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Multivariate Statistical Analysis of Three Crania Housed at the University of Montana Physical Anthropology Lab

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MULTIVARIATE STATISTICAL ANALYSIS OF THREE CRANIA HOUSED AT THE UNIVERSITY OF MONTANA PHYSCIAL ANTHROPOLOGY LAB

By

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The purpose of this research was to attempt to identify the population affinity of three crania (UMFC 103, 104, and 120), housed at the University of Montana Physical Anthropology Lab, using multivariate statistical analyses. A database collected by Dr. Hanihara and another collected by researchers at the University of Michigan were used for comparative purposes. Multiple populations from both databases were chosen so as to be representative of various Asian, African, Indian, and Native American populations. Two variations of each of the databases were used in the following statistical analyses: principal components analysis and discriminant function analysis. It was shown that the Michigan database was more effective at classifying UMFC 103, 104, and 120 into one of the predetermined populations than the Hanihara database. Based on these analyses UMFC 103 is tentatively classified as Taiwanese aboriginal and UMFC 120 as South Chinese. These classifications are based on the discriminant function analysis with the Michigan database and all show significant typicality probabilities.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 : INTRODUCTION

The attempted classification of unknown individuals into one of many predetermined groups through the use of craniofacial measurements is a common task for anthropologists, particularly forensic anthropologists (Howells, 1995; Powell and Neves, 1999; Jantz and Ousley, 2001; Brace et al., 2008). There has been much debate about the effectiveness of various techniques used by anthropologists to accomplish this goal (Albrecht, 1992; Wolpoff, 1995; Armelagos and Van Gerven, 2003). The purpose of the research described herein was to attempt to determine the population affinity of three biological specimens (University of Montana Forensic Collection 103, 104, and 120) housed at the University of Montana Physical Anthropology Lab.

UMFC 103, 104, and 120 were utilized for this analysis because they typify modern human morphology and for this reason are used as learning tools for both human osteology and forensic anthropology students at the University of Montana. These skeletons were obtained from Skulls Unlimited International Inc. and are thought to have originated from somewhere within the countries of China or India. For most of the 20th-century, India was the leading source of human skeletons. In 1985, after years of internal legal challenges, India banned the sale of human remains. Since that time the few skeletons that make it through United States customs legally are from China (Elder, 2006). Despite this, Skulls Unlimited International Inc. does not provide any information as to country of origin from which a specific skeleton may have been acquired. Therefore, the proposed population affinity is not based on any actual paperwork stating what country these skeletal remains originated from.

There are two basic methods used by anthropologists in osteological analysis of human remains: anthroposcopy and osteometry. Anthroposcopy, as far as its application to estimating ancestry, pertains to visual observation of discernible differences between Whites, Blacks, Asians, and other groups. The second method, osteometry, uses metric methods to assess ancestry. This thesis is an attempt to determine whether or not UMFC 103, 104, and 120 can be shown within a 95% confidence interval to be of Chinese or Indian descent based on multivariate statistical analyses of craniofacial measurements.

Metric methods have been used for distinguishing ancestry since the early 1900s (Krogman, 1962). These methods typically provide a most probable group for a skeleton of unknown ancestry, however, the results from metric techniques can be deceptive in their apparent accuracy. This is because the distribution of measurements used in these methods are based on samples which may or may not be representative of the population from which the individual originated (Byers, 2005). This problem is addressed in the current research by calculating a discriminant function based on a large number of modern Asian populations as UMFC 103, 104, and 120 are thought to be descended from an Asian population, specifically Chinese or Indian.

Eugene Giles and Orville Elliot popularized the use of discriminant functions to assess ancestry on the basis of cranial measurements in their pioneering article written in 1962. Discriminant function analysis uses any number of measurements to distinguish between two or more predetermined groups (Byers, 2005). A number of anthropologists have argued against the use of multivariate statistical techniques to determine population affinities (Albrecht, 1992; Wolpoff, 1995). Both of these authors focused on the

problems with attempting to assess population affinities of fossils, but the same problems apply when these techniques are used with modern skeletal remains.

The main criticism against using multivariate statistical analyses to classify individuals into a predetermined population is that the prospect that the individual in question is not a member of any of the groups represented is generally ignored by researchers. A potential solution to this criticism is to use typicality probabilities which do not force an individual to be classified into one of the predetermined groups, i.e. the possibility that the individual is not a member of any of the groups is considered (Albrecht, 1992).

Craniofacial measurements are used because they have been shown by many researchers to be a good proxy for analyzing genetic variation (Relethford, 1994, 2002, 2004b; Brace et al., 2001, 2006, 2008). Relethford (1994) showed that craniometric variation is equivalent to the variation exhibited based on genetic markers and mitochondrial DNA (mtDNA). The other reason that craniofacial measurements are used is that they can be considered relatively neutral; in other words, they are unaffected for the most part by natural selection (Relethford, 1994, 2002, 2004a; Brace et al., 2001, 2006, 2008; Hanihara and Ishida, 2009).

Boas (1910, 1911, 1912) was able to show that cranial form is plastic to some extent based on various factors; including, nutrition. However, a number of researchers have shown that though cranial plasticity is a real phenomenon, it does not erase or obscure population relationships which can be studied through cranial measurements (Gravlee et al., 2003a, 2003b; Relethford, 2004a). Craniofacial measurements are thought, therefore, to be a useful measure of assessing population affinities.

Currently, discriminant functions using cranial measurements are the most popular method for estimating ancestry (Byers, 2005). This study questions this popular practice and raises the question, 'should this technique be continued and what alternative do anthropologists have when faced with attempting to estimate the population affinity of an unknown individual?' Despite the recent publication by Ousley et al. (2009) which claims that humans can be accurately classified into groups based on geographic origin, I believe that my research demonstrates the need for further research in this area utilizing craniometric data other than the, in my opinion, over frequently used Howells dataset.

CHAPTER 2 : BACKGROUND INFORMATION

Before I can begin discussing my research it is important to provide some details as to the history of craniometric studies. Although the history presented here is by no means comprehensive it is essential to understanding my research, as well as some of the motivations for doing this type of research. It is also necessary to discuss the history of "race" as this term has been and continues to be used extensively throughout the craniometric literature. Finally, it is equally important to introduce the statistics that are used in this analysis and some of the history of their use especially as they pertain to craniometric studies.

History of Craniometric Research

In the perspective of the West European scientific tradition, the first systematic application of human data in design was performed by Pieter Camper. He published *An Investigation about the Best Kind of Shoes* in 1781. In this analysis, Camper emphasized the value of anatomical and anthropometric design criteria over fashion concern in terms of the production of shoes. He is much more famous, however, for his comparison of the angles of the facial profile between monkeys, apes, and humans.

His famous "facial angle" is produced by drawing a tangent touching the forehead and the upper lip and measuring the angle made by that line and a line that intersects the ear opening and the juncture of the upper lip and the lower border of the nose (Brace, 2005). Camper did not place various human groups into categories, but instead viewed these groups as part of a hierarchical continuum.

This view held sway for awhile among Enlightenment thinkers and was certainly prominent in the work of Johann Friedrich Blumenbach (Brace, 1982, 2005). Physical anthropology as a discipline can be traced to Blumenbach and he is often given the title of "father of physical anthropology" (Brace and Montagu, 1965). Blumenbach was a professor of anatomy at the University of Gottingen, Germany. He was a pre-Darwinian scholar and, as a result, his work was not influenced to any extent by evolutionary concepts. He did, however, attempt to explain human differences by viewing them as adaptive responses to differing environments. Blumenbach's writings addressed all aspects of human variation—skeletal, internal organs, hair, skin, teeth, and similarities and differences when compared with nonhuman primates (Brace and Montagu, 1965).

Blumenbach's work has been considered typological in nature (Cook, 2006), but that is not completely accurate. While Blumenbach did recognize five "varieties" of humans, he believed that since each grades into the other, it is arbitrary where one chooses to draw the lines (Brace, 1982, 2005). Between 1790 and 1828, Blumenbach published a series of detailed descriptions of 65 crania, including provenience information as well as engraved illustrations of each.

Although Blumenbach's work cannot be considered craniometric in nature; his work was very influential in the American research of Samuel George Morton, who can be considered the next major contributor to physical anthropology (Brace, 1982, 2005). Morton was a Philadelphia physician-anthropologist working in the early to middle 19th-century. It was Morton's intention to expand on the craniological approach started by Blumenbach in his *Decades…Craniorum* (1790-1828) and devote a major volume to the study of cranial form in the Native Americans of the western hemisphere (Brace, 2005).

He accomplished this goal in 1839 with the publication of the monumental volume entitled *Crania Americana*, a study that was designed to address the physical diversity of the Native American. Morton made the assumption that similarities in skeletal morphology reflected heritage relationships. In *Crania Americana*, Morton tested the prevalent theories of New World peoples that attributed the ancient monuments of civilization to an extinct race of immigrants from the Old World. Morton's findings in both, *Crania Americana* and his study of Egyptian antiquities (1844), are limited to the observation that ancient crania are as distinct racially as recent ones.

The most important contribution, in terms of craniometrics, that Morton made to physical anthropology was in the invention of numerous measurements that he used to compare a multitude of specimens from around the world (Brace, 2005). Morton defined 10 linear measurements, one angle, and an internal capacity with four component measurements in *Crania Americana*. He can be said to have initiated the use of metrics in comparing human biological forms (Brace, 2005).

Although Morton's contributions were largely ignored during the 19th-century, he is considered an intellectual ancestor to today's physical anthropologists (Gould, 1981; Brace, 1982, 2005; Cook, 2006). His work has been re-evaluated by Stephen J. Gould, who found that Morton had subconsciously finagled his measurements involving cranial capacity in order that his results might meet his preconceived notions. Despite the fact that Morton was a staunch polygenist and thought that human groups could be arranged hierarchically with Blacks ranking the lowest; this does not alter the significant contribution that he has made to the study of human variation.

The next major contributor to craniometric analysis is the French physician Pierre Paul Broca (Brace, 1982, 2005). Some recognition has been shown for the fact that Broca was "heir to both the French and the American traditions of polygenism" [Stocking, 1968:40]. Yet the extent to which he represented the continuation of Morton's efforts had not been pointed out until Brace did so in 1982. In 1859, Broca founded the Societe d'Anthropologie de Paris and in 1867, the Laboratoire d'Anthropologie. Then in 1875-1876, the famed Ecole d'Anthropologie was established. This federation of society, laboratory, and school, known informally as Broca's institute, was the center of late 19th- and early 20th-century French anthropology (Spencer, 1982).

Broca's important contribution to craniometric research was in his standardization of measurements and the development of instruments by which those standard measurements could be taken on both, living humans and on human skeletons. In this aspect, Broca simply started with the measurements of Morton and added and elaborated (Brace, 2005). Broca's work was influential in the establishment of physical anthropology in America.

Ales Hrdlicka studied briefly with a student of Broca's at the Ecole d'Anthropologie. Based on these few months of training in anthropology, Hrdlicka's goal was to bring the anthropology of France to America. He wanted to found a school of anthropology just as Broca had. Hrdlicka was never able to fully realize this goal, but he did succeed, between 1914 and 1920, in attracting a constant stream of workers to his lab at the National Museum of Natural History in Washington, D.C. for instruction in anthropology and anthropometric techniques (Spencer, 1982).

During this period, Hrdlicka launched the American Journal of Physical Anthropology. This event was an important landmark in the profession's history for several reasons, including: 1) it had the instantaneous effect of securing the discipline's identity, 2) it provided Hrdlicka with a chance to codify the discipline in broader and more modern terms, and 3) it gave him a platform from which to persist with his campaign to legitimize physical anthropology as an individual science (Spencer, 1982).

Despite Hrdlicka's profound effect on physical anthropology, the most important influence in establishing the discipline of anthropology in America was that of Franz Boas. Boas was born in Germany and earned his doctorate in physics. He then became a protégé of the physician and anthropologist Rudolf Virchow, who was founder and director of the Berliner Gesellschaft fur Anthropologie, Ethnologie und Urgeschichte. Boas assisted Virchow in the Ethnological Museum in Berlin before he came to America in the mid-1880s in search of professional employment (Brace, 2005).

Boas played an important role in establishing the intellectual outlook of the anthropological programs at Harvard, Columbia, Chicago, and Berkeley. Boas' outlook was strongly influenced by his anthropological mentor in Berlin, Rudolf Virchow, who can be considered the founder of German anthropology. Virchow based German anthropology on the model pioneered in France by Paul Broca. Virchow's protégé, Boas, was famous for showing the change in metric proportions between ancestors and descendants in certain groups (Boas, 1899, 1910, 1911, 1912). Boas (1911, 1912) used craniometric analyses extensively in his work. He was vital in influencing the future of craniometric research, particularly in the United States (Brace, 2005).

Paul Rivet, a Boasian anthropologist, was influential in South America and contributed to the organization of physical anthropology as a discipline in Bolivia, Brazil, Ecuador, and Mexico (Leon, 1977). Rivet published four important papers on prognathism. These studies were remarkable in terms of their sample size and exhaustiveness (Rivet, 1909b, 1909c, 1910a, 1910b). Rivet compared several measures of the facial angle, beginning with 5615 humans, 151 apes, and 334 monkeys (1909c) adding series as the study continued.

Rivet demonstrated that the facial angle varied with age and sex; also it had no consistent relationship to cranial index and facial index. Rivet showed that geographical races include populations that differ extensively in facial angle, and that the various measures of facial projection are not equivalent. This last finding laid to rest the enterprise begun by Camper; arranging races in order of facial projection (Cook, 2006).

Rudolf Martin, a German anthropologist in the early 1900s, was of vital importance in standardizing craniometric measurements. Despite the fact that there is no clear discussion of his importance in terms of physical anthropology, most likely because his work is published in German, his landmarks and measurements are widely used. He published a three volume collection in 1928, which defined numerous landmarks of the crania and defined a number of cranial measurements that could be used when studying human variation. The landmarks and measurements defined by Martin have been and continue to be widely used in craniometric research. Woo and Mourant (1934) made extensive use of Martin's landmarks. Howells (1973) uses Martin's cranial measurements in his study of the cranial variation in man. Although Martin's contribution has not been explicitly mentioned, it is evident that his measurements are

still in use today (Howells, 1973, 1989, 1995; Hanihara, 1997; Brace et al., 2001, 2006, 2008; Hanihara and Ishida, 2009).

The anthropologists mentioned above played a key role in establishing physical anthropology and, specifically, craniometric research as a valid field of study. There are a number of other important anthropologists, not mentioned due to time and space restrictions, who also played an important historical role in establishing physical anthropology. After this extensive historical background, it is now important to direct attention to the paradigm underlying early craniometric studies.

The Typological Paradigm: The Concept Underlying Early Craniometric Studies

In any craniometric study the issue of race is always lingering just below the surface. Early craniometric research was done under the guise of the typological paradigm which later developed into the race concept. Although race has been and still remains a controversial topic within anthropology, the concept of race has its root much deeper (Armelagos and Van Gerven, 2003). As early as the 14th-century before the Common Era, the Egyptians assigned humans to four categories based on color. Red was representative of themselves, yellow the Asians to the east, white the people to the north, and black the African populations to the south (Gosset, 1963).

Greek philosophers, in the centuries before the Common Era, imagined a *scala naturae* along which all the byproducts of nature could be arranged in an upward progression from inanimate objects through the types of humanity to God (Mayr, 1988). By the 18th-century, this envisioned scale became transformed into the "Great Chain of Being" (Lovejoy, 1936). Carolus Linnaeus was instrumental in classifying organisms

along this hierarchical chain. Linnaeus, like most scholars of the Enlightenment, pictured the Great Chain as a series of discrete steps, each occupying a unique position in the hierarchy in relation to God at the top (Brace, 2005).

The placement of humans along the Great Chain was enhanced by the work of Camper during the 1790s. His development of the facial angle was used to classify human groups hierarchically. The lowest races were considered to have the most projecting (or animalistic) faces while the higher races had flatter faces. The ideal was said to be the flat face which was represented extensively in Greco-Roman statues (Meijer, 1997). Camper did not, however, make categorical distinctions between various human groups so as to make them appear to be members of different species (Brace, 2005).

During this time, two important ideas were brought into focus. These ideas were: races were real and races were rankable. This led to the question: Where did races come from? Were races the result of a monogenic or polygenic origin? In terms of this debate, Johann Blumenbach fell squarely on the side of monogenism, but this did not mean that he was at all adverse to ranking human groups (Armelagos and Van Gerven, 2003). Blumenbach's understanding of race combined elements from the works of Kant and Buffon (Larson, 1994). Kant attributed human variability to the effects of climate on an ideal ancestral type. Thus, variability was the result of degeneration—meant as an accommodation to local conditions—of a single original type that was of intermediate skin color (Cook, 2006).

A concise statement of Blumenbach's concept of race is this quotation from the English translation of his 1775 work *De generis humani varietate native*: "the variations

of skin color, stature, body proportions, etc., which we have been able to observe, considerable though they may appear at first sight, have no absolute value; they all merge gradually one with another and, accordingly, classification into human races is arbitrary" [Bendyshe (1865), quoted in Comas (1960:16)]. As presented here, it seems obvious that Blumenbach did not agree with the prevailing 17th-century definition of races as constant varieties. It is equally evident that different researchers have arrived at different conclusions as to Blumenbach's ranking or not ranking of human "varieties" based on his work.

Samuel Morton, contrary to Blumenbach's monogenism, was a strong proponent of the polygenic origin of human races. Morton (1844) measured crania from around the world in an attempt to rank races as well as determine the antiquity of racial types. Differences in features like cranial capacity were believed to have great antiquity and, as a result, supported polygenesis. God, it seemed, had fashioned not one human type but many unequal kinds (Armelagos and Van Gerven, 2003).

The development of evolutionary theory after 1859 and the discovery of Mendelian genetics after 1900 had the potential to compel a reevaluation of the concept of race. But that potential was not immediately realized. Though Darwinism ended the monogenesis-polygenesis debate in favor of a new "scientific" monogenesis, degenerationists reacted by simply turning their theory upside down. The fall from Adam became an ascent from the ape. It is not surprising; therefore, that racial determinism remained a potent force in the post-Darwinian era (Armelagos and Van Gerven, 2003).

Evolutionism did not serve to shift science away from Linnaean taxonomy, but actually reinforced taxonomic description (Armelagos and Van Gerven, 2003). Post-

Darwinian osteological studies were not ready to abandon race, instead the comparative study of race seemed to be the only way in which humans would be able to reconstruct our evolutionary history. During this time, "primitive races" became living fossils and were viewed as evolutionary survivors of the different stages through which more "advanced" races had evolved. The key to this was to find a cranial trait or combination of traits by which races could be classified and ranked into evolutionary hierarchies (Armelagos and Van Gerven, 2003).

In order to reach this goal, Paul Broca developed many of the anthropometric instruments which were used in racial assessment in the late 1880s. He also helped to define many of the cranial landmarks that were necessary in establishing measurement standards. However, the methods of anthropometry failed to provide answers to many of the most basic questions regarding race: How many races are there? And in what order can these so-called races be ranked (Armelagos and Van Gerven, 2003)?

During the first half of the 20th-century, physical anthropology continued to focus on issues of race and determining the number and relative value of races. Earnest A. Hooton was vital in keeping the typological paradigm alive in the United States. Franz Boas, on the other hand, criticized the basic tenets of racial typology. He used his research on the plasticity of the cranium in immigrants to the United States to ask important questions like: How can the fixity of human races be accepted when traits such as the cephalic index changed in magnitude in the span of one generation (Boas, 1912)? Boas also wondered how it was possible to know the number of races or hope to establish a ranking among them in lieu of the evidence that he had presented for cranial transformation (Armelagos and Van Gerven, 2003).

Although Boas was a major force in the promotion of racial equality, his criticism of evolutionists such as L. H. Morgan and E. B. Tylor led him to become a strong anti-evolutionist (Baker, 1994). So despite his positive contributions, his antievolutionary stance was overwhelming and did not offer a clear alternative to physical anthropologists wanting to research human variation. In fact, his students and followers were forced to study questions of diffusion and had few methods to use other than description (Armelagos and Van Gerven, 2003). The time was ripe for change and the introduction of a new methodology that could be utilized without assuming racial typologies and biological determinism (Caspari, 2003).

The "Extermination" of the Typological Paradigm: A New Physical Anthropology

The early 1950s saw the discovery of the double helix and the emergence of population studies, but osteological studies continued to reflect the conflicts of racial typology (Armelagos and Van Gerven, 2003). In 1951, Sherwood L. Washburn published "The New Physical Anthropology," an essay which became a manifesto for the modern era. Washburn made a promise of a "new physical anthropology" that would be profoundly different from the old one. The "old physical anthropology" remained descriptive in nature, while new theoretical perspectives would be dominant in the new. The most important concept that Washburn introduced was that hypothesis testing based on theories of adaptation and evolution would be the hallmark of modern research (Washburn, 1951).

However, a shift away from race and description would not come easily. W W Howells rejected these attempts. He stated, "My purpose is not the study of growth but

of taxonomy, of the variation between existing recent populations in the dry skull" [Howells, 1971:210 quoted in (Armelagos and Van Gerven, 2003:58)]. But in 1964, Howells' student C. Loring Brace pointed out that races, and even populations are inadequate for the study of human variation. Brace advocated the study of individual traits; the study of their distribution and the selection that causes their variation. The study of clines became a focus of research rather than races (Caspari, 2003).

According to Caspari (2003), the shift in focus from race to population as a unit of study must be paired with the elimination of populational thinking to completely move away from purely descriptive analyses. Populations cannot be considered simply another term for race; they cannot be thought of as breeding populations, isolated from other groups (Caspari, 2003). The introduction of multivariate statistical analyses was vital in wrestling researchers from typological studies, although it did not completely eliminate typological analyses of skeletal remains (Armelagos et al., 1982).

Use of Multivariate Statistics in Craniometric Research

In 1896, Pearson first applied his regression analysis to cranial material in an examination of the correlation between cranial width and length among different racial groups. These types of correlation analyses continued throughout the 1920s (Armelagos et al., 1982). Pearson and Davin, in 1924, published an investigation that differed markedly from earlier studies and has become a classic in both anthropology and statistics. Pearson and Davin used a sample of 1600 Egyptian crania in an attempt to determine the major facts accounting for specific patterns of correlations in the human skull (Armelagos et al., 1982).

Pearson and Davin (1924) were attempting to use cranial measurements to distinguish between “organic” and “spurious” correlations. Organic correlations measured the relationships between distinct regions of the crania and spurious correlations were a reflection of redundant measures within the same functional system. This division could have laid the groundwork for functional craniology, but its application remained largely statistical (Armelagos and Van Gerven, 2003).

The earliest analytical methods for crania were predominantly restricted to descriptive, or univariate statistics. Howells (1969:312) emphasized that univariate statistics are the statistics of measurements—not individuals or populations. While comparisons between populations may proceed one measurement at a time, or potentially two at a time as in the case of an index, the statistics of populations as well as the treatment of individual specimens in the context of their parent population had to await the introduction of multivariate statistical procedures by Fisher (1936), Hotelling (1933), Mahalanobis et al. (1949), and Rao (1948, 1952), among others, starting in the third decade of the twentieth century (Pietrusewsky, 2000).

Multivariate statistical procedures comprise a family of related mathematical procedures that allow for the simultaneous analysis of multiple variables recorded for individuals from one or more groups (Pietrusewsky, 2000). Despite the advantages of using multivariate analyses, the analysis of metric data using these procedures was slow to gain widespread usage. Much of the initial reluctance can be attributed to the extensive and tedious computations that were involved. General applications of multivariate methods had to wait for the invention of the mainframe computer in the late 1960s and early 1970s (Pietrusewsky, 2000).

There are a number of multivariate statistical procedures that are commonly used in craniometric studies. These include, but are not limited to: factor analysis, principal components analysis, discriminant function analysis, and generalized distance. The latter two procedures are designed to handle two or more groups, while principal components analysis, factor analysis, and related techniques are designed to investigate underlying patterns in a single group. The interest in doing these types of analyses using craniometric measurements continues to this day as can be witnessed by the number of publications over the past three decades (Howells, 1973, 1989, 1995; Relethford, 1994; Brace et al. 2001, 2006, 2008) to list a few.

Howells published a number of studies that utilized multivariate statistical techniques on craniofacial measurements (Howells, 1957, 1972, 1973, 1989, 1995). Howells (1957, 1972, 1973) used factor analysis and principal components analysis to study human variation between populations. He stated the reasons for the appropriateness of multivariate analyses in handling populations very succinctly in 1973:3-4:

> "Methods of multivariate analysis…allow a skull to be treated as a unit, i.e., as a configuration of the information contained in all its measurements. Next, they allow populations to be treated as configurations of such units, taking account of their variation in shape because they in turn are handled as whole configurations of individual dimensions. Finally, the relations and differences between all the populations being considered are set forth in terms of their several individual multivariate ranges of variation. Thus it is possible to see the range of the whole species in such complete and objective informational terms. That is the importance of multivariate statistics: they fit the model of populations looked on not as centroids or means, but as swarms of the varying individuals who compose them; and the differentiation of these swarms from one another constitutes a statement of the degree and nature of the difference between the populations. Although the information is ultimately limited by the measurements selected to describe the skull, their relationships and their relative taxonomic significance are not otherwise biased by the worker [quoted in Pietrusewsky, 2000:378]."

The area of craniometric research uses a variety of multivariate statistical analyses. Another form of statistical analysis that has seen increased application is the Relethford-Blangero model (Relethford and Blangero, 1990). Relethford and Blangero expanded the Harpending-Ward model (Harpending and Ward, 1982), which was constructed for allele frequencies to include cases of multivariate quantitative traits. In the Relethford-Blangero model an R-matrix is estimated for a number of populations using quantitative traits. The diagonal of the matrix provides a standardized distance for each population to the centroid, which is the hypothetical group that would exist if the populations were not divided from each other (Relethford and Blangero, 1990).

In the Harpending-Ward model each population has an observed level of heterozygosity. This is replaced with a summary measure of additive genetic variance in the Relethford-Blangero model. In both models, the variance is related negatively to the distance to the centroid. Populations that are near to the centroid have a considerable amount of internal variation, while populations far from the centroid have very little internal variation. This is the case because drift and low migration rates in isolated populations move the populations away from the centroid and homogenize them (Konigsberg, 2006).

Much more recently, there has been "a revolution in morphometrics" (Rohlf and Marcus, 1993) within the last decade based on the analysis of three-dimensional coordinate data. Benfer (1975) first described a caliper-based method for "digitizing" the human skull, but this method was awkward and had a high error rate. As a result, routine analysis of three-dimensional coordinate data had to wait for the development of relatively inexpensive, reliable, and transportable three-dimensional digitizers

(Konigsberg, 2006). The "new morphometry" has been applied regularly to problems in the analysis of human cranial sexual dimorphism and growth, but there have been few studies which focus on biodistance analysis among archaeological human skeletal samples with the exception of Ashley McKeown's (2000) dissertation.

Recent Craniometric Studies

In recent years there have been a number of studies that have utilized craniometric variation to: compare populations, study population history, and attempt to identify the population affinity of an individual (Howells, 1973, 1989, 1995; Relethford, 1994, 2002; Hanihara, 1997; Hanihara et al., 2008; Hanihara and Ishida, 2009). Craniometrics are utilized because many studies have shown them to be relatively neutral and, therefore, to be mostly unaffected by selective forces (Brace, 1989; Brace et al., 1991; Brace and Tracer, 1992; Relethford, 1994; Brace et al., 2001). Despite the fact that Boas did demonstrate that cranial indices are plastic in humans, the majority of researchers today believe that though this is true the amount of plasticity is minimal enough as to have no major influence on cranial variation in terms of populations (Gravlee et al., 2003a; 2003b; Relethford, 2004a).

In 1991 Relethford looked at genetic drift in terms of anthropometric variation in various populations in Ireland. Many early studies tended to focus on the supposed resistance of quantitative traits to genetic drift. Based on the work of Birdsell (1950), numerous researchers claimed that because quantitative traits are the result of multiple loci, changes resulting from genetic drift at the different loci must cancel one another out. As a result of this suggestion, quantitative traits were considered to be relatively immune

to the effects of genetic drift. This belief has become frequent in the anthropological literature (e.g., Relethford and Lees, 1982), despite the fact that a number of articles have shown that drift does in fact affect quantitative traits in the same way it affects single-locus characters (Bulmer, 1980; Falconer, 1981; Rogers and Harpending, 1983).

Relethford (1991), in an extension of previous analyses, considered the potential impact of genetic drift on the pattern of among-group variation using a predicted "drift distance." Body and craniofacial measurements are used for 259 adult males aged 16 to 75 years. An R-matrix is used to supply estimates of genetic similarity within and among populations relative to the contemporary means of allele frequency in a region. Relethford found that genetic drift has had a significant influence on the genetic structure of seven populations in 19th-century Ireland.

In 1994 Relethford analyzed craniometric variation among modern human populations using Howells (1989) dataset. Howells' (1989) study looked at worldwide craniometric variation on the basis of comparisons of modern crania with several archaic forms. He concluded that modern human craniometric variation is fairly limited. Relethford's (1994) analysis made a formal comparison of craniometric variation as compared to genetic marker variation. Many discussions have assumed that there is greater morphological differentiation relative to genetic differentiation (Nei and Roychoudhury, 1982; Stringer and Andrews, 1988). Nei and Roychoudhury state that morphological variation among major races is "conspicuous" [1982:40]. Stringer and Andrews state that our species "shows great morphological variation, however, in contrast to this, genetic variation between human populations is low overall" [1988:1264]. Relethford (1994) presents estimates of the degree of population differentiation among

world regions based on craniometric data. He then compares these estimates to typical values found from studies of genetic markers and mtDNA. Relethford's findings indicate that the degree of differentiation is essentially the same in both genetic markers and craniometric data.

In 1995 Howells used the data that he had collected (1973, 1989) in an attempt to assess the effectiveness of classifying an unknown individual into the correct group. Howells wanted to use individuals that were not used in the construction of the discriminant function. His results were mixed; however, in terms of the simple purpose of estimating affiliation of a modern skull, he considered his results as very good. In the case of classifying prehistoric individuals into a modern sample, the results were not as good. Howells had limited success in distinguishing regions craniometrically, that is in setting up regional samples to which an individual can be assigned as successfully as they can be affiliated with specific samples. However, he did find that such samples clustered well in accordance with regional expectations. Overall, Howells suggested that based on his results individuals assign themselves better to specific populations rather than to "races" or regional samples.

Brace et al. (2001) studied the old world sources of new world craniofacial variation. The authors state that metric variables record inherited differences in cranial and facial form by documenting minor variations in the arrangement of suture placement, length, and other minutiae in the construction of the cranial vault and face. Brace et al. (2001) maintain that the various configurations of craniofacial form cluster regionally and are not distributed in clinal fashion in relation to the intensity of differing selective force strengths (Brace and Hunt, 1990; Brace and Tracer, 1992; Brace et al., 1993). Also

configurations of facial form, once established, seem to stay stable over considerable spans of time.

Jantz and Owsley (2001) looked at variation among early North American crania using craniometric measurements. Fossil crania were compared to the worldwide database by Howells (1989) because only three of the Howells' populations are Native American, Jantz and Owsley supplemented the Native American samples with six other historic samples. The analysis was based on 22 measurements which quantify overall length, breadth, facial variation, projections from the transmeatal axis, and facial projections. The authors used the posterior probability to determine which of the reference groups each fossil cranium was most likely to belong to. Along similar lines, the typicality probability was used to indicate where a given specimen falls in relation to the variability of the reference groups. Based on this analysis, Jantz and Owsley concluded that the diversity of early American crania makes it inadvisable to pool them into a single Paleoamerican sample for purposes of analysis. They also deduced that the most parsimonious explanation of the demonstrated morphological and genetic relationships is that the ancient immigrants were replaced or assimilated by more recent ones.

There has been much debate among anthropologists as to the relative merits of posterior versus typicality probabilities in individual classification. Albrecht (1992) suggested that typicality probabilities should be used rather than posterior probabilities because they do not eliminate the possibility that the individual in question could be a member of a group other than the ones being used for comparison. By allowing for the possibility that the individual may be a member of a group not represented a fossil is not

classified based on the fact that it is nearest to that group's centroid whether or not it is outside the range of variation exhibited by that population.

Relethford (2002) studied global human genetic diversity by looking at craniometrics and skin color. Based on the results obtained, craniometric traits closely resemble the components of variation obtained from genetic marker and DNA polymorphism data. The craniometric data used were originally collected by Howells (1989) and consist of 57 craniometric measurements on 1,734 crania from 18 populations in six major geographic regions. Relethford concluded that the global patterns of craniometric variation can be considered, on average, selectively neutral.

In 2002 Sparks and Jantz reanalyzed Boas' (1910) data set in an attempt to determine whether or not cranial plasticity exists among humans. Sparks and Jantz (2002, 2003) proposed that the Boas data provided evidence of slight developmental plasticity. The authors suggested that Boas had misinterpreted the results of his cranial studies. Gravlee et al. (2003a, 2003b) suggested that Boas did get it right and that there was evidence of plasticity. Both sets of authors showed that there was cranial plasticity present; however, they differed in their interpretations as to the amount and effects of cranial plasticity. Sparks and Jantz (2002, 2003) found that there was cranial plasticity present but that it was so minimal as to be insignificant. The authors suggested that cranial plasticity did not affect population affinities and that there is a strong genetic component to craniofacial morphology. Gravlee et al. (2003a, 2003b) also found that plasticity was present in the cranium and that it was slight, but they said that this is what Boas had himself stated about his findings.

Relethford (2007) says that his reading of the studies suggests that craniometric traits do show some evidence of developmental plasticity, but the magnitude of these changes is not sufficient to erase patterns of population relationships. Relethford concludes that although plasticity does exist for craniometric traits, it does not as a result obscure underlying genetic differences between populations. This suggests that there is continued potential for such traits in the study of human population structure and history. Studies performed by Relethford (2004a, 2004b) examined global patterns of craniometric variation and found that they reflect both population affinities and natural selection. However, it was shown that natural selection does not obscure the underlying patterns of population relationships (Relethford, 2004a).

Relethford (2004b) examined measures of genetic similarity for global datasets for classical genetic markers, microsatellite DNA markers, and craniometrics. He found the same rate of distance decay, the effects of the isolation by distance model, in all three types of data. As with studies of apportionment of genetic diversity, this close association suggests that multivariate patterns of craniometric variation emulate those of neutral genetic variation to a large extent (Relethford, 2004b).

In 2006, Brace et al. performed another craniometric study; this time looking at similarities and differences between living human populations and their prehistoric predecessors using 24 craniofacial measurements. The authors believe that because the distribution of craniometric variation behaves in a similar fashion to that of genetic markers they can be considered neutral and of no adaptive significance. For this reason, they demonstrate the extent of genetically shared relationships between adjacent populations.

Hanihara and Ishida (2009) studied the population history of the Jomon, Neolithic inhabitants of Japan, using 34 craniofacial measurements. They used an R-matrix analysis to assess the regional diversity of the Jomon skeletal series. An average heritability of 0.55, as proposed by Devor (1987), was used in building the R-matrix. A second R-matrix was built using a heritability of 0.40 which Carson (2006) recently found to be more accurate for the specific craniofacial measurements used in the analysis.

The authors found that the apportionment of regional diversity estimated from the craniometric data indicates that the majority of the diversity of the Jomon people existed within regions. The authors' findings also suggest that the Jomon ancestors of the northern part of Japan might have expanded southward to Honshu Island. Further analyses indicated that the Jomon cranial series share a piece of their ancestral gene pool with early north-eastern Asians (Hanihara and Ishida, 2009).

A particularly important paper in terms of the research presented in the current study is Brace et al.'s (2008) analysis of the Kennewick remains. In this analysis, Brace and co-workers attempt to determine which population(s) Kennewick man is most similar to. The measurements craniofacial measurements were converted to Z scores in this analysis because this allowed the combination of male and female data without having to worry about sex-related differences in sheer body size in the dimensions of the specimens measured.

Brace et al. (2008) created an R-matrix for the Asian and Pacific populations that were included in their analysis following Relethford and Blangero's (1990) method. The authors also performed a discriminant function analysis and examined the canonical variates that were obtained. A posterior probability and typicality probability were also

calculated. The R-matrix values along with those for the Kennewick individual were treated by the neighbor-joining procedure and plotted as web-like trees. Kennewick is always shown to be at the end of a long twig. This is the result of Kennewick being an individual specimen with single figures and no standard deviation for each variable, but all the other twigs are for groups with mean dimensions and common variance. The results of this study show that the Kennewick individual is consistently on the same twig as the Ainu of Japan and Polynesians. This result is maintained no matter what combination of other groups is used. The typicality probability supports this result.

CHAPTER 3 : MATERIALS AND METHODS

Materials

The three crania that were used for the current study are housed at the University of Montana and are part of the University of Montana Forensic Collection (UMFC). They were purchased as complete skeletons from a biological supply company called Skulls Unlimited International Inc. The acquisition numbers assigned to these individuals are: UMFC 103 (Figure 3.1 and 3.2), UMFC 104 (Figure 3.3 and 3.4), and UMFC 120 (Figure 3.5 and 3.6).

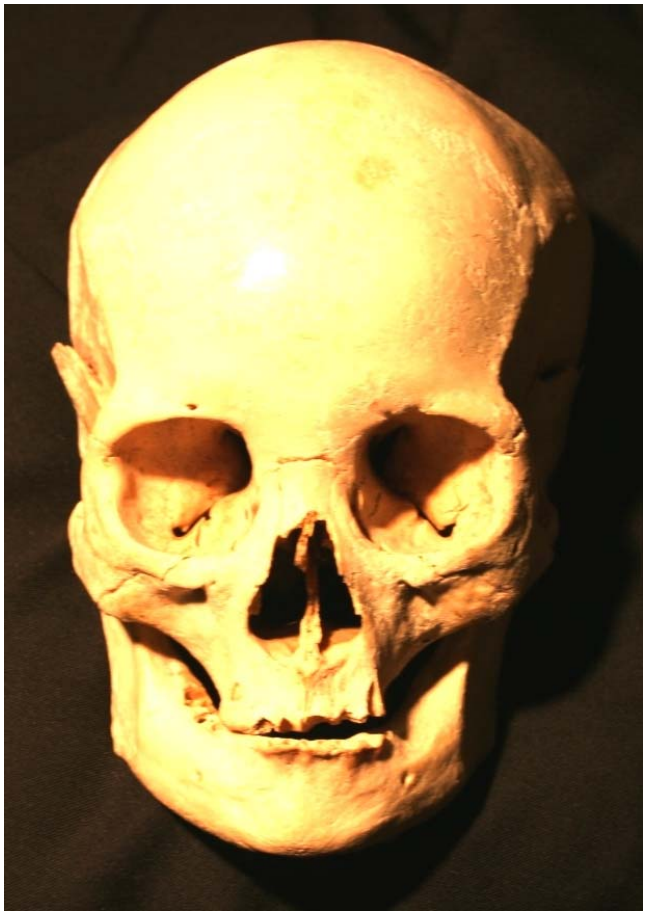

Figure 3.1. UMFC 103.

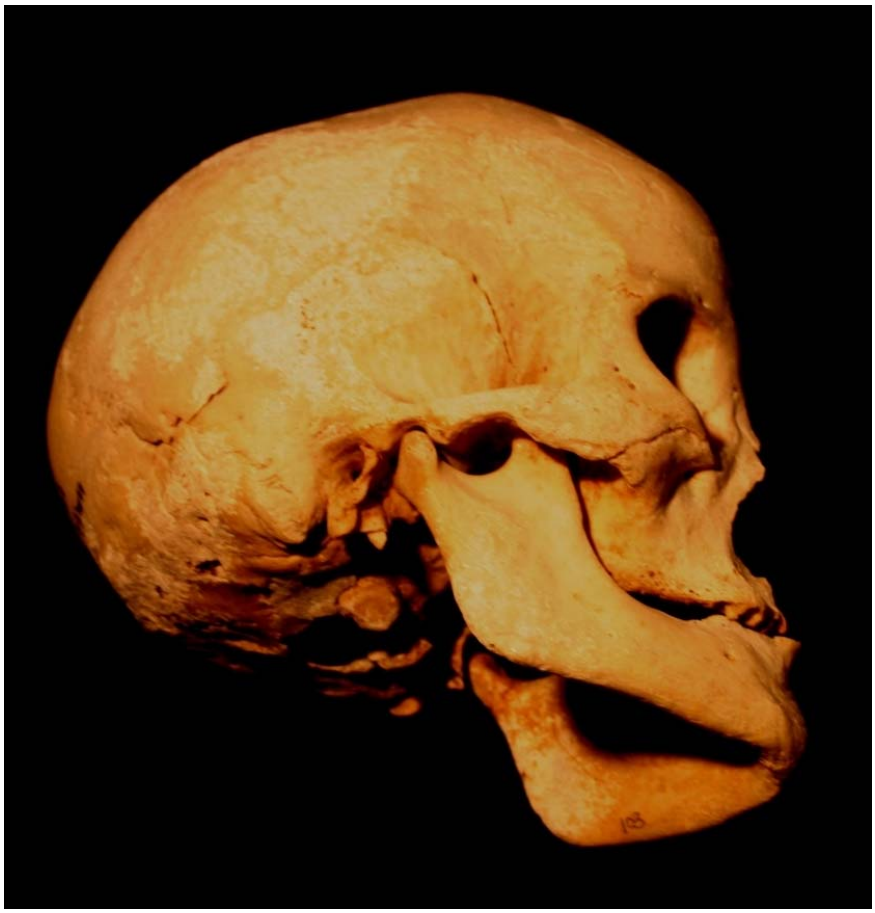

Figure 3.2. UMFC 103, profile view.

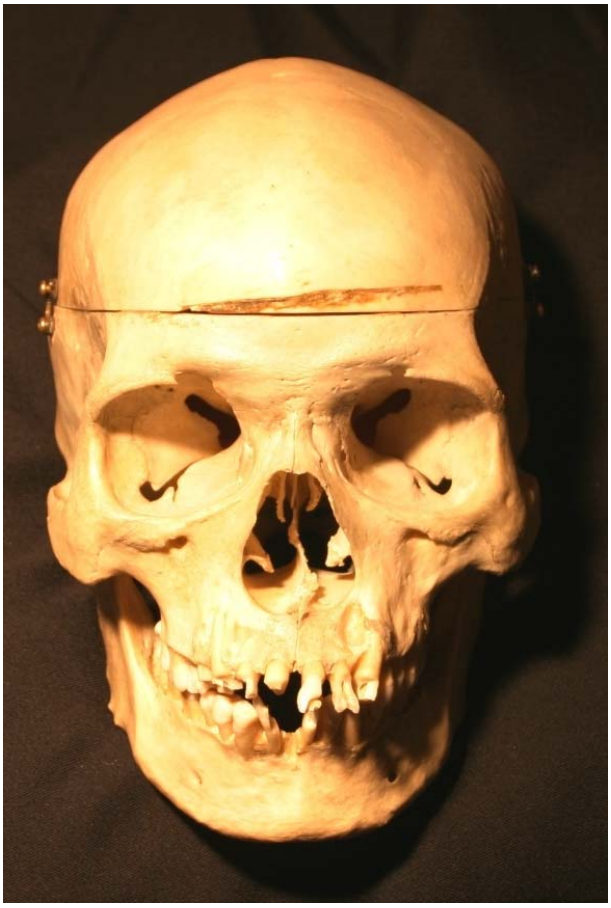

Figure 3.3. UMFC 104.

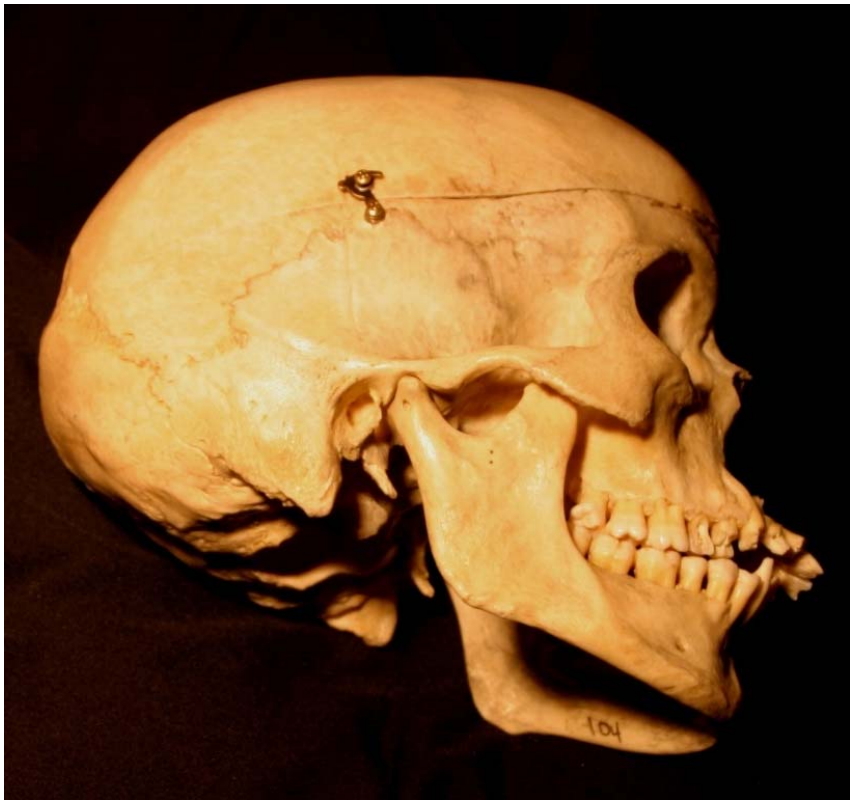

Figure 3.4. UMFC 104, profile view.

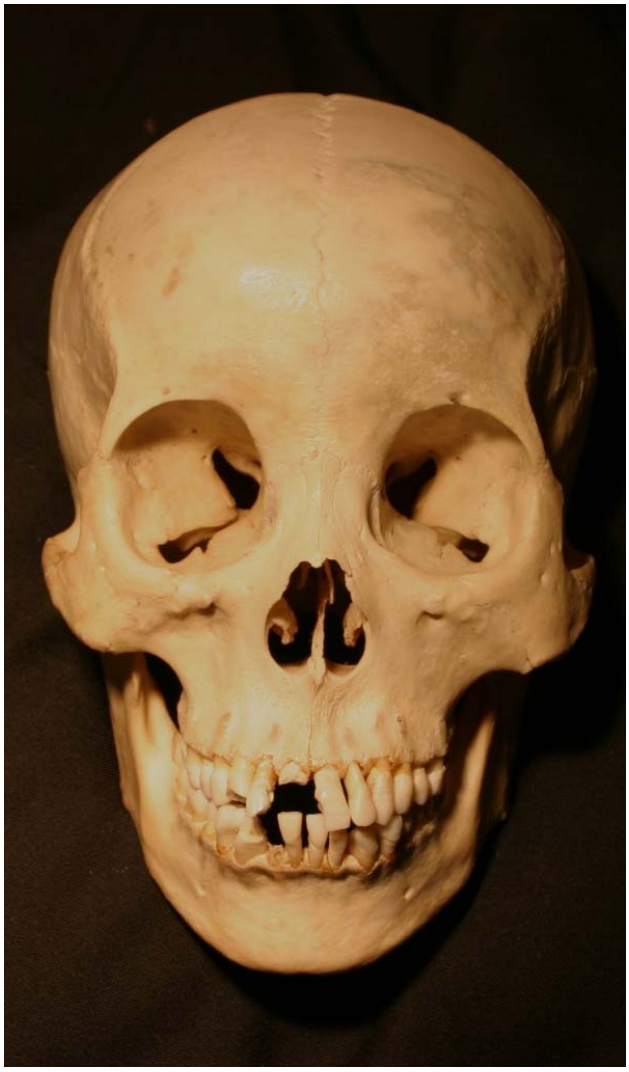

Figure 3.5. UMFC 120.

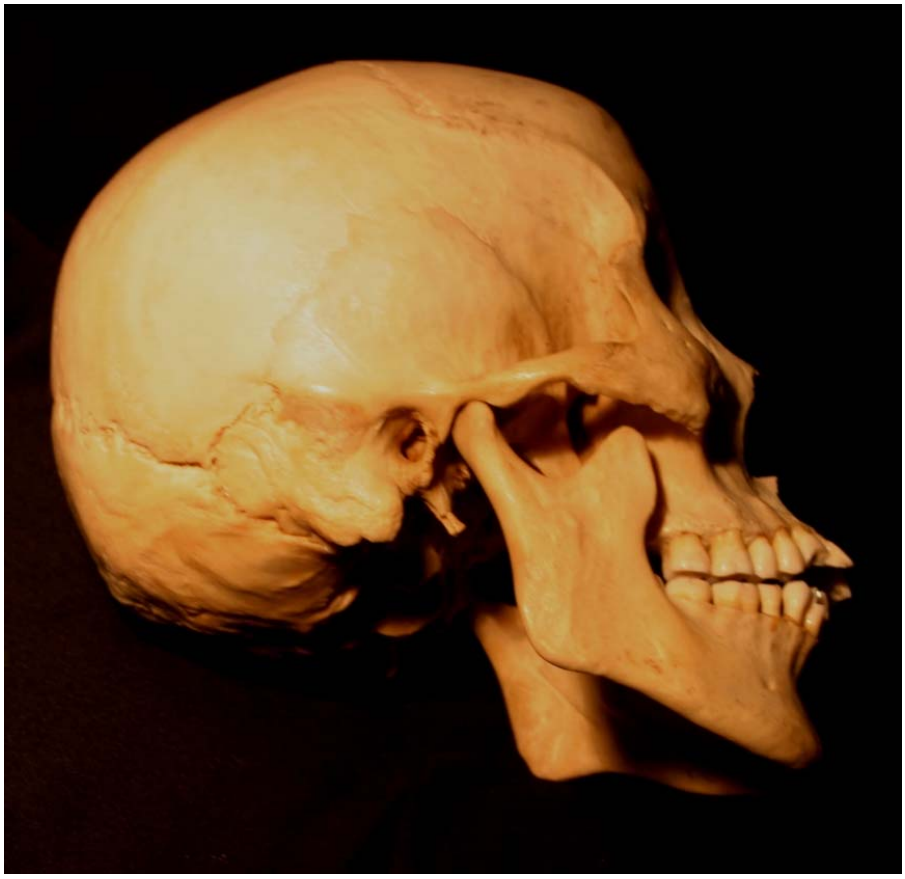

Figure 3.6. UMFC 120, profile view.

A Microscribe 3.0, 3-dimensional digitizer, was used to collect coordinate data for each cranium. Craniofacial measurements were then calculated from the coordinate data for all three individuals. These measurements were compared to data from two different craniofacial measurement databases. The first database was collected by researchers at the University of Michigan and consists of 21 craniofacial measurements (Table 3.1 below) collected on individuals from populations around the world. The individuals come from modern, historic, and prehistoric populations (Brace et al., 2001, 2006, 2008). The second database was collected by Dr. T Hanihara at the Medical School of Saga University. His database consists of 45 craniometric measurements (Table 3.2 below)

collected on individuals from different populations worldwide. The measurements compiled in Hanihara's database are taken from individuals from modern as well as historic and prehistoric populations (Hanihara, 1997; Hanihara et al., 2008; Hanihara and Ishida, 2009).

Table 3.1. Michigan Database Craniometric Measurements.

Craniofacial measurement	**Definition**	**Source**
Nasal height	Average height from nasion to the lowest point on the border of the nasal aperture on either side.	Martin No. 55
Nasal bone height	Length of the nasomaxillary suture.	Martin No. 56(2)
Piriform Aperture Height	Average from the two points on the margin of the piriform aperture inferiorly to rhinion.	Martin No. 55(1)
Nasion Prosthion Length	Nasion to prosthion.	Martin No. 48
Nasion Basion	Nasion to basion.	Martin No. 5
Basion Prosthion	Basion to prosthion.	Martin No. 40
Superior nasal bone width	Distance between left and right nasomaxillarae.	Martin No. 57(2)
Simotic width	Minimum transverse breadth of the generally hourglass shape of the two nasal bones.	Howells, 1973
Inferior nasal bone width	Dimension between the right and left inferior terminus of the nasomaxillary suture, along the margin of the piriform aperture.	Martin No. 57(3)
Nasal breadth	Maximum width of the piriform aperture.	Martin No. 54
Simotic subtense	Subtense from simotic chord to the nasal bridge.	Howells, 1973
Inferior simotic subtense	Same as above measurement, but taken from points outlined in measurement #9.	Brace and Hunt, 1990
Fronto-orbital width subtense at nasion	Subtense from frontomalare posterior to nasion.	Woo and Mourant, 1934
Mid-orbital width subtense at rhinion	Anterior projection of the nose off the facial plane as measured from where the maxillo-malar suture crosses the orbital rim to rhinion.	Woo and Mourant, 1934
Bizygomatic breadth	Maximum breadth across the zygomatic arches.	Martin No. 45
Glabella opisthocranion	Length from glabella to opisthocranion.	Martin No. 1
Maximum cranial breadth	Maximum breadth of the cranium usually somewhere around the parietal eminence.	Martin No. 8
Basion Bregma	Height from basion to bregma.	Martin No. 17
Basion Rhinion	Basion to rhinion.	Brace and Hunt, 1990
Width at measurement #13	Distance from frontomalare temporale to frontomalare temporale.	Brace and Hunt, 1990
Width at measurement #14	Distance from right maxillo-malar suture to left maxillo-malar suture.	Woo and Mourant, 1934

Table 3.2. Hanihara Database Craniometric Measurements.

Craniometric measurement	Source
1. Maximum cranial length (GOL)	Howells, 1973
2. Nasion-opisthocranion (NOL)	Howells, 1973
3. Cranial base length (BNL)	Howells, 1973
4. Maximum cranial breadth (XCB)	Howells, 1973
5. Minimum frontal breadth (M9)	Martin, 1928
6. Maximum frontal breadth (XFB)	Howells, 1973
7. Biauricular breadth (M11)	Martin, 1928
8. Biauricular breadth (AUB)	Howells, 1973
9. Biasterionic breadth (ASB)	Howells, 1973
10. Basion-bregma height (BBH)	Howells, 1973
11. Sagittal frontal arc (M26)	Martin, 1928
12. Sagittal parietal arc (M27)	Martin, 1928
13. Sagittal occipital arc (M28)	Martin, 1928
14. Nasion-bregma chord (FRC)	Howells, 1973
15. Bregma-lambda chord (PAC)	Howells, 1973
16. Lambda-opisthion chord (OCC)	Howells, 1973
17. Basion prosthion length (BPL)	Howells, 1973
18. Breadth between frontomalare temporale (M43)	Martin, 1928
19. Bizygomatic breadth (ZYB)	Howells, 1973
20. Middle facial breadth (M46)	Martin, 1928
21. Nasion prosthion height (NPH)	Howells, 1973
22. Interorbital breadth (DKB)	Howells, 1973
23. Orbital breadth (M51)	Martin, 1928
24. Orbital breadth (M51a)	Martin, 1928
25. Orbital height (OBH)	Howells, 1973
26. Nasal breadth (NLB)	Howells, 1973
27. Nasal height (NLH)	Howells, 1973
28. Nasal height (M55)	Martin, 1928
29. Palate breadth (MAB)	Howells, 1973
30. Mastoid height (MDH)	Howells, 1973
31. Mastoid width (MDB)	Howells, 1973
32. Bicondylar breadth (M65)	Martin, 1928
33. Bigonial breadth (M66)	Martin, 1928
34. Maximum projective length of mandible (M68(1))	Martin, 1928
35. Height of mandibular symphysis (M69)	Martin, 1928
36. Corpus mandibulae width (M69(3))	Martin, 1928
37. Minimum anteroposterior width of the ramus (M71a)	Martin, 1928
38. Ramus height (M70)	Martin, 1928
39. Ramus breadth (M71)	Martin, 1928
40. Breadth between frontomalare orbitale (M43(1))	Martin, 1928
41. Frontal subtense (No 43c)	Brauer, 1988
42. Minimum horizontal breadth of the nasalia/simotic chord (M57, WNB)	Martin, 1928; Howells, 1973
43. Simotic subtense (No 57a, SIS)	Brauer, 1988; Howells, 1973
44. Breadth between zygomaxillare anterius/Zygomaxillary chord (M46b, ZMB)	Martin, 1928; Howells, 1973
45. Zygomaxillary subtense (No 46c, SSS)	Brauer, 1988; Howells, 1973

Both of these databases are extremely large and as a result not all of the populations sampled are used for comparison in the present analysis. The populations that were used were chosen based on geographic location and the predicted population affinity of UMFC 103, 104, and 120. The commonly held belief that most biological supply companies obtained human skeletons from India before 1985 and China after 1985 led to populations being chosen which were in close geographic proximity to these two countries. The reference populations chosen from the Michigan database are listed in Table 3.3 (see below) and the reference populations chosen from the Hanihara database are listed in Table 3.4 (see below). The populations are also displayed on maps (see Figures 3.7 and 3.8).

Table 3.3. Michigan Database Reference Populations for this Study.

Population	Female (#)	Male (#)	Total (#)
Mexico	6	9	15
Japan	77	173	250
Ainu	23	33	56
South China	7	20	27
Polynesia	73	62	135
Chuckchi	7	12	19
Thai	27	37	64
Melanesia	21	28	49
Philippine Negrito	10	10	20
Philippine Manobo	12	11	23
Heilongjiang	8	10	18
Aleut	15	15	30
Hong Kong	35	73	108
Peru	29	26	55
Vedda	13	15	28
Tamil	7	10	17
Tierra del Fuego	7	15	22
Eskimo	59	72	131
Athabaskan	27	21	48
South India	12	23	35
Buriat	9	7	16
Hebei	18	15	33
Henan	6	23	29
Haida	24	25	49
Blackfoot	17	15	32
Taiwan aboriginal	14	22	36
Maryland	12	14	26
Merida	23	25	48
Australia	19	32	51
Mongolia	54	74	128
WAfrica	51	54	105
TOTAL	**722**	**981**	**1703**

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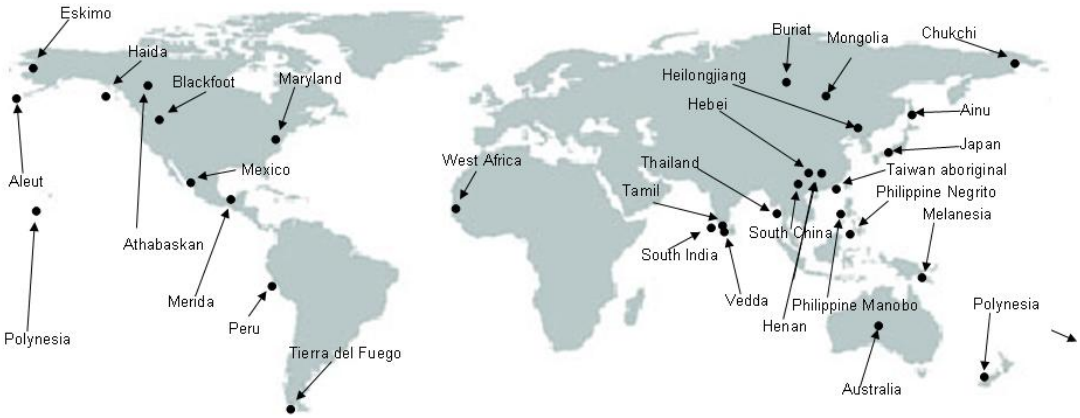


Figure 3.7. Map of Michigan Database Reference Populations.

Table 3.4. Hanihara Database Reference Populations for this Study.

Population	Females (#)	Males (#)	Total (#)
Aleut	98	92	190
North Australia	5	49	54
South Australia	19	63	82
Tasmania	6	13	19
Chile	11	16	27
Patagonia	11	47	58
Mexico	33	55	88
Peru	140	210	350
Ainu Hokkaido	25	51	76
Ainu Sakhalin	10	23	33
North Han	13	57	70
North China, Manchurian	0	40	40
Japan	39	113	152
Eskimo, Alaska	211	241	452
Vedda	3	12	15
Buriat	9	21	30
Chuckchi	2	18	20
Mongol	51	121	172
Polynesia Marquesas	20	58	78
Borneo	5	61	66
Philippine Negrito	7	20	27
Sumatra	2	26	28
Thai	10	29	39
Gabon	4	60	64
Ivory	0	21	21
South Han	0	58	58
Korea	0	19	19
Tibet	11	49	60
Bengal	22	45	67
Calcutta	0	15	15
Nepal	5	24	29
Fiji	3	26	29
Caledonia	9	30	39
Solomon	21	50	71
New Zealand	19	98	117
Burma	3	68	71
Iraq	4	15	19
Cameroon	15	30	45
Ghana	34	45	79
Nigeria	1	26	27
Tanzania	23	71	94
Somalia	3	42	45
Kenya	19	60	79
TOTAL	**926**	**2288**	**3214**

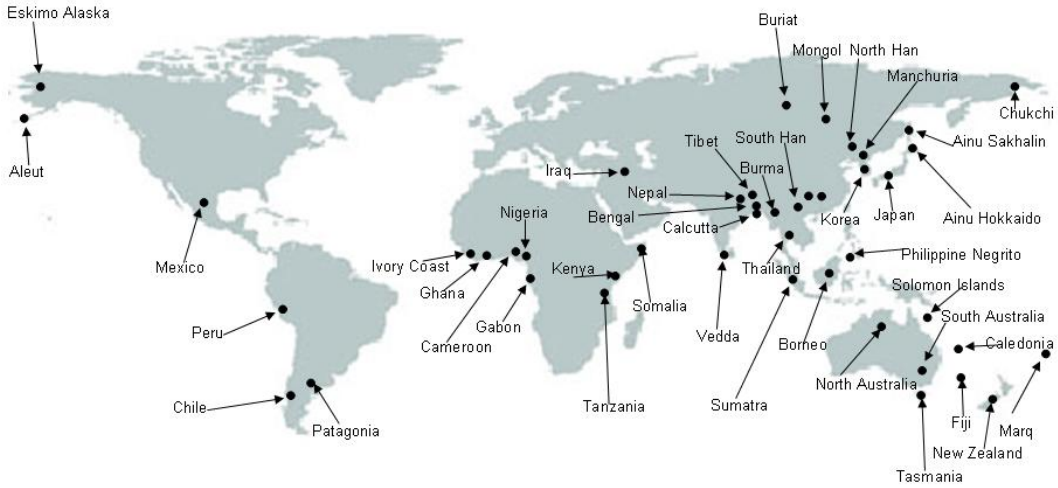


Figure 3.8. Map of Hanihara Database Reference Populations.

Methods

Data Collected for UMFC 103, 104, and 120

Coordinate data was observed on craniofacial landmarks for each individual using the Microscribe 3.0 digitizer. The landmarks used to calculate the Michigan database craniofacial measurements are listed in Figure 3.9 (see below) and those for the Hanihara database craniofacial measurements in Figure 3.10 (see below). The 2-dimensional craniofacial measurements were calculated using the Pythagorean Theorem in Microsoft Excel. The 2-dimensional linear craniofacial measurements for the Michigan dataset

were computed by the DISTANCE3D program by free statistical package R (Umeda and Seguchi, 2005).

1. M: center of the ear hole (left)
2. M: center of the ear hole (right)
3. Nasion
4. Dacryon
5. Ectoconchion a (left)
6. ZO (left)
7. Subspinale
8. Zygomaxillare (left)
9. Prosthion
10. p2/M1 (left)
11. Bregma
12. Nasal sill (left)
13. Nasal sill (right)
14. Superior terminate at nasomaxillary suture (left)
15. Superior terminate at nasomaxillary suture (right)
16. Jugale (left)
17. Jugale (left)
18. Nasospinale
19. Rhinion
20. Simotic (left)
21. Simotic (middle)
22. Simotic (right)
23. Inferior nasal bone width (left)
24. Inferior nasal bone width (right)
25. Nasal breadth (left)
26. Nasal breadth (right)
27. Frontomalare temporale (left)
28. Frontomalare orbitale (left)
29. Frotomalare orbitale (right)
30. Frontomalare temporale (right)
31. Midorbital width (left)
32. Midorbital width (right)
33. Bizygomatic (left)
34. Bizygomatic (right)
35. Glabella
36. Max cranial breadth (left)
37. Max cranial breadth (right)
38. Minimum nasal tip (left)
39. Minimum nasal tip (right)
40. Basion
41. Opisthocranion
42. Lambda
43. Inion
44. Opisthion
45. Lowest point of mastoid process (left)
46. Lowest point of mastoid process (right)
47. Orale
48. Endomalare (left)
49. Endomalare (right)
50. Plate cross point
51. Edge of dental arch (left)
52. Edge of dental arch (right)
53. m1/m2 inside point (left)
54. m1/m2 inside point (right)
55. c/p1 outside point (left)
56. c/p1 outside point (right)

Figure 3.9. Landmarks for Michigan Database.

Figure 3.10. Landmarks for Hanihara Database.

1. Glabella
2. Bregma
3. Lambda
4. Opisthocranion
5. Opisthion
6. Basion
7. Prosthion
8. Nasion
9. Maximum cranial breadth (right)
10. Maximum cranial breadth (left)
11. Frontotemporale (right)
12. Frontotemporale (left)
13. Maximum frontal breadth (right)
14. Maximum frontal breadth (left)
15. Auriculare (right)
16. Auriculare (left)
17. Asterion (right)
18. Asterion (left)
19. Maxillofrontale (right)
20. Maxillofrontale (left)
21. Zygion (right)
22. Zygion (left)
23. Midfacial breadth (right)
24. Midfacial breadth (left)
25. Dacryon (right)
26. Dacryon (left)
27. Maxillofrontale
28. Ectoconchion
29. Orbital height (upper)
30. Orbital height (lower)
31. Alare (right)
32. Alare (left)
33. Lowest point on the border of the nasal aperture (right)
34. Lowest point on the border of the nasal aperture (left)
35. Ectomalare (right)
36. Ectomalare (left)
37. Lowest point on the mastoid process (right)
38. Right ear hole
39. Mastoid breadth (posterior)
40. Mastoid breadth (anterior)
41. Frontomalare temporale (right)
42. Frontomalare temporale (left)
43. Nasion
44. Frontomalare orbitale (right)
45. Frontomalare orbitale (left)
46. Simotic chord (right)
47. Simotic chord (left)
48. Nasion
49. Deepest part of bridge of nose
50. Zygomaticus anterius (right)
51. Zygomaticus anterius (left)
52. Subspinale

During digitizing any irregularities of the cranium were noted and an estimation of sex was made based on the morphology of the cranium as well as the os coxae. The sex of these three individuals was estimated based on procedures described in Buikstra and Ubelaker's (1994) *Standards for Data Collection*. UMFC 103 was estimated to be male mainly due to the morphology of the os coxae. The left os coxa had a narrow greater sciatic notch, a broad ischiopubic ramus, and the presence of a faint preauricular sulcus. The same can be said of the right os coxa. However, the cranium was very gracile with small mastoid processes, very little muscle marking in the occipital region, no projection in the brow ridge area, and a greater than 90 degree gonial angle. Despite the fact that the cranium seems more characteristically female in terms of morphology, the morphological features of the os coxae indicate that this individual is indeed male.

UMFC 104 was estimated to be female based on the combined morphology of the cranium and os coxae. The cranium was very gracile with very few distinct muscle markings, the presence of a slightly protruding glabellar region, medium size mastoid processes, and sharp eye orbits. The left os coxa had a wide greater sciatic notch, the presence of a ventral arc, and the presence of a fairly shallow preauricular sulcus. The same can be said of the right os coxa. All of these traits combined indicate that this individual is most likely female.

UMFC 120 is tentatively estimated to be male, however; there are ambiguous features present in both the cranium and os coxae. The cranium is fairly gracile overall; there are slight muscle markings in the nuchal region, smooth eye orbits, medium size mastoid processes, and a close to 90 degree gonial angle. The left and right os coxae had fairly broad greater sciatic notches, broad ischiopubic rami, no ventral arcs, and slight

preauricular sulci. Overall, there are morphological features which result in conflicting sex estimates, but because the os coxae appear to be more male; the sex for this individual is estimated as male.

UMFC 103 had some disfiguration of the cranium which may have been the result of disease processes or the processing of the cranium by Skulls Unlimited. There was thickening present on the outside of the cranium which may be attributed to anemia, however, this was not researched any further because it was beyond the scope of the current study and was not believed to have detrimentally affected the digitizing of the cranium. A few of the landmarks had to be estimated due to the fact that the nasal bones were broken on both the left and right sides. Also there were no teeth present in the maxillary dental arcade and so those landmarks which were to be taken on the dental arcade had to be estimated. There were no irregularities present in either UMFC 104 or UMFC 120. Also all of the bones were present in their entirety so that no landmark locations had to be estimated.

Comparison with Michigan Database

The first database with which UMFC 103, 104, and 120 were compared is the Michigan database. Using the statistical program SPSS 16.0 a descriptive analysis was run to determine the exact number of individuals in each population and also to determine the number of males and females present within each population (see Table 3.3). Twenty-one craniofacial measurements were used in the analysis. Any individuals with missing data were eliminated from the analysis. Those populations with less than 15 individuals were excluded from analysis because a normal distribution could not be assumed for populations with fewer than this number of individuals.

A principal components analysis (PCA) was run using the reference populations in an attempt to determine if the craniofacial measurements being used were indeed able to show population similarity related to geographic proximity and probable shared population history. A second principal components analysis was then run with SPSS 16.0 using the populations described above and UMFC 103, 104, and 120. The second PCA was run to look at the potential similarities between UMFC 103, 104, and 120 and the reference populations. The purpose of principal components analysis is to focus on the covariation (or interrelationship) among a large number of variables taken from a single sample in order to attempt to identify common patterns of variation. PCA does not use any criterion for maximizing differences among groups. Individual specimens can be located on these factors (Pietrusewsky, 2000). The principal components analysis was conducted as an exploratory technique as well as to get an estimate of what measurements seem to be important in terms of the variation exhibited by populations. The component matrix produced was used to make this determination.

The statistical program DISCR 2.41 (Oe and Seguchi, 2003) was used to perform a discriminant function analysis to classify UMFC 103, 104, and 120. The discriminant function analysis utilized a technique known as cross validation which tests the accuracy of the classification of known individuals based on the discriminant functions calculated. The 1st and 2nd and 2nd and 3rd canonical variates were graphed to look at variation in terms of the selected populations and UMFC 103, 104, and 120. The canonical variates are plotted to show the reference populations and the unknown individuals in order to see the allocation of the unknown individuals. The main purpose of discriminant function analysis is to maximize differences between groups. The new variables which result

from discriminant function analysis can be considered uncorrelated or independent. Individuals and/or groups can be placed in a multidimensional space after this transformation in order to provide a means of visualizing these interrelationships. In most cases, the first few newly calculated variables account for the majority of the variation among groups (Pietrusewsky, 2000).

Finally, DISCR 2.41 was used to calculate Mahalanobis distances in order to calculate typicality probabilities and posterior probabilities for the classification of UMFC 103, 104, and 120. Mahalanobis distance is computed by maximizing the difference between pairs of groups. This is done by maximizing the between-group variance to the pooled within-group variance. This procedure transforms the original variables to a new uncorrelated set of variables (Pietrusewsky, 2000). Posterior probabilities assume that the unknown individual belongs to one of the groups included in the analysis. The posterior probabilities, as a result, sum to 1. Typicality probabilities evaluate how likely it is that the unknown individual belongs to any, or none, of the groups based on the average variability of all the groups in the analysis (Pietrusewsky, 2000). Each of these individuals was assigned to one of the selected populations based on statistical similarities.

After these initial statistical tests, another statistical analysis was performed in an attempt to eliminate the effects of sheer size differences between populations. An analysis was run on this data using a shape transformation described by Darroch and Mosimann (1985). In this transformation, the geometric mean is calculated and then used to calculate shape variables for each measurement for each individual. This transformation is said to eliminate size differences to enable the analysis of differences in

shape only (Darroch and Mosimann, 1985). The transformed data was then submitted to the same statistical analyses as described above.

Comparison with Hanihara Database

The next step in the analysis was to compare UMFC 103, 104, and 120 to the selected populations from the Hanihara database (see Table 3.4). Although the Hanihara database consists of 45 craniofacial measurements, only 34 measurements were used in the initial analysis. The measurements were eliminated in accordance with published papers (Hanihara, 1997; Hanihara et al., 2008; Hanihara and Ishida, 2009). The measurements eliminated include all of the mandibular measurements (#s 32-39 in Table 3.2) as well as measurements #7, #24, and #28. A descriptive analysis was run using SPSS 16.0 as described above; the same procedure was followed in eliminating populations from the analysis. SPSS 16.0 was again used to perform two principal components analyses. Then, DISCR 2.41 was used to run a discriminant function analysis as described above. Posterior and typicality probabilities were again calculated. After this initial analysis was performed a second statistical analysis was run by performing the geometric mean shape transformation on the 34 individual measurements as a way to eliminate size differences between populations (Darroch and Mosimann, 1985).

CHAPTER 4 : RESULTS

Comparison with Michigan Database using 21 Craniofacial Variables

The principal components analysis (PCA) was performed as an exploratory method. Its purpose in terms of this study was to look at the variation present within the reference populations. The 1st three principal components account for 55.59% of the variation present within the sample. The component matrix was used to determine which craniofacial measurements were contributing to the 1st three principal components (see Table 4.1 below). The first principal component can be considered to be a result of size because all of the loadings are positive and most are fairly high. The second principal component seems to be separating populations based on width of the nasal bones. The third principal component is separating populations on the basis of the subtense measurements. For the purposes of the current analysis, only the 1st three principal components were evaluated as a general explanation of variation present in the sample.

Table 4.1. PCA Component Matrix: Michigan Database, 21 Variables.

Component Matrix[a]

	Component				
	1	2	3	4	5
nasal height	.685	-.403	.155	.316	.038
nasal bone height	.466	-.470	.157	.358	.150
piriform aperture height	.620	-.072	.457	-.086	-.232
nasion prosthion length	.707	-.394	.104	.235	.085
nasion basion	.789	-.019	-.244	-.374	.228
basion prosthion	.616	.089	-.377	-.421	.100
superior nasal bone width	.252	.686	.041	.409	.375
simotic width	.172	.797	-.008	.309	.304
inferior nasal bone width	.337	.252	-.442	.450	.091
nasal breadth	.322	.265	-.475	.412	-.301
simotic subtense	.398	.476	.534	.034	.128
inferior simotic subtense	.488	.084	.650	.001	-.041
frontoorbital width subtense at nasion	.385	.491	-.016	-.188	-.213
mid orbital width subtense at rhinion	.434	.377	.599	-.240	-.169
bizygomatic breadth	.796	-.249	-.078	.185	-.153
glabella opisthocranion	.702	-.030	-.285	-.242	.024
maximum cranial breadth	.467	-.310	.095	.497	-.097
basion bregma	.568	-.193	-.189	-.269	.331
basion rhinion	.828	.021	-.041	-.385	.160
width at 13 (fronto malar temporalis)	.773	.031	-.222	.078	-.271
mid orbital width (width at 14)	.328	.448	-.220	-.052	-.520

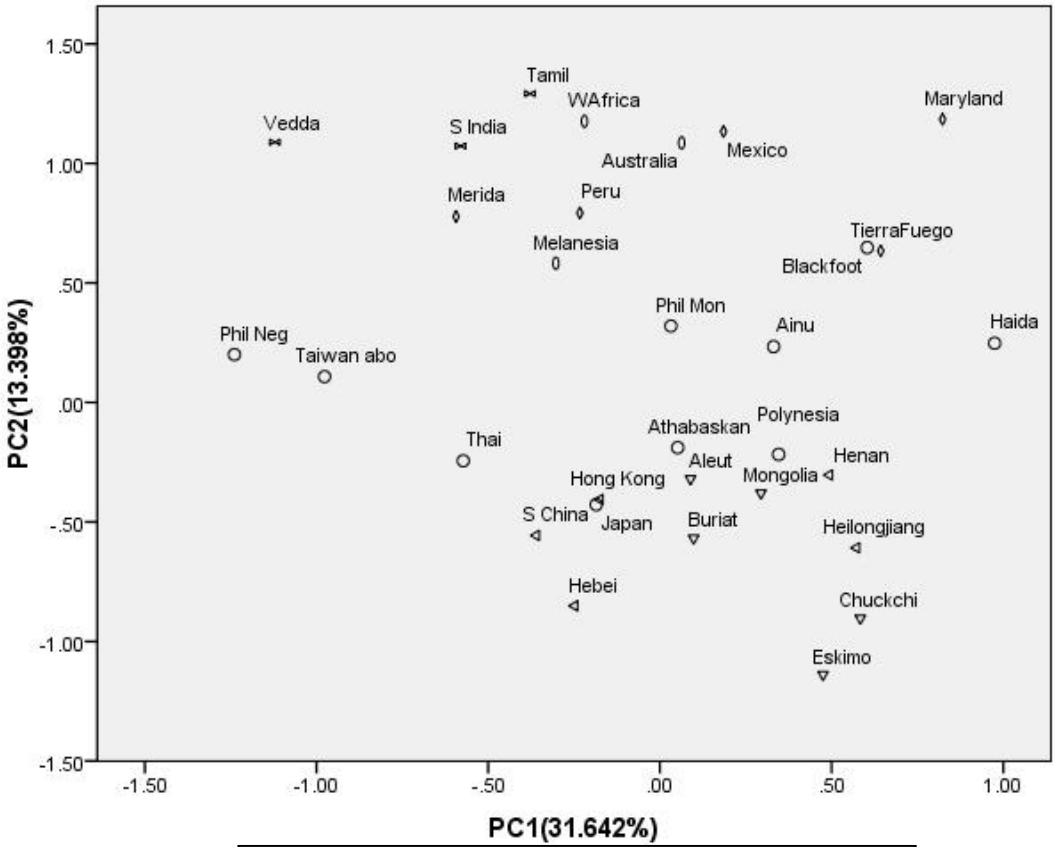
Extraction Method: Principal Component Analysis.

a. 5 components extracted.

The 1st three principal components were graphed to visualize the variation present within the populations sampled. The first graph (Figure 4.1 below) shows the variation

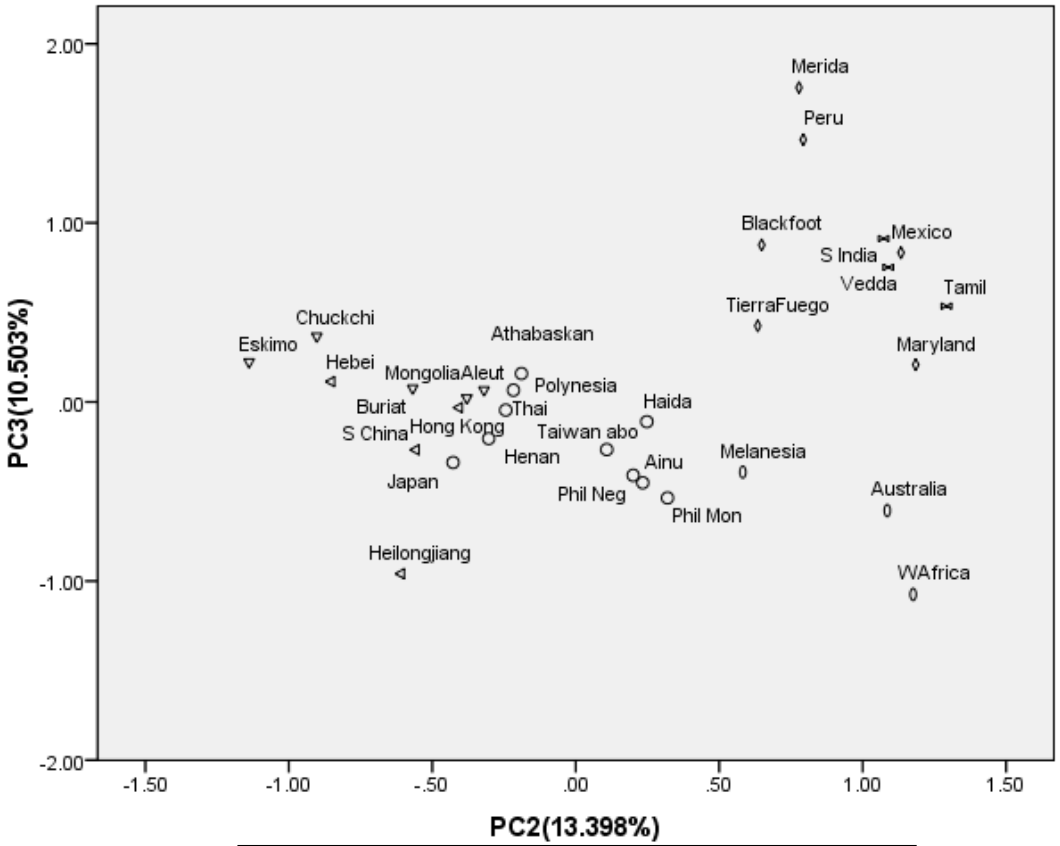
present based on principal component 1 (PC1) which accounts for 31.64% of the variation present within the sample and is a size factor and principal component 2 (PC2) which accounts for 13.40% of the variation and is a factor of nasal bone width. This graph shows clear geographic clustering of groups with West Africa, Australia, and Melanesia close to each other and many of the Chinese groups are close together as well. Also the Indian groups show a pretty clear clustering. The graph of PC2 vs. PC3 also demonstrates clear geographic clustering (see Figure 4.2 below). Most of the American populations are clustered together along with the Indian populations. The West African, Australian, and Melanesian populations cluster towards the bottom of the graph.

When the PCA is run again, but this time with UMFC 103, 104, and 120 the results are not as geographically clear (see Figures 4.3 and 4.4). The plot of PC1 vs. PC2 (Figure 4.3) is compressed somewhat because UMFC 103, 104, and 120 appear to be much smaller in terms of overall size than the sample populations. There is a clustering of the Chinese samples used and the Buriat, Mongol, Chukchi, and Eskimo populations. Other than this general cluster there does not appear to be any clear distribution of populations. UMFC 103 and 104 are closest to the Vedda population. The second graph (Figure 4.4 below) shows the variation present based on PCs 2 and 3. This graph clearly separates populations from North America (except Haida and Athabaskan), South America, and India from all other populations and UMFC 103, 104, and 120. This separation is based on PC3 which is a factor of the subtense measurements. UMFC 103 and 104 are close to the Australian, Melanesian, and West African populations. UMFC 120 is closest to the Eskimo and Chukchi populations.



- Northern Asia and Northern North America: Aleut, Athabaskan, Buriat, Chukchi, Eskimo, Haida, Mongolia
- North and South America: Blackfoot, Maryland, Merida, Mexico, Peru, Tierra del Fuego
- India: South India, Tamil, Vedda
- SE Asia: Philippine Manobo, Philippine Negrito, Taiwan aboriginal, Thailand
- China: Hebei, Heilongjiang, Henan, Hong Kong, South China

Figure 4.1. PC1 vs. PC2: Michigan Database, 21 Variables.



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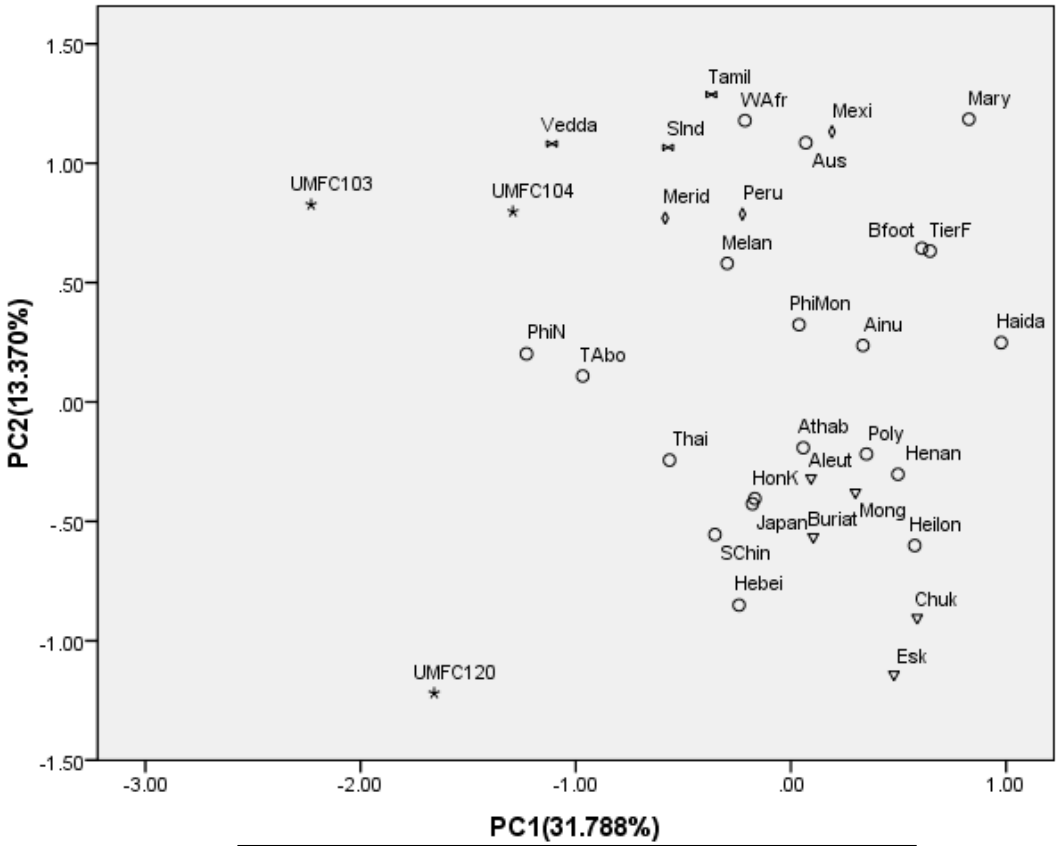
- India: South India, Tamil, Vedda
- SE Asia: Philippine Manobo, Philippine Negrito, Taiwan aboriginal, Thailand
- China: Hebei, Heilongjiang, Henan, Hong Kong, South China

Figure 4.2. PC2 vs. PC3: Michigan Database, 21 Variables.



- Northern Asia and Northern North America: Aleut, Athabaskan, Buriat, Chukchi, Eskimo, Haida, Mongolia
- North and South America: Blackfoot, Maryland, Merida, Mexico, Peru, Tierra del Fuego
- India: South India, Tamil, Vedda
- SE Asia: Philippine Manobo, Philippine Negrito, Taiwan aboriginal, Thailand
- China: Hebei, Heilongjiang, Henan, Hong Kong, South China

Figure 4.3. PC1 vs. PC2: Michigan Database and UMFC 103, 104, and 120; 21 Variables.

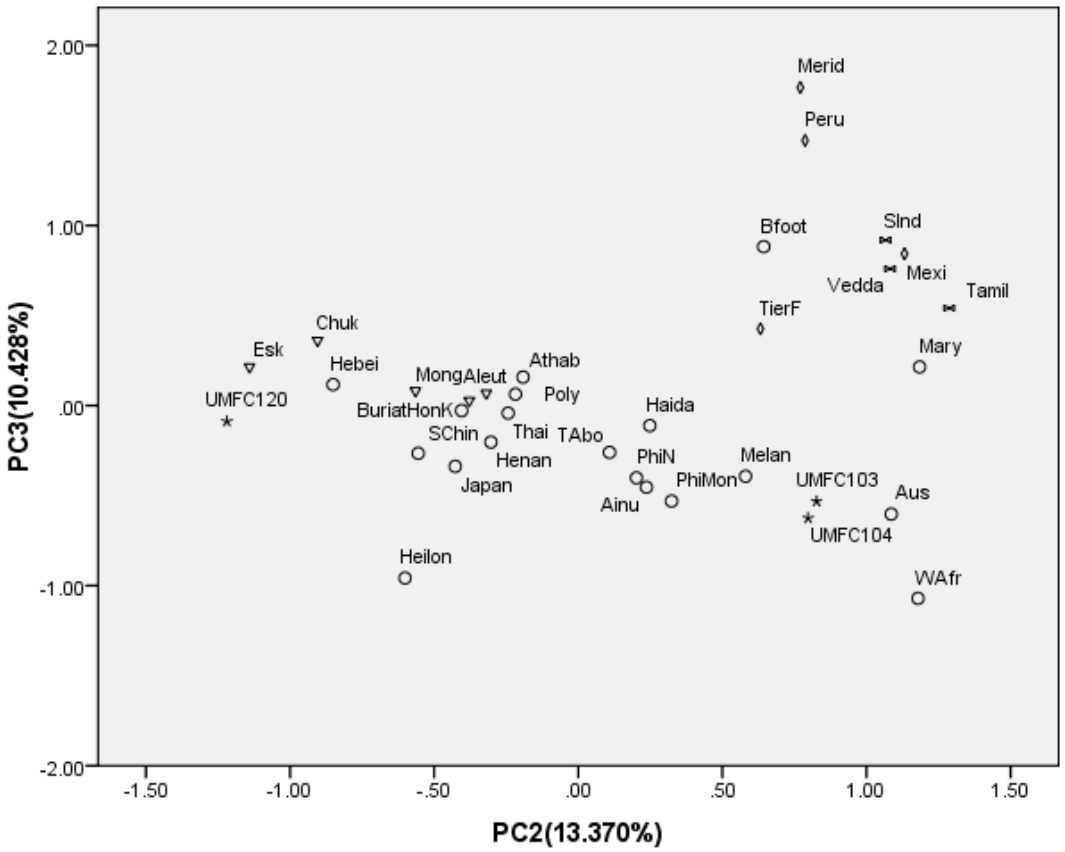


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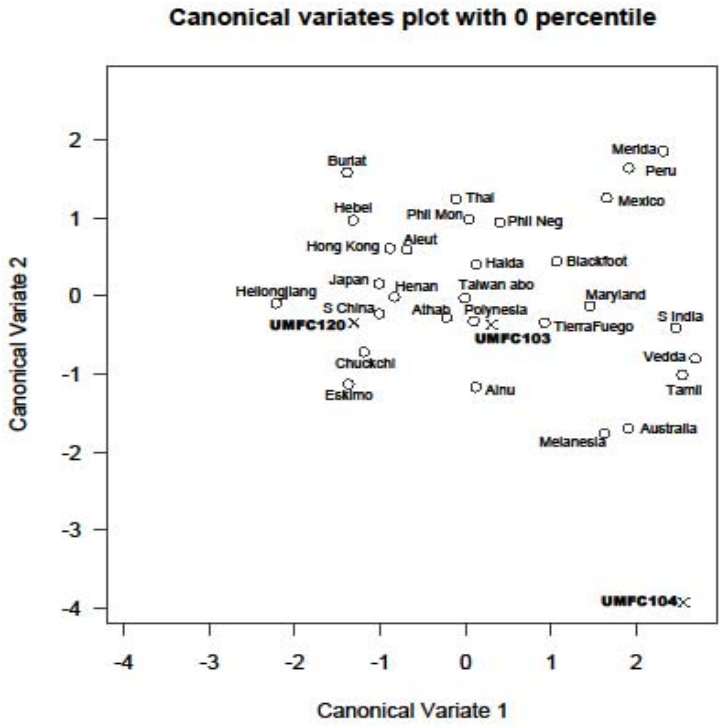
Figure 4.4. PC2 vs. PC3: Michigan Database and UMFC 103, 104, and 120; 21 Variables.

The discriminant function analysis was conducted to look at the potential similarities between any of the selected populations and UMFC 103, 104, and 120. The 1st and 2nd and 1st and 3rd canonical variates (CV) were graphed (see Figures 4.5 and 4.6 below). CV1 accounts for 29.53% of the differences between populations, CV2 15.80%, and CV3 12.15%. The graph of CV1 vs. CV2 (Figure 4.5) shows that UMFC 103 and 120 are shown to be within the range of variation that is exhibited by the reference populations. UMFC 104, however, is well outside the range of variation exhibited. The CV1 vs. CV3 plot demonstrates the same patterns in terms of UMFC 103 and 120. UMFC 104, however, is now nearer to the reference populations, specifically the Indian reference populations.

Figure 4.5. CV1(29.53%) vs. CV2(15.80%): Michigan Database, 21 Variables.



- Northern Asia and Northern North America: Aleut, Athabaskan, Buriat, Chukchi, Eskimo, Haida, Mongolia
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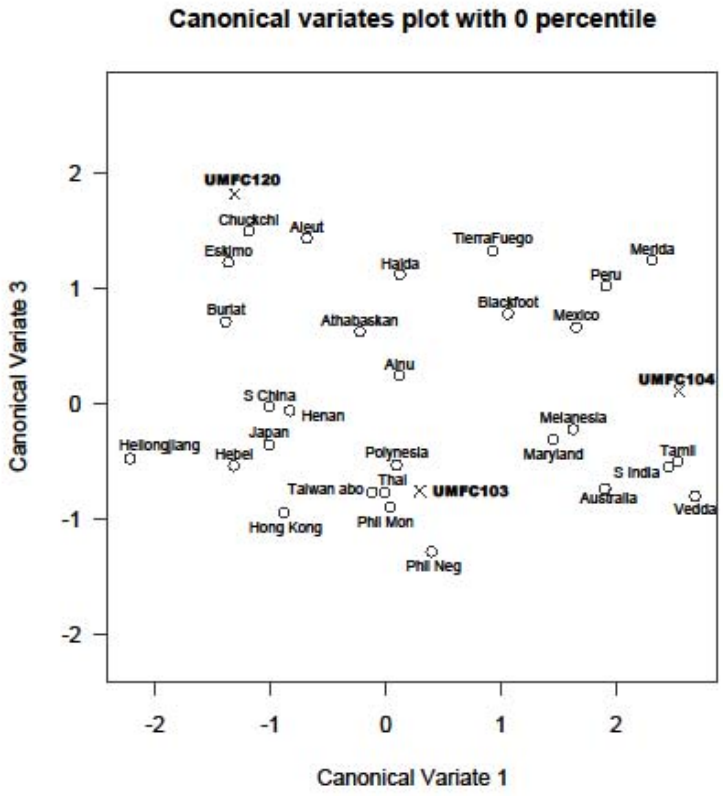
- India: South India, Tamil, Vedda
- SE Asia: Philippine Manobo, Philippine Negrito, Taiwan aboriginal, Thailand
- China: Hebei, Heilongjiang, Henan, Hong Kong, South China



- Northern Asia and Northern North America: Aleut, Athabaskan, Buriat, Chukchi, Eskimo, Haida, Mongolia
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- India: South India, Tamil, Vedda
- SE Asia: Philippine Manobo, Philippine Negrito, Taiwan aboriginal, Thailand
- China: Hebei, Heilongjiang, Henan, Hong Kong, South China

Figure 4.6. CV1 (29.53%) vs. CV3 (12.15%): Michigan Database, 21 Variables.

The discriminant function analysis classified UMFC 104 as a member of the Melanesian group with a posterior probability of 0.682 and a typicality probability of 0.020 based on an F distribution. The posterior probabilities, typicality probabilities, and Mahalanobis distances for the nearest five populations are shown below in Table 4.2. UMFC 120 was grouped with the sample from South China based on a posterior probability of 0.448 and a typicality probability of 0.134 (see Table 4.3 below). Finally, UMFC 103 was calculated to be most similar to the Taiwanese aboriginal sample with a posterior probability of 0.861 and a typicality probability of 0.134 (see Table 4.4 below).

Table 4.2. Probabilities and Mahalanobis Distances relating UMFC 104 to the five closest groups using the reference populations.

	Melanesia	Australia	Ainu	Vedda	Tamil
PostProb	**0.682**	0.130	0.070	0.052	0.049
TypProb	**0.020**	0.008	0.006	0.007	0.012
MahDist	**37.885**	41.877	42.156	43.129	42.540

Table 4.3. Probabilities and Mahalanobis Distances relating UMFC 120 to the five closest groups using the reference populations.

	SChina	**Eskimo**	**Athabask**	Chukchi	TaiwanAbo
PostProb	**0.448**	**0.280**	**0.127**	0.054	0.029
TypProb	**0.134**	**0.071**	**0.062**	0.071	0.035
MahDist	**30.217**	**32.320**	**33.929**	33.607	36.608

Table 4.4.Probabilities and Mahalanobis Distances relating UMFC 103 to the five closest groups using the reference populations.

	TaiwanAbo	PhilNeg	SChina	Hebei	Athabask
PostProb	**0.861**	0.037	0.035	0.017	0.017
TypProb	**0.134**	0.049	0.040	0.024	0.020
MahDist	**31.259**	37.973	37.377	39.566	40.480

Comparison with Michigan Database using 21 Craniofacial Measurements Transformed by the Geometric Mean

The results of the PCA of the Michigan database using all 21 craniofacial measurements adjusted by the geometric mean show that there are three principal components with eigenvalues of greater than one that account for 66% of the variation present in the data set. The component matrix obtained from the PCA with three components extracted is shown below (Table 4.5). The first principal component seems to be separating the cranial measurements from the measurements of the facial dimensions. PC2 can be labeled projection of the nasal area and nasal width. PC3 appears to be separating upper facial flatness and nasal bone height measurements.

Table 4.5. PCA Component Matrix: Michigan Database, 21 Shape Variables.

Component Matrix[a]

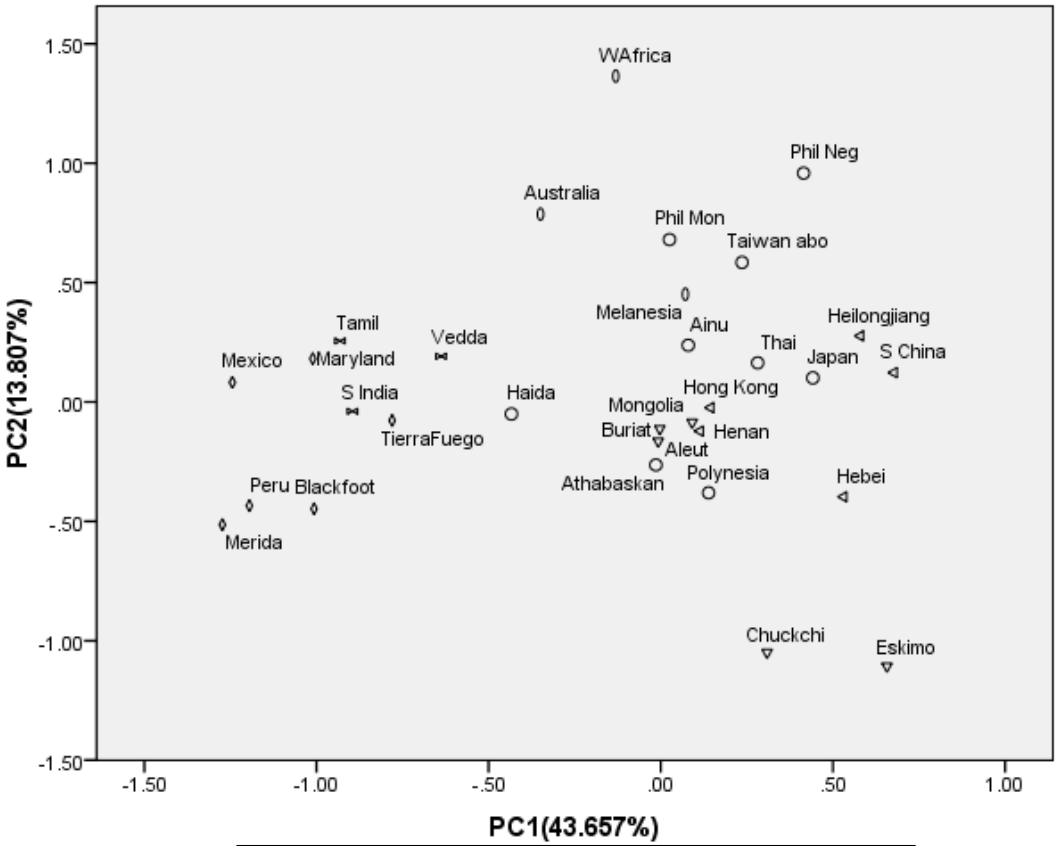
	Component		
	1	2	3
SVnasoht	.716	-.327	-.386
SVnasobn	.436	-.389	-.544
SVpoht	.295	-.597	.174
SVnaprlng	.727	-.304	-.337
SVnasbas	.867	.063	.246
SVbaspros	.796	.174	.303
SVsupnas	-.539	.587	-.286
SVsimwid	-.535	.680	-.114
SVinfnasb	.382	.494	-.326
SVnasbrdt	.558	.476	-.098
SVsimsub	-.767	-.183	.063
SVinfsims	-.421	-.643	.008
SVfowsb	-.010	.258	.515
SVmowsu	-.417	-.422	.541
SVbizygo	.881	-.079	-.090
SVglabopi	.876	.110	.174
SVmaxbred	.784	-.023	-.221
SVbasibre	.841	.039	.113
SVbasirhi	.815	-.084	.324
SVfmtfmt	.882	.134	.093
SVmowidt	.424	.374	.370

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

The graph of PC1 vs. PC2 shows some clustering based on geography. The American populations are clustered together as are the Indian populations (Figure 4.7). The Chinese populations and surrounding areas also form a cluster. The plot of PC2 vs.

PC3 also demonstrates clustering based on geographic proximity (Figure 4.8). The Indian populations are clearly clustered as are the West African, Australian, and Melanesian populations. The Chinese populations and surrounding areas are clustered near the bottom of the graph as well. Once UMFC 103, 104, and 120 are added the distribution of reference populations changes somewhat. The graph of the 1st and 2nd principal components is shown in Figure 4.9 below. UMFC 103 and 120 are quite distant from all of the populations sampled, while UMFC 104 is nearer to the range of variation exhibited by the populations. There is no distinct clustering exhibited. The graph of PC2 vs. PC3 shows that UMFC 120 is in the midst of many of the populations. UMFC 120 is close to the South Chinese and Thailand populations (Figure 4.10 below). UMFC 103 and 104, on the other hand, are quite distinct.



- Northern Asia and Northern North America: Aleut, Athabaskan, Buriat, Chukchi, Eskimo, Haida, Mongolia
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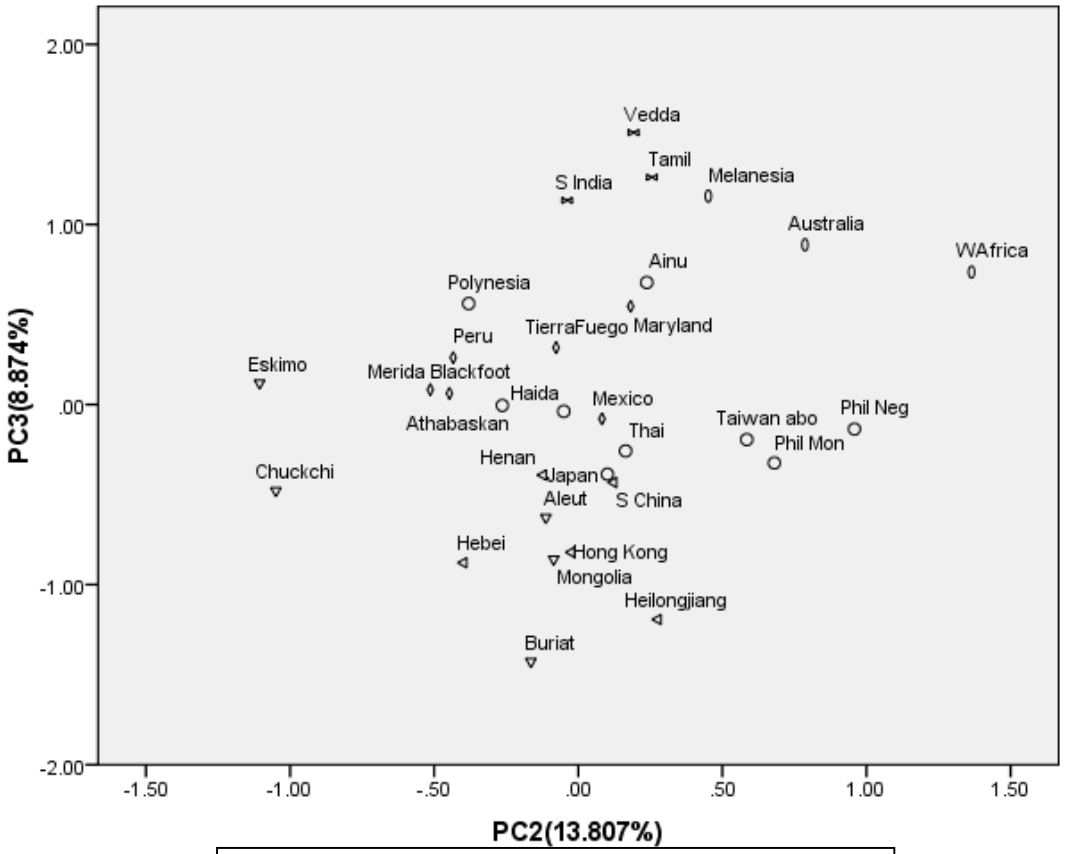
Figure 4.7. PC1 vs. PC2: Michigan Database, 21 Shape Variables.



- Northern Asia and Northern North America: Aleut, Athabaskan, Buriat, Chukchi, Eskimo, Haida, Mongolia
- North and South America: Blackfoot, Maryland, Merida, Mexico, Peru, Tierra del Fuego
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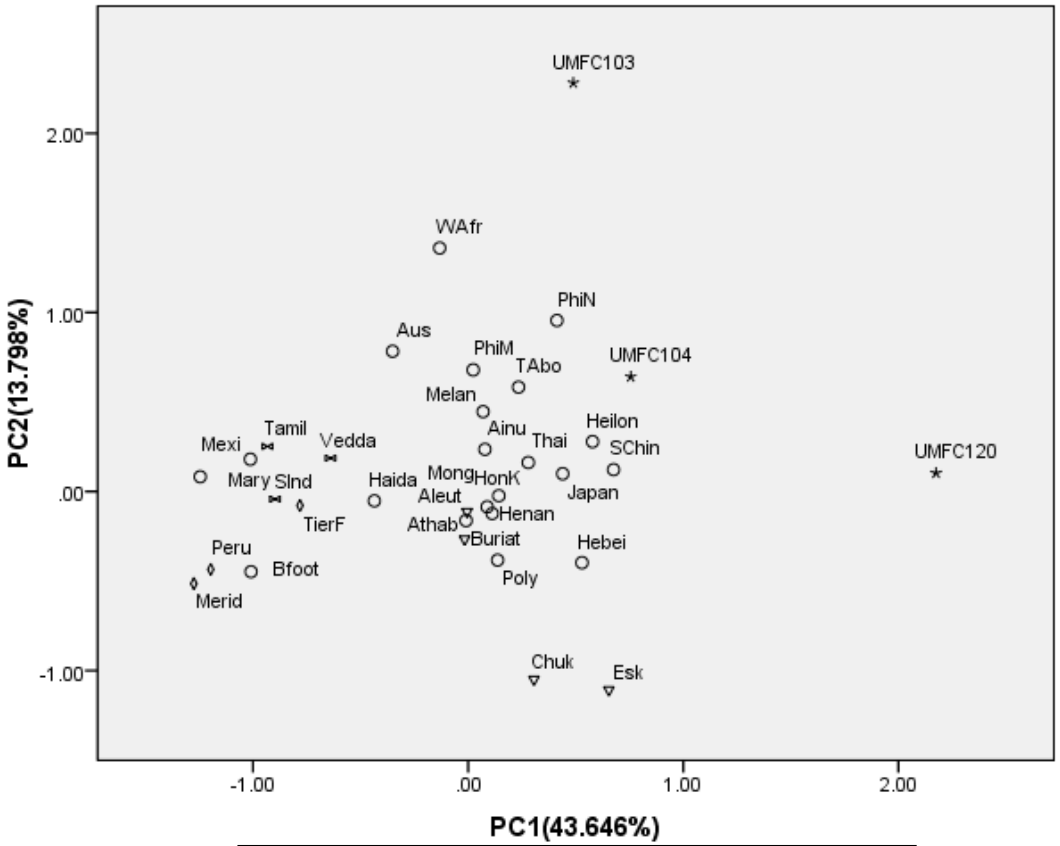
Figure 4.8. PC2 vs. PC3: Michigan Database, 21 Shape Variables.



- Northern Asia and Northern North America: Aleut, Athabaskan, Buriat, Chukchi, Eskimo, Haida, Mongolia
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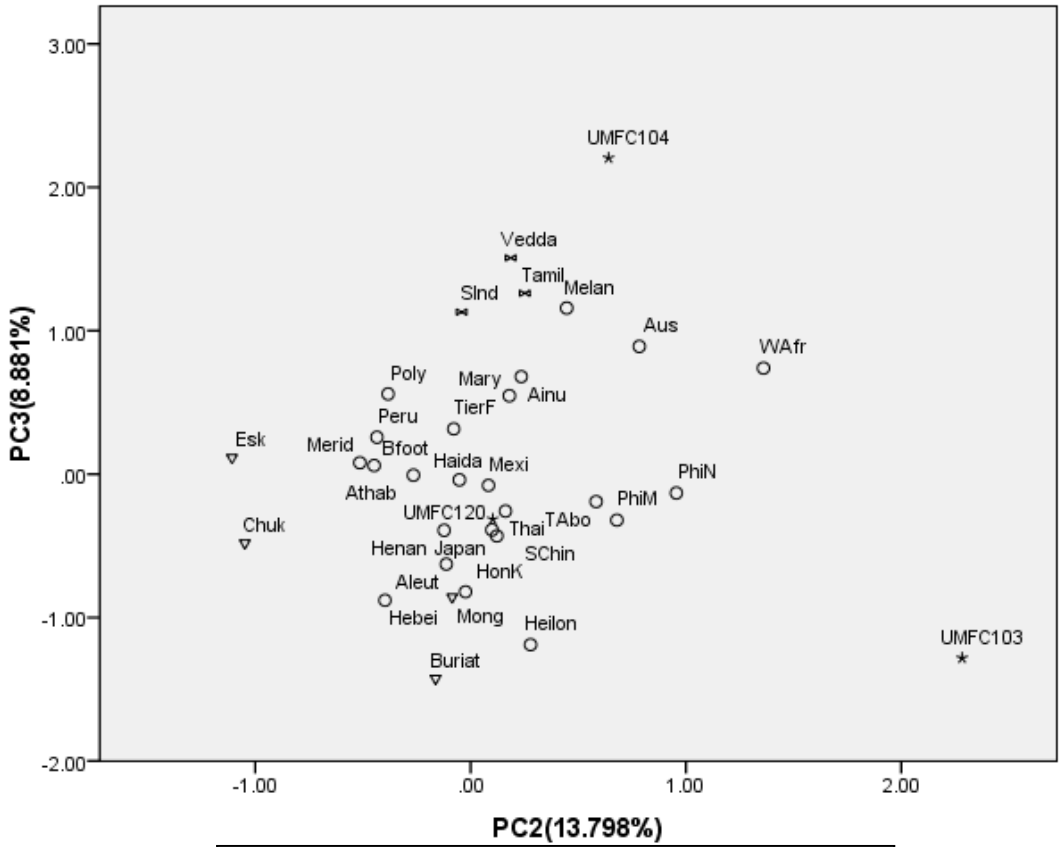
Figure 4.9. PC1 vs. PC2: Michigan Database and UMFC 103, 104, and 120; 21 Shape Variables.



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- SE Asia: Philippine Manobo, Philippine Negrito, Taiwan aboriginal, Thailand
- China: Hebei, Heilongjiang, Henan, Hong Kong, South China

Figure 4.10. PC2 vs. PC3: Michigan Database and UMFC 103, 104, and 120; 21 Shape Variables.

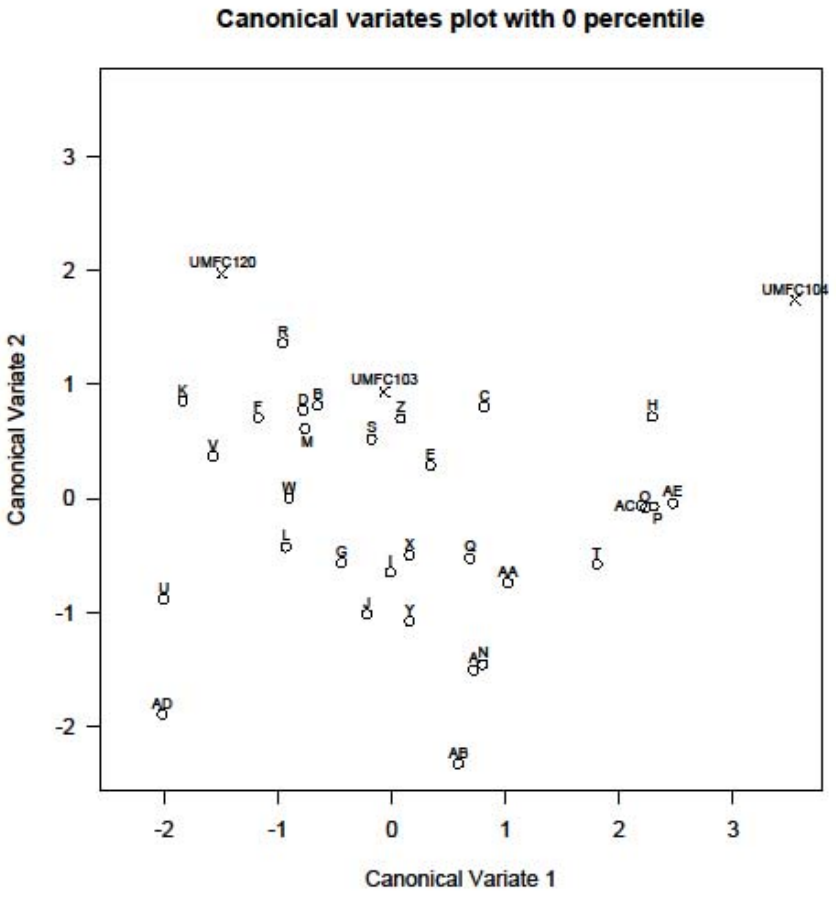
The results of the discriminant function analysis of the Michigan database using 21 shape variables are shown below (Figures 4.11 and 4.12). The graph of CV1 vs. CV2 shows that UMFC 104 is quite distinct from all of the sample populations (Figure 4.11). UMFC 103 is close to the Taiwan Aboriginal and Athabaskan samples. UMFC 120 is

fairly distinct, but is somewhat near the Eskimo and Heilongjiang samples. In terms of UMFC 103, 104, and 120, Figure 4.12 demonstrates the same relationships.

Table 4.6. Legend for Reference Populations used in Canonical Variates Plots for Michigan Database, 21 Shape Variables.

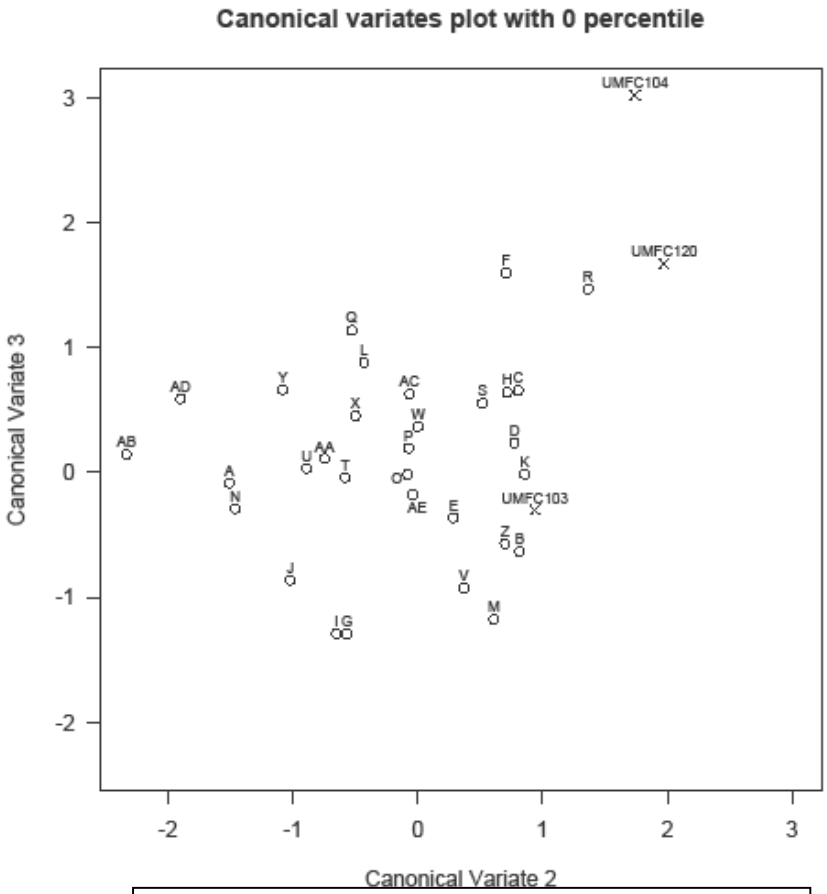
A: Mexico	G: Thai	M:HongKong	S: Athaba	Y: Bfoot AE: WAfric
B: Japan	H: Melanesia	N: Peru	T: SIndia	Z: TAbo
C: Ainu	I: PhilNeg	O: Vedda	U: Buriat	AA: Mary
D: SChina	J: PhilMon	P: Tamil	V: Hebei	AB: Merida
E: Polynes	K: Heilong	Q: Tierra	W: Henan	AC: Australia
F: Chukchi	L: Aleut	R: Eskim	X: Haida	AD: Mongolia

Figure 4.11. CV1(30.25%) vs. CV2(17.74%): Michigan Database, 21 Shape Variables.



- Northern Asia and Northern North America: Aleut (L), Athabaskan(S), Buriat(U), Chukchi(F), Eskimo(R), Haida(X), Mongolia(AD)
- North and South America: Blackfoot(Y), Maryland(AA), Merida(AB), Mexico(A), Peru(N), Tierra del Fuego(Q)
- India: South India(T), Tamil(P), Vedda(O)
- SE Asia: Philippine Manobo(J), Philippine Negrito(I), Taiwan aboriginal(Z), Thailand(G)
- China: Hebei(V), Heilongjiang(K), Henan(W), Hong Kong(M), South China(D)

Figure 4.12. CV2(17.74%) vs. CV3(11.07%): Michigan Database, 21 Shape Variables.



- Northern Asia and Northern North America: Aleut (L), Athabaskan(S), Buriat(U), Chukchi(F), Eskimo(R), Haida(X), Mongolia(AD)
- North and South America: Blackfoot(Y), Maryland(AA), Merida(AB), Mexico(A), Peru(N), Tierra del Fuego(Q)
- India: South India(T), Tamil(P), Vedda(O)
- SE Asia: Philippine Manobo(J), Philippine Negrito(I), Taiwan aboriginal(Z), Thailand(G)
- China: Hebei(V), Heilongjiang(K), Henan(W), Hong Kong(M), South China(D)

UMFC 104 classified with the Ainu based on the discriminant function analysis. The posterior probability was 0.587 and the typicality probability was 0.007 (see Table 4.7 below). UMFC 120 was grouped with the Eskimo with a posterior probability of 0.517 and a typicality probability of 0.013 (see Table 4.8 below). UMFC 103 was grouped with the Taiwanese aboriginals with a posterior probability of 0.243 and a typicality probability of 0.013 (see Table 4.9 below).

Table 4.7. Probabilities and Mahalanobis Distances relating UMFC 104 to the five closest groups using the reference populations.

	Ainu	Melanesia	Australia	Tamil	Vedda
PostProb	**0.587**	0.363	0.043	0.004	0.002
TypProb	**0.007**	0.006	0.002	0.001	0.000
MahDist	**41.788**	42.396	46.772	49.194	51.914

Table 4.8. Probabilities and Mahalanobis Distances relating UMFC 120 to the five closest groups using the reference populations.

	Eskimo	SChina	Chukchi	Athabask	Hebei
PostProb	**0.517**	0.333	0.102	0.014	0.011
TypProb	**0.013**	0.019	0.014	0.002	0.003
MahDist	**36.498**	36.677	37.014	42.991	43.596

Table 4.9. Probabilities and Mahalanobis Distances relating UMFC 103 to the five closest groups using the reference populations.

	SChina	TaiwanAbo	Japan	Ainu	HongKong
PostProb	**0.243**	0.242	0.061	0.061	0.061
TypProb	**0.013**	0.019	0.014	0.002	0.003
MahDist	**36.498**	36.677	37.014	42.991	43.596

Comparison with Hanihara Database using 34 Craniofacial Measurements

The results of the principal components analysis for the Hanihara database using 34 craniofacial measurements are shown below. The 1st three PCs account for 53.30% of the variation present within the sample. The component matrix (Table 4.10 below) calculated by PCA displays the loadings of each of the variables for the eight principal components with eigenvalues greater than one. Only the loadings based on the 1st three

principal components will be evaluated for the purposes of this study. The first principal component is clearly a result of size, all of the loadings are positive and the majority of them are large. The loadings of PC2 are difficult to decipher, but generally speaking it seems to be separating length measurements from breadth and height measurements. PC3, although difficult to decipher as well, can be labeled cranial vault measurements versus facial measurements.

Table 4.10. PCA Component Matrix: Hanihara Database, 34 Variables.

Component Matrix[a]

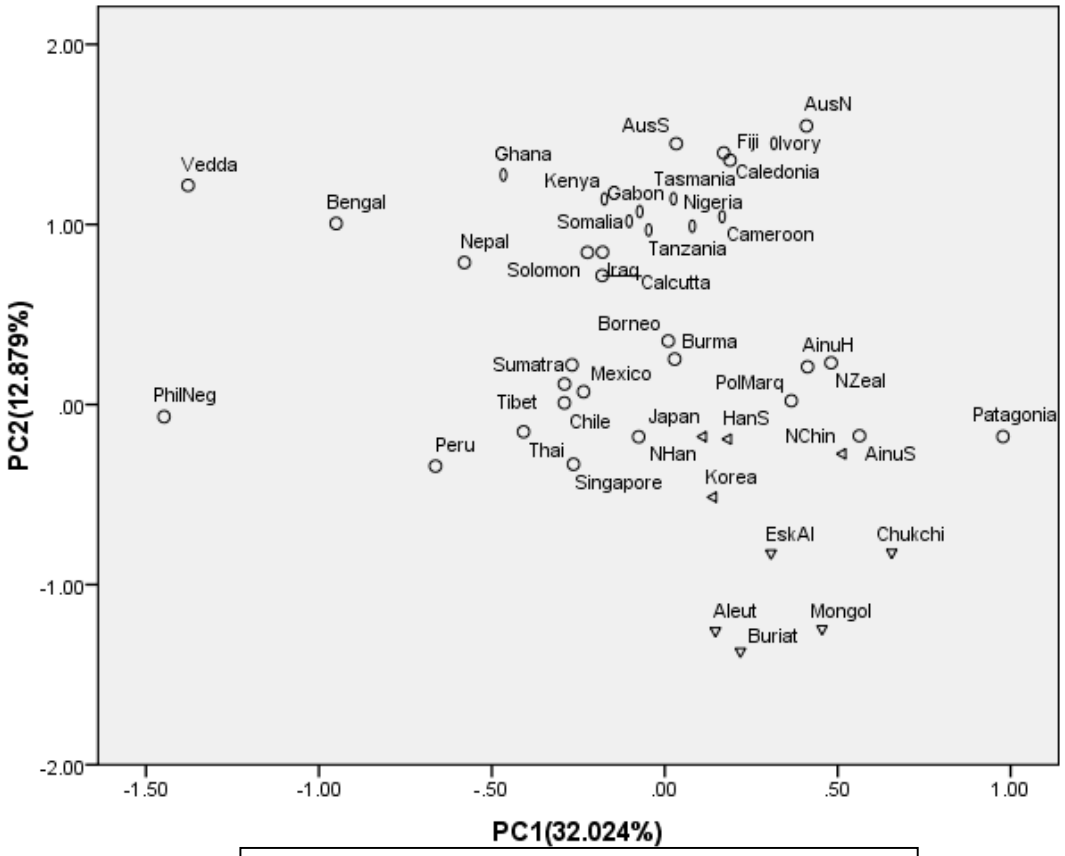
	Component							
	1	2	3	4	5	6	7	8
GOL	.759	.347	-.347	.066	-.074	-.162	-.090	.155
NOL	.751	.311	-.354	.077	-.060	-.212	-.093	.173
BNL	.716	.187	.002	.233	-.315	-.102	.026	-.037
XCB	.489	-.590	-.068	-.236	.390	.062	.134	-.044
M9	.607	.236	.191	-.285	.147	-.276	.058	-.056
XFB	.548	-.294	-.055	-.444	.376	-.023	.182	-.077
AUB	.641	-.608	.089	-.042	.112	.100	.076	.047
ASB	.576	-.398	-.043	.038	.304	-.040	.045	.175
BBH	.589	.200	-.418	-.014	-.103	.165	.058	-.160
M26	.543	.278	-.413	-.297	-.056	-.107	.123	-.505
M27	.322	.558	-.294	-.403	-.059	.317	.117	.417
M28	.416	-.139	-.485	.414	.384	-.189	-.360	.106
FRC	.662	.144	-.404	-.168	-.025	-.101	.168	-.448
PAC	.392	.585	-.334	-.363	-.053	.239	.057	.410
OCC	.381	-.092	-.528	.376	.354	-.147	-.366	.000
BPL	.546	.281	.229	.275	-.277	-.064	-.218	-.030
M43	.815	.099	.360	-.099	-.013	-.202	-.048	.042
ZYB	.796	-.382	.153	-.010	.019	.079	.005	.060
M46	.670	-.373	.217	.023	-.084	.276	-.177	-.021
NPH	.646	-.445	-.044	.108	-.185	.014	.185	.089
DKB	.295	.470	.394	-.295	.270	-.068	-.261	-.026
M51	.724	.003	.252	.030	-.286	-.309	.038	.065
OBH	.399	-.465	.005	.045	-.219	-.284	.265	.187
NLB	.340	.314	.315	-.231	.171	.127	-.345	-.127
NLH	.662	-.395	-.054	.103	-.177	.081	.221	.023
MAB	.648	-.022	.214	.082	-.038	.267	-.150	-.078
MDH	.495	.235	-.048	.191	.074	.503	.054	-.084
MDB	.500	.158	.084	.237	.075	.412	.018	-.061
M431	.784	.152	.408	-.094	-.049	-.232	-.059	.072
No43c	.233	.626	.262	.243	.049	-.235	.274	-.023
M57WNB	.038	.464	.341	.130	.576	-.072	.161	.026
NO57aSIS	.119	.266	.124	.448	.433	.036	.511	.081
M46bZMB	.705	-.218	.288	.026	-.052	.283	-.181	-.049
No46cSSS	.185	.433	.069	.465	-.087	.221	.185	-.149

Extraction Method: Principal Component Analysis.

a. 8 components extracted.

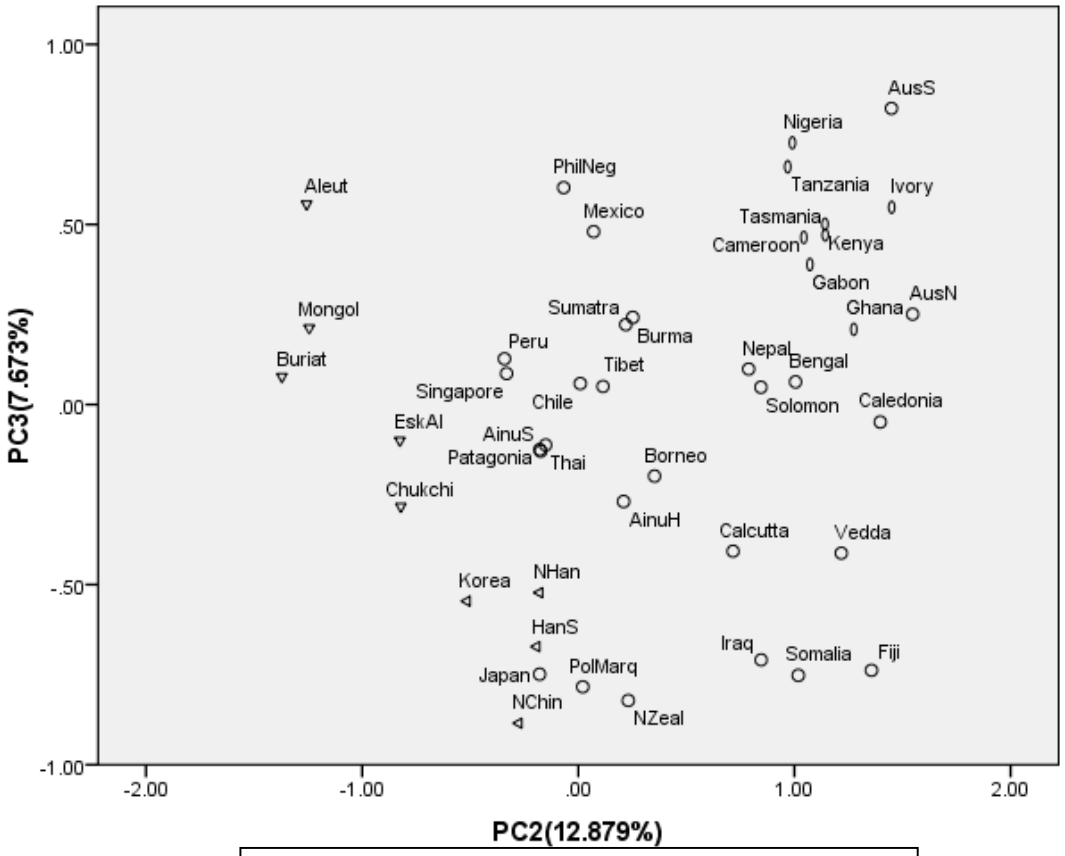
The 1st three principal components were graphed as described above for visual purposes. The plot of PC1 vs. PC2 shows clear geographic clustering (Figure 4.13 below). The African populations are clustered together along with the Australian populations. Also the Aleut, Chukchi, Buriat, Mongol, and Eskimo are all close together

which would be expected based on geographic proximity and shared environmental conditions. The graph of PC2 vs. PC3 shows less clear clustering (Figure 4.14 below). The African populations are all in the same general region along with the Australian populations. Once UMFC 103, 104, and 120 are added to the PCA the clustering based on geographic proximity is obscured. The graph of PC1 versus PC2 (Figure 4.15) shows that most of the populations used in the analysis are clustered together with only a few outliers. These outliers include UMFC 103, 104, and 120 and the Vedda, Bengal, and Philippine Negrito populations. UMFC 103 and 104 are closest to the Vedda and Bengal reference populations. The graph of PC2 versus PC3 (Figure 4.16) again shows one large cluster with a few outliers; most notably UMFC 104 and 120. UMFC 103 is very close to the sample from Caledonia.



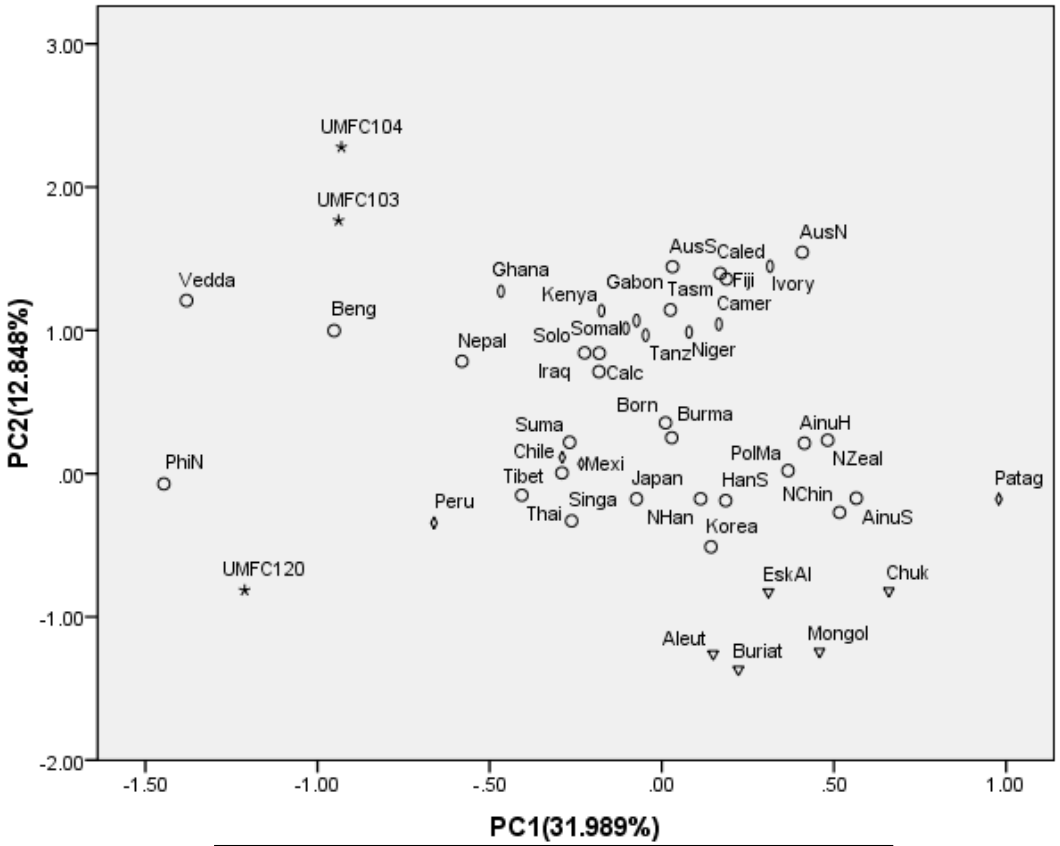
- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.13. PC1 vs. PC2: Hanihara Database, 34 Variables.



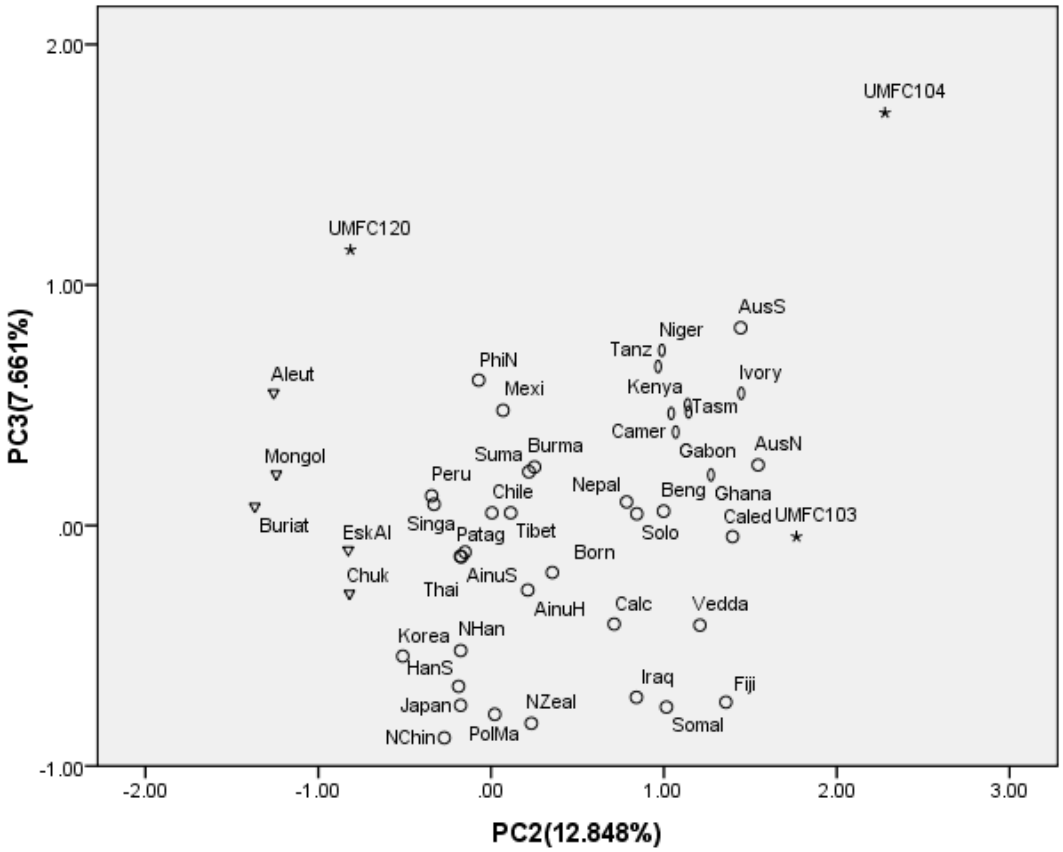
- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.14. PC2 vs. PC3: Hanihara Database, 34 Variables.



- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.15. PC1 vs. PC2: Hanihara Database and UMFC 103, 104, and 120; 34 Variables.



- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.16. PC2 vs. PC3: Hanihara Database and UMFC 103, 104, and 120; 34 Variables.

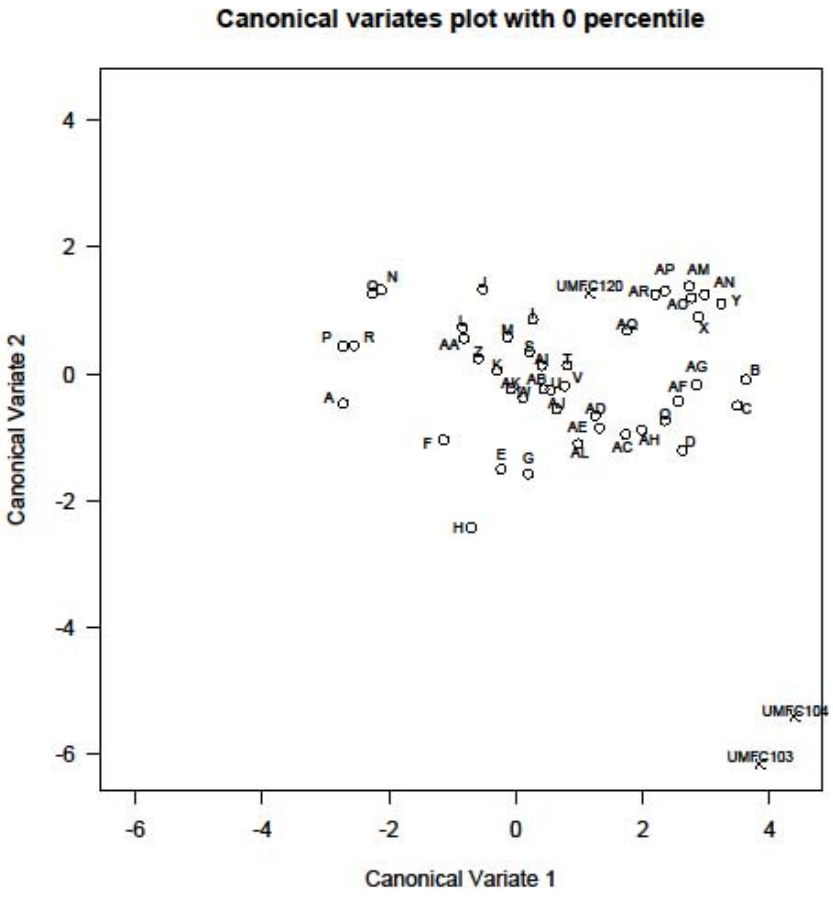
The results of the discriminant function analysis for the Hanihara database are shown below (Figures 4.17 and 4.18). In the graph of CV1 vs. CV2 (Figure 4.17 below), UMFC 103 and 104 are clustered together completely separated from all other

populations used in the analysis. UMFC 120 is near the Tanzanian, Somalian, and Kenyan populations. In the graph of CV2 vs. CV3 (Figure 4.18 below), UMFC 103, 104, and 120 are clearly separated from all other populations. UMFC 103 and 104 are again close together; while UMFC 120 is completely separated.

Table 4.11. Legend for Reference Populations used in Canonical Variates Plots for Hanihara Database, 34 Variables.

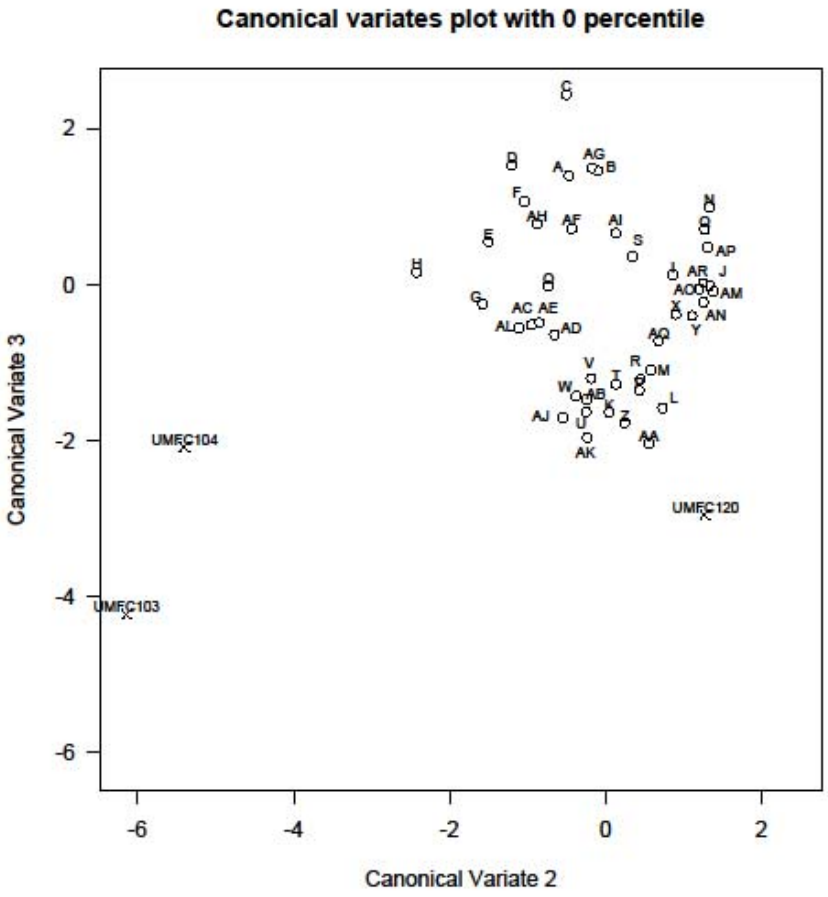
A: Aleut	N: EskAl	AA: Korea	AN: Ghana
B: AusN	O: Vedda	AB: Tibet	AO: Nigeri
C: AusS	P: Buriat	AC: Bengal	AP: Tanzan
D: Tasm	Q: Chukchi	AD: Calcutta	AQ: Somal
E: Chile	R: Mongol	AE: Nepal	AR: Kenya
F: Patagonia	S: PolMarq	AF: Fiji	
G: Mexico	T: Borneo	AG: Caledonia	
H: Peru	U: PhilNeg	AH: Solomon	
I: AinuH	V: Sumatra	AI: NZeal	
J: AinuS	W: Thai	AJ: Burma	
K: NHan	X: Gabon	AK: Singapore	
L: NChin	Y: Ivory	AL: Iraq	
M: Japan	Z: HanS	AM: Cameroon	

Figure 4.17. CV1(33.70%) vs. CV2(11.50%): Hanihara Database, 34 Variables.



- North Asia and Bering Areas: Aleut(A), Buriat(P), Chukchi(Z), Eskimo Alaska(N), Mongol(R)
- Central and South America: Chile(E), Mexico(G), Patagonia(F), Peru(H)
- China: North Han(K), North China(L), South Han(Z)
- India: Calcutta(AD), Vedda(O)
- Africa: Cameroon(AM), Gabon(X), Ghana(AN), Ivory Coast(Y), Kenya(AR), Nigeria(AO), Somalia(AQ), Tanzania(AP)
- SE Asia: Borneo(T), Burma(AJ), Thailand(W), Tibet(AB), Philippine Negrito(U), Sumatra(V)
- Australia and Polynesia: Caledonia(AG), Fiji(AF), Marquesas Polynesia(S), New Zealand(AI), North Australia(B), Solomon Islands(AH), South Australia(C), Tasmania(D)

Figure 4.18. CV2(11.50%) vs. CV3(7.60%): Hanihara Database, 34 Variables.



- North Asia and Bering Areas: Aleut(A), Buriat(P), Chukchi(Z), Eskimo Alaska(N), Mongol(R)
- Central and South America: Chile(E), Mexico(G), Patagonia(F), Peru(H)
- China: North Han(K), North China(L), South Han(Z)
- India: Calcutta(AD), Vedda(O)
- Africa: Cameroon(AM), Gabon(X), Ghana(AN), Ivory Coast(Y), Kenya(AR), Nigeria(AO), Somalia(AQ), Tanzania(AP)
- SE Asia: Borneo(T), Burma(AJ), Thailand(W), Tibet(AB), Philippine Negrito(U), Sumatra(V)
- Australia and Polynesia: Caledonia(AG), Fiji(AF), Marquesas Polynesia(S), New Zealand(AI), North Australia(B), Solomon Islands(AH), South Australia(C), Tasmania(D)

The discriminant function analysis classified UMFC 104 as a member of the Vedda group with a posterior probability of 0.987 and a typicality probability of 0 (see Table 4.12 below). UMFC 103 was also classified as Vedda with a posterior probability of 0.938 and a typicality probability of 0 (see Table 4.13 below). UMFC 120 was classified as Sumatra with a posterior probability of 0.970 and a typicality probability of 0 (see Table 4.14 below).

Table 4.12. Probabilities and Mahalanobis Distances relating UMFC 104 to the two closest groups using the reference populations.

	Vedda	Bengal
PostProb	**0.987**	0.000
TypProb	**0.000**	0.000
MahDist	**442.792**	454.918

Table 4.13. Probabilities and Mahalanobis Distances relating UMFC 103 to the three closest groups using the reference populations.

	Vedda	Bengal	Burma
PostProb	**0.938**	0.060	0.002
TypProb	**0.000**	0.000	0.000
MahDist	**439.163**	447.995	454.535

Table 4.14. Probabilities and Mahalanobis Distances relating UMFC 120 to the five closest groups using the reference populations.

	Sumatra	Ivory	Kenya	Borneo	Tibet
PostProb	**0.970**	0.007	0.006	0.005	0.005
TypProb	**0.000**	0.000	0.000	0.000	0.000
MahDist	**338.696**	346.636	349.093	350.555	350.309

Comparison with Hanihara Database using 34 Craniofacial Measurements Transformed by the Geometric Mean

The principal components analysis for the Hanihara database using 34 shape transformed craniofacial measurements shows that 49.04% of the variation present is accounted for by the 1st three PCs. The component matrix calculated from the PCA of the Hanihara database using 34 shape transformed craniofacial measurements is shown in

Table 4.15 below. Only the 1st three principal components are shown. PC1 seems to be roughly separating the cranial vault measurements from the facial measurements. PC2 and PC3 are uninterpretable; it is not clear exactly which measurement variation is being represented.

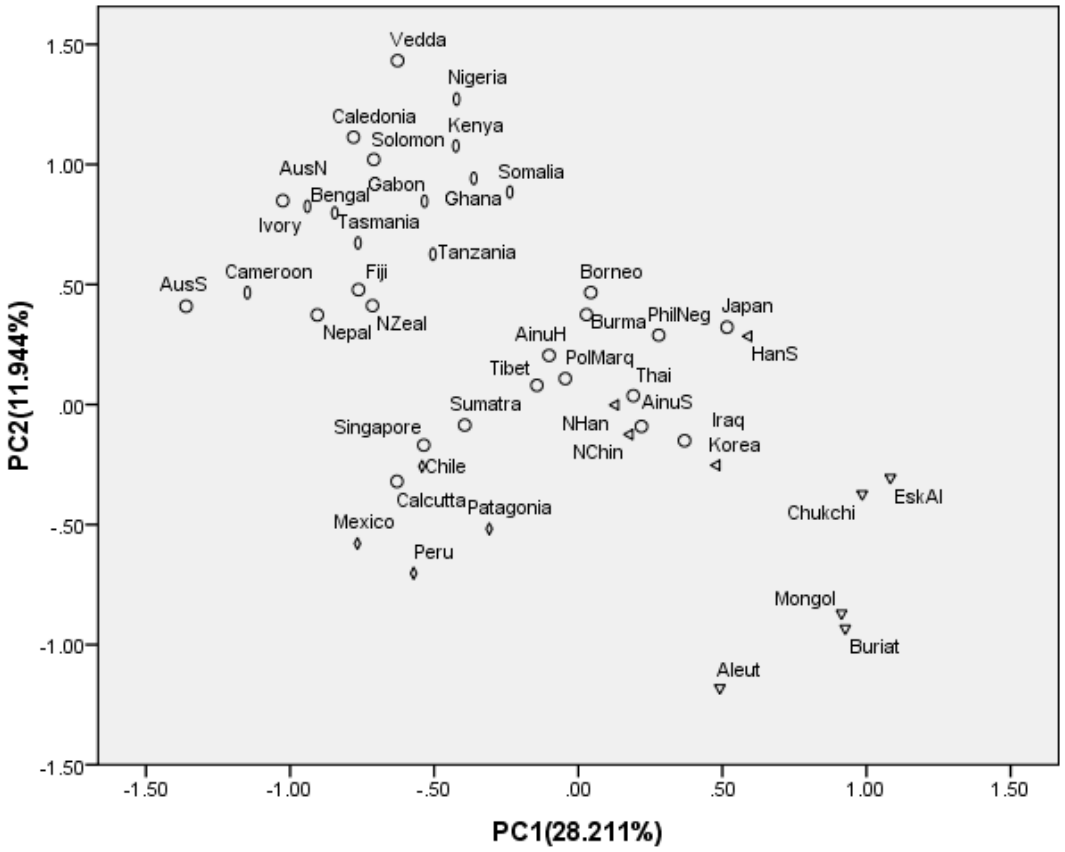
Table 4.15. PCA Component Matrix: Hanihara Database, 34 Shape Variables.

	1	2	3
SV_GOL	.579	.612	-.192
SV_NOL	.608	.575	-.208
SV_BNL	.490	.228	.108
SV_XCB	.694	-.296	-.193
SV_M9	.402	.273	.406
SV_XFB	.653	-.054	-.046
SV_AUB	.731	-.487	-.061
SV_ASB	.637	-.240	-.187
SV_BBH	.523	.400	-.267
SV_M26	.505	.542	-.158
SV_M27	.171	.688	-.046
SV_M28	.408	.040	-.556
SV_FRC	.603	.406	-.247
SV_PAC	.224	.747	-.067
SV_OCC	.449	.131	-.528
SV_BPL	.277	.201	.331
SV_M43	.629	.033	.606
SV_ZYB	.733	-.416	.102
SV_M46	.637	-.407	.150
SV_NPH	.596	-.394	-.152
SV_DKB	-.144	.278	.566
SV_M51	.638	.045	.408
SV_OBH	.623	-.211	-.067
SV_NLB	.064	.179	.406
SV_NLH	.568	-.381	-.173
SV_MAB	.408	-.167	.204
SV_MDH	-.179	-.036	-.128
SV_MDB	-.149	-.153	-.017
SV_M431	.564	.075	.677
SV_No43c	-.553	.273	.291
SV_M57WNB	-.718	-.022	.128
SV_No57aSIS	-.747	-.249	-.242
SV_M46bZMB	.558	-.358	.260
SV_No46cSSS	-.385	.123	-.056

Extraction Method: Principal Component Analysis.

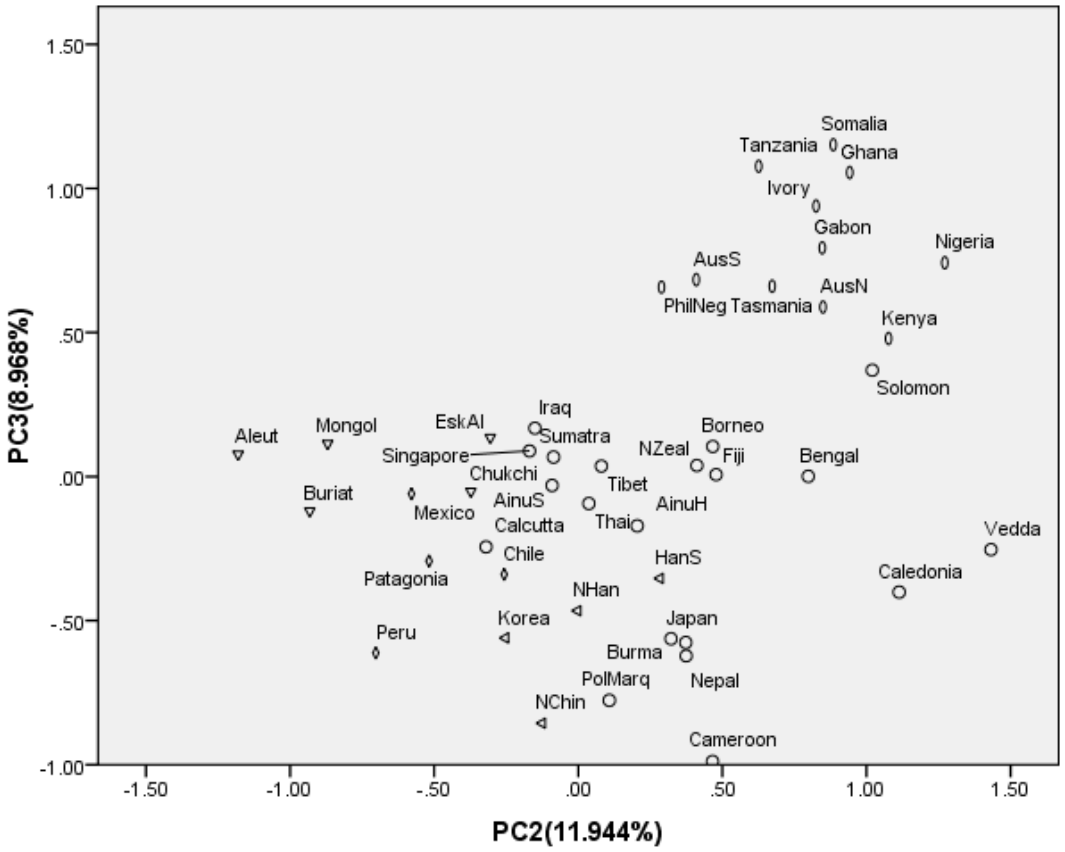
a. 9 components extracted.

The graph of PC1 versus PC2 is shown in Figure 4.19 below. There are three distinct clusters shown. One of the clusters is composed of the African, Australian, Indian, and surrounding area populations. The second cluster is composed of the New World, Chinese, Japanese, and surrounding area populations. The third cluster is composed of the Buriat, Mongol, Chukchi, Aleut, and Eskimo populations. The graph of PC2 vs. PC3 shows two distinct clusters and a few outliers (Figure 4.20 below). One cluster is again composed of the African, Australian, and Tasmanian populations, while the other is composed of the remainder of the populations. The Caledonian, Calcutta, and Bengal populations are shown to be outliers. Once UMFC 103, 104, and 120 are added there is some clustering of the African populations based on PC2, but overall there is not a distinctive pattern shown (see Figure 4.21 below). UMFC 103 and 104 are close together and are separated from all the population samples. UMFC 120 is close to the Mongolian, Chukchi, Buriat, and Alaskan Eskimo populations. The graph of PC2 vs. PC3 shows that UMFC 120 is distinct from all other populations (see Figure 4.22 below). There is distinct clustering present in this graph; the African and Australian populations are clustered high on PC3 and to the right on PC2. UMFC 104 is clustered with the African and Australian populations. UMFC 103 is clustered with the remaining populations towards the bottom of the graph.



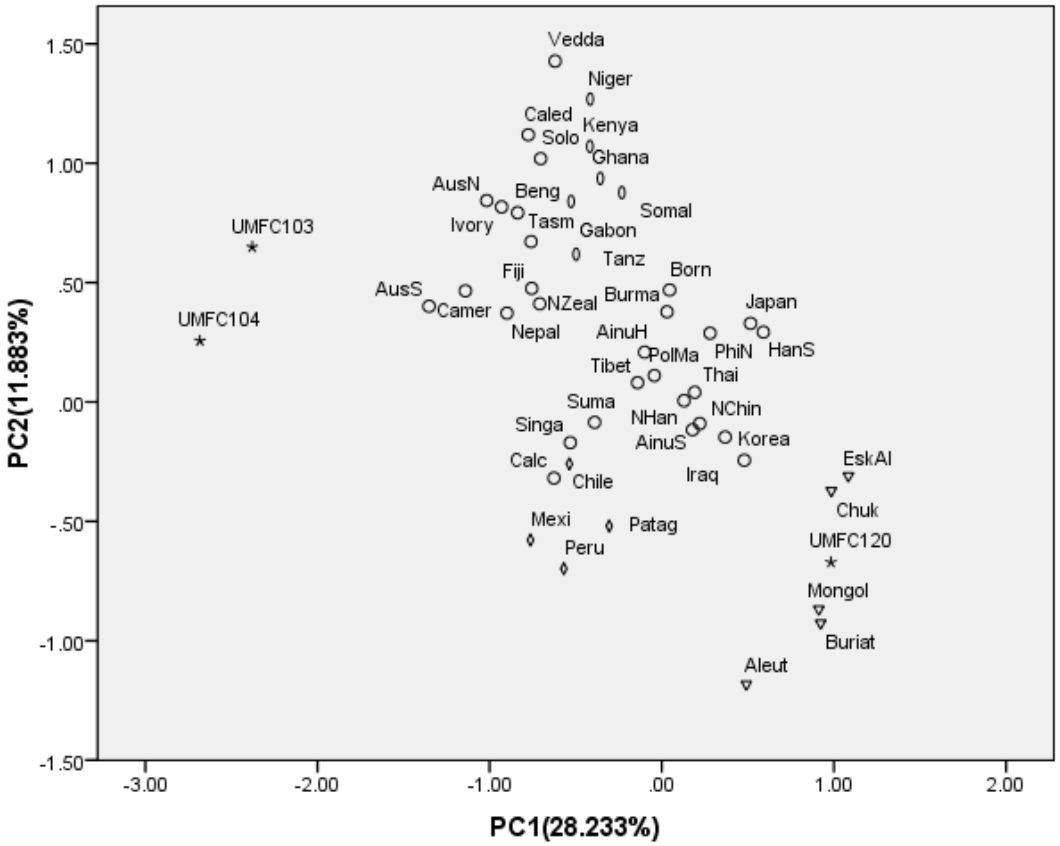
- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.19. PC1 vs. PC2: Hanihara Database, 34 Shape Variables..



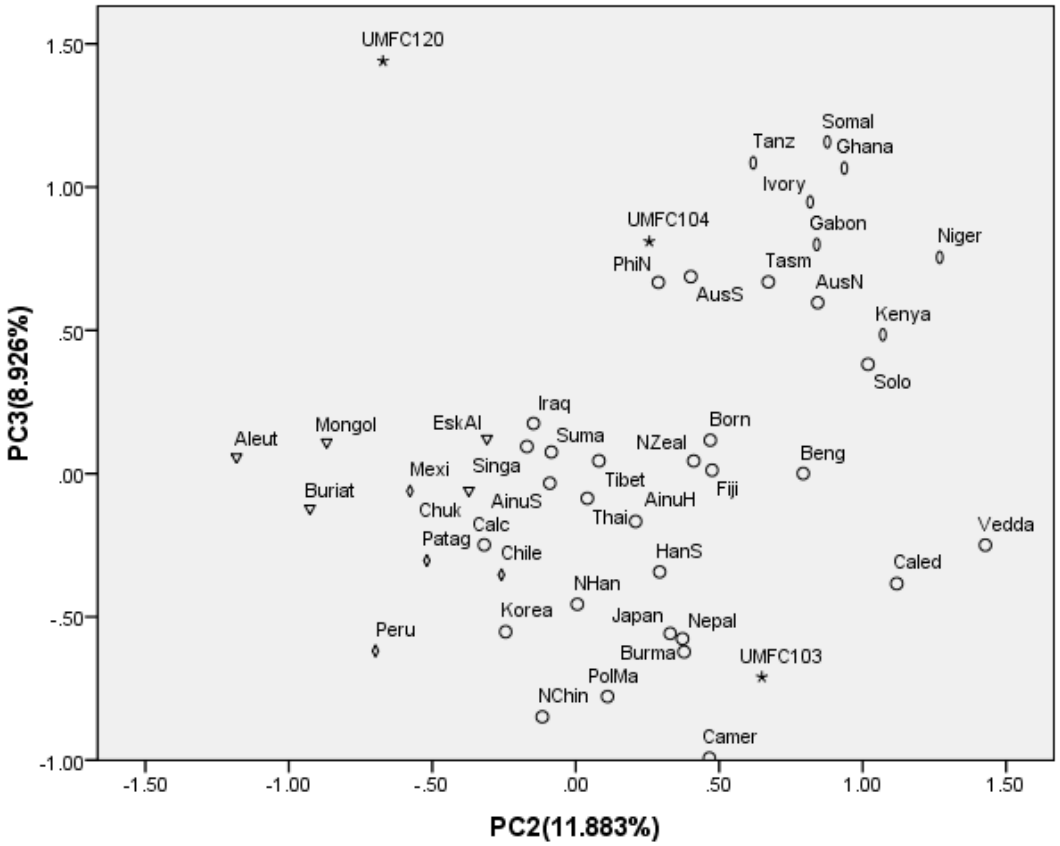
- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.20. PC2 vs. PC3: Hanihara Database, 34 Shape Variables.



- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.21. PC1 vs. PC2: Hanihara Database and UMFC 103, 104, and 120; 34 Shape Variables.

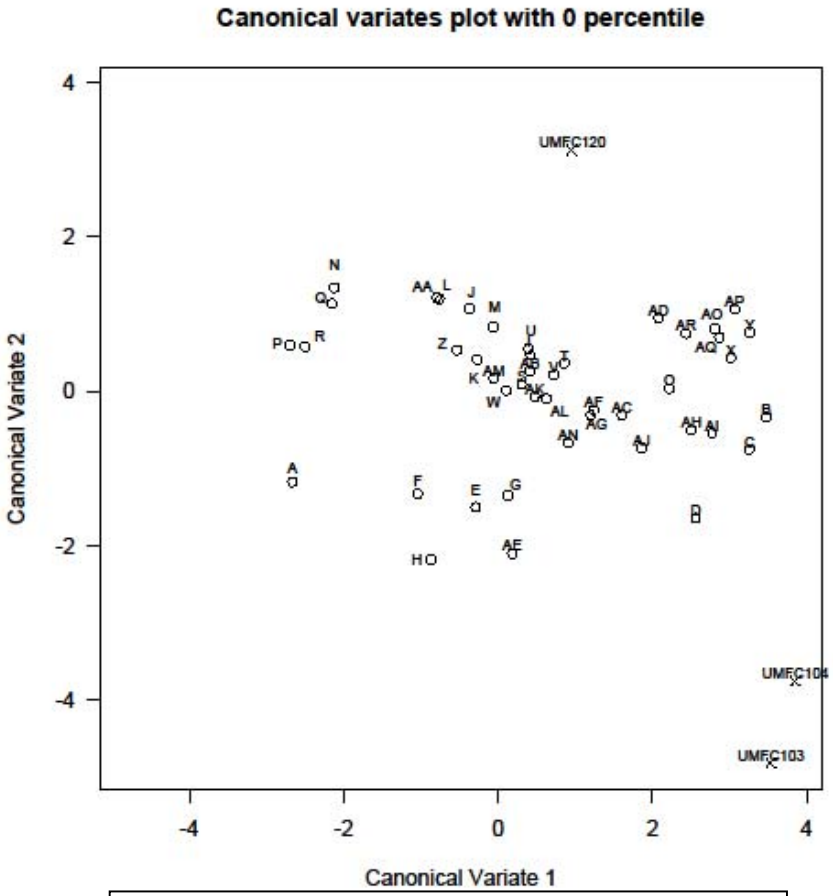


- North Asia and Bering Areas: Aleut, Buriat, Chukchi, Eskimo Alaska, Mongol
- Central and South America: Chile, Mexico, Patagonia, Peru
- China: North Han, North China, South Han
- India: Calcutta, Vedda
- Africa: Cameroon, Gabon, Ghana, Ivory Coast, Kenya, Nigeria, Somalia, Tanzania
- SE Asia: Borneo, Burma, Thailand, Tibet, Philippine Negrito, Sumatra
- Australia and Polynesia: Caledonia, Fiji, Marquesas Polynesia, New Zealand, North Australia, Solomon Islands, South Australia, Tasmania

Figure 4.22. PC2 vs. PC3: Hanihara Database and UMFC 103, 104, and 120; 34 Shape Variables.

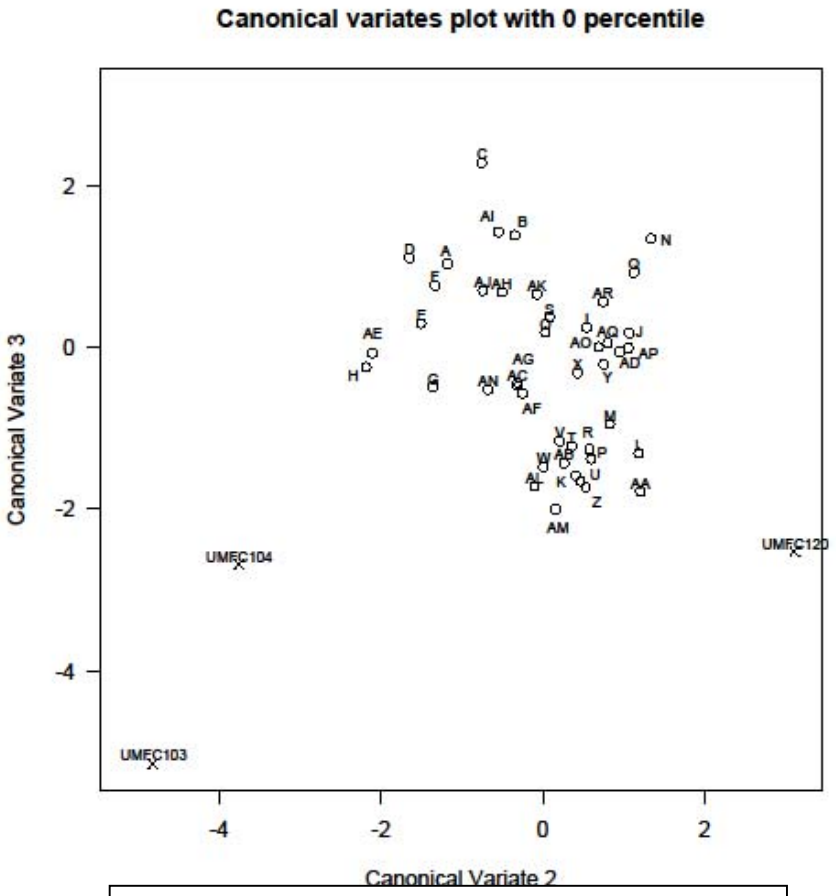
The first 1st three canonical variates calculated from the discriminant function analysis are graphed below (Figures 4.23 and 4.24). UMFC 103, 104, and 120 are shown to be quite distinct from any of the reference populations. UMFC 103 and 104 are shown to be fairly similar while UMFC 120 is quite distinct on both plots.

Figure 4.23. CV1(36.92%) vs. CV2(14.31%): Hanihara Database, 34 Shape Variables.



- North Asia and Bering Areas: Aleut(A), Buriat(P), Chukchi(Z), Eskimo Alaska(N), Mongol(R)
- Central and South America: Chile(E), Mexico(G), Patagonia(F), Peru(H)
- China: North Han(K), North China(L), South Han(Z)
- India: Calcutta(AD), Vedda(O)
- Africa: Cameroon(AM), Gabon(X), Ghana(AN), Ivory Coast(Y), Kenya(AR), Nigeria(AO), Somalia(AQ), Tanzania(AP)
- SE Asia: Borneo(T), Burma(AJ), Thailand(W), Tibet(AB), Philippine Negrito(U), Sumatra(V)
- Australia and Polynesia: Caledonia(AG), Fiji(AF), Marquesas Polynesia(S), New Zealand(AI), North Australia(B), Solomon Islands(AH), South Australia(C), Tasmania(D)

Figure 4.24. CV2(14.31%) vs. CV3(12.21%): Hanihara Database, 34 Shape Variables.



- North Asia and Bering Areas: Aleut(A), Buriat(P), Chukchi(Z), Eskimo Alaska(N), Mongol(R)
- Central and South America: Chile(E), Mexico(G), Patagonia(F), Peru(H)
- China: North Han(K), North China(L), South Han(Z)
- India: Calcutta(AD), Vedda(O)
- Africa: Cameroon(AM), Gabon(X), Ghana(AN), Ivory Coast(Y), Kenya(AR), Nigeria(AO), Somalia(AQ), Tanzania(AP)
- SE Asia: Borneo(T), Burma(AJ), Thailand(W), Tibet(AB), Philippine Negrito(U), Sumatra(V)
- Australia and Polynesia: Caledonia(AG), Fiji(AF), Marquesas Polynesia(S), New Zealand(AI), North Australia(B), Solomon Islands(AH), South Australia(C), Tasmania(D)

UMFC 104 classifies with the Vedda group based on a posterior probability of 0.752 and a typicality probability of 0 (see Table 4.16 below). UMFC 103 is classified as Vedda as well with a posterior probability of 0.571 and a typicality probability of 0 (see Table 4.17 below). UMFC 120 is classified as Sumatra with a posterior probability of 0.918 and a typicality probability of 0 (see Table 4.18 below). These results cannot be relied upon because the Mahalanobis distances which are calculated are too large.

Table 4.16. Probabilities and Mahalanobis Distances relating UMFC 104 to the two closest groups using the reference populations.

	Vedda	Bengal
PostProb	**0.752**	0.247
TypProb	**0.000**	0.000
MahDist	**442.813**	455.140

Table 4.17. Probabilities and Mahalanobis Distances relating UMFC 103 to the five closest groups using the reference populations.

	Vedda	Bengal	Burma	Calcutta	Borneo
PostProb	**0.571**	0.415	0.012	0.001	0.001
TypProb	**0.000**	0.000	0.000	0.000	0.000
MahDist	**438.192**	447.321	453.993	455.818	461.042

Table 4.18. Probabilities and Mahalanobis Distances relating UMFC 120 to the five closest groups using the reference populations.

	Sumatra	Kenya	Ivory	Cameroon	Tibet
PostProb	**0.918**	0.038	0.026	0.002	0.002
TypProb	**0.000**	0.000	0.000	0.000	0.000
MahDist	**339.573**	351.282	348.829	360.566	351.46

CHAPTER 5 : DISCUSSION

Principal Components Analysis

The graphs of PC1 vs. PC2 using both forms of the Michigan database show that groups which share morphological similarities as a result of geographic proximity are clustered (see Figures 4.1, 4.2, 4.7 and 4.8). In these graphs the distribution appears to be fairly geographic in nature and is a reflection to some extent of the isolation by distance model. These graphs show that the craniofacial measurements used in the Michigan database are effective at examining similarities between populations which are close in geographic proximity and are, therefore, likely to have a shared population history. However, there is no clear separation of regional groups which gives the overall impression of morphological overlap between major geographic regions. This supports Relethford's (1994) analysis of craniometric variation in the Howells data, which showed that around 10% of modern human craniometric variation is among groups, and the remaining 90% is within groups.

When the PCA is run including UMFC 103, 104, and 120 with the reference populations from the Michigan database the geographic distribution becomes less clear (see Figures 4.3, 4.4, 4.9 and 4.10). UMFC 103, 104, and 120 are shown to be quite distant from the reference populations in most cases. In the plots of PC1 vs. PC2, I think that the reason for the distinct nature of UMFC 103, 104, and 120 is due to the fact that they are very small in terms of overall size. Although the shape transformation was performed as a means of minimizing differences in sheer size, it was not very effective at bringing UMFC 103 and 120 into close proximity to the reference populations. UMFC

104 was shown to be somewhat near to the Taiwanese aboriginal, Philippine Negrito, and Heilongjiang populations. This is very interesting because these populations can be considered to be small in terms of cranial size as well.

The results of the PCA from the Hanihara database using 34 variables also demonstrates that the craniofacial measurements used are effective at examining population similarities in terms of morphological variation of the cranium. The graph of PCs 1 and 2 based on 34 craniofacial measurements from the Hanihara database shows clustering based on geographic distance (see Figure 4.13). There is some general clustering of the African, Australian, and Polynesian samples which indicates that there is significant overlap of variation present within these regional populations. The fact that there is really only one large cluster formed with a few outliers suggests that these populations are fairly similar to one another in terms of PC1 and PC2.

The results of the PCA performed on the Hanihara database using the shape transformation show very distinctive clustering (see Figure 4.19). There are three distinct clusters which indicates that the populations which compose these clusters are quite similar in terms of cranial morphology. This suggests that these groups have a shared population history and have possibly exchanged genes extensively throughout history.

Once the PCA is run including UMFC 103, 104, and 120 the clear geographic distribution is somewhat obscured. This is due in part to the fact that UMFC 103, 104, and 120 are small in terms of overall size which results in PC1 being elongated to account for the size difference. In general, UMFC 103, 104, and 120 are shown to be separated from all of the reference populations. UMFC 120 is shown to be clustered with

the Aleut, Buriat, Mongol, Chukchi, and Eskimo in the graph of PC1 vs. PC2 from the shape transformed Hanihara database (see Figure 4.21).

The results of all the principal components analyses can be said to reflect the findings of many researchers (Lewontin, 1972; Relethford, 1994) who have shown that there is more variation present within populations than among them. Although in some of the plots a clear distribution of populations based on geographic proximity and shared population history is shown, overall there is so much overlap in terms of population variation that it is difficult to see this clearly using craniofacial measurements; at least in terms of this analysis. A recent study by Hunley et al. (2009) said that there is still debate among anthropologists as to whether or not human genetic variation is a factor of isolation by distance or long-range migrations and bottlenecks. In concurrence with Hunley et al. (2009), I think that the principal components analyses performed in the current study indicate that there will not be a simple resolution to this debate. It seems evident that human genetic variation is a result of both of these phenomena.

Canonical Variates calculated from Discriminant Function Analysis

The plot of CV1 vs. CV2 calculated from the discriminant function analysis for the Michigan database using 21 craniofacial measurements shows that UMFC 103 and 120 are similar to several of the reference populations in terms of morphology (see Figure 4.3). UMFC 103 is very close to the Polynesian, Athabaskan, and Taiwanese aboriginal samples. It is extremely interesting because these three populations are not in close geographic proximity and so it is difficult to determine why they would appear to be so close morphologically. UMFC 103 does not appear to be closest to the Taiwanese

aboriginal sample, but this is again only the plot of CV1 vs. CV2. UMFC 104 is very far away from all of the reference populations, but is closest to the Melanesian and Australian samples. This demonstrates graphically why UMFC 104 is classified as Melanesian and why the typicality probability is so low. The plot of CVs 1 and 2 shows some geographic clustering. UMFC 120 is close to the Chukchi, Eskimo, South Chinese, and Heilongjiang reference populations. The nearness of these reference populations, in terms of CV1 and CV2, may suggest that there has been gene flow historically throughout South China, the Chukchi Peninsula, and the New World.

In the plot of CV1 vs. CV2 (Figure 4.7) for the Michigan database using the shape transformed variables UMFC 104 is again shown to be distinct. UMFC 104 is separated from the reference populations; however, the closest populations are Melanesia and West Africa indicating that there are some morphological similarities to these reference populations. UMFC 120 is also fairly distant from all of the reference populations; the closest populations are the Eskimo and Heilongjiang samples. This is very similar to the results seen in the plot of CV1 vs. CV2 (Figure 4.3). UMFC 120 appears to be morphologically similar to these groups because they potentially share a common ancestor. UMFC 103 is very close to the Athabaskan, Taiwanese aboriginal, and Japanese reference populations. This indicates that there may be morphological similarities based on underlying genetics between UMFC 103 and these populations. I expected that when the shape transformation was performed UMFC 103, 104, and 120 would be closer to the reference populations. This was not the case which suggests that size plays an important role in examining differences between populations. Simply

attempting to eliminate its effect does not seem to make the discriminant function any more effective.

The graph of CV1 vs. CV2 for the Hanihara database with 34 craniofacial measurements shows that UMFC 103 and 104 are very similar to each other, but quite distinct from all of the reference populations (Figure 4.11). The plot of CV2 vs. CV3 demonstrates the same relationship between UMFC 103 and 104 and the reference populations (Figure 4.12). The distinct nature of UMFC 104 is shown in the canonical variate plots from both the Michigan and Hanihara databases. However, UMFC 103 is much closer to the reference populations in the canonical variates plot from the Michigan database. The only explanation that I can offer for this difference is that the craniofacial measurements used by Hanihara are not useful for assessing these particular unknown individuals.

UMFC 120 is shown to be close to the cluster of African populations in the plot of CV1 vs. CV2. This is quite different from the results obtained using the Michigan database. UMFC 120 is shown to be similar to several Chinese populations. The plot of CV2 vs. CV3 does not bring UMFC 120 any closer to the reference populations in question. Although some of the nearest populations are from Japan, China, and Korea. This seems more in line with the results obtained using the Michigan database. I think that the reason for this disparity is that the craniofacial measurements used in the Hanihara dataset are much more a reflection of overall size than those measurements used in the Michigan dataset.

In the final discriminant function analysis of the Hanihara database, the results are much the same (see Figures 4.16 and 4.17). The plot of CV1 vs. CV2 shows that UMFC

103 and 104 are quite similar on the basis of both the 1st and 2nd canonical variates. UMFC 103 and 104 are completely separated from all reference populations in the plots of CV1 vs. CV2 and CV2 vs. CV3. These plots also show that UMFC 120 is quite distinct from the reference populations when the shape transformation is used. It is evident from these graphs that eliminating size differences does not aid in identifying similarities between individuals and the populations selected for study in the analysis from the Hanihara database using the shape transformed variables.

The results of the discriminant functions analyses as shown by the plots of CV1 vs. CV2 and CV2 vs. CV3 are different depending on which database is used and whether or not the shape transformation is performed on the craniofacial measurements. In the analyses using both the Michigan and Hanihara databases the transformation of the craniofacial measurements in an attempt to eliminate size differences was not able to minimize the differences between UMFC 103, 104, and 120 and the reference populations. In fact the case was the opposite; the differences between UMFC 103, 104, and 120 were magnified to an even greater extent.

Group Classification

Overall, in terms of classifying UMFC 103, 104, and 120, I obtained much more robust results from the Michigan database (see Table 5.1 below). The typicality probabilities calculated for UMFC 103 and 120 were significant (within the range of variation exhibited by a reference population) when the Michigan database was used with 21 craniofacial measurements. The classifications resulting from the use of the Michigan database with 21 shape transformed craniofacial measurements did not have significant

typicality probabilities. Based on the typicality probability calculated for the most likely group classification of UMFC 103 using the Michigan database and 21 craniofacial measurements, I am unable to rule out the possibility that UMFC 103 may be closely related morphologically to the sample representative of Taiwanese aboriginals. When the shape transformed variables are used UMFC 103 is classified as South Chinese, but the typicality probability is less than 0.05 which indicates that UMFC 103 is outside of the 95% range of variation exhibited by the South Chinese sample. This suggests that size is an important factor when attempting to classify individuals into a specific group.

The classifications for UMFC 104 using the variations of the Michigan database are less robust. UMFC 104 is classified as Melanesian when the Michigan database with 21 craniofacial measurements is used, but the typicality probability is only 0.02. The shape transformed Michigan database classifies UMFC 104 as Ainu with a very low typicality probability. I was unable to obtain any clear indication of group classification for UMFC 104. Although UMFC 104 has fairly high posterior probabilities using the two forms of the Michigan database, the typicality probabilities were too low to say with any certainty which of the reference populations, if any, UMFC 104 may be morphologically similar to.

UMFC 120 is grouped with South China in the first analyses using the Michigan database and 21 craniofacial measurements and with the Eskimo in the shape transformed analysis. The classification of UMFC 120 as South Chinese has a typicality probability which is well within the 95% range of variation exhibited by the South Chinese reference population. The classification of UMFC 120 as Eskimo, however, does not show a significant typicality probability. UMFC 120 is outside of the 95% range of variation of

the Eskimo population when the shape transformed variables are used. Based on the typicality probability calculated for the most likely group classification of UMFC 120 using the Michigan database with 21 craniofacial measurements, I am unable to eliminate the possibility that UMFC 120 may be closely related morphologically to the South Chinese reference population.

The results from the Michigan database seem to indicate that the most likely classifications are obtained when 21 untransformed craniofacial measurements are used. The results also suggest that size should not be completely eliminated because it is extremely important in assessing population affinities. When the shape transformed craniofacial measurements were used the group classifications for all individuals changed and the typicality probabilities were outside the 95% range of the reference populations. UMFC 103 and 120 are tentatively classified as Taiwanese aboriginal and South Chinese based on this analysis. This is not a definitive classification and I am merely suggesting that based on this particular analysis UMFC 103 and 120 may be closely related morphologically to these two reference populations.

The typicality probabilities calculated for UMFC 103, 104, and 120 using the two variations of the Hanihara database are insignificant. I cannot say with any reliability that UMFC 103, 104, and 120 are closely related to any of the populations that were chosen for comparison based on the Hanihara database. Although very high posterior probabilities are obtained in many cases, it is clear that this is merely a factor of these individuals being forced into one of the predetermined groups. There are a number of explanations for the poor results obtained for the classification of UMFC 103, 104, and 120 using the Hanihara database. One potential explanation is that UMFC 103, 104, and

120 are not members of any of the reference populations used for this analysis. Another explanation is that due to the small sample size of some of the reference populations the Mahalanobis distances could not be accurately calculated and as a result a strong classification could not be obtained.

Table 5.1. Posterior and Typicality Probabilities for UMFC 103, 104, and 120.

Database	Individual	Group classification	Posterior probability	Typicality probability
Michigan 21	UMFC 103	Taiwan aboriginal	0.861	0.134
	UMFC 104	Melanesia	0.682	0.02
	UMFC 120	South China	0.448	0.134
Michigan 21 SV	UMFC 103	South China	0.243	0.013
	UMFC 104	Ainu	0.587	0.007
	UMFC 120	Eskimo	0.517	0.013
Hanihara 34	UMFC 103	Vedda	0.938	0
	UMFC 104	Vedda	0.987	0
	UMFC 120	Sumatra	0.97	0
Hanihara 34 SV	UMFC 103	Vedda	0.571	0
	UMFC 104	Vedda	0.752	0
	UMFC 120	Sumatra	0.918	0

The results of the analyses using both the Michigan and Hanihara databases are quite different. The use of the Michigan database gave significant typicality probabilities only when the 21 craniofacial measurements were used without the shape transformation. The typicality probabilities calculated for the Hanihara database, both variants, were all less than 0.001. The Michigan database appears to be better able to classify UMFC 103, 104, and 120. The populations chosen from both databases are comparable and so the difference in group classification of UMFC 103, 104, and 120 does not appear to be a result of differences in the populations represented. A possible explanation for this difference is that the craniofacial measurements used in the Michigan database are better

suited to classification of unknown individuals. This may be because the Michigan database craniofacial measurements are focused on looking at facial variation rather than overall cranial variation.

CHAPTER 6 : CONCLUSIONS

This study has demonstrated the difficulties that anthropologists face when attempting to determine an individual's population affinity based solely on examination of skeletal cranial remains. The use of discriminant function analysis and multivariate statistics, although widely accepted as an appropriate means of assessing population affinity, was shown in this study to be a complicated process at best. I was able to classify UMFC 103 and 120 into a potentially morphologically similar group based on the calculation of typicality probabilities, but this was done only tentatively and cannot be considered a definitive classification.

It is clear based on these analyses that the use of different craniofacial measurements in multivariate statistical analyses can drastically alter the classification of an individual. This study suggests that the craniofacial measurements used by Dr. Brace and his colleagues at the University of Michigan are more effective than those used by Dr. Hanihara when used to calculate a discriminant function in order to classify UMFC 103 and 120. It is my feeling that this is the case because these measurements are focused on the nuances of facial characteristics rather than the entire cranium. The dataset collected by Dr. Hanihara is extensive and it seems that his measurements are quite useful when looking at regional variation, but are not particularly effectual in terms of individual classifications.

It is also evident from these statistical analyses that the shape transformation described by Darroch and Mosimann (1985) does not more robustly classify these individuals. It was expected that by performing this shape transformation, particularly

with the Hanihara database, I would be able to better assess the similarities in morphology between UMFC 103, 104, and 120 and the populations selected for comparison. The results obtained show that this was not the case. This indicates to me that size differences between populations are essential when looking at the variation between populations in an attempt at classification of unknown individuals. It has been demonstrated that only 10 to 15% of the total human variation is the result of differences between populations (Lewontin, 1972; Relethford, 1994) and it is clear to me that size is a large component of this variation.

I am unable to say based on the statistical analyses performed that UMFC 103 and 104 are morphologically similar to Chinese or Indian populations. I can say that UMFC 120 may be morphologically similar to the South Chinese sample based on the typicality probability calculated using the discriminant function analysis of the Michigan database with 21 craniofacial measurements. UMFC 103 is classified as Taiwanese aboriginal. The Taiwanese aboriginal reference population was shown to be very close to the Chinese reference populations in the principal components and discriminant function analyses. Although UMFC 103 and 104 are not classified as either Chinese or Indian, this does not mean that they are not members of these groups. Both China and India are extremely large countries with large, diverse populations. UMFC 103 and 104 may be members of either of these populations, but the samples that I have used for comparison may not be representative of the entire range of variation present within these countries. Also several of the reference populations have fairly small sample sizes which could contribute to the poor results obtained for the classification of these individuals, especially when the Hanihara database was used.

It is evident from this research that classifications obtained from discriminant function analyses should not be considered as fact, but seen simply as a possible solution. Ousley et al. (2009) were able to show that the use of prior information is very helpful when attempting to determine an individual's ancestry. However, the use of prior knowledge does not help much when prehistoric remains are being analyzed. Also it is impossible to use prior information when the location from which skeletons were found or, in the case of biological specimens, acquired is not known. Relethford (2009) showed that it is much easier to clearly separate populations regionally than into specific populations. Therefore, it may be useful to cluster populations regionally before attempting a classification based on discriminant function analysis. There are numerous questions about the effectiveness of discriminant function analysis in classifying individuals, but it is clear from current research (Konigsberg et al., 2009; Ousley et al., 2009) that anthropologists are not willing to throw away the baby with the bath water quite yet.

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