all canines (uc, lc) were examined for the degree of expression of an accessory ridge on the lingual surface of the canines between the cusp apex and the distal marginal ridge.

0 Absent
1 Faint
2 Weak
3 Moderate
4 Strong

p = 1-4 / 0-4

Cusp number, hypocone of maxillary first deciduous molar
The development of the hypocone on the anterior molar was scored using Hanihara’s 1963 criteria.

2  Eocone and protocone present
3M  Eocone, protocone, and metacone present
3H  Eocone, protocone, and hypocone present
4-  All four cusps present, hypocone reduced
4  All four cusps present, no reduction in hypocone

For the purposes of calculating presence and absence frequencies, expression 2 remains expression 2, expression 3M = 3, 3H = 4, with 4- and 4 being combined into expression 5.

p = 5 / 2-5

Cusp number, hypocone of maxillary second deciduous molar
Using Hanihara’s 1963 criteria, the development of the second deciduous molar’s hypocone was scored.

3 +A  Eocone, protocone, metacone present, small distally placed hypocone
3 +B
4-  Eocone, protocone, metacone attached to small hypocone by distal ridge
4  Eocone, protocone, metacone and large hypocone

For the purposes of calculating presence and absence frequencies, expression 3+A becomes 3, expression 3+B becomes expression 4, with expressions 4- and 4 become expression 5 and 6 respectively.

p = 5-6 /3- 6
Cusp 5
An accessory cusp located between the metacone and hypcone of the upper second molar (um2) was scored at present or absent following Sciulli 1998 criteria.

0 Absent
1 Present

\[ p = 1 / 0-1 \]

Carabelli’s trait
Elaborations of mesiolingual surface of um2 was scored using Grine’s (1986) criteria.

0 Absent
1 pit or groove present
2 two grooves, roughly parallel
3 welt or cusp with apex not free
4-6 free cusp(s) increasing in size

\[ p = 2-6 / 0-6 \]

m1 cusp number
Enumeration of cusps present on the lower anterior molar

2 Eoconid and metaconid present
3 Eoconid, metaconid, and hypoconid present
4 Eoconid, metaconid, hypoconid and entoconid present
5 Eoconid, metaconid, hypoconid, entoconid, and hypoconulid present
6-8 accessory cusps on distal marginal ridge

\[ p = 5-8 / 2-8 \]

Molar groove pattern
Relationship among principle cusps of lower m2 is scored yielding the following groove patterns (Sciulli 1998):

1 +: Eoconid, metaconid, hypoconid and entoconid in contact
2 X: eoonid and entoconid in contact
3 Y: metaconid and hypoconid in contact

\[ p = 3 / 1-3 \]
**m2 cusp number**

Enumeration of cusps present on the lower anterior molar

1. Eoconid, metaconid, hypoconid, entoconid present
2. Eoconid, metaconid, hypoconid, entoconid, and hypoconulid present
3. Eoconid, metaconid, hypoconid, entoconid, hypoconulid, and the tuberculum sextum present

p was not calculated for this trait.

**Deflecting wrinkle**

The course of the medial ridge of the metaconid of lm2 was scored as straight or deflected distally using Sciulli’s (1998) criteria.

0 Absent
1 Swelling on metaconid
2 Small deflecting wrinkle
3 Strong deflecting wrinkle

p = 2-3 / 0-3

**Protoconulid**

The development of elaborations of the mesiobuccal surface of lm2 was scored using Grine’s (1986) criteria.

0 Absent
1 pit in buccal groove
2 curved buccal groove
3 small cusp, initial groove
4 slight cusp
5 moderate cusp
6 large cusp

p = 1-6 / 0-6
**Tuberculum sextum or cusp 6**

The development of the accessory cusp 6, located between the hypoconulid and entoconulid, was scored using Turner’s *et al.* (1991) criteria:

- 0 Absent
- 1 hypoconulid >> C 6
- 2 hypoconulid > C 6
- 3 hypoconulid = C 6
- 4 hypoconulid < C 6
- 5 hypoconulid << C 6

\[ p = 1-5 / 0-5 \]

**Tuberculum itermedium or cusp 7**

The development of the accessory cusp 7, located between the metaconid and the entoconid, was scored following Sciulli’s (1998) criteria:

- 0 Absent
- 1 Weak grooves at metaconid and entoconid
- 2 C 7 on metaconid weakly
- 3 small distinct cuspule
- 4 medium size cusp
- 5 large cusp

\[ p = 1-5 / 0-5 \]

**Mesial trigoid crest**

The present or absence of a continuous ridge from the distal border of the eocnid to the distal border of the metaconid was scored using Turner’s *et al.* (1991) criteria

- 0 Absent
- 1 Present

\[ p = 1 / 0-1 \]
APPENDIX B

DESCRIPTION OF METRIC TRAITS
The abbreviations in the metric analysis are as follows: u = maxillary teeth, l = mandibular teeth, i = incisors, 1 = central, 2 = lateral, c = canine, m1 = anterior molar, m2 = posterior molar. The following measurements (excluding m\textsuperscript{1}pbl, m\textsuperscript{2}pbl, m\textsubscript{3}abl, m\textsubscript{4}abl, and ch\textsubscript{1}-ch\textsubscript{6}) represent the most commonly taken measurements in skeletal and dental analyses. M\textsuperscript{1}pbl, M\textsuperscript{2}pbl, M\textsubscript{1}abl, M\textsubscript{2}abl, and ch\textsubscript{1}-ch\textsubscript{6} were measured to examine shape variations within populations.

<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<td>i\textsuperscript{1}bl</td>
<td>maxillary central incisor buccal lingual width</td>
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<tr>
<td>i\textsuperscript{1}md</td>
<td>maxillary central incisor mesial distal width</td>
</tr>
<tr>
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APPENDIX C

MORPHOLOGICAL TRAIT EXPRESSION FREQUENCIES AND WEIGHTED AVERAGES
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APPENDIX D

MONTE CARLO ANALYSES
1. A12 (Abington 12th century) vs A17 (Abington 17th century) = \(A_T\) (total Abington data)
2. \(A_T\) vs. P (Poundbury) = AP (pooled Abington and Poundbury data)
3. S (Spitalfields) vs. M (modern English) = SM (pooled Spitalfields and modern data)

4. AP vs. SM = pooled total English data

Top of matrix = measurements which are significantly different, Bottom of matrix = number of measurements

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Table D.1 Monte Carlo Analysis of Metric Data
1. A12 (Abington 12th century) vs A17 (Abington 17th century) = A_T (total Abington data)
2. A_T vs. P (Poundbury) = AP (pooled Abington and Poundbury data)
3. S (Spitalfields) vs. M (modern English) = SM (pooled Spitalfields and modern data)
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Top of matrix = measurements which are significantly different, Bottom of matrix = number of measurements

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Table D.2 Monte Carlo Analysis of Morphological Data
APPENDIX E

MORPHOLOGICAL TRAITS ABSENCE/ PRESENCE FREQUENCIES
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APPENDIX F

CHI-SQUARE RESULTS - TRAIT COMPARISON
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<td>.094</td>
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\(\chi^2_{0.05(1)} = 3.84\)
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<td>4.15*</td>
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\( \chi^2_{05(1)} = 3.84 \)
APPENDIX G

MEAN MEASURE OF DIVERGENCE AND CHI-SQUARE VALUES
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<th>Carabelli’s trait</th>
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<td>England/ Dallas</td>
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\[ \chi^2_{0.05(1)} = 3.84 \]

* = significantly different
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<th>m, protostylid</th>
<th>m, enoconulid c6</th>
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\[
\chi^2_{05(1)} = 3.84
\]

* = significantly different
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\[ \chi^2_{05(1)} = 3.84 \]

* = significantly different
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<td>MMD= .1903761 ± .04</td>
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$\chi^2_{05(9)} = 16.91$

* = significantly different
APPENDIX H

LOGISTIC DISCRIMINATION ANALYSIS
70- 79%

TWO TRAIT CROSSES

i² shovel shape/ m¹ cusp number
maxillary canine shovel shape/ m¹ cusp number
i¹ tuberculum dentale/ m¹ cusp number
i² tuberculum dentale/ m¹ cusp number
maxillary canine tuberculum dentale/ m¹ cusp number
mandibular canine distal ridge/ m¹ cusp number
m¹ cusp number/ m² fifth cusp
m¹ cusp number/ Carabelli’s trait
m¹ cusp number/ m₂ deflecting wrinkle
m¹ cusp number/ m₂ entoconulid
m¹ cusp number/ m₂ metaconulid
m¹ cusp number/ m₂ mesial trigoid crest

THREE TRAIT CROSSES

i² shovel shape/ maxillary canine shovel shape/ m¹ cusp number
i² shovel shape/ i¹ tuberculum dentale/ m¹ cusp number
i² shovel shape/ i² tuberculum dentale/ m¹ cusp number
i² shovel shape/ maxillary canine shovel shape/ m¹ cusp number
i² shovel shape/ mandibular canine distal ridge/ m¹ cusp number
i² shovel shape/ m¹ cusp number/ m² fifth cusp
i² shovel shape/ m¹ cusp number/ Carabelli’s trait
i² shovel shape/ m¹ cusp number/ m₂ deflecting wrinkle
i² shovel shape/ m¹ cusp number/ m₂ entoconulid
i² shovel shape/ m¹ cusp number/ m₂ metaconulid
i² shovel shape/ m¹ cusp number/ m₂ mesial trigoid crest
maxillary canine shovel shape/ i¹ tuberculum dentale/ m¹ cusp number
maxillary canine shovel shape/ i² tuberculum dentale/ m¹ cusp number
maxillary canine shovel shape/ maxillary canine tuberculum dentale/ m¹ cusp number
i² shovel shape/ mandibular canine distal ridge/ m¹ cusp number
maxillary canine shovel shape/ m¹ cusp number/ m² fifth cusp
maxillary canine shovel shape/ m¹ cusp number/ Carabelli’s trait
maxillary canine shovel shape/ m¹ cusp number/ m₂ deflecting wrinkle
maxillary canine shovel shape/ m¹ cusp number/ m₂ entoconulid
maxillary canine shovel shape/ m¹ cusp number/ m₂ metaconulid
maxillary canine shovel shape/ m¹ cusp number/ m₂ mesial trigoid crest
i¹ tuberculum dentale/ i² tuberculum dentale/ m¹ cusp number

Table H. 1 Summary List of 70% and above Logistic Discrimination Functions
Bolton Brush and Memphis Samples - Continued
| i° tuberculum dentale/ maxillary canine tuberculum dentale/ m¹ cusp number |
| i° tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number |
| i° tuberculum dentale/ m¹ cusp number/ Carabelli’s trait |
| i° tuberculum dentale/ m¹ cusp number/ m₂ deflecting wrinkle |
| i° tuberculum dentale/ m¹ cusp number/ m₂ entoconulid |
| i° tuberculum dentale/ m¹ cusp number/ m₂ metaconulid |
| i° tuberculum dentale/ m¹ cusp number/ m₂ mesial trigoid crest |
| i° tuberculum dentale/ m² fifth cusp/ m¹ cusp number |
| i° tuberculum dentale/ maxillary canine tuberculum dentale/ m¹ cusp number |
| i² tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number |
| i² tuberculum dentale/ m¹ cusp number/ m² fifth cusp |
| i² tuberculum dentale/ m¹ cusp number/ Carabelli’s trait |
| i² tuberculum dentale/ m¹ cusp number/ m₂ deflecting wrinkle |
| i² tuberculum dentale/ m¹ cusp number/ m₂ entoconulid |
| i² tuberculum dentale/ m¹ cusp number/ m₂ metaconulid |
| i² tuberculum dentale/ m¹ cusp number/ m₂ mesial trigoid crest |
| maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number |
| maxillary canine tuberculum dentale/ m¹ cusp number/ m² fifth cusp |
| maxillary canine tuberculum dentale/ m¹ cusp number/ Carabelli’s trait |
| maxillary canine tuberculum dentale/ m¹ cusp number/ m₂ deflecting wrinkle |
| maxillary canine tuberculum dentale/ m¹ cusp number/ m₂ entoconulid |
| maxillary canine tuberculum dentale/ m¹ cusp number/ m₂ metaconulid |
| maxillary canine tuberculum dentale/ m¹ cusp number/ m₂ mesial trigoid crest |
| mandibular canine distal ridge/ m¹ cusp number/ m² fifth cusp |
| mandibular canine distal ridge/ m¹ cusp number/ Carabelli’s trait |
| mandibular canine distal ridge/ m¹ cusp number/ m₂ deflecting wrinkle |
| mandibular canine distal ridge/ m¹ cusp number/ m₂ entoconulid |
| mandibular canine distal ridge/ m¹ cusp number/ m₂ metaconulid |
| mandibular canine distal ridge/ m¹ cusp number/ m₂ mesial trigoid crest |
| m¹ cusp number/ m² fifth cusp/ Carabelli’s trait |
| m¹ cusp number/ m² fifth cusp/ m₂ deflecting wrinkle |
| m¹ cusp number/ m² fifth cusp/ m₂ entoconulid |
| m¹ cusp number/ m² fifth cusp/ m₂ metaconulid |
| m¹ cusp number/ m² fifth cusp/ m₂ mesial trigoid crest |
| m¹ cusp number/ Carabelli’s trait/ m₂ deflecting wrinkle |
| m¹ cusp number/ Carabelli’s trait/ m₂ entoconulid |
| m¹ cusp number/ Carabelli’s trait/ m₂ metaconulid |
| m¹ cusp number/ Carabelli’s trait/ m₂ mesial trigoid crest |
| m¹ cusp number/ m₂ deflecting wrinkle/ m₂ entoconulid |
| m¹ cusp number/ m₂ deflecting wrinkle/ m₂ metaconulid |
| m¹ cusp number/ m₂ deflecting wrinkle/ m₂ mesial trigoid crest |
Table H.1 Continued

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Table H.1 Continued

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| i^1 tuberculum dentale/ maxillary canine tuberculum dentale/ m^1 cusp number/ m^2 mesial trigoid crest |
| i^1 tuberculum dentale/ mandibular canine distal ridge/ m^1 cusp number/ m^2 fifth cusp |
| i^1 tuberculum dentale/ mandibular canine distal ridge/ m^1 cusp number/ Carabelli’s trait |
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| i^1 tuberculum dentale/ m^1 cusp number/ m^2 fifth cusp/ m^2 deflecting wrinkle |
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| i^1 tuberculum dentale/ m^1 cusp number/ Carabelli’s trait/ m^2 mesial trigoid crest |
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| i^1 tuberculum dentale/ m^1 cusp number/ m^2 entoconulid/ m^2 mesial trigoid crest |
| i^1 tuberculum dentale/ m^1 cusp number/ m^2 metaconulid/ m^2 mesial trigoid crest |
| i^2 tuberculum dentale/ maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m^1 cusp number |
| i^2 tuberculum dentale/ maxillary canine tuberculum dentale/ m^1 cusp number/ m^2 fifth cusp |
| i^2 tuberculum dentale/ maxillary canine tuberculum dentale/ m^1 cusp number/ Carabelli’s trait |
| i^2 tuberculum dentale/ maxillary canine tuberculum dentale/ m^1 cusp number/ m^2 deflecting wrinkle |
| i^2 tuberculum dentale/ maxillary canine tuberculum dentale/ m^1 cusp number/ m^2 entoconulid |
| i^2 tuberculum dentale/ maxillary canine tuberculum dentale/ m^1 cusp number/ m^2 metaconulid |
Table H.1 Continued

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\( i^2 \) tuberculum dentale/ mandibular canine distal ridge/ m\(^1\) cusp number/ m\(^2\) fifth cusp
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\( i^2 \) tuberculum dentale/ mandibular canine distal ridge/ m\(^1\) cusp number/ m\(^2\) deflecting wrinkle
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maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m\(^1\) cusp number/ m\(^2\) deflecting wrinkle
maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m\(^1\) cusp number/ m\(^2\) entoconulid
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maxillary canine tuberculum dentale/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) deflecting wrinkle
maxillary canine tuberculum dentale/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) entoconulid

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Table H.1 Continued

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193
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80% accuracy

i² shovel shape/ m¹ cusp number/ m² entoconulid/ m₂ mesial trigoid crest

i² tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number/ m² entoconulid
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### maxillary canine shovel shape/ m$^1$ cusp number

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**i² shovel shape/ mandibular canine distal ridge/ m¹ cusp number**

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**maxillary canine shovel shape/ m¹ cusp number/ Carabelli’s trait**

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**maxillary canine shovel shape/ m¹ cusp number/ m² fifth cusp**

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**maxillary canine shovel shape/ m¹ cusp number/ m₂ deflecting wrinkle**

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### Table H.2 Continued

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Table H.2 Continued

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<th>i² tuberculum dentale/ m¹ cusp number/ m₂ mesial trigoid crest</th>
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<th>maxillary canine tuberculum dentale/ ( m^1 ) cusp number/ ( m^2 ) fifth cusp</th>
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<td>--------------------------------------------------</td>
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<tr>
<td>N2 = 99</td>
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Table H.2 Continued

**mandibular canine distal ridge/ m₁ cusp number/ Carabelli’s trait**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ deflecting wrinkle**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ entoconulid**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ metaconulid**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ deflecting wrinkle**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ metaconulid**

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### m\textsuperscript{1} cusp number/ Carabelli’s trait/ m\textsubscript{2} metaconulid

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<th>i\textsuperscript{1} tuberculum dentale/ mandibular canine distal ridge/ m\textsuperscript{1} cusp number/ m\textsuperscript{2} fifth cusp</th>
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Table H.2 Continued

**i\textsuperscript{1} tuberculum dentale/ mandibular canine distal ridge/ m\textsuperscript{1} cusp number/ m\textsubscript{2} mesial trigoid crest**

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N1 = 97  
N2 = 87  
correct = 73.9%

**i\textsuperscript{1} tuberculum dentale/ m\textsuperscript{1} cusp number/ m\textsuperscript{2} fifth cusp/ Carabelli’s trait**

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N1 = 90  
N2 = 93  
correct = 71%

**i\textsuperscript{1} tuberculum dentale/ m\textsuperscript{1} cusp number/ m\textsuperscript{2} fifth cusp/ m\textsuperscript{2} deflecting wrinkle**

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N1 = 87  
N2 = 86  
correct = 72.8%

**i\textsuperscript{1} tuberculum dentale/ m\textsuperscript{1} cusp number/ m\textsuperscript{2} fifth cusp/ m\textsuperscript{2} entoconulid**

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N1 = 86  
N2 = 89  
correct = 74.9%
Table H.2 Continued

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N2 = 89  
correct = 73.2% | N1 = 96  
N2 = 86  
correct = 72.5% |

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| N1 = 99  
N2 = 109  
correct = 74.5% | N1 = 97  
N2 = 102  
correct = 74.2% |
| white | black | total | white | black | total |
| white 68 | 31 | 99 | white 72 | 25 | 97 |
| black 22 | 87 | 109 | black 26 | 75 | 102 |
| total 90 | 118 | 155 | total 98 | 100 | 147 |

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N2 = 105  
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| white 77 | 19 | 96 | white 76 | 24 | 100 |
| black 25 | 80 | 105 | black 28 | 77 | 105 |
| total 102 | 99 | 157 | total 104 | 101 | 153 |
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maxillary canine tuberculum dentale/ m¹ cusp number/ m² fifth cusp/ entoconulid

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**mandibular canine distal ridge/ m¹ cusp number/ Carabelli’s trait/ m² mesial trigoid crest**

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**mandibular canine distal ridge/ m¹ cusp number/ m² deflecting wrinkle/ m² entoconulid**

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**mandibular canine distal ridge/ m¹ cusp number/ m² deflecting wrinkle/ m² metaconulid**

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**mandibular canine distal ridge/ m¹ cusp number/ m² deflecting wrinkle/ m² mesial trigoid crest**

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# TWO TRAIT DISCRIMINANT FUNCTIONS

### i² shovel shape/ m¹ cusp number

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### maxillary canine shovel shape/ m¹ cusp number

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### i¹ tuberculum dentale/ m¹ cusp number

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### i² tuberculum dentale/ m¹ cusp number

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Table H.3 Logistic Discrimination Functions - Continued

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Table H.3  Continued

**maxillary canine tuberculum dentale/ \( m_1 \) cusp number**

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**mandibular canine distal ridge/ \( m_1 \) cusp number**

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**\( m_1 \) cusp number/ \( m_2 \) fifth cusp**

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**\( m_1 \) cusp number/ Carabelli’s trait**

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**\( m_1 \) cusp number/ \( m_2 \) deflecting wrinkle**

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Table H.3  Continued

$m^1$ cusp number/ $m_2$ entoconulid

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$m^1$ cusp number/ $m_2$ metaconulid

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$m^1$ cusp number/ $m_2$ mesial trigoid crest

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Table H.3  Continued

**THREE TRAIT DISCRIMINANT FUNCTIONS**

### $i^2$ shovel shape/ maxillary canine shovel shape/ m' cusp number

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### $i^2$ shovel shape/ i' tuberculum dentale/ m' cusp number

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### $i^2$ shovel shape/ i' tuberculum dentale/ m' cusp number

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### i² shovel shape/ m¹ cusp number/ Carabelli’s trait

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### i² shovel shape/ m¹ cusp number/ m₂ deflecting wrinkle

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### Table H.3  Continued

#### i² shovel shape/ m¹ cusp number/ m₂ entoconulid

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#### i² shovel shape/ m¹ cusp number/ m₂ metaconulid

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#### i² shovel shape/ m¹ cusp number/ m₂ mesial trigoid crest

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#### maxillary canine shovel shape/ i¹ tuberculum dentale/ m¹ cusp number

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Table H.3  Continued

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**maxillary canine shovel shape/ maxillary canine tuberculum dentale/ m\textsuperscript{1} cusp number**

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**i\textsuperscript{2} shovel shape/ mandibular canine distal ridge/ m\textsuperscript{1} cusp number**

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**maxillary canine shovel shape/ m\textsuperscript{1} cusp number/ m\textsuperscript{2} fifth cusp**

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Table H.3  Continued

maxillary canine shovel shape/ m1 cusp number/ Carabelli’s trait

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maxillary canine shovel shape/ m1 cusp number/ m2 deflecting wrinkle

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maxillary canine shovel shape/ m1 cusp number/ m2 entoconulid

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maxillary canine shovel shape/ m1 cusp number/ m2 metaconulid

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maxillary canine shovel shape/ m₁ cusp number/ m₂ mesial trigoid crest

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i¹ tuberculum dentale/ i² tuberculum dentale/ m₁ cusp number

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i¹ tuberculum dentale/ maxillary canine tuberculum dentale/ m₁ cusp number

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i¹ tuberculum dentale/ mandibular canine distal ridge/ m₁ cusp number

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Table H.3  Continued

i<sup>1</sup> *tuberculum dentale/ m<sup>1</sup> cusp number/ Carabelli’s trait

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i<sup>1</sup> *tuberculum dentale/ m<sup>1</sup> cusp number/ m<sub>2</sub> deflecting wrinkle

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i<sup>1</sup> *tuberculum dentale/ m<sup>1</sup> cusp number/ m<sub>2</sub> entoconulid

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i<sup>1</sup> *tuberculum dentale/ m<sup>1</sup> cusp number/ m<sub>2</sub> metaconulid

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Table H.3  Continued

i¹ **tuberculum dentale/ m¹ cusp number/ m₂ mesial trigoid crest**

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i¹ **tuberculum dentale/ m² fifth cusp/ m¹ cusp number**

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i² **tuberculum dentale/ maxillary canine tuberculum dentale/ m¹ cusp number**

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i² **tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number**

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\textit{i^2} \textit{tuberculum dentale/ m^1 cusp number/ m^2 fifth cusp}

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\textit{i^2} \textit{tuberculum dentale/ m^1 cusp number/ Carabelli’s trait}

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\textit{i^2} \textit{tuberculum dentale/ m^1 cusp number/ m^2 deflecting wrinkle}

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\textit{i^2} \textit{tuberculum dentale/ m^1 cusp number/ m^2 entoconulid}

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\(i^2\) tuberculosis dentale/ m\(^1\) cusp number/ m\(^2\) metaconulid

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\(i^2\) tuberculosis dentale/ m\(^1\) cusp number/ m\(^2\) mesial trigoid crest

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maxillary canine tuberculosis dentale/ mandibular canine distal ridge/ m\(^1\) cusp number

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maxillary canine tuberculosis dentale/ m\(^1\) cusp number/ m\(^2\) fifth cusp

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maxillary canine tuberculum dentale/ m¹ cusp number/ Carabelli’s trait

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maxillary canine tuberculum dentale/ m¹ cusp number/ m₂ deflecting wrinkle

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maxillary canine tuberculum dentale/ m¹ cusp number/ m₂ entoconulid

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maxillary canine tuberculum dentale/ m¹ cusp number/ m₂ metaconulid

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maxillary canine tuberculum dentale/ m\textsuperscript{1} cusp number/ m\textsubscript{2} mesial trigoid crest

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mandibular canine distal ridge/ m\textsuperscript{1} cusp number/ m\textsuperscript{2} fifth cusp

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mandibular canine distal ridge/ m\textsuperscript{1} cusp number/ Carabelli’s trait

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mandibular canine distal ridge/ m\textsuperscript{1} cusp number/ m\textsubscript{2} deflecting wrinkle

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Table H.3  Continued

**mandibular canine distal ridge/ m¹ cusp number/ m₂ entoconulid**

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**mandibular canine distal ridge/ m¹ cusp number/ m₂ metaconulid**

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**mandibular canine distal ridge/ m¹ cusp number/ m₂ mesial trigoid crest**

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**m¹ cusp number/ m² fifth cusp/ Carabelli’s trait**

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Table H.3  Continued

**m₁ cusp number/ m² fifth cusp/ m₂ deflecting wrinkle**

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**m₁ cusp number/ m² fifth cusp/ m₂ entoconulid**

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**m₁ cusp number/ m² fifth cusp/ m₂ metaconulid**

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**m₁ cusp number/ m² fifth cusp/ m₂ mesial trigoid crest**

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Table H.3  Continued

\textbf{m\texttextsuperscript{1} cusp number/ Carabelli’s trait/ m\texttextsuperscript{2} deflecting wrinkle}

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Table H.3  Continued

**m₁ cusp number/ m₂ deflecting wrinkle/ m₂ entoconulid**

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**m₁ cusp number/ m₂ deflecting wrinkle/ m₂ metaconulid**

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**m₁ cusp number/ m₂ deflecting wrinkle/ m₂ mesial trigoid crest**

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**m₁ cusp number/ m₂ entoconulid/ m₂ metaconulid**

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**m₁ cusp number/ m₂ entoconulid/ m₂ mesial trigoid crest**

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**m₁ cusp number/ m₂ metaconulid/ m₂ mesial trigoid crest**

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Table H.3  Continued

**FOUR TRAIT DISCRIMINANT FUNCTIONS**

*i*\(^2\) gravel shape/ maxillary canine shovel shape/i*\(^1\) tuberculum dentale/ m*\(^1\) cusp number

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*i*\(^2\) shovel shape/ maxillary canine shovel shape/ i*\(^2\) tuberculum dentale/ m*\(^1\) cusp number

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*i*\(^2\) shovel shape/ maxillary canine shovel shape/ maxillary canine tuberculum dentale/ m*\(^1\) cusp number

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*i*\(^2\) shovel shape/ maxillary canine shovel shape/ mandibular canine distal ridge/ m*\(^1\) cusp number

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\( i^2 \) shovel shape/ maxillary canine shovel shape/ \( m^1 \) cusp number/ Carabelli’s trait

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\( i^2 \) shovel shape/ maxillary canine shovel shape/ \( m^1 \) cusp number/ \( m^2 \) deflecting wrinkle

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\( i^2 \) shovel shape/ maxillary canine shovel shape/ \( m^1 \) cusp number/ \( m^2 \) entoconulid

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\( i^2 \) shovel shape/ maxillary canine shovel shape/ \( m^1 \) cusp number/ \( m^3 \) metaconulid

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\( i^2 \) shovel shape/ maxillary canine shovel shape/ \( m^1 \) cusp number/ \( m_1 \) mesial trigoid crest

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\( i^2 \) shovel shape/ \( i^1 \) tuberculum dentale/ \( i^2 \) tuberculum dentale/ \( m^1 \) cusp number

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\( i^2 \) shovel shape/ \( i^1 \) tuberculum dentale/ maxillary canine tuberculum dentale/ \( m^1 \) cusp number

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\[ \text{i}^2 \text{ shovel shape/ } i^1 \text{ tuberculum dentale/ mandibular canine distal ridge/ } m^1 \text{ cusp number} \]

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\[ \text{i}^2 \text{ shovel shape/ } i^1 \text{ tuberculum dentale/ } m^1 \text{ cusp number/ } m^2 \text{ fifth cusp} \]

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\[ \text{i}^2 \text{ shovel shape/ } i^1 \text{ tuberculum dentale/ } m^1 \text{ cusp number/ Carabelli’s trait} \]

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\[ \text{i}^2 \text{ shovel shape/ } i^1 \text{ tuberculum dentale/ } m^1 \text{ cusp number/ } m^2 \text{ deflecting wrinkle} \]

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### i² shovel shape/ i¹ tuberculum dentale/ m¹ cusp number/ m² entoconulid

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### i² shovel shape/ i¹ tuberculum dentale/ m¹ cusp number/ m₂ mesial trigoid crest

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\( i^2 \) shovel shape/ \( i^2 \) tuberculum dentale/ mandibular canine distal ridge/ \( m^1 \) cusp number

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\( i^2 \) shovel shape/ \( i^2 \) tuberculum dentale/ \( m^1 \) cusp number/ \( m^2 \) fifth cusp

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\( i^2 \) shovel shape/ \( i^2 \) tuberculum dentale/ \( m^1 \) cusp number/ Carabelli’s trait

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\( i^2 \) shovel shape/ \( i^2 \) tuberculum dentale/ \( m^1 \) cusp number/ \( m^2 \) deflecting wrinkle

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i² shovel shape/ i² tuberculum dentale/ m¹ cusp number/ m² entoconulid

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i² shovel shape/ i² tuberculum dentale/ m¹ cusp number/ m² metaconulid

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i² shovel shape/ i² tuberculum dentale/ m¹ cusp number/ m₂ mesial trigoid crest

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i² shovel shape/maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number

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\( i^2 \) shovel shape/ maxillary canine tuberculum dentale/ \( m^1 \) cusp number/ \( m^2 \) fifth cusp

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\( i^2 \) shovel shape/ maxillary canine tuberculum dentale/ \( m^1 \) cusp number/ Carabelli’s trait

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\( i^2 \) shovel shape/ maxillary canine tuberculum dentale/ \( m^1 \) cusp number/ \( m^2 \) deflecting wrinkle

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\( i^2 \) shovel shape/ maxillary canine tuberculum dentale/ \( m^1 \) cusp number/ \( m^2 \) entoconulid

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Table H.3  Continued

\(i^2\) shovel shape/ maxillary canine tuberculum dentale/ \(m^1\) cusp number/ \(m^2\) metaconulid

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\(i^2\) shovel shape/ maxillary canine tuberculum dentale/ \(m^1\) cusp number/ \(m^2\) mesial trigoid crest

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\(i^2\) shovel shape/ mandibular canine distal ridge/ \(m^1\) cusp number/ \(m^2\) fifth cusp

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\(i^2\) shovel shape/ mandibular canine distal ridge/ \(m^1\) cusp number/ Carabelli’s trait

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Table H.3  Continued

$i^2$ shovel shape/ mandibular canine distal ridge/ $m^1$ cusp number/ $m^2$ deflecting wrinkle

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$i^2$ shovel shape/ mandibular canine distal ridge/ $m^1$ cusp number/ $m^2$ entoconulid

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$i^2$ shovel shape/ mandibular canine distal ridge/ $m^1$ cusp number/ $m^2$ metaconulid

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$i^2$ shovel shape/ mandibular canine distal ridge/ $m^1$ cusp number/ $m_2$ mesial trigoid crest

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\( i^2 \) shovel shape/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ Carabelli’s trait

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\( i^2 \) shovel shape/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) deflecting wrinkle

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\( i^2 \) shovel shape/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) entoconulid

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\( i^2 \) shovel shape/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) metaconulid

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$i^2$ shovel shape/ $m^1$ cusp number/ $m^2$ fifth cusp/ $m_2$ mesial trigoid crest

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$i^2$ shovel shape/ $m^1$ cusp number/ Carabelli’s trait/ $m^2$ deflecting wrinkle

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$i^2$ shovel shape/ $m^1$ cusp number/ Carabelli’s trait/ $m^2$ entoconulid

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$i^2$ shovel shape/ $m^1$ cusp number/ Carabelli’s trait/ $m^2$ metaconulid

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Table H.3  Continued

$i^2$ shovel shape/ $m^1$ cusp number/ Carabelli’s trait/ $m_2$ mesial trigoid crest

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$i^2$ shovel shape/ $m^1$ cusp number/ $m^2$ deflecting wrinkle/ $m^2$ entoconulid

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$i^2$ shovel shape/ $m^1$ cusp number/ $m^2$ deflecting wrinkle/ $m_3$ mesial trigoid crest

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**i¹ tuberculum dentale/ i² tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number**

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**i¹ tuberculum dentale/ i² tuberculum dentale/ m¹ cusp number/ m² fifth cusp**

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**i¹ tuberculum dentale/ i² tuberculum dentale/ m¹ cusp number/ Carabelli’s trait**

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**i¹ tuberculum dentale/ i² tuberculum dentale/ m¹ cusp number/ m² deflecting wrinkle**

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i¹ tuberculosis dentale/ i² tuberculosis dentale/ m¹ cusp number/ m² metaconulid

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i¹ tuberculosis dentale/ maxillary canine tuberculosis dentale/ m¹ cusp number/ m² fifth cusp

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i¹ tuberculosis dentale/ maxillary canine tuberculosis dentale/ m¹ cusp number/ Carabelli’s trait

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i¹ tuberculosis dentale/ maxillary canine tuberculosis dentale/ m¹ cusp number/ m² deflecting wrinkle

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$i^1$ *tuberculum dentale/ maxillary canine tuberculum dentale/ $m^1$ cusp number/ $m_2$ mesial trigoid crest

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$i^1$ *tuberculum dentale/ mandibular canine distal ridge/ $m^1$ cusp number/ $m^2$ fifth cusp

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\(i^1\) tuberculum dentale/ mandibular canine distal ridge/ \(m^1\) cusp number/ Carabelli’s trait

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\(i^1\) tuberculum dentale/ mandibular canine distal ridge/ \(m^1\) cusp number/ \(m^2\) deflecting wrinkle

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\(i^1\) tuberculum dentale/ mandibular canine distal ridge/ \(m^1\) cusp number/ \(m^2\) entoconulid

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\(i^1\) tuberculum dentale/ mandibular canine distal ridge/ \(m^1\) cusp number/ \(m^2\) metaconulid

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i^1\ tuberculum dentale/ mandibular canine distal ridge/ m^1 cusp number/ m^2 mesial trigoid crest

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i^1 tuberculum dentale/ m^1 cusp number/ m^2 fifth cusp/ Carabelli’s trait

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i^1 tuberculum dentale/ m^1 cusp number/ m^2 fifth cusp/ m^2 deflecting wrinkle

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i^1 tuberculum dentale/ m^1 cusp number/ m^2 fifth cusp/ m^2 entoconulid

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\(i^1\) *tuberculum dentale/ \(m^1\) cusp number/ \(m^2\) fifth cusp/ \(m^2\) metaconulid

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\(i^1\) *tuberculum dentale/ \(m^1\) cusp number/ Carabelli’s trait/ \(m^2\) deflecting wrinkle

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\(i^1\) *tuberculum dentale/ \(m^1\) cusp number/ Carabelli’s trait/ \(m^2\) entoconulid

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\(i^1\) *tuberculum dentale/ \(m^1\) cusp number/ Carabelli’s trait/ \(m^2\) metaconulid

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### i¹ tuberculum dentale/ m¹ cusp number/ m² deflecting wrinkle/ m² entoconulid

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### i¹ tuberculum dentale/ m¹ cusp number/ m² deflecting wrinkle/ m₂ mesial trigoid crest

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Table H.3  Continued

i1 tuberculum dentale/ m1 cusp number/ m2 entoconulid/ m2 metaconulid

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i1 tuberculum dentale/ m1 cusp number/ m2 entoconulid/ m2 mesial trigoid crest

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i1 tuberculum dentale/ m1 cusp number/ m2 metaconulid/ m2 mesial trigoid crest

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i1 tuberculum dentale/ maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m1 cusp number

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Table H.3 Continued

i² tuberculum dentale/ maxillary canine tuberculum dentale/ m¹ cusp number/ m² fifth cusp

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i² tuberculum dentale/ maxillary canine tuberculum dentale/ m¹ cusp number/ Carabelli’s trait

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i² tuberculum dentale/ maxillary canine tuberculum dentale/ m¹ cusp number/ m² deflecting wrinkle

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i² tuberculum dentale/ maxillary canine tuberculum dentale/ m¹ cusp number/ m² entoconulid

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**$i^2$ tuberculum dentale/ maxillary canine tuberculum dentale/ $m^1$ cusp number/ $m^2$ metaconulid**

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**$i^2$ tuberculum dentale/ maxillary canine tuberculum dentale/ $m^1$ cusp number/ $m_2$ mesial trigoid crest**

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**$i^2$ tuberculum dentale/ mandibular canine distal ridge/ $m^1$ cusp number/ $m^2$ fifth cusp**

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**$i^2$ tuberculum dentale/ mandibular canine distal ridge/ $m^1$ cusp number/ Carabelli’s trait**

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Table H.3  Continued

\( i^2 \) tuberculum dentale/ mandibular canine distal ridge/ \( m^1 \) cusp number/ \( m^2 \) deflecting wrinkle

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\( i^2 \) tuberculum dentale/ mandibular canine distal ridge/ \( m^1 \) cusp number/ \( m^2 \) entoconulid

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\( i^2 \) tuberculum dentale/ mandibular canine distal ridge/ \( m^1 \) cusp number/ \( m^2 \) metaconulid

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\( i^2 \) tuberculum dentale/ mandibular canine distal ridge/ \( m^1 \) cusp number/ \( m^2 \) mesial trigoid crest

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Table H.3  Continued

\(i^2\) **tuberculum dentale/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ Carabelli’s trait**

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\(i^2\) **tuberculum dentale/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) deflecting wrinkle**

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\(i^2\) **tuberculum dentale/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) entoconulid**

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\(i^2\) **tuberculum dentale/ m\(^1\) cusp number/ m\(^2\) fifth cusp/ m\(^2\) metaconulid**

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Table H.3  Continued

\(i^2\) tuberculosis dentale/ m\(^1\) cusp number/ m\(^3\) fifth cusp/ m\(_2\) mesial trigoid crest

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\(i^2\) tuberculosis dentale/ m\(^1\) cusp number/ Carabelli’s trait/ m\(^3\) deflecting wrinkle

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\(i^2\) tuberculosis dentale/ m\(^1\) cusp number/ Carabelli’s trait/ m\(^3\) entoconulid

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\(i^2\) tuberculosis dentale/ m\(^1\) cusp number/ Carabelli’s trait/ m\(^3\) metaconulid

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303
Table H.3  Continued

\(i^2\) *tuberculum dentale/ m\(^1\) cusp number/ Carabelli’s trait/ m\(_2\) mesial trigoid crest

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\(i^2\) *tuberculum dentale/ m\(^1\) cusp number/ m\(^2\) deflecting wrinkle/ m\(^2\) entoconulid

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\(i^2\) *tuberculum dentale/ m\(^1\) cusp number/ m\(_2\) mesial trigoid crest

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Table H.3  Continued

\( \text{i^2 tuberculosis dentale/ m^1 cusp number/ m^2 entoconulid/ m^2 metaconulid} \)

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\( \text{i^2 tuberculosis dentale/ m^1 cusp number/ m^2 entoconulid/ m_2 mesial trigoid crest} \)

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\( \text{i^2 tuberculosis dentale/ m^1 cusp number/ m^2 metaconulid/ m_2 mesial trigoid crest} \)

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\( \text{maxillary canine tuberculosis dentale/ mandibular canine distal ridge/ m^1 cusp number/ m^2 fifth cusp} \)

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**maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number/ Carabelli’s trait**

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**maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number/ m² deflecting wrinkle**

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**maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number/ m² entoconulid**

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**maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m¹ cusp number/ m² metaconulid**

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Table H.3  Continued

maxillary canine tuberculum dentale/ mandibular canine distal ridge/ m₁ cusp
number/ m₂ mesial trigoid crest

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maxillary canine tuberculum dentale/ m₁ cusp number/ m² fifth cusp/ Carabelli’s
trait

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maxillary canine tuberculum dentale/ m₁ cusp number/ m² fifth cusp/ m² deflecting
wrinkle

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maxillary canine tuberculum dentale/ m₁ cusp number/ m² fifth cusp/ m²
entoconulid

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Table H.3  Continued

**maxillary canine tuberculum dentale/ m¹ cusp number/ m² fifth cusp/ m² metaconulid**

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**maxillary canine tuberculum dentale/ m¹ cusp number/ m² fifth cusp/ m² mesial trigoid crest**

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**maxillary canine tuberculum dentale/ m¹ cusp number/ Carabelli’s trait/ m² deflecting wrinkle**

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**maxillary canine tuberculum dentale/ m¹ cusp number/ Carabelli’s trait/ m² entoconulid**

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maxillary canine tuberculum dentale/ m¹ cusp number/ m² deflecting wrinkle/ m₂ mesial trigoid crest

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maxillary canine tuberculum dentale/ m¹ cusp number/ m² entoconulid/ m² metaconulid

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maxillary canine tuberculum dentale/ m¹ cusp number/ m² entoconulid/ m₂ mesial trigoid crest

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maxillary canine tuberculum dentale/ m¹ cusp number/ m² metaconulid/ m₂ mesial trigoid crest

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**mandibular canine distal ridge/ m¹ cusp number/ m² fifth cusp/ Carabelli’s trait**

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**mandibular canine distal ridge/ m¹ cusp number/ m² fifth cusp/ m² deflecting wrinkle**

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**mandibular canine distal ridge/ m¹ cusp number/ m² fifth cusp/ m² metaconulid**

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mandibular canine distal ridge/ m¹ cusp number/ m² fifth cusp/ m₃ mesial trigoid crest

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mandibular canine distal ridge/ m¹ cusp number/ Carabelli’s trait/ m² deflecting wrinkle

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mandibular canine distal ridge/ m¹ cusp number/ Carabelli’s trait/ m² entoconulid

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**mandibular canine distal ridge/ m₁ cusp number/ Carabelli’s trait/ m₂ mesial trigoid crest**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ deflecting wrinkle/ m₂ entoconulid**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ deflecting wrinkle/ m₂ metaconulid**

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**mandibular canine distal ridge/ m₁ cusp number/ m₂ deflecting wrinkle/ m₂ mesial trigoid crest**

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mandibular canine distal ridge/ m¹ cusp number/ m² entoconulid/ m² metaconulid

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mandibular canine distal ridge/ m¹ cusp number/ m² entoconulid/ m₂ mesial trigoid crest

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mandibular canine distal ridge/ m¹ cusp number/ m² metaconulid/ m₂ mesial trigoid crest

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m¹ cusp number/ m² fifth cusp/ Carabelli’s trait/ m² deflecting wrinkle

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**m¹ cusp number/ m² fifth cusp/ Carabelli’s trait/ m² entoconulid**

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**m¹ cusp number/ m² fifth cusp/ Carabelli’s trait/ m² metaconulid**

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**m¹ cusp number/ m² fifth cusp/ Carabelli’s trait/ m₂ mesial trigoid crest**

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**m¹ cusp number/ m² fifth cusp/ m² deflecting wrinkle/ m² entoconulid**

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Table H.3  Continued

\( m^1 \text{ cusp number/ } m^2 \text{ fifth cusp/ } m^2 \text{ deflecting wrinkle/ } m^2 \text{ metaconulid} \)

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\( m^1 \text{ cusp number/ } m^2 \text{ fifth cusp/ } m^2 \text{ deflecting wrinkle/ } m_2 \text{ mesial trigoid crest} \)

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\( m^1 \text{ cusp number/ } m^2 \text{ fifth cusp/ } m^2 \text{ entoconulid/ } m^2 \text{ metaconulid} \)

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\( m^1 \text{ cusp number/ } m^2 \text{ fifth cusp/ } m^2 \text{ entoconulid/ } m_1 \text{ mesial trigoid crest} \)

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Table H.3  Continued

\( m_1 \) cusp number/ \( m_2 \) fifth cusp/ \( m_1 \) metaconulid/ \( m_2 \) mesial trigoid crest

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\( m_1 \) cusp number/ Carabelli’s trait/ \( m_2 \) deflecting wrinkle/ \( m_1 \) entoconulid

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\( m_1 \) cusp number/ Carabelli’s trait/ \( m_2 \) deflecting wrinkle/ \( m_1 \) metaconulid

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\( m_1 \) cusp number/ Carabelli’s trait/ \( m_2 \) deflecting wrinkle/ \( m_2 \) mesial trigoid crest

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\[ \text{m}^1 \text{ cusp number/ Carabelli’s trait/ } m^2 \text{ entoconulid/ } m^2 \text{ metaconulid} \]

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\[ \text{m}^1 \text{ cusp number/ Carabelli’s trait/ } m^2 \text{ entoconulid/ } m_2 \text{ mesial trigoid crest} \]

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\[ \text{m}^1 \text{ cusp number/ Carabelli’s trait/ } m^2 \text{ metaconulid/ } m_2 \text{ mesial trigoid crest} \]

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\[ \text{m}^1 \text{ cusp number/ } m^2 \text{ deflecting wrinkle/ } m^2 \text{ entoconulid/ } m^2 \text{ metaconulid} \]

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Table H.3  Continued

$m_1$ cusp number/ $m_2$ deflecting wrinkle/ $m_2$ entoconulid/ $m_2$ mesial trigoid crest

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$m_1$ cusp number/ $m_2$ deflecting wrinkle/ $m_2$ metaconulid/ $m_2$ mesial trigoid crest

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$m_1$ cusp number/ $m_2$ entoconulid/ $m_2$ metaconulid/ $m_2$ mesial trigoid crest

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APPENDIX I

UNIVARIATE STATISTICS AND NORMALITY TABLES
i′bl  maxillary central incisor buccolingual width
i′md  maxillary central incisor mesiodistal width
i′bl  maxillary lateral incisor buccolingual width
i′md  maxillary lateral incisor mesiodistal width
cbl  maxillary canine buccolingual width
cmd  maxillary canine mesiodistal width
m1′abl  maxillary first premolar anterior buccolingual width
m1′pbl  maxillary first premolar posterior buccolingual width
m1′md  maxillary first premolar mesiodistal width
m2′abl  maxillary second premolar anterior buccolingual width
m2′pbl  maxillary second premolar posterior buccolingual width
m2′md  maxillary second premolar mesiodistal width
i′bl  mandibular central incisor buccolingual width
i′md  mandibular central incisor mesiodistal width
i′bl  mandibular lateral incisor buccolingual width
i′md  mandibular lateral incisor mesiodistal width
gbl  mandibular canine buccolingual width
gmd  mandibular canine mesiodistal width
m1′abl  mandibular first premolar anterior buccolingual width
m1′pbl  mandibular first premolar posterior buccolingual width
m1′md  mandibular first premolar mesiodistal width
m2′abl  mandibular second premolar anterior buccolingual width
m2′pbl  mandibular second premolar posterior buccolingual width
m2′md  mandibular second premolar mesiodistal width
ch1  Chord 1 on second premolar
ch2  Chord 2 on second premolar
ch3  Chord 3 on second premolar
ch4  Chord 4 on second premolar
ch5  Chord 5 on second premolar
ch6  Chord 6 on second premolar
N  Number of individuals
\bar{x}  Mean
SD  Standard Deviation
LCL  Lower Confidence Level (95%)
UCL  Upper Confidence Level (95%)
g1  Fisher’s g1
\hat{g}  Fisher’s g2
sk  D’Angostino Skewness
p  Probability level
k  D’Angostino Kurtosis
om  D’Angostino Omnibus

Table I.1  Key to Univariate Normality Tables
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Table I.13 England Log Data - continued
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| **cmd** | 79 | 1.75 | .05 | 1.74 | 1.76 | .24 | .63 | .9 | .37 | 1.21 | .23 |
| **m abl** | 85 | 1.92 | .06 | 1.91 | 1.94 | .39 | .03 | 1.49 | .14 | .26 | .79 |
| **m pbl** | 83 | 1.83 | .07 | 1.81 | 1.85 | .03 | -.03 | .12 | .91 | .14 | .89 |
| **m md** | 78 | 2.06 | .05 | 2.05 | 2.07 | -.21 | .27 | -.78 | .44 | .68 | .5 |
| **m abl** | 83 | 2.12 | .06 | 2.11 | 2.13 | -.09 | .26 | -.37 | .71 | .68 | .49 |
| **m pbl** | 84 | 2.13 | .06 | 2.12 | 2.14 | -.23 | -.05 | -.9 | .37 | .09 | .93 |
| **m md** | 83 | 2.3 | .05 | 2.29 | 2.31 | -.25 | .51 | -.99 | .32 | 1.06 | .29 |
| **ch1** | 82 | 1.44 | .11 | 1.42 | 1.47 | -.24 | 1 | -.91 | .36 | 1.67 | .09 |
| **ch2** | 84 | 1.16 | .15 | 1.12 | 1.19 | -.16 | 6.33 | -.84 | 0 | 4.39 | .0 |
| **ch3** | 83 | 1.17 | .09 | 1.16 | 1.19 | .43 | -.12 | 1.63 | .1 | -.05 | .96 |
| **ch4** | 82 | 1.32 | -.09 | 1.3 | 1.34 | -.87 | 1.24 | -.3 | .04 | 0 | 1.92 |
| **ch5** | 83 | 1.48 | .1 | 1.46 | 1.5 | .13 | -.3 | .51 | .61 | -.51 | .61 |
| **ch6** | 77 | 1.61 | .08 | 1.59 | 1.63 | -.22 | -.3 | .84 | .4 | -.46 | .65 | .92 | .63 |
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Appendix J

Multivariate Normality Graphs
Figure J.1 European American buccolingual multivariate normality graph
Figure J.2  European American buccolingual/ mesiodistal multivariate normality graph
Figure J.3  European American mesiodistal multivariate normality graph
MULTIVARIATE NORMALITY GRAPH
AFRICAN AMERICAN (DALLAS) RAW DATA

Figure J.4 African American buccolinguial multivariate normality graph
Figure J.5 African American buccolingual/mesiodistal multivariate normality graph
Figure J.6  African American mesiodistal multivariate normality graph
Figure J.7  England buccolinguual multivariate normality graph
Figure J.8  England buccolingual/mesiodistal multivariate normality graph
Figure J.9  England mesiodistal multivariate normality graph
Figure J.10  India buccolingual multivariate normality graph
Figure J.11  India buccolingual/ mesiodistal multivariate normality graph
Figure J.12  India mesiodistal multivariate normality graph
Figure J.13  African American buccolingual multivariate normality graph
Figure J.14  African American buccolingual/mesiodistal multivariate normality graph
Figure J.15  African American mesiodistal multivariate normality graph
Figure J.16  African buccolinguial multivariate normality graph
Figure J.17  African buccolingual/mesiodistal multivariate normality graph
Figure J.18  African mesiodistal multivariate normality graph
APPENDIX K

HOMOGENEITY OF COVARIANCE MATRICES
Pooled Within Covariance Matrix of all 6 Samples
Mesial-Distal Log Data

Observations

Bolton Brush European Americans = 86
Memphis African Americans = 66
India = 100
Freedman African Americans = 73
England = 26
West Africa = 18

DF = 368

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Table K.1 Mesial Distal Data Homogeneity of Covariance matrix - continued
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Natural Log of Determinant of Within Covariance Matrix  
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Bartlett-Box Homogeneity Tests

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As the observed F is approximately equal to the F_{0.01}, the covariance matrices can be pooled. A F_{0.01} was used instead of a F_{0.05}, due to the large degree of freedom.
Table K.1 Continued

Within-Class Covariance Matrix of European American Sample

Observations
Bolton Brush European Americans = 86
DF = 85

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### Within-Class Covariance Matrix of Memphis African American Sample

**Observations**
Memphis African Americans = 66  
DF = 65

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**Within-Class Covariance Matrix of Freedman African American Sample**

**Observations**
Freedman African Americans = 73  DF = 72

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### Within-Class Covariance Matrix of England Sample

**Observations**

England = 26  DF = 25

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### Within-Class Covariance Matrix of West Africa Sample

**Observations**
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Pooled Covariance Matrix of 4 Samples

Observations
Bolton Brush European Americans = 86
Memphis African Americans = 60
India = 100
Freedman African Americans = 72

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Table K.2 Buccolingual/ Mesiodistal Data Homogeneity of Covariance Matrix - continued
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Natural Log of Determinant of Within Covariance Matrix  -120.567593

Bartlett-Box Homogeneity Tests

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As the observed $F > F_{0.1}$, the covariance matrices cannot be pooled. A $F_{0.1}$ was used instead of a $F_{0.5}$, due to the large degree of freedom.
# Pooled Within Covariance Matrix of all 6 Samples

## Observations

- Bolton Brush European Americans = 98
- Memphis African Americans = 63
- India = 100
- Freedman African Americans = 74
- England = 31
- West Africa = 17

DF = 377

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Table K.3  Buccolinguual Data Homogeneity of Covariance Matrix - continued
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Natural Log of Determinant of Within Covariance Matrix  
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Bartlett-Box Homogeneity Tests

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<th>DF2</th>
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<th>F Prob</th>
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As the observed $F > F_{0.1}$, the covariance matrices cannot be pooled. A $F_{0.1}$ was used instead of a $F_{0.05}$, due to the large degree of freedom.
APPENDIX L

PRINCIPAL COMPONENTS ANALYSIS TABLES
<table>
<thead>
<tr>
<th>VARIABLES</th>
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<th>ISOMETRIC HYPOTHETICAL 1st EIGENVECTOR</th>
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<td>UCMD</td>
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<td>.31623</td>
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\[ \cos \theta = .995846 \]
\[ \theta = 5.2242 \]
\[ \text{Chi-square} = 34.833285 \]
\[ \text{DF} = 9 \]

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<td>3rd</td>
<td>.002928</td>
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60.96%  
72.04%  
77.94%

Table L.1  Principle Component Analysis of All Six Samples - Mesial Distal Log Data
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<th>VARIABLES</th>
<th>BOLTON BRUSH OBSERVED 1st EIGENVECTOR</th>
<th>MEMPHIS OBSERVED 1st EIGENVECTOR</th>
<th>ALLOMETRIC HYPOTHEtical 1st EIGENVECTOR</th>
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<td>.2034</td>
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<td>-.177260</td>
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<td>.2034</td>
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<td>LM1PBL</td>
<td>-.225536</td>
<td>-.197181</td>
<td>.2034</td>
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<tr>
<td>LM2PBL</td>
<td>-.204857</td>
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**BOLTON BRUSH**

\[
\cos \theta = 0.984583 \\
\theta = 10.07388781 \\
\text{Chi-square} = 21.3887 \\
\text{DF} = 9
\]

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<tr>
<td>2&lt;sup&gt;ND&lt;/sup&gt;</td>
<td>.015833</td>
</tr>
<tr>
<td>3&lt;sup&gt;RD&lt;/sup&gt;</td>
<td>.011493</td>
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**MEMPHIS**

\[
\cos \theta = 0.989975 \\
\theta = 8.11976 \\
\text{Chi-square} = 16.9481 \\
\text{DF} = 9
\]

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Table L.2 European American and Memphis African American Samples Buccal Lingual Log Data
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<th>FREEDMAN OBSERVED 1st EV</th>
<th>ENGLAND OBSERVED 1st EV</th>
<th>ISOMETRIC HYPOTHETICAL 1st EV</th>
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<td>-.282634</td>
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<th>ENGLAND</th>
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<td>Cos θ = .987036</td>
</tr>
<tr>
<td>θ =</td>
<td>6.422023</td>
<td>θ = 9.23586</td>
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<td>Chi-square =</td>
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Table L.3  India, Freedman African American and England - Buccal Lingual Log Data - Continued
Table L.3 Continued

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<tr>
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<td>.004968</td>
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<td>2&lt;sup&gt;ND&lt;/sup&gt; .005437</td>
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<tr>
<td>3&lt;sup&gt;RD&lt;/sup&gt;</td>
<td>.004436</td>
<td>3&lt;sup&gt;RD&lt;/sup&gt; .003084</td>
<td>3&lt;sup&gt;RD&lt;/sup&gt; .004648</td>
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<tr>
<td>2&lt;sup&gt;ND&lt;/sup&gt;</td>
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<td>71.89%</td>
<td>70.84%</td>
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<td>78.77%</td>
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<td>-----------</td>
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<td>LI1BL</td>
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\[\cos \theta = 0.922404\]
\[
\theta = 22.7199 \\
\text{Chi-square} = 114.41466 \\
\text{DF} = 9
\]

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Table L.4  West Africa - Buccal Lingual Log Data
### OBSERVED 1st EIGENVECTORS

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<th>FREEMAN</th>
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### ISOMETRIC HYPOTHETICAL 1st EIGENVECTOR

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<th>FREEDMAN</th>
</tr>
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<tbody>
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<tr>
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Table L.5. European American, Memphis and Freedman African American Buccal Lingual and Mesial Distal Log Data - Continued
Table L. 5 Continued

**EIGENVALUES AND PERCENTAGES**

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<th>Freedman</th>
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<td>1&lt;sup&gt;ST&lt;/sup&gt; .005618</td>
<td>1&lt;sup&gt;ST&lt;/sup&gt; .054286</td>
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<tr>
<td></td>
<td>43.07%</td>
<td>48.86%</td>
</tr>
<tr>
<td>2&lt;sup&gt;ND&lt;/sup&gt; .016526</td>
<td>2&lt;sup&gt;ND&lt;/sup&gt; .013429</td>
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<tr>
<td></td>
<td>55.92%</td>
<td>60.66%</td>
</tr>
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<tr>
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<td>ISOMETRIC HYPOTHEtical 1º EIGENVECTOR</td>
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<td>-------------------------</td>
<td>--------------------------------------</td>
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Cos \( \theta = .991084 \)
\( \theta = 7.6774726 \)
Chi-square = 23.672638
DF = 19

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Table L.6  India  Buccal Lingual and Mesial Distal Log Data
APPENDIX M

F TEST RESULTS FOR MAHALANOBIS’ DISTANCE
## Pair comparisons

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- not significantly different
APPENDIX N

LINEAR DISCRIMINANT FUNCTION ANALYSIS
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Table N.1 Discriminant Functions - Six Samples
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Table N.2  Discriminant Function - Bolton Brush, Memphis, Freedman, England and West Africa
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Table N.3 Discriminant Function - European/European-Derived and African/African-Derived Samples
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Table N.4 Discriminant Functions - Modern American Samples
APPENDIX O

QUADRATIC DISCRIMINATION ANALYSIS AND RESULTS
\[ H = -0.5X_0 (S_1^{-1} - S_2^{-1})X_0 + (\bar{X}_1 S_1^{-1} - \bar{X}_2 S_2^{-1})X_0 - K \]

\( X_0 \) = logarithmic transformed BL measurements of unknown individual

\[ \bar{X}_1 = 1.57959, 1.45643, 1.73500, 2.08194, 2.19663, 1.23520, 1.33673, 1.57316, 1.76571, 2.12388 \]

\[ \bar{X}_2 = 1.58730, 1.50571, 1.80238, 2.15952, 2.26143 1.28921, 1.39651, 1.66968, 1.83714, 2.17079 \]

\[ S_1 = \]

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Table O.1 Quadratic Discriminant Function - continued
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Gullah Test Subjects

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Score $\leq 0 = P_1$
Score $> 0 = P_2$

$P_1 = \text{Bolton Brush (European American)}$
$P_2 = \text{Memphis (African American)}$

Table O. 2 Results of Quadratic Discriminant Function -Bolton Brush / Memphis
APPENDIX P

RESULTS OF TEST SAMPLES
### Discriminant functions:

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<th>Value</th>
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<td>$i^2td/m'cn/c6$ (79.4%)</td>
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<td>$i^2td/lcdr/m'cn/c6$ (80.4%)</td>
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<td>$m'cn$</td>
<td>-1.2003</td>
<td>$i^2td$</td>
<td>2.0119</td>
<td>$i^2td$</td>
<td>3.0150</td>
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<td>-.9434</td>
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<td>3.871 + -1.2003(7) + -.9434 (0) = -1.144</td>
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<td>3.871 + -1.2003(6) + -.9434 (0) = -3.3308</td>
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<td>3.871 + -1.2003(6) + -.9434 (0) = -3.3308</td>
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<td>3.871 + -1.2003(6) + -.9434 (0) = -3.3308</td>
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<td>3.871 + -1.2003(6) + -.9434 (0) = -3.3308</td>
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<td>3.871 + -1.2003(7) + -.9434 (0) = -1.144</td>
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<td>3.871 + -1.2003(6) + -.9434 (0) = -3.3308</td>
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<td>3.871 + -1.2003(4) + -.9434 (0) = -0.9302</td>
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<td>3.871 + -1.2003(8) + -.9434 (0) = -5.7314</td>
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Table P.1 Logistic Discriminant Functions on Test Subjects - continued
Table P.1 continued

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<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(0) = -3.7259$</td>
</tr>
<tr>
<td>7</td>
<td>$3.8743 + 2.0119(0) + 1.2667(7) + -0.9284(0) = -4.9926$</td>
</tr>
<tr>
<td>8</td>
<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(0) = -3.7259$</td>
</tr>
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<td>9</td>
<td>$3.8743 + 2.0119(0) + 1.2667(7) + -0.9284(0) = -4.9926$</td>
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<tr>
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<td>$3.8743 + 2.0119(0) + 1.2667(5) + -0.9284(0) = -2.4592$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(7) + -0.9284(0) = -4.9926$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(0) = -3.7259$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(5) + -0.9284(0) = -2.4592$</td>
</tr>
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<td>16</td>
<td>$3.8743 + 2.0119(0) + 1.2667(7) + -0.9284(0) = -4.9926$</td>
</tr>
<tr>
<td>17</td>
<td>$3.8743 + 2.0119(0) + 1.2667(5) + -0.9284(0) = -2.4592$</td>
</tr>
<tr>
<td>18</td>
<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(0) = -3.7259$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(0) = -3.7259$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(0) = -3.7259$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(3) + -0.9284(0) = 0.07420$</td>
</tr>
<tr>
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</tr>
<tr>
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<td>$3.8743 + 2.0119(0) + 1.2667(7) + -0.9284(1) = -5.9210$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(0) = -3.7259$</td>
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<tr>
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<td>$3.8743 + 2.0119(0) + 1.2667(8) + -0.9284(0) = -6.2593$</td>
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<td>$3.8743 + 2.0119(0) + 1.2667(3) + -0.9284(0) = 0.07420$</td>
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<tr>
<td>28</td>
<td>$3.8743 + 2.0119(0) + 1.2667(7) + -0.9284(0) = -4.9926$</td>
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<td>29</td>
<td>$3.8743 + 2.0119(0) + 1.2667(3) + -0.9284(0) = 0.07420$</td>
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<tr>
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<td>$3.8743 + 2.0119(0) + 1.2667(6) + -0.9284(2) = -5.5827$</td>
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Table P.1 continued

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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
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<tr>
<td>3</td>
<td>4.1218+3.0150 (1) + -2.4145 (0) + -1.3422 (7) + -0.9951 (2)= -4.2488</td>
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<tr>
<td>4</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
</tr>
<tr>
<td>5</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
</tr>
<tr>
<td>6</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
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<tr>
<td>7</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
</tr>
<tr>
<td>8</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
</tr>
<tr>
<td>9</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
</tr>
<tr>
<td>10</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (5) + -0.9951 (0)= -2.5892</td>
</tr>
<tr>
<td>11</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
</tr>
<tr>
<td>12</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
</tr>
<tr>
<td>13</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
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<tr>
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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (5) + -0.9951 (0)= -2.5892</td>
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<td>16</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
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<td>17</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (5) + -0.9951 (0)= -2.5892</td>
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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (0)= -3.9314</td>
</tr>
<tr>
<td>21</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (3) + -0.9951 (0)= 0.09520</td>
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<td>22</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
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<tr>
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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (3) + -0.9951 (0)= 0.09520</td>
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<tr>
<td>28</td>
<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (7) + -0.9951 (0)= -5.2736</td>
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<td>29</td>
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<td>4.1218+3.0150 (0) + -2.4145 (0) + -1.3422 (6) + -0.9951 (2)= -5.9216</td>
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Test Subjects:

Bolton Brush - Individuals 1-15
Gullah - Individual 16-30

If positive D₁ (European American/Bolton Brush)
If negative D₂ (African American/ Memphis)
<table>
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<th>Individual</th>
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<th>England</th>
<th>West Africa</th>
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* largest number — allocated as

Table P.2  Linear Discriminant Functions on Test Subjects - Bolton Brush - continued
Table P.2  Continued

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<th>Individual</th>
<th>Bolton Brush</th>
<th>Bolton Memphis</th>
<th>Freedman</th>
<th>England</th>
<th>West Africa</th>
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Table P.3  Linear Discriminant Functions on Test Subject - Gullah - continued
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