

THE EVALUATION OF MACROMORPHOSCOPIC TRAITS TO DETERMINE SECULAR
CHANGE AMONG A SAMPLE OF AFRICAN AND AMERICAN BLACKS

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ABSTRACT

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Forensic anthropologists utilize human craniofacial and postcranial skeletal morphological variation to assist in personal identification during medicolegal investigations, predominately to estimate the decedent's ancestry. Typically, cranial metric and nonmetric morphological traits are used. However, to more fully understand the patterns of variation in modern populations, it is necessary to consider and analyze the frequency of trait expression and the distribution of those traits within and between populations, as well as to understand any secular changes affecting trait manifestation. This research focuses on the frequency distribution and inter-trait correlations of 17 cranial macromorphoscopic traits to demonstrate the ability of these traits as measures of secular trends. A sample of crania from Native African and American Black populations were used. Fifteen of the 17 macromorphoscopic trait expressions differed significantly ($p < 0.05$) between these population groups. Correspondence analysis allowed a small degree of interpretation of secular change for each individual trait and sample, while a Canonical Analysis of the Principal Coordinates allowed observation of both short-term and long-term changes in trait expression, documenting a general narrowing and shortening of the face within African groups from the Nubians up to Modern American Blacks. Such within-group variation demonstrates that cranial macromorphoscopic traits can indeed be used to assess ancestry accurately, are best assessed in a statistical framework, and these traits can be utilized to assess population relatedness and temporal changes through the examination of secular change.

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CHAPTER 1 INTRODUCTION

Researchers from a variety of fields understand that human populations are biologically variable, and that this variation is observable. Looking between nations, between cities, or even between households, variation can be viewed in facial and body morphologic features and characteristics. Forensic anthropologists take advantage of this variation to assist in personal identification during medicolegal investigations of missing or unknown person cases through ancestry assessment. Ancestry from human skeletal remains can be accomplished through both metric analysis—measurements of the cranial and postcranial skeleton—and nonmetric analysis—visual inspection of morphological trait variants. The latter is often the preferred method as it can be accomplished rapidly, is inexpensive, and can be conducted on fragmented remains (Hefner et al., 2012; Rhine, 1990).

As far back as Linnaeus in the 18th century, scientists and philosophers saw evidence for biologically-distinct races through polygenic traits, leading to categorization of humans based on phenotype. In the early 20th century, E. A. Hooton used both metric and nonmetric traits to identify three biologically discrete races—White, Negroid, and Mongoloid—that were further separated into subcategories of race (Hefner et al., 2012; Sauer, 1992). Hooton's student, Stanley Garn, reified the concepts of race and ancestry, first truly separating the two ideas in the field of anthropology. Garn studied human variation and classification based on the phenotypic similarities of people from the same geographical space (Hefner et al., 2012). While Garn still considered those with similar traits to be “races,” he was one of the first to recognize the differences in ancestry based on geography and gene flow. However, while correlating social race to geographic ancestry was an improvement, race and ancestry were based on broad assertions and categorizations of human variability (Hefner et al., 2012; Rhine, 1990; Sauer,

1992). This led to the traditional approach of ancestry assessment, which comprises observing defined cranial nonmetric traits, comparing these traits to a pre-determined list, and assigning ancestry based on those comparisons (Brues, 1990; Rhine, 1990). More recent studies, however, have emphasized that no single trait is exclusive to a single population, and that ancestry should not be decided by reference to a single, isolated trait (Krogman and Iscan, 1986; Rhine, 1990; Hefner, 2009). Rather, the frequency of expression and distribution of multiple skeletal nonmetric traits should be considered and analyzed statistically and holistically, for patterns that aid in a better understanding of spatial and temporal variation (Rhine, 2009; Hefner, 2009; Hefner et al., 2012; Sauer, 1992). To help understand these patterns of variation in modern populations, secular changes of each trait should also be understood, as both time and environment may affect skeletal changes.

The goal of this thesis is to evaluate African ancestry, specifically secular changes in Native African and American Black populations from different temporal and spatial backgrounds, and determine whether knowledge of these changes can help the forensic anthropology community account for variation present in subpopulations. This type of work is important in forensic anthropology, as individuals of all ancestries, including those of the American Black populations, have been victim to incidents—homicides, suicides, accidental deaths, missing persons—resulting in unidentified remains. Ritter (2007) described the incredible number of missing individuals and unidentified remains in the United States as “the Nation’s silent mass disaster.” Over 40,000 sets of human remains that cannot be identified through conventional means are held in evidence rooms of medical examiners throughout the country, but only about 15% of these have been entered into the Federal Bureau of Investigation’s (FBI) National Crime Information Center (NCIC) database (Ritter, 2007). As of 31 December 2016,

there were 8,431 active entries for unidentified individuals in the NCIC's Missing Unidentified Person File (FBI, 2017). Of those, 894 were from 2016. This number consisted of: 80.5% deceased unidentified bodies; 0.9% unidentified catastrophe victims; and 18.6% living persons who could not ascertain their identity (FBI, 2017). When a deceased individual's identification is unknown, a forensic anthropologist is often called upon to assist in a positive identification. Part of this medicolegal process is the formation of a biological profile, including an ancestry assessment. With regards to secular change, a lot of work has been done on the metric changes in the cranium. For instance, secular change in relation to the American Black population was extensively tested by Spradley (2006). However, there is very limited literature related to the determination of secular change in cranial nonmetric traits. A lack of quantitative measures for human cranial variation poses a problem in ancestry assessment as variation has been shown to be greater within than between major geographic regions or ancestries (Relethford, 1994). A study by Williams et al. (2005) demonstrated misclassification of Nubian crania using the program FORDISC 2.0 and concluded that statistically defined populations cannot adequately represent biological variation due to the plethora of differences in historical, cultural, and biological criteria among population groups. On investigating FORDISC 3.0, L'Abbé et al. (2013) also observed misclassification when looking at the crania of North and South African Blacks and Whites and found that population-specific datasets are necessary in order to accurately classify ancestry.

Forensic Anthropology: Ancestry Assessment and the Medicolegal Process

Despite past, and even current, controversial views of race and ancestry, research has illustrated the essential role the assessment of ancestry plays in the biological profile. Therefore,

physical categorization is necessary. To the physical or forensic anthropologist, race and ancestry are not biological categorizations, but rather race is viewed as a social label; ancestry is an individual's geographic point of origin (Christensen et al., 2013). As Brues (1992) explained:

To the physical anthropologist, race is simply a phenomenon to be explained, as it is to the zoologist who sees the same kind of geographical diversity within nearly all widespread species. As a phenomenon, race is the fact that geographically separated populations differ in their gene frequencies and range of phenotypic variation, which therefore may be used to estimate the probability that an individual's area of ancestry is more probably one place than another (Brues, 1992:125).

Innovation and improvement in cranial measurement and interpretation has been slow, largely due to the small number of experts in the field and the vast majority of variation within populations and subpopulations. However, with renewed interest in the field of forensic anthropology, these data are steadily growing. As a result, knowledge and understanding of variation is flourishing.

The current research has the potential to influence the field of forensic anthropology, and forensic science in general. Forensic anthropology has been a part of forensic science since the time of Hooton when he and his students attempted to understand criminal behavior based on measurements and observations of the skull. Krogman helped unite anthropology and the medicolegal process when he drafted "A Guide to the Identification of Human Skeletal Material" for the FBI in 1939. In this guide, Krogman briefly outlined the biological profile and the features that would help an agent correctly analyze skeletal remains. For ancestry, Krogman described what he considered to be the three "major stocks of Mankind" (Krogman, 1939)—White, Yellow and Black—and the three major subdivisions of the White—Nordic, Alpine, and Mediterranean. Lists of the most common cranial traits or characters accompanied his race categories. This publication was a landmark for physical anthropology. It was the first time an anthropology article pertaining to identification was featured in a journal focused on forensic

science (Stewart and Kerley, 1979). Since that time, improvements have been made in the determination of the biological profile as well as the role of forensic anthropologists in medicolegal cases. The American Academy of Forensic Sciences (AAFS), originally founded in 1950, established the formation of a physical anthropology section in 1972 (Yaşar Işcan, 1988). Discussions at these meetings eventually resulted in a two-year grant (1986 – 1988) from the National Institute of Justice (NIJ) to support development of the Forensic Databank (FDB), a relational database that includes various forensic data, such as craniometric measurements (Ousley and Jantz, 1998; Jantz and Moore-Jansen, 1988). As of 2017, the American Board of Anthropology (ABFA) has certified 119 diplomates, which is the highest level of forensic qualification to work on medico-legal cases.

Despite these advances, fields of forensic science, including forensic anthropology, have been criticized for: a lack of definition and method standardization, a lack of inter-observer errors and error rates, and a lack of conformity. The United States Supreme Court case *Daubert v. Merrell Dow Pharmaceuticals, Inc.* in 1993 led to a push in the forensic community to apply more standardization to the field (Christensen, 2004; Christensen and Crowder, 2009). Hence, all aspects of skeletal analysis need to have a standardized and accepted basis. More prominently, the National Academy of Sciences (NAS) released a report in February 2009 in reference to recommendations to improve the field of forensic science. Some of these recommendations were structural. However, other recommendations concerned the accreditation of crime labs, the certification of examiners, and the standardization of methodology. Perhaps the most important recommendation was the need for validation studies, standardization, and some measure of the degree of certainty in research. The report stated: “Among existing forensic methods, only nuclear DNA analysis has been rigorously shown to have the capacity to consistently, and with a

high degree of certainty, demonstrate a connection between an evidentiary sample and a specific individual or source” (NAS Report, 2009).

In the past, ancestry assessment, specifically using cranial nonmetric traits, was viewed as more of an art than a science, relying mostly on experience and training (Rhine, 1990). Statistical applications and the calculation of significance in trait manifestations, as well as general acceptance by the scientific community, are all necessary components of a method if it is to be upheld in a court of law.

The use of nonmetric traits in ancestry assessments have developed and improved recently. The historical methods of ancestry assessment were not validated, due in large part to the methods’ reliance on experience rather than some level of objectivity (Hefner, 2009). However, newer methods rely on validated definitions and procedures tied to measures of intra- and inter-observer error. This thesis will add to the growing set of data on the statistical assessment of ancestry, tying in measures of secular change among modern American Black individuals. Recognizing and understanding secular changes and the resulting shifts in the patterns of trait expression within population groups will permit more valid assessments of ancestry from skeletal remains. From a forensic standpoint, it is important to document the secular changes present among population groups. As secular change is a product of both genetic and environmental influence, craniofacial secular changes will continue to occur (Jantz, 2001). Therefore, documenting the patterns of these cranial changes will help in the determination of trends for ancestry assessment.

Goals

Due to the incredible level of variation in the mid-facial region of the skull (Brues, 1990; Rhine, 1990), this analysis focused on cranial macromorphoscopic traits, which are cranial nonmetric traits used by forensic anthropologists to assess ancestry. Macromorphoscopic traits—defined as “quasicontinuous variables of the cranium that can be reflected as soft-tissue differences in the living” (Hefner et al., 2012: 295)—were scored for new data, and compared with data currently housed in the Macromorphoscopic Databank (MaMD; Hefner 2016). Goals for this thesis were three-fold: 1) to use cranial macromorphoscopic traits to add to the growing set of data in the statistical assessment of ancestry; 2) to evaluate secular change and shifts in patterns of trait expression, primarily among a sample of Native African and American Black populations; and 3) to assess the ability and potential of macromorphoscopic trait analysis to measure secular change. The four skeletal samples used in this study derived from various time periods and geographic locations.

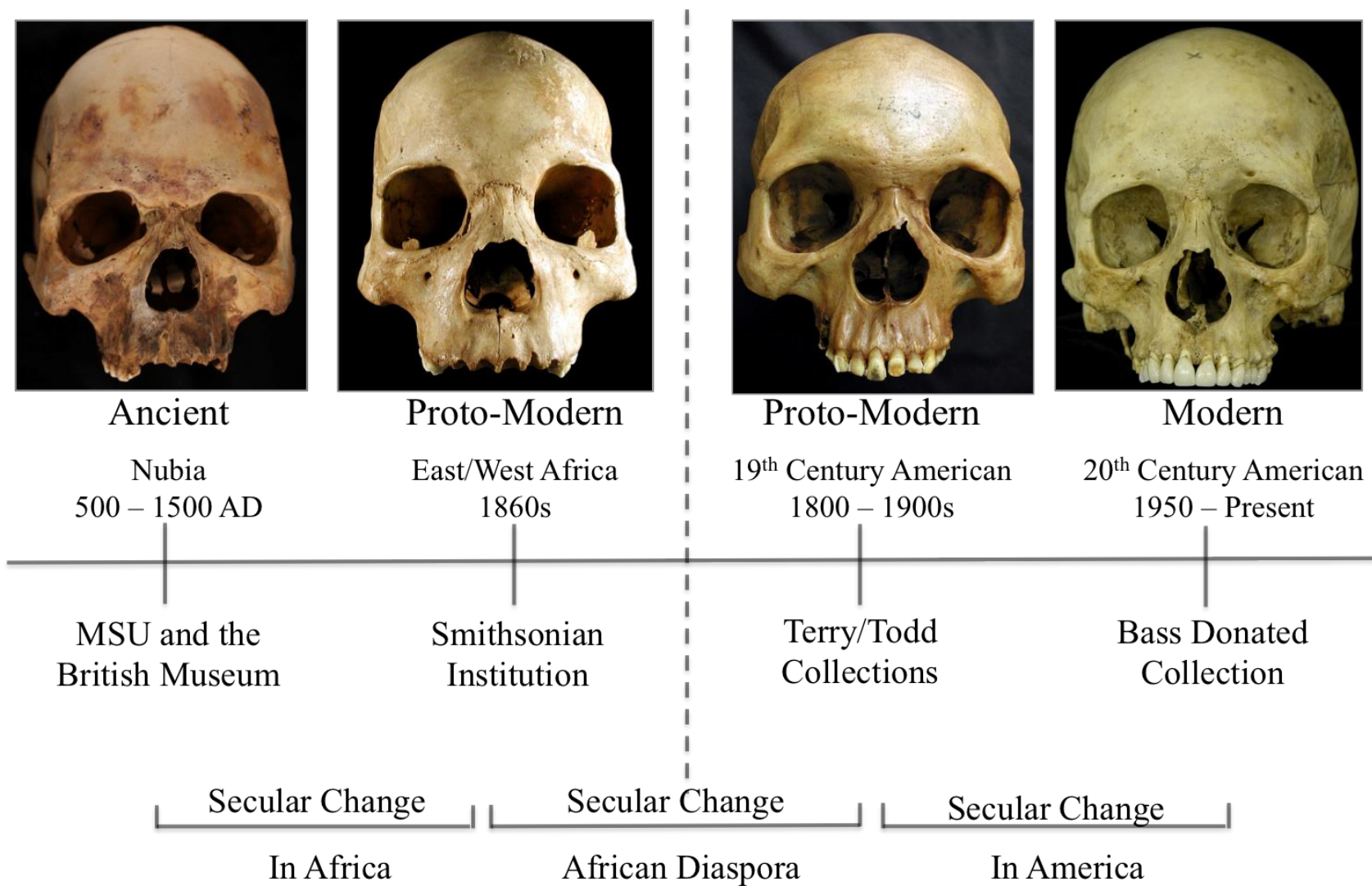


Figure 1-1. Diagram of the proposed samples, time periods, and collections. Ancient photograph provided by Leah (2017). Proto-Modern and Modern photographs provided by Hefner (2017).

Hypotheses

Three hypotheses are tested to address the above goals. They are:

Hypothesis 1:

Null: There is no difference in the frequency of macromorphoscopic traits between males and females in the Nubian sample.

Alternative: There is a significant difference in expression between males and females in the Nubian sample.

Hypothesis 2:

Null: Significant cranial secular change has not occurred in the Native African and American Black populations.

Alternative: Statistically-significant cranial secular change has taken place in the Native African and American Black populations over time. Secular change has occurred both over the expanse of time of the four sample collections, as well as over short segments of time between each sample.

Hypothesis 3:

Null: The Modern American Black population does not display significant secular change.

Alternative: Among the four samples, the Modern American Black displays the most significant cranial secular change due to gene flow and environmental adaptation.

To address the goals and hypotheses above, Chapter 2 presents a literature review of the history of race and ancestry throughout the 18th and 19th centuries, the methods used for cranial nonmetric traits, the use of these traits in secular change, and cranial studies involved in both the

African Diaspora and Nubian history. Chapter 3 discusses the samples and methodologies used to trace secular for American Black ancestry. Chapter 4 reviews the results. Chapter 5 discusses the results, and Chapter 6 presents the concluding remarks.

CHAPTER 2 LITERATURE REVIEW

Introduction

In order to fully appreciate the relevance and applicability of ancestry assessment in forensic anthropology, a review of a small part of the history is necessary. A literature search yielded a plethora of sources and, therefore, the scope of this historical review is limited by necessity.

This chapter discusses the history of the “race debate” and the transformation of the concept of race into the separate, but related, concepts of ancestry and race. Methodologies, such as the utilization of metric and nonmetric traits, and the cranial macromorphoscopic traits used in this thesis are reviewed. Lastly, as this thesis is heavily related to secular change, a brief overview of the history and excavations in Nubia; the African Diaspora; and the utilization of ancestry assessment in forensic anthropology and medicolegal cases are also reviewed.

Race and Ancestry

Before discussing the history of race and ancestry in forensic anthropology, some terminology should be provided. Race and ancestry, while often used inter-changeably, do not share the same meaning. However, they are undeniably linked although the definition of each of these terms has shifted throughout history. Popular modern conceptualizations of race are derived from 19th and early 20th century ideologies, when differences in race were determined by externally-visible traits, such as skin color and the size and shape of the head. While deemed scientific at the time, these categorizations were imbued with non-biological attributes that defined supposed biological groups based on aspects of culture and perceived behaviors. As physical anthropology has advanced in the modern era, revisions have been necessary.

In 1996, the American Academy of Physical Anthropology (AAPA) released a “Statement on Biological Aspects of Race” (Hagen, 1996). In this document, eleven points were covered in some detail. The basic premise of that document includes the following conclusions: all humans today share a common descent; biological differences between humans are the result of both genetic and environmental factors; there are obvious physical differences between people living in different geographic locations; humanity cannot be classified into discrete geographic categories; and the genetic component of each population is subject to outside influencing factors over time (Hagen, 1996). In 1998, the American Anthropological Association (AAA) made a similar statement; the main difference is that the word *race* always included quotations (i.e. “race” and “racial”). This, and many other publications, has further led to the misunderstandings and frequently ambiguous use of the term “race.” While race and ancestry were initially considered the same, race is now considered a social construct developed for social, economic, education, and political reasons. Ancestry, often confused with race, has been a contentious topic due to the historical, categorized, and labeled perspective of traits and human variability (Sauer, 1992). The term “ancestry,” however, technically refers to an individual’s ancestral geographic region of origin (Christensen et al., 2013). Ancestry is what many refer to as the “biological race” (Ousley et al., 2009). It is “a division of a species which differs from other divisions by the frequency with which certain hereditary traits appear among its members” (Brues, 1977:1). Therefore, ancestry or biological races are those who share heritable traits that make them similar to each other, but also distinct from other biological races (Ousley et al., 2009). Phenotypic human variation is geographically patterned and may be influenced by factors such as mutation, gene flow, and the environment. Therefore, ancestry assessment is based on the observations of biological traits and skeletal measurements corresponding to these variations.

The standards for ancestry assessment are constantly updated and improved. The National Institute of Standards and Technology (NIST) devised the Organization of Scientific Area Committees (OSAC), which replaced the Scientific Working Groups (SWG) in 2014, to improve quality infrastructure and standard development for fields in forensic science. The Anthropology section is a subcommittee of the Crime Scene/Death Investigation Scientific Area Committee and works to improve and update the anthropological standards and guidelines for the recovery and analysis of human remains, including the ancestral assessment portion of the biological profile.

Historical Background: Brief History of the 19th and 20th Centuries

According to Reed (2006), physical anthropology found its beginning during the Enlightenment Period when naturalists focused strongly on classification of humans. Based on population observation, different groups were assumed to be biologically different because of their physical appearance. Therefore, early biologists and anthropologists established criteria to evaluate and compare the differences between the various races they observed, particularly in the cranium (Reed, 2006). Race has been used to refer to aspects of both biological and cultural variation, and has been applied to everything from geography to genes (Relethford, 2009). While race may not be the best way to describe and analyze variation, the historical roots of biological relationships and race are intimately intertwined. Since the 18th century, the understanding of biological variation has improved, and the techniques and methods used to evaluate variation have grown. The concept of race, most likely an interest for as long as visibly distinguishable groups have interacted, arose concurrently with the age of colonialism. At their earliest, races were categorized by skin color, hair color, and facial feature shape. Linnaeus (1707-1778), the

father of modern taxonomy, was the first to classify humans in his book *Systema Naturae* in 1758.

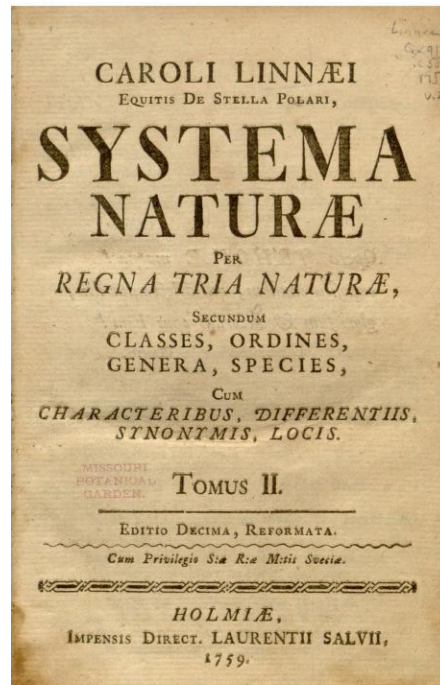


Figure 2-1. The title-page of the 10th edition of Linnaeus's *Systema Naturae* (1758).

He distinguished four subspecies of human: *Homo sapiens africanus*, *Homo sapiens americanus*, *Homo sapiens asiaticus*, and *Homo sapiens europæus* (Hefner et al., 2012; Reed, 2006; Linnaeus, 1758). These classifications were not based on anatomical observations, but rather on skin color, skin tissue morphology, and difference in behavior. Linnaeus believed in the Great Chain of Being, a hierarchy of organized life with each race holding an inherent position. In doing so, Linnaeus set the stage for biological “types” and the comparative classification still utilized in modern biology.

While Linnaeus's view of variation was mostly accepted, there were some who held a different view of variation. Johann Blumenbach (1752-1840), the father of physical anthropology, conducted research in Germany and used biometric analysis to delineate different

human groups. He believed that human variety was influenced by outside stressors such as climate, environment, and what he termed the ‘mode of life’ (Reed, 2006). Blumenbach categorized humans as “varieties” with noticeable changes in soft tissue and skeletal development due to heritability in one geographical space over time. Therefore, he reclassified humans into five varieties (with associated skin color): Caucasian (white), Mongolian (yellow), Ethiopian (black), American (red), and Malayan (brown) (Hefner et al., 2012; Reed, 2006).

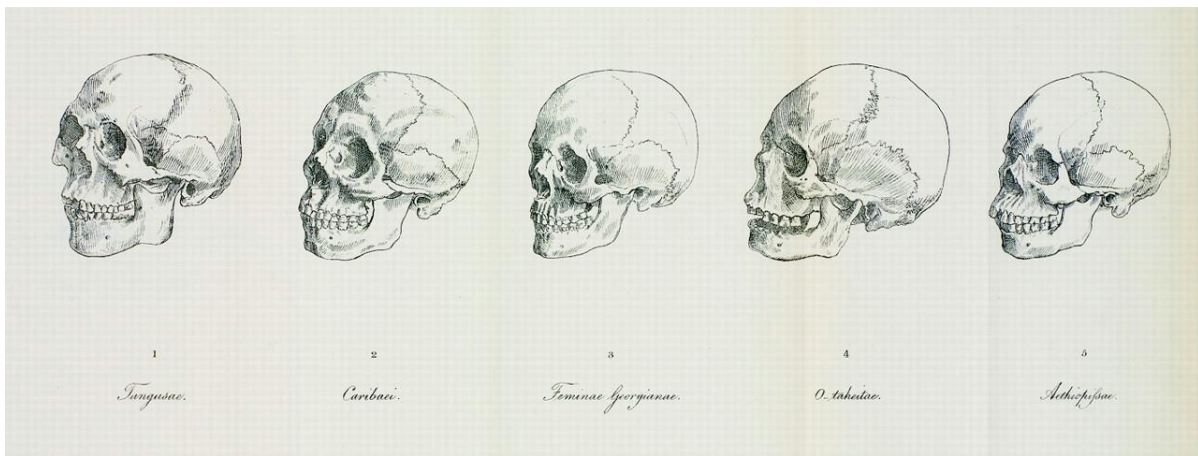


Figure 2-2. Sketch of the five varieties of classified humans from the third edition of Blumenbach's MD thesis (1775).

Unlike Linnaeus, who believed in a hierarchy, Blumenbach believed in the Lamarckian theory of heredity, where individuals inherit “acquired traits”. Therefore, his vision was that these various classifications resulted from the “degenerative hypothesis” (Hefner, 2007). That is, although all humans share the same origin, degeneration to the current varieties was due to population migration and environmental shifts. Blumenbach also realized that people within a certain area resembled their ancestors and shared similar traits (Hefner, 2007; Brace, 1997). Besides geographic origin, degeneration, and hair and skin color, Blumenbach also distinguished races based on cranial and body dimensions. Throughout his career, Blumenbach collected a large number of measurements from both living populations and skeletal material. He suggested that

the cranium may exhibit differentiating traits necessary to assign ancestry and, as such, his five classifications (Figure 2-2) were based on this craniometry.

Simultaneous with Blumenbach's work, Philadelphia anatomist and physician Samuel G. Morton (1799-1851) was making contributions to craniology in the United States. Morton's interest may have originally stemmed from his preparation of a class lecture entitled "The Different Forms of the Skull as Exhibited in the Five Races of Men," based on Blumenbach's teachings (Renschler and Monge, 2013). However, Morton found that he lacked sufficient sample sizes for each of the five races. Therefore, he amassed his own collection, which was soon large enough to earn the nickname "the American Golgotha" (Renschler and Monge, 2013). The Samuel George Morton Cranial Collection is still housed at the University of Pennsylvania's Museum of Archaeology and Anthropology and is one of the most famous collections in the world, frequently used for cranial studies. Using his collection, Morton made great contributions to the polygenist movement, a group that believed humans could be classified into distinct biological groups each having separate origins (compare this to monogenism – the belief that all humans had a single, biblical origin). Using cranial measurements of samples from around the world, Morton was one of the first to use differences in cranial morphology, and not just polygenic traits, to study human variation. His first, and possibly best known, work was *Crania Americana* (1839), which includes hand-drawn cranial illustrations (Figure 2-3).

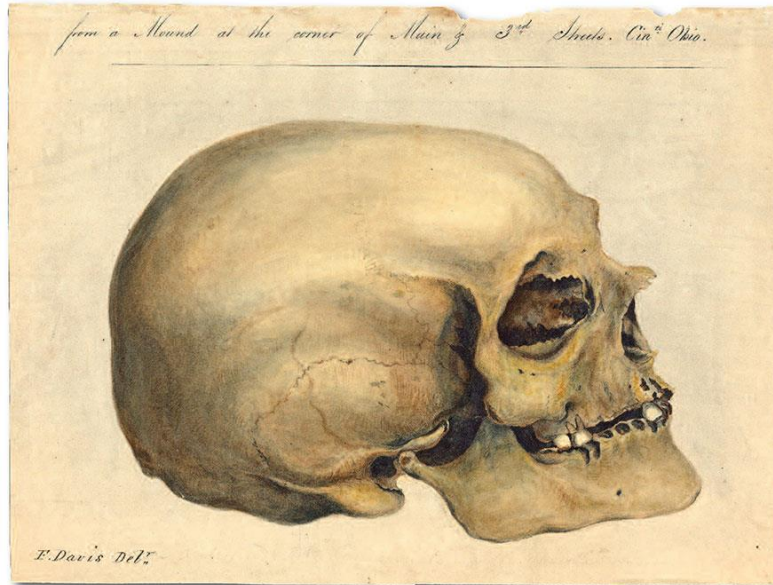


Figure 2-3. Plate of a hand-drawn illustration by John Collins from *Crania Americana* (Morton, 1939).

Morton's work has since been criticized, particularly after Gould's *The Mismeasure of Man* (1996). However, his conclusions on human variation had a major impact on American anthropology and many of his techniques of cranial measurement are still used today (Brace, 1997). Early cranial studies, such as those of Blumenbach and Morton, have perhaps negatively impacted the race concept. These early studies contributed to the "original sin" of anthropology (Hefner, 2007; Levi-Strauss, 1952) with the establishment of racial determinism based on social and behavioral characteristics. It is using race, in a biological sense, as relevant evidence to understand the "production of civilization" (Levi-Strauss, 1952) and the hierarchy of some human groups over others.

At the turn of the 20th century, enough research had been done that scholars generally understood and were aware of the fact that there was more to human diversity and variation than typology. However, race, and not ancestry, was still the predominant topic. Anthropology after Morton, and prior to the Modern era, was merely researchers still concerned with the ideals of

slavery in the United States (Brace, 2005). As the 19th century neared its end, the strife and struggle caused by the American Civil War was gaining strength. Anthropology was shifting its emphasis, focusing on the misconceptions and misuse of the race concept (Gould, 1996). Almost a century after Blumenbach and Morton, two anthropologists—Franz Boas and Earnest A. Hooton—emerged, each having a lasting impact on the concept of race and the modern view of ancestry in the United States.

Franz Uri Boas (1858 – 1942) was a German-American anthropologist often considered the “Father of American Anthropology.” Originally from Germany, Boas migrated to America due to the growing anti-Semitic climate in Germany (Hefner, 2007). On his arrival, Boas was offered a position at Columbia University, where he established the first Ph.D. anthropology program in America. Boas was adamantly opposed to the contemporary views of race, as he believed strongly in the idea of human variation as a way to explain human differences. Therefore, he sought to separate biological and morphological characteristics of race from economic and social implications. In a well-known study, *Changes in Bodily Form of Descendants of Immigrants* (1910), Boas used head measurements to demonstrate changes in body dimensions within one generation (Truesdell, 2005). He noticed drastic changes in cephalic indices in immigrants, which he attributed to changes in biological/environmental factors. This opposed the mainstream thinking of scientists and researchers who believed that the form of the skull was constant in each race and cranial indices would allow consistent conclusions about race (Hefner, 2007). While Boasian approach focused on cranial measurement and human variation, Hooton approached the idea that human races could be identified and defined by cranial measurements and cranial nonmetric traits.

Hooton and a Legacy

Earnest Albert Hooton (1887 – 1954) was a physical anthropologist, best known for his work in the Department of Anthropology at Harvard University. Hooton's career at Harvard began in 1913. His time there spanned four decades and comprised some of the most important contributions to today's more modern understanding and assessment of human ancestry (Hefner, 2007; Garn and Giles, 1995). His research career, according to Spencer (1997), can be divided into three sequential foci: skeletal biology; criminal anthropology; and constitutional studies. All three of these were based on Hooton's staunch belief in the use of morphological features in "race." Hooton (1926a) defined "race" as follows:

A race is a great division of mankind, the members of which, though individually varying, are characterized as a group by a certain combination of morphological and metrical features, principally non-adaptive, which have been derived from their common descent.

A primary race is one which has been modified only by the operation of evolutionary factors, including the selection of its own intrinsic variations and of the modifications, adaptive or non-adaptive, possibly caused by environmental stimuli.

A secondary or composite race is one in which a characteristic and stabilized combination of morphological and metrical features has been effected by a long-continued intermixture of two or more primary races within an area of relative isolation (Hooton, 1926a:312).

Obviously, Hooton had a firm grasp of the morphological variations present in the human crania. Similar to his predecessors, Hooton attempted to categorize humans into four classes—Whites or Caucasians; Negroids; Mongoloids; and Intermediates—based on hair-form, cranial index, nasal index, pigmentation and stature. Each of these four classes comprised at least three different races (Hooton, 1926a). These classes can be viewed in Figure 2-4.

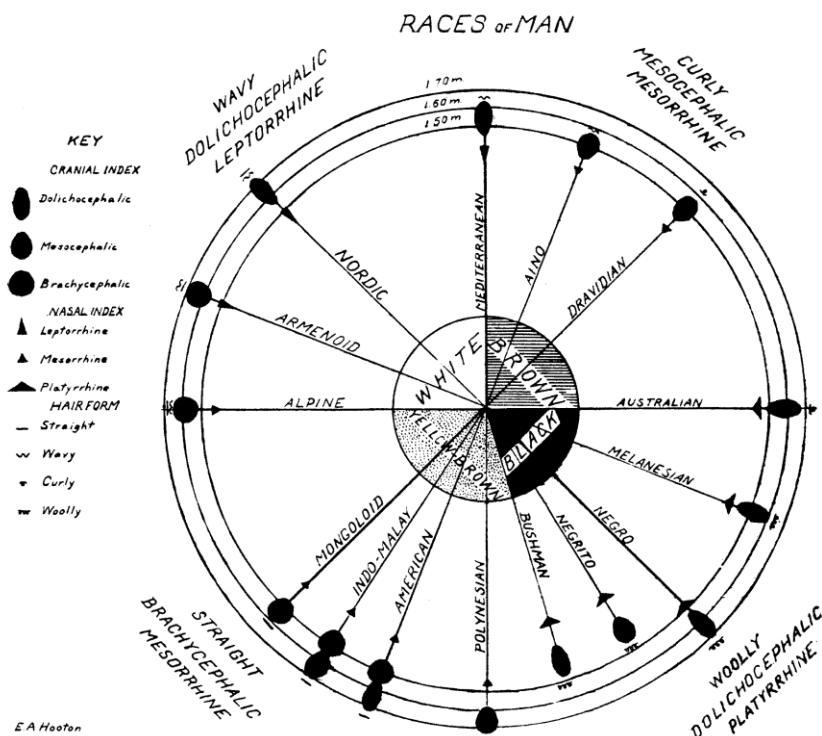


Figure 2-4. Hooton's classifications, or "Races of Man" (Hooton, 1926a: 313).

However, unlike his predecessors, Hooton attempted to understand regional variation based on statistical assessments of data (Hefner, 2009).

From very early on in his career, Hooton attempted to find combinations of metric and nonmetric traits to designate races. He turned his attention to large skeletal assemblages, such as his study *The Indians of Pecos Pueblos* (1930), in order to collect metric and morphological data for analyses. The Pecos study comprised the skeletal remains of over 500 individuals of all ages and is considered a turning point in human skeletal biology due to the large sample size (Garn and Giles, 1995). It was large enough to view age changes in the prehistoric skeletal population as well as to document the presence and effect of pathological conditions over time. He also introduced the racial category pseudo-types. From the Pecos site in New Mexico, Hooton characterized eight separate "morphological types" using both morphological and metric analysis (Hefner, 2007; Woodbury, 1932). For instance, Native American individuals who expressed

nonmetric traits resembling what was traditionally thought of as “African” were termed “Pseudo-Negroids” (Hooton, 1930). Those reminiscent of the aboriginal Australian were re-labeled “Pseudo-Australoid” (Hooton, 1930; Woodbury, 1932). Hooton did not view these trait correlations as a genetic relationships or even as secular change or gene flow between the founding of the pueblo in ca. 1100 AD and its final desertion in 1838 (Woodbury, 1932). Rather, with his “type” analysis and descriptions of typical form, Hooton believed these discordant morphologies were evidence of a heterogeneous population.

Hooton is also remembered for his anthropometric studies of living individuals, which started in the 1930s. As an early physical anthropologist interested in behavior, he had a keen interest in criminal types. Hooton believed there was a link between race and criminal acts. He collected cranial measurements from nearly 14,000 criminals and 3,000 civilians from ten different states (Hefner, 2007; Garn and Giles, 1995), the findings of which he published in *The American Criminal: An Anthropologic Study* (1939). Hooton stated that there was a significant difference between the cranial measurements of criminals from those of civilians. As explanation, he offered morphologic criteria for distinguishing criminals, such as lower foreheads and an excess of nasal deflections (Hefner, 2007).

While the findings of Hooton’s criminal studies have since been debunked, his methodology is considered a stepping-stone in the field of anthropology as most of the nonmetric traits used by forensic anthropologists today for ancestry assessment derive directly from Hooton’s “Harvard List” (Birkby et al., 2008; Hefner, 2009). His recording forms for this massive study consisted of ten 5x8 pages, four for the cranium and six for the post-cranial skeleton (Brues, 1990). All trait observations were pre-coded to be entered on 80-column punch cards for sorting and tabulation.

PEABODY MUSEUM OF HARVARD UNIVERSITY — CRANIAL OBSERVATIONS AND INDICES

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PEABODY MUSEUM OF HARVARD UNIVERSITY — CRANIAL OBSERVATIONS AND INDICES

Code B

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Figure 2-5. Pages from the Harvard recording forms. Obtained from Brues's chapter *Skeletal Attribution of Race* (Gill and Rhine, 1990:3-4).

Due to the simple categorical technique of presence versus absence in nonmetric traits, as well as the technique's reliance on shape and morphology, Hooton believed that "morphological features which can be observed and described but cannot be measured are probably of greater anthropological significance than diameters and indices" (Brues, 1990; Hefner et al., 2012; Hooton, 1930). Brues indicated that Hooton was also one of the first in the field to recognize the need for standardization, which he presented through the Harvard List. He developed the Statistical Laboratory at Harvard's Peabody Museum and maintained the most sophisticated "data crunching" operation that anthropologists had until the 1950s (Spencer, 1997; Brues, 1990; Garn and Giles, 1995). It was a major step to establish standardization, consistency, and statistical analyses in forensic anthropology, a model that is still undergoing refinement and renewal.

Like Blumenbach, Hooton's approach was typological. While he saw the presence of morphological variation in humans, he attributed the differences to the existence of discreet biological races with individuals sharing similar traits. Many of Hooton's students adopted these views. For instance, his student Carleton Coon wrote his dissertation on the adaptive significance of racial features and what he deemed to be typical racial forms (Hefner, 2007). His book *The Origin of Races* (1962) had a lasting impact on physical anthropology and the concept of race. It was not until Hooton's student, Stanley Garn, that race was first reconsidered, switching focus from typology to geography and gene flow.

Stanley Garn (1922 – 2007) was a human biologist and, later in life, an educator at the University of Michigan. Garn first entered Harvard in 1939 where he was first introduced to physical anthropology. He stated “it was Anthropology and specifically Physical Anthropology that captured my attention for it dealt with people and human biological variability and evolutionary practice and primate” (Brace, 2008:126). However, it was not until Garn re-enrolled in Harvard for his graduate education in the 1940s that he became a Hooton student. During his studies and travels, Garn noticed that groups of people living within the same geographic area resembled each other more so than people living in other geographical areas (Hefner, 2007). In his book *Human Races* (1961), Garn utilized the first two chapters to discuss the use of the term “race”. He suggested race could be split into categories of descending hierarchy—geographical race, local race, and microrace—in order to delimit the size of the groups analyzed or discussed. Garn (1961) defined nine geographic races: *Amerindian*, *Asiatic*, *Australian*, *Melanesian*, *Micronesian*, *Polynesian*, *Indian*, *African*, and *European*. The criteria for these categories were geography and movement between or among these locations, rather than phenotypic traits such as hair color or head shape. Therefore, within the nine geographic races, local races were

described as either: distinct, isolated groups; or large local races with noticeable levels of gene flow. When these local races were further broken down into smaller units, they were described as microraces. However, Garn did not provide a definition of this category as he had for the other two categories. Rather, he noted that “precise boundaries can not be drawn” and that members of one microrace may display phenotypes similar to another. More importantly, Garn recognized and distinguished how gene flow appeared to occur more often within a geographical area rather than between such areas. He also, unlike many before him, emphasized the influences of environmental factors, such as climate, on phenotypic expression.

Another of Hooton’s students having a lasting impact on the understanding of human variation in physical anthropology was Alice Brues (1913 – 2007). Although Brues originally enrolled in school to study comparative religions, her interests soon drifted to biological variation after meeting Hooton. Her dissertation work was based on human genetics and the phenotypic inheritance of traits like eye color and body build within family groups. After graduating and becoming only the second woman in the United States to earn her Ph.D. in physical anthropology (Hefner, 2007), Brues stayed at Harvard as a research associate at the Peabody Museum to work on the statistical analysis of anthropometric data. Brues, like Hooton, was interested in criminology and the medicolegal aspect of anthropology. Also like her advisor, she realized the lack of standards and scientific rigor for some anthropological analyses. In her 1992 article on the forensic diagnosis of race, Brues stated:

The anthropologist rarely appears in court; his task is to guide an investigation which turns up other and more trial-worthy kinds of evidence. Indications of age and sex are more or less standardized. But identification of the most probable race or populations affiliation is much more complex and difficult and continues to be a challenge to the anthropologist (Brues, 1992:125).

Lack of standardization led Brues's to research nasal contour morphology. She classified the nasal root contour into three categories: low and rounded ("quonset hut"); low to moderate ("tent"); and high and somewhat pinched ("church with a steeple"). She related these trait expressions to "Negroids," "Mongoloids," and "Caucasoids," respectively. Brues urged new methods that would quantify the variations within the different race types. Her passion for the application of anthropological techniques to criminal investigation was passed on to many of her students. One of those students was Stanley Rhine.

The Traditional Method

One of the first attempts at a concise reference volume for ancestry assessment in forensic anthropology is the *Skeletal Attribution of Race*, edited by Gill and Rhine (1990). Within this volume, two important chapters outline the foundational knowledge on the topic. Brues' (1990) chapter "The Once and Future Diagnosis of Race" provides a brief historical perspective on race and ancestry. Brues traces ancestry assessment back to its beginning, including Martin's 79 cranial measurements in *Lehrbuch der Anthropologie* (1914), Hrdlička's 32 skull measurements in his series of *Catalogues of Crania National Museum* (1920, 1924), and Hooton's "Harvard forms". However, the *Skeletal Attribution of Race* is perhaps best known for its chapter "Non-metric Skull Racing" by Rhine (1990).

Rhine received his Ph.D. from the University of Colorado in 1969 under the guidance of Alice Brues. Therefore, much of his thinking and understanding of ancestry was heavily influence by Brues and, indirectly, Hooton. His ideas pertaining to ancestry were typological and he applied these views to the determination of race in a forensic setting, specifically comprehensive and relevant to forensic anthropologists (Krogman and Iscan, 1986). Rhine

(1990) described lists of morphological traits useful for the identification of race when analyzing a skull. He discussed three sets of sketches depicting the principal traditional cranial nonmetric traits of differing racial groups, including American Caucasoid, Southwestern Mongoloid, and American Black.

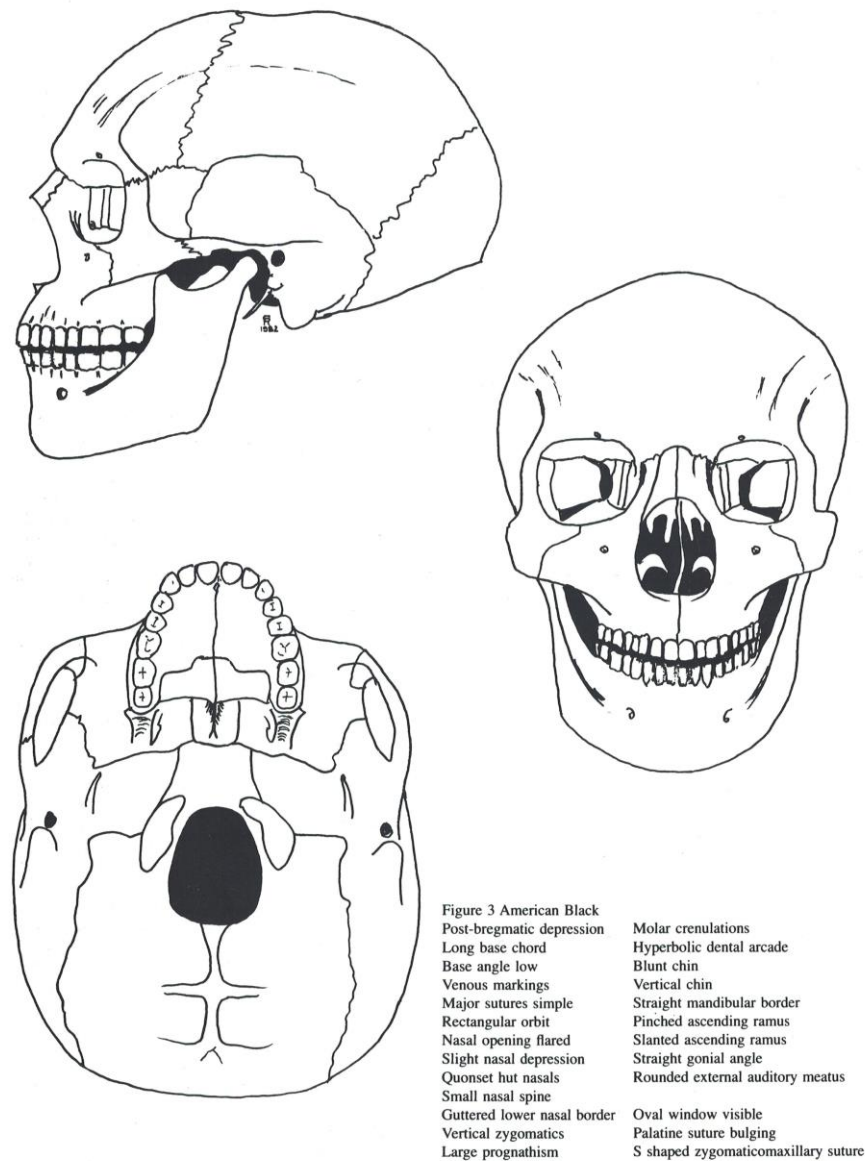


Figure 2-6. Rhine's sketch and nonmetric trait list for American Blacks in his chapter "Nonmetric Skull Racing" (Gill and Rhine, 1990:12).

These models were based on Krogman and Isçan's chapter on racial affinity in *The Human Skeleton in Forensic Medicine* (1986). Krogman and Isçan summarized the works of previous studies and discussed the craniofacial traits and distribution of race-related morphological traits in the three races: Caucasoid, Negroid, and Mongoloid, as well as their major subraces. Their conclusion was that race can be determined from the skull in 85% to 90% of cases (Krogman and Isçan, 1986; Sauer, 1992). Based on these descriptions, Rhine used eighty-seven skulls from the Maxwell Museum collection for analysis. These illustrations, the result of the 1981 Mountain, Desert and Coastal Forensic Anthropologists meeting, have been the main resource for forensic anthropologists since its publication.

While Rhine listed cranial nonmetric traits commonly viewed in these racial backgrounds, he also stated that *Homo sapiens* are highly variable. As discussed previously, ancestry assessment is complex in nature, further complicated by admixture and the seemingly elastic and multi-definitional nature of race; the term 'race' has different meanings to different people, and is often mistakenly interchanged with ancestry (Stewart and Kerley, 1979). Therefore, training and experience are essential, as is the knowledge that assessment should not be based on a single isolated trait (Krogman and Isçan, 1986; Rhine, 1990; Hefner, 2009). Rhine emphasized continued research of nonmetric traits as a necessary next step.

From Linnaeus and continuing into the present, contemporary worldviews and understandings of race and human variation have been presented. As can be seen by this history, the current concept and understanding of ancestry is the product of a slow evolution from misconception. Within the past decade, the introduction of new technologies and methods of analysis has revived interest in ancestry assessment, advancing the analysis of ancestry data by leaps and bounds.

Metric and Nonmetric Traits

Despite advances and progress in genetic analysis, the morphological analysis of skeletal material is still the most frequently used method for studying the variability of human populations (Ricaud et al., 2010). Physical and forensic anthropologists traditionally use metric methods and nonmetric traits to study human variation. Metric analysis is characterized by standard definitions of measurement that are collected using precise instruments and are analyzed statistically (Hefner et al., 2012). There are multiple ways to analyze metric measurements with statistical methodology, including the use of indices and ratios, as well as univariate and multivariate analysis. However, all of these metric evaluations are rooted in the metric standards set at the Frankfurter Verständigung (Frankfurt Convention) of 1882 (Hefner et al., 2012). Today, the computer program FORDISC 3.0 (Jantz and Ousley, 2005) is the most commonly used tool for analyzing craniometric data in a forensic context. This program utilizes discriminate function analysis. FORDISC 3.0 is a computer program that contains cranial measurements of known individuals (known biological parameters) from twenty-eight different populations. After taking the measurements of an unknown skull, the data can be input into the FORDISC 3.0 program to calculate a linear discriminate function and classify the skull into one of the population reference groups.

For osseous nonmetric trait analysis, the cranium is primarily used for genotypic data, while postcranial traits are used less frequently. This is for two reasons. The first is that cranial nonmetric traits, also sometimes referred to as epigenetic or quasi-continuous, have a long history in comparative human research due to early fascination with brain size and cranial capacity (Gould, 1996). In early human anatomical research, cranial nonmetric traits were first defined as skeletal “anomalies” or “abnormalities” (Wilson, 2010). Consequently, more literature

and documentation is dedicated to the cranial versus the postcranial traits. The second reason for using the cranium for analysis is that there are more clearly definable and recordable traits within the cranium than any other part of the body. Cranial nonmetric traits—also referred to as discrete, epigenetic [sic] or discontinuous traits—are widely and successfully used as an efficient morphological approach to the study of biological variation. Like their metric counterparts, cranial nonmetric traits can be used to calculate biological distance measures similar to those found in genetic analyses (Ricaud et al., 2010). Nonmetric traits are morphological features that vary in their degree of expression and are recorded on a scale (Wilson, 2010). Buikstra and Ubelaker (1994) provide the most succinct definition. Cranial nonmetric traits are “dichotomous, discontinuous, epigenetic traits; nonpathological variations of skeletal tissues that can be better classified as present or absent (or as a point on a morphological gradient; e.g., small to large) rather than quantified by a measurement” (Buikstra and Ubelaker, 1994: 85). Because nonmetric traits are discontinuous, trait presence or sample frequency is the primary descriptive expression.

Looking through the literature, one can see that there are many different nonmetric traits throughout the cranium that may be observed, although the actual number of nonmetric traits varies. Within these bones, the number of nonmetric traits varies throughout the related literature. Berry and Berry (1967) viewed thirty nonmetric traits; Ossenberg (1970) recorded twenty-eight different nonmetric traits; and Hefner (2009) scored sixteen different nonmetric cranial traits. As previously discussed, Hooton (1930) and Rhine (1990) provided sketches and lists of observed nonmetric traits typically viewed in each “race.” For instance, when observing the nasal bones, Rhine (1990) describes: “tower nasals” in American Caucasoid; “tented” nasals in Southwestern Mongoloid; and “Quonset hut” nasals in American Black. The skeletal traits used for study are based on the availability of expressed traits in the examined skeletal collection

of individuals. In recent research, these nonmetric traits have been known interchangeably, and in the traditional sense, as morphoscopic traits.

Cranial nonmetric traits have not been standardized to the same level as metric traits. Within the literature on nonmetric traits, it is apparent that experience is required to utilize this method. Hooton (1926b) stated, “They [nonmetric traits] are capable of classification according to presence or absence, grade of development and form, if the observer is experienced and is able to maintain a consistent standard for morphological appraisals.” Rhine (1990) described anthroposcopy as being “as accurate as anthropometry when in experienced hands and when numerous traits are used.” However, nonmetric traits are often preferred over metric because they are relatively simple to collect and can be amassed from fragmented assemblages (Reed, 2006; Wilson, 2010). Despite attempts to propose the collection of nonmetric traits through continuous variables, nonmetric traits are normally defined as either present or absent, open or closed, and more or fewer (Wilson, 2010).

Cranial Macromorphoscopic Traits

In recent years, there has been renewed interest in the topic of ancestry assessment among forensic anthropologists. Hefner has greatly expanded research into ancestry assessment through the analysis of cranial nonmetric traits. His principle focus is macromorphoscopic traits, which are different from the traditional cranial nonmetric traits made prevalent by Hooton and by Rhine (1990, 1993). Traditional cranial nonmetric, or discrete, traits are phenotypic, discontinuous, epigenetic variants that are classified through presence and absence or through the rating of morphology on a gradient scale, rather than measurement (Hefner et al., 2012). Comparatively, Hefner defines macromorphoscopic traits as “quasicontinuous variables of the

cranium that can be reflected as soft-tissue differences in the living” (Hefner et al., 2012). While traditional nonmetric traits are focused on extreme trait values in populations, macromorphoscopic traits focus on facial contour and overall patterns of trait distribution for the purpose of personal identification for a single individual (Hefner, 2009; Hefner et al., 2012).

Macromorphoscopic traits are divided into five classes: assessing bone shape; bony feature morphology; suture shape; presence/absence data; and feature prominence/protrusion (Hefner, 2009; Hefner et al., 2012). In his 2009 study, “Cranial Nonmetric Variation and Estimating Ancestry,” Hefner discussed the variability in predicting ancestry in human skeletal remains using macromorphoscopic traits and the limitations of the experience-based, unscientific approach previously employed by the majority of forensic anthropologists. Hefner explored the frequency distribution of eleven nonmetric traits in four samples, which he described as African, Asian, European, and Native American. His analysis found that no single individual had all eleven of the “expected” trait values listed by Rhine (1990). The resulting frequency distributions of Hefner’s test show that “compiled trait lists for ancestry ignore a substantial amount of variation within groups” (Hefner, 2009: 991) and are more subjective than objective. This supports his earlier research, which found that “the actual trait frequencies of these traits are much lower than assumed” (Hefner, 2009: 986), and that only between 17% and 51% of a population would express the most common traits of that population (Hefner 2009; Hefner et al., 2012). Therefore, Hefner and colleagues suggest that forensic anthropologists usually estimate ancestry through the cranial *Gestalt* along with *post hoc* trait selection after positive identification. To comply with the *Daubert* guidelines, which address reliability and validity in forensic technique and methodology, Hefner advocated the use of standard drawings and

definitions of each trait (which the software program Macromorphoscopes utilizes as described by Hefner (2009) and Hefner et al. (2012)).

Nonmetric Traits, Morphological Variation, and Secular Change

Nonmetric traits can be used for more than just ancestry assessment in forensic anthropology. In bioarchaeology, nonmetric traits and human variation have been used to measure and/or calculate biodistance, kinship, and migration. As this thesis demonstrates, nonmetric traits also can be used to measure secular change.

Cranial morphologic variation and secular change have been well documented in physical anthropology. However, morphological variation is an exceedingly broad topic that, likewise, corresponds to complex causes that are perhaps not yet fully understood. In the mid to late 20th century, focus on cranial variation shifted from general description of typology to the processes that influenced and attributed to phenotypic variation (Spradley, 2006). Because cranial morphology is a polygenic quantitative trait (Buikstra et al., 1990), cranial analyses has the potential to gain insight on how humans adapt to their environments and their shifts in environment, as well as other factors that influence human variation.

Plasticity, Genetics, and Secular Change

Any consideration of secular change must start with a brief discussion of Boas and his classic immigrant study conducted with funding from the United States Immigration Commission in 1909 and 1910 (Jantz, 2004; Sparks and Jantz, 2002). Just as Hooton is known for his Harvard List, Boas is known for his observations of cranial morphology change in the descendants of immigrants who traveled to the United States (Jantz and Meadows Jantz, 2000;

Sparks and Jantz, 2002; Sparks and Jantz, 2003; Wescott and Jantz, 2005). As previously discussed, one of his greatest contributions to biological anthropology was his study *Changes in Bodily Form of Descendants of Immigrants* (Boas, 1910). This study was best known for its analysis of the “central tabernacle of the doctrine” of race and the cephalic index (Gravlee et al., 2003; Tanner, 1981). In addition, Boas, an immigrant himself was interested in cranial morphology due the passage of laws restricting immigration based on head form and race (Jantz and Logan, 2010). The cephalic index was a measure of the ratio of head breadth to length and was used by anthropologists and anthropometrists at this time due to its supposed stability in determining race. Racial classification was based on three main assumptions: resistance to environmental influence; isolation from the affect of cultural practice; and the demonstration of heritability (Gravlee et al., 2003; Gould, 1996, Montagu, 1997). The morphology of the head was believed to satisfy all of these standards. In response to this sentiment, Boas collected craniometric data from nearly 18,000 individuals from seven populations, which included both American and foreign-born individuals (Jantz and Logan, 2010; Hefner et al., 2012). From this study, Boas concluded that the environment significantly influenced cranial morphology within a single generation (Boas, 1910, 1912):

In most of the European types that have been investigated the head form, which has always been considered one of the most stable and permanent characteristics of human races, undergoes far-reaching changes coincident with the transfer of the people from European to American soil. For instance, the east European Hebrew, who has a very round head, becomes more long-headed; the south Italian, who in Italy has an exceedingly long head, becomes more short-headed; so that both approach a uniform type in this country, so far as the roundness of the head is concerned... This fact is one of the most suggestive ones discovered in our investigation, because it shows that not even those characteristics of a race which have proved to be most permanent in their old home remain the same under our new surroundings; and we are compelled to conclude that when these features of the body change, the whole bodily and mental make-up of the immigrants may change.
[Boas, 1910:7-8]

In summary, Boas made the assumption that Europeans from various geographical regions,

migrated to a common American environment, were homogenized (Jantz, 2004). He described this change as “plasticity,” or the observed phenotypic adaptation to abrupt changes in the environment (Jantz and Logan, 2010; Spradley, 2006). Boas’ study was revolutionary and, while it did not immediately stop the use of the cephalic index or the creation of laws against immigration, it did pave the way to general acceptance of environmental influence on cranial morphology.

Boas’ work influenced many new studies on immigration. Many of his own students continued his work on morphology, the environment, and immigration. However, there is a noticeable gap in literature since that time (Sparks and Jantz, 2003). The cause of this is unclear, but more recently, there has been debate and reanalysis of Boas’ original data. Some of these reanalysis studies include: Sparks (2001); Sparks and Jantz (2002); Sparks and Jantz (2003); Gravlee et al. (2003); and Jantz and Logan (2010). Perhaps one of the most notable critiques of the Boas study is his lack of analytical and statistical technique. Care should be taken to not overstate this criticism, as current analytical techniques and computer-related methodologies were not present during Boas’ time. Therefore, reanalysis has focused on replicating and expanding on Boas’ work using modern methods (Relethford, 2009).

Overall, anthropologists suggest that cranial plasticity is caused by environmental factors, in agreement with the conclusions drawn by Boas. However, recent studies have discussed that variation in micro-evolutionary processes, such as selective pressures, admixture, and gene flow play a role in concordance with environmental influence. Through multivariate analysis, Sparks and Jantz (2002) showed that changes in environment produced relatively minor effects on cranial morphology relative to ancestry and that temporal change often occurred in the absence of migration or environmental change. However, they also found that facial breadth of

individuals had a slightly higher environmental variance component (Sparks, 2001; Sparks and Jantz, 2002). Therefore, there are two types of change—short-term and long-term—that develop based on different influences (Jantz and Meadows Jantz, 2000). Short-term changes are understood to involve one or two generations and are a result of environmental shifts and changes in health and nutrition (Smith et al., 1986; Cameron et al., 1990; Jantz and Meadows Jantz, 2000), while longer-term changes are likely to occur due to both environmental shifts and genetic components (Schwidtzky and Rösing, 1990; Jantz and Meadows Jantz, 2000). Rather than the specific immigration or movement of individuals that influence Boas’ work, it is both short-term and long-term change, and the factors that influence each, that affect secular change—physical changes that occur within a population as a result of gene flow and environmental shift (Spradley, 2006). Cranial variation is affected by plasticity, gene flow, and natural selection, and each can be linked at some level with migration: movement to a new environment can result in plasticity; movement and *in situ* adaptation can result in natural selection; and geographic distance may effect gene flow (Relethford, 2004).

Secular Change in Regards to the Four Population Samples

Much work has been done to understand human variation in different regions of the world. Discussion of all of this work would be a huge undertaking. However, it is perhaps prudent to briefly review previous work during the four temporal periods used in the analysis of this thesis, and the circumstances that may have influenced cranial human variation. The four populations used in this thesis are of African and American Black ancestry from Ancient Nubia, Proto-Modern Africa, Proto-Modern America, and Modern America. These periods are

discussed below in reverse order to highlight the difficulties of determining the degree to which environmental and genetic factors may influence secular change.

Modern Sample: 19th and 20th Century America

Secular changes in regards to stature and other bodily components have been fairly well documented; and cranial secular changes have been central to anthropological studies for over a century (Jantz and Meadows Jantz, 2016). In comparing 19th and 20th century American skeletons from the Terry Collection, Angel (1982) proposed differences in cranial structure, particularly the cranial base, due to nutrition and health conditions. For his dissertation, Moore-Jansen (1989) performed multivariate craniometric analysis among Afro-American and Euro-American populations from 1750 to the present to view cranial variation and secular trends. For the Afro-American series, Moore-Jansen (1989) observed minor changes in the shape of the crania, but a general decrease in cranium size with a decrease in cranial length, base, and height. Craniofacial changes included a trend towards a shortening and narrowing of the face over time. In contrast, the Euro-American sample was characterized by an increased facial projection and height, but a decrease in vault size and facial breadth. Secular changes were most observed in the cranial base, vault and height. While the causes of these trends are complex, Moore-Jansen (1989) discussed that changes in the Afro-American crania could be reflective of either genetic and/or nutritional influence. As the sample represented 19th and 20th century crania, there may have been shifts in socio-economic standing and health, as well as a later “relaxation of the selective pressure” (Moore-Jansen, 1989).

Jantz and Meadows Jantz (2000), Jantz (2001), and Wescott and Jantz (2005) all analyzed morphological changes in American White and Black crania, derived from the Terry

and Hamann-Todd collections and the FDB, during the 19th and 20th centuries. Jantz and Meadows Jantz (2000) viewed five craniofacial dimensions—glabella-occipital length, basion-bregma height, maximum cranial breadth, nasion-prosthion height, and bizygomatic breadth. They found clear evidence of secular changes in the craniofacial morphology with shape changes more pronounced than size changes. Both the cranial vault and the face tended to become higher and narrower, though changes in the face were less marked than the vault. It was concluded that the observed secular changes were most likely due to changes in health and nutrition. However, Jantz and Meadows Jantz (2000) advised caution in excluding the possibility of genetic influences. Jantz (2001) used fifteen standard cranial measurements, and Wescott and Jantz (2005) regarded thirteen cranial landmarks remodeled from traditional craniometric measurements. Like Jantz and Meadows Jantz (2000), both agreed that there were notable changes in vault height, base length, and total length, all increasing over time, while, simultaneously, the overall vault and face narrowed. Furthermore, changes in cranial shape were more pronounced than was the increase in size. Modifications within the vault were greater than those of the face. When comparing American Black populations to American Whites, it was seen that while the crania differed in morphology—American Black were long and narrow and White were short and high—the lengthening and narrowing of the vault for each population proceeded along an approximately parallel course of secular change. Jantz (2001) discussed cranial change in Americans from 1850 to 1975 and detailed:

It is evident that 19th century American whites are morphometrically similar to European samples, but 20th century samples, especially late 20th century samples, are strongly differentiated. A similar situation is seen in 19th century blacks, except they are to some degree intermediate between Africans and Europeans, presumably because of admixture and environmental change. Like whites, late 20th century blacks are strongly differentiated from their 19th century ancestors. Most striking about the relationships is that late 20th century whites and blacks are about as similar to each other than either is to its 19th century ancestors. (Jantz, 2001; p. 787).

Jantz and Meadows Jantz (2016) extended the findings of Jantz and Meadows Jantz (2000) and Jantz (2001) and aimed to examine the possible mechanisms that may have influenced these changes through an analysis of cranial vault dimensions in white Americans with birth years from 1820 to 1990. Even with a much shorter span of time, Jantz and Meadows Jantz (2016) again reported the crania becoming higher and narrower with a larger and longer cranial base. While specific causes could not be identified, Jantz and Meadows Jantz (2016) believed that plasticity could not be the only influencing factors. Rather, they discuss that Americans have experienced an increase in heterozygosity due to the breakdown of ethnic intermarriage.

To help further the understanding of these concepts and the nature of the anatomic cranial transformation, Wescott and Jantz (2005) used landmarks and Cartesian coordinates to view change over time. Their results showed that secular change in American crania was concentrated within the base and posterior aspect of the skull with minimum changes to the superior vault and face. The implications of this in regards to secular change were broken down into four categories. The first was nature of changes, which simply refers to the natural movement of cranial landmarks, as was described early on by Moore-Jansen (1989). The Wescott and Jantz (2005) study supported these two studies by showing how cranial base is subject to more secular change than the superior vault due to the movement of bregma superiorly and basion inferiorly over time. The second was plasticity and genetic variation, and the third was proximate causes, or changes that occur during growth and development. As a reminder, both functionally- and developmentally-related traits, such as those found in the cranium, will be co-inherited and respond to evolution and outside factors in coordination during the growth period. Lastly, Wescott and Jantz (2005) discuss ultimate causes of secular change, including nutrition and

biomechanical responses to changes in diet. For instance, past studies have demonstrated how an increased diet of softer, more processed food relates to a narrower dental arch and narrower facial breadth. In reality, all of these factors probably affect plasticity and secular change, but on different levels depending on both genetic and environmental influences (Wescott and Jantz, 2005). However, the interaction between genes and the environment pertaining to cranial polygenic traits is still not fully understood.

Proto-Modern: The African Diaspora and Secular Change

Based on observations of American individuals in the 19th and 20th centuries, American crania have clearly changed significantly in the past 150 years, attributable to America's diverse history. When discussing the ancestry of American Black individuals, it is necessary to go back to the African Diaspora. Spradley's (2006) study on secular change represents the predominate literature on the subject.

The African Diaspora (mid-15th to mid-18th centuries) refers to the "forced emigration of Africans to European and British colonies for the purpose of providing slave labor" (Spradley, 2006:19). The African Diaspora operated as part of the "triangle trade." As implied in the name, the triangle trade comprised three steps: 1) commercial goods from Europe were shipped to Africa for sale and trade for enslaved Africans; 2) the enslaved Africans were transported through the "Middle Passage" to the West Indies to be sold in America for plantation labor; and, 3), lastly, the ships would be loaded with goods such as sugar and tobacco to return to Europe. The cycle would then continue.

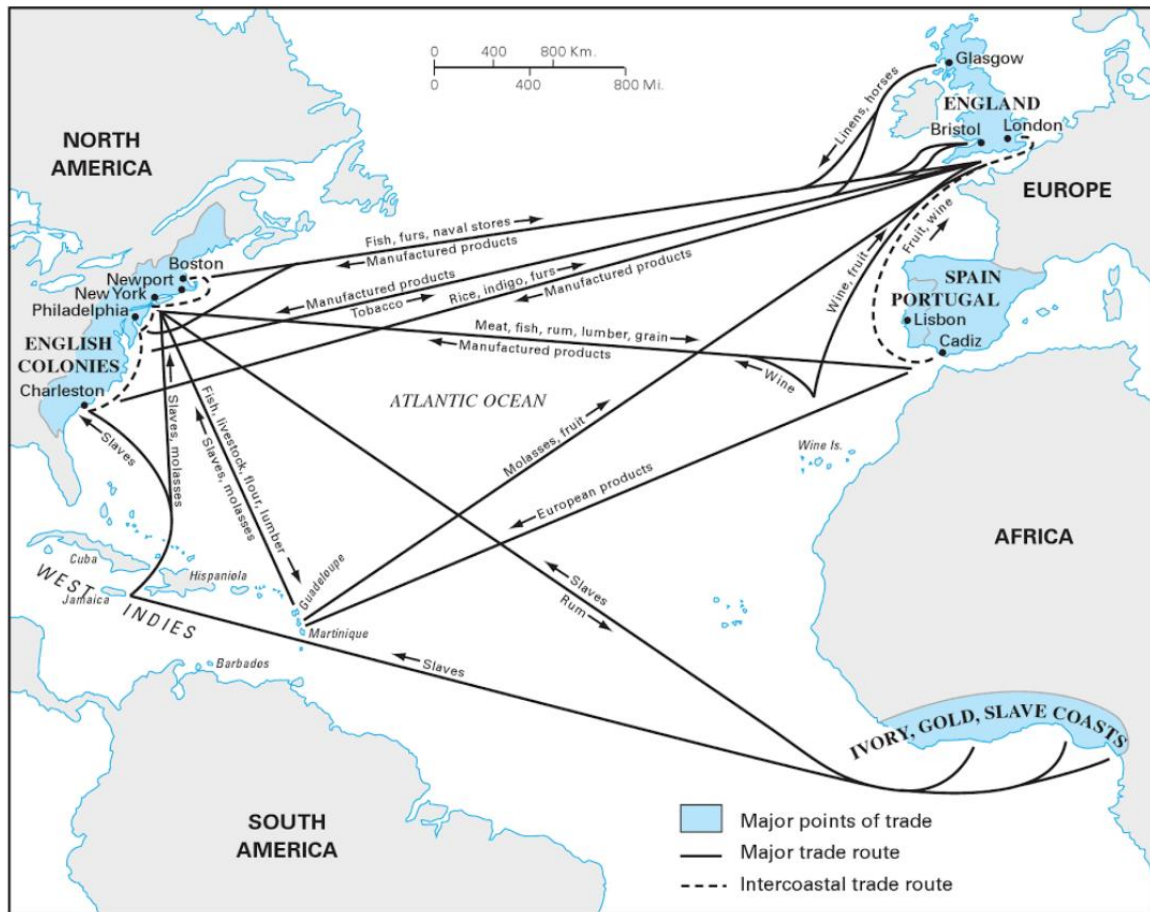


Figure 2-7. The “Triangle Trade” route. Obtained from *Western Civilization: Ideas, Politics, & Society, Volume II: From 1600* (Perry et al., 2012: 448).

While the first documentation of Africans in American colonies dates back to 1526, it is not until the latter part of the 17th century that American colonies became heavily involved in the slave trade (Spradley, 2006).

The Atlantic slave trade was an important link between Africa and the other continents, particularly America, for at least two centuries. However, there is uncertainty regarding the exact origin of those enslaved, although scholars generally accept that the majority of enslaved Africans originated from West and Central Africa (Curtin and Vansina, 1964). For certain periods, ship manifests contained information regarding the number of slaves they carried and the geographic origins of these slaves. However, many different nations participated in the trade

and, with political and economic shifts, the source of the trade and the distribution of slaves in America changed constantly. Historians recognize eight main coastal ports of trade: Senegambia; Sierra Leone; Windward Coast; Gold Coast; Bight of Benin; Bight of Biafra; Angola; and Mozambique (Spradley, 2006). However, while these points of trade are accepted, these origins may not have been the geographic origin of the individual slaves (Spradley, 2006; Rawley, 1981). With such a large number of slaves transported—Curtin (1969) estimated that approximately 9,566,100 slaves were transported to the New World from 1451 to 1870, though this number is heavily debated as an underestimate—Africans from the interior must also have been captured and taken to the coast by middlemen for trade (Spradley, 2006).

Enslaved Africans had a very different life in the American colonies experiencing shifts in environment, climate, and standard of living. America had ample land for plantations and the cultivation of crops, such as tobacco, rice, sugar, and cotton. With increased economic demand, there was an increased need for slave labor. Spradley (2016) suggests significant craniofacial secular change, resulting from the change in environmental conditions and living standards, occurred from 1700 to 1975 due to the African Diaspora.

Past literature has suggested that West Africans from the 18th and 19th centuries, considered ancestral to Modern American Blacks, display different craniofacial morphologies in comparison to American Blacks (Spradley, 2006). The West African populations displayed a short and high cranium, while the American Black population display long and narrow. This follows the lengthening and narrowing pattern described above by Jantz and Meadows Jantz (2000), Jantz (2001) and Wescott and Jantz (2005).

The samples for Spradley's (2016) study derived from both African (East and West) and American populations, partitioned into quarter-century groups. Based on her analysis of cranial

variables, she found significant craniofacial secular change in the American Black population. Over time, there was an increase in facial and nasal height, but a concomitant decrease in vault height, vault width, frontal breadth, bi-orbital breadth, inter-orbital width, and nasal breadth. This partially supports previous research on secular change (Jantz and Meadows Jantz, 2000). These studies and Spradley's agree that the greatest cranial change was in vault height as it increased from the 19th to the 20th century. However, while Spradley observed significant change in the face, Jantz and Meadows Jantz (2000), Jantz (2001) and Wescott and Jantz (2005) saw more noticeable changes in the cranial vault than in the face. Spradley (2006) believes this reflects more time-depth in her sample, which extends back to the 18th century. While the former two studies largely support secular change due to plasticity, Spradley's results show a close relationship both phenotypically and genotypically for American Blacks, who are somewhat intermediate to West Africans and American Whites. Not only has secular change occurred due to various factors, but these changes are evident and measurable on the cranium.

Ancient: Nubian History and Cranial Morphology

Nubia, which extended southward along the Nile River Valley from the first cataract in southern Egypt to the southern frontier of modern day Sudan, has a unique history due to its role in trade and migration through the African landscape (Hurst, 2013; Van Gerven, 1982). Nubia is often considered the corridor of Africa and the cradle of civilization due to its connection to both sub-Saharan Africa and the Mediterranean. Thus, Nubia is of particular interest to those studying long-term trends in human cultural and biological adaptation.

Geographically, the Nile comprises six cataracts (Figure 2-8), and Nubia was divided into three main regions: Lower Nubia (the southern portion of modern day Egypt, between the first

and second cataract); Upper Nubia (extending from the second to fourth cataract); and Southern Nubia (a continuation of Upper Nubia into modern day northern Sudan, including the sixth cataract). The distance from the First Cataract to the Sixth Cataract is approximately 800 km (Hassan, 2007). These regions were named based on the northerly flow of the Nile River. Therefore, Upper Nubia was actually located further upstream and at a higher elevation than the lower region (Carlson and Van Gerven, 1979). Due to its central location along the Nile River in the hottest and most arid region in the ancient world, Nubia was the nucleus of diverse cultures as surrounding civilizations were dependent on Nubia and the Nile River Valley for survival. Located just to the east of the Sahara Desert, the region was mostly inhospitable, with the exception of a thin strip of land along the banks of the Nile River that became a highway for travelers and traders (Welsby, 2002; Soler, 2012).

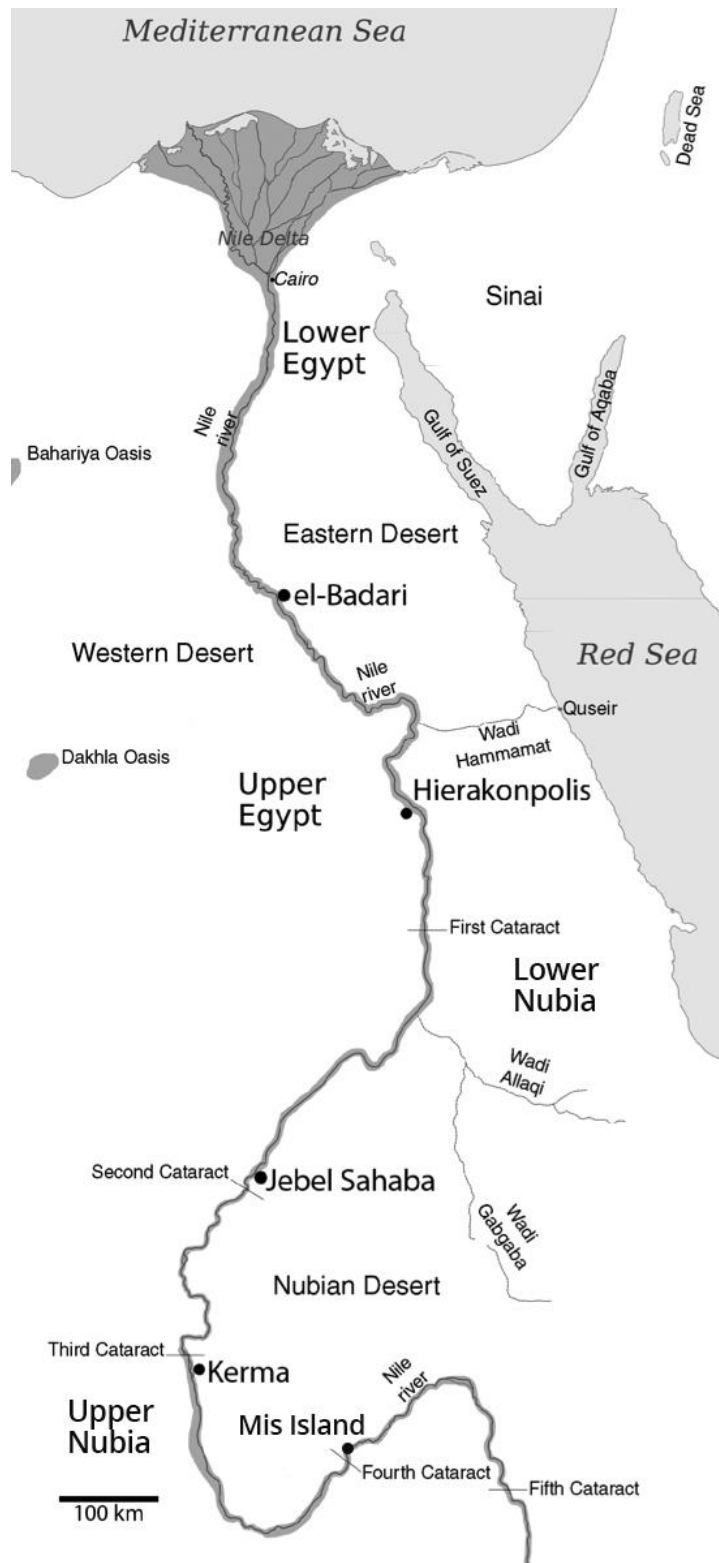


Figure 2-8. Map of Nubia and its proximity to the Mediterranean and sub-Saharan Africa. Adapted from Stock et al. (2011). Edited by author to include “Lower Nubia,” “Upper Nubia,” and “Mis Island.”

The location and historical role of Nubia may be explanation enough for the intense interest that archaeologists, bioarchaeologists and physical anthropologists have in the region, but Nubia is also a site of interest due to the level of antiquity present. Nubia's monuments, artifacts, and skeletal remains have been remarkably preserved due to the arid environment and the dry desert sands (Van Gerven, 1982). However, there has been an increased urgency to excavate, document, and preserve this antiquity due to the progressive inundation of Lower Nubia by the ever-shifting Nile River. Excavations have revealed much about Medieval Nubia's rich history. Carlson and Van Gerven (1979) reported over 36 major archaeological expeditions in Lower Nubia and the excavation of over 1,000 archaeological sites up until that time due to the construction of dams at Aswan.

The first expedition to salvage Nubian antiquity from the rising waters was in 1907 when George A. Reisner, and later C.M. Firth, conducted the First Archaeological Survey of Nubia (Van Gerven, 1982). These early surveys focused heavily on cemetery remains and funerary architecture. They related changes in both artifacts and burial customs, which suggested major shifts in population successive cultural periods. Therefore, Reisner designated archaeological population periods based on these artifacts and potential migration events with each group initiated by the arrival of distinct, biologically unrelated groups (Godde, 2012; Prowse and Lovell, 1995). These periods were re-classified by Batrawi (1945) based on cranial measurements, and have been added on to based on cultural evolution seen in the shifting archaeological record (Carlson and Van Gerven, 1979). Table 2-1 below presents a comprehensive list of the chronology of Nubian culture based on previous literature combined and current knowledge of Nubian history. Note that the time periods listed vary in range based on the source, and that many of these Nubian cultures exist simultaneously alongside each other

in different regions of Nubia.

Table 2-1. Nubian population cultures.	
Nubian Culture	Time Period
Christian Period	550 - 1400 AD
X-Group (Ballana Period)	320 - 550 AD
Meroitic Period	ca. 250 BC - 320 AD
Napatan Period	747 - 200 BC
Egyptian	1950 - 1100 BC
Pharaonic	1550 - 1070 BC
Late Kerma	1550 - 1440 BC
Classical Kerma (Kush)	1700 - 1550 BC
Middle Kerma	ca. 2000 - 1700 BC
Early Kerma	ca. 2100 BC
C-Group	ca. 2300 - 1550 BC
Intermediate Period	ca. 2300 - 1550 BC
A-Group	ca. 3800 - 3000/2700 BC

These time periods are divided due to an expanse of Nubian history, including regular flooding, evacuation and hiatus from fluctuations of the Nile River and periods of aridity, trade, migration, war, and invasion. A more thorough analysis of Nubia's history is necessary for full understanding of cranial morphology as plasticity may shift due to both short and long term segments of time. This is too large of an undertaking for this thesis because Nubia has been occupied for as far back as at least 6000 BC (Haynes, 1992). Comprehensive explanations of the time periods are covered by Batrawi (1945, 1946), Nielsen (1970), Carlson and Van Gerven (1979), and Edwards (2004). However, Nubia had intense interactions with its neighbors and was invaded and occupied multiple times in its history. Nubia was no stranger to warfare. In fact, the *Sti* bow is the symbol of Nubia due to their prowess as archers (Welsby, 2004). Nubia's attackers nicknamed them "pupil smiters" and "archers of the eyes." The Egyptians called Nubia "Ta-Seti," meaning "Land of the Bow," and often recruited Nubian archers in the Egyptian military (Zayed, 1981). While details of the Nubian campaigns are lacking, it is known that Nubia was

invaded and occupied by both Roman and Egyptian populaces numerous times. The campaigns of Egyptian rulers Thutmose I, Thutmose II, and Thutmose III reached the Third Cataract, and possibly even the Fourth Cataract during the period of the New Kingdom, when the Nubian Kingdom of Kush was in power (Kirwan, 1957). There is also evidence of the Roman Empire in Nubia as far back as Herodotus when the Nubian Kingdom of Meroe was in power. Two well-known and well-documented Roman campaigns in Nubia are that of Gaius Petronius (25-21 BC), and later Emperor Nero (61 AD) (Kirwan, 1957). The Nubian location was also coveted due to their wealth in resources. Nubia, possibly named from the Egyptian word for gold (“nbu”), was rich in gold, incense, ivory, ebony, oils, and semi-precious stones that was coveted by both Egypt and the Roman Empire (Sherif, 1981). In times of peace, there was a steady flow of trade along the Nile River, as well as overland, which helped decrease time of travel due to the Nile’s massive bends. Several desert routes used for trade and military travel are named in the literature, including: the Elephantine Road, which left the river at Aswan and travelled through the western desert parallel to the river’s course (Welsby, 2004); the Korosko Road, which travelled through the eastern desert parallel to the river and connected Lower Nubia to Upper Nubia (Welsby, 2004); as well as the Maheila and Bayuda Roads situated slightly west of the fourth cataract (Lohwasser, 2010).

Since that first excavation in 1907, interest in Nubian history and its disconnected cultural periods has continued. Plans to construct the Aswan High Dam inspired The International Campaign to Save the Monuments of Nubia (1959 – 1969), which was the first collaborative international rescue effort involving The United Nations Educational, Scientific and Cultural Organization (UNESCO) (Van Gerven, 1982; Hassan, 2007). Construction of a second dam at the Fourth Cataract began in 2003, which caused over a dozen national and

international salvage missions in Northern Sudan (Kleinitz and Näser, 2011). In 2006 and 2007, the Sudan Archaeological Research Society and The British Museum, in collaboration with Michigan State University, excavated three medieval Nubian Christian cemeteries located on Mis Island in the Fourth Cataract of the Nile due to the construction of the Merowe Dam (Ginns, 2007; Soler, 2012). Since its completed construction in 2008, the Merowe Dam has flooded approximately 180 km of the ancient Nile River Valley cultural landscape (Kleinitz and Näser, 2011).

The Nubian sample used in this thesis, from cemeteries 3-J-10 and 3-J-11, were from the collaborative British Museum and Michigan State University salvage mission. These cemeteries were from a small farming community on the fringes of the Medieval Nubian Christian Kingdom of Makuria, one of three Nubian kingdoms during the Medieval “Christian” Period (Ginns, 2007; Hurst, 2013; Soler, 2012). While Edwards (2004) discusses the origin of the Nubian kingdoms to be from populations of the Nubian River Valley and the surrounding desert area, overall certainty is still undetermined. However, research into the history during this time is extensive (Edwards, 2004). The Medieval Nubian Period spanned roughly 1000 years (mid-5th to the early 15th centuries). During this time, there were three distinct kingdoms situated along the Nile River: Nobadia (First – Third Cataracts); Makuria (Third – Fifth Cataracts); and Alwa (upstream of the Fifth Cataract). All three of these Christian kingdoms emerged in the mid-6th century and they are believed to share a high degree of biological continuity with the previous Kushite state, which ruled from the 9th century BC to the 4th century AD (Edwards, 2004; Soler, 2012). During the reign of the three kingdoms, trade continued to flow between Egypt and Nubia. However, war, raids, and invasions intermittently interrupted times of political, social, and cultural peace between Egypt and Nubia. The Nubian kingdoms eventually collapsed due to the spread and

influence of Egyptian Muslims and Arab desert tribes. The kingdom of Makuria, of which Mis Island was a part, collapsed in AD 1365 (Edwards, 2004; Soler, 2012). The Christian era of Medieval Nubia officially ended with the fall of Alwa in AD 1502 (Edwards, 2004; Soler, 2012).

Due to the abundance of human remains excavated and recovered from cemeteries, it is perhaps unsurprising that anatomical evidence played a key role in designating the rise and fall of Nubia's historic periods. Nubian population structure has been the subject of huge debate, resulting in a multitude of literature discussing biological continuity using mostly craniometrics (Godde, 2012), though the majority of these appear to be based on Lower Nubia with little mention of Upper Nubia. It is likely that Lower Nubia is the source of greater interest due to its closer proximity to Egypt and Egyptian populations. However, it is also likely that the higher interest is due to the higher level of preservation based on Nubian topography—Upper and Lower Nubia were clearly designated due to the shift in environment as Lower Nubia contained largely desert terrain and Upper Nubia contained grass savanna and forests among its hills (Carlson and Van Gerven, 1979)—and more salvage missions due to the construction of Aswan Dam and the creation of Lake Nasser. However, salvage missions in Upper Nubia have yielded interesting results when compared to Lower Nubia. A 1949 archaeology preliminary report of the Fourth Cataract described a poor, somewhat isolated area with evidence of habitation to the Christian period, but with little-to-no evidence of European interaction (Gray, 1949). Likewise, Grzyski (2004) provides insight on the landscape archaeology of the Middle Nile Valley and the apparent dependence on agriculture between 1000 BC and AD 1500. Soler (2012), Hurst (2013), and Vollner (2016) discuss the small, isolated agricultural communities in this region.

Because of the varying social and economic roles of different regions and times of the Nile River Valley, there are multiple theories regarding Nubia and biological continuity. Carlson

and Van Gerven (1979) provided a comprehensive discussion of Nubian history and the shift of hypotheses in 1960 due to The International Campaign to Save the Monuments of Nubia. One theory that budded in early Nubian archaeology was the “theory of successive populations” or “multiple migration hypothesis” originally set forth by Adams (1966, 1968), which suggested the migration of alien peoples into the area (Carlson, 1976; Prowse and Lovell, 1995). This was evident through the “racial” distinctions observed between Egypt and Nubia and between the different cultural periods (Table 2-1) in the Nile River Valley. “Advances” in Nubian culture during the Meroitic period were believed to coincide with an increase in Caucasoid (Egyptian) types, and cultural “decline” during the X-Group phase was due to an increase in “Negroid elements” as new travelers settled (Carlson and Van Gerven, 1979). Burials were labeled by race type, such as “Nubian,” “Egyptian,” “Negro,” and “foreigner” (Elliot-Smith and Wood-Jones, 1910; Carlson and Van-Gerven, 1979). One of the more pertinent theories, based on the amount of “Negroid” or “Caucasoid” traits or characteristics observed in skeletal remains, was that there were two racial “types” along the Nile River Valley: the “Upper Nile type” exhibited a high concentration of “Negroid traits;” and that the “Lower Nile type” lacked “Negroid features” (Morant, 1925, 1935). Morant saw this as evidence of admixture between the “Negroids” to the south and the “Caucasoids” to the north. This change in skin color between Upper and Lower Nubia has been noticed since as early as the Roman Empire. The Greek and Romans referred to all the territory south of Egypt by the Greek name Ethiopia, which means “Land of the Burnt Faces,” while the first Arab travelers referred to Nubia as “Baled-as-Sudan,” meaning “Land of the Blacks” (Adam, 1981; Haynes, 1992).

Post-1960 researchers generally agreed that biological continuity can be observed throughout all the time periods, and it has been shown that modern Nubians are the direct

biological descendants of populations occupying the regions as far back as the Mesolithic times (Carlson and Van Gerven, 1979) and perhaps as far back as the Paleolithic (Carlson, 1976). Therefore, the main debate for Nubian biological evolution has now become whether Nubians evolved due to biological diffusion—contact with other peoples, regardless if this was due to invasion or migration, resulting in gene flow along the Nile River Valley—or evolved *in situ*—genetic isolation within Nubian and Egyptian groups (Godde, 2009).

Nielsen (1970) drafted an impressive doctoral thesis based on metric and nonmetric anatomical variations of skeletal remains excavated during the Scandinavian Joint Expedition to Sudanese Nubia during 1963 and 1964. He looked at crania from a range of Nubian cultural periods including the A-Group, C-Group, Pharaonic, Meroitic, X-Group, Christian, and Muhammedan. Based on cranial measurements, Nielsen found no difference in variability between the sexes, suggesting homogeneity and indicating that both sexes came from the same population for all groups. Using multivariate analysis and Mahalanobis D^2 measures, he determined that the C-Group was distinct with the Meroitic, X-Group, and Christian forming a “common” group. Overall, Nielsen concluded that populations of Nubia were genetically similar; however, Nielsen saw a trend that the Nubian crania tended to become less dolichocephalic over time.

Carlson (1976) analyzed cranial morphological variation in Nubian populations extending from the A-Group through the Christian period. He noticed a trend in Nubian crania over the last 5,000 – 12,000 years (3400 BC – 1500 AD). Multiple discriminant analysis on 48 anatomical reference points of cranial radiographs revealed a shift from lower and more elongated cranial vaults to a shorter and taller vault. The facial portion of the crania also became more inferiorly-posteriorly located with respect to the vault, and there was a general reduction in

robusticity. Carlson (1976) attributed this cranial shift to progressive changes due to the masticatory complex and change in subsistence patterns, later proposed by Carlson and Van Gerven (1979) as the masticatory-functional hypothesis. Research has indicated that the A-Group through the C-Group of Lower Nubia had not yet fully adapted to the shift from hunting gathering to agriculture (Adams, 1967). However, over time and with an increase in trade and economy, Nubia was a fully functioning agricultural state by the time of the Christian period.

To add to this, Prowse and Lovell (1995) analyzed skeletal samples from the A and C-Groups, which were obtained from the Scandinavian Joint Expedition to Nubia in 1963 and 1964. Using 45 cranial nonmetric traits, Prowse and Lovell supported biological continuity due to *in situ* evolution. As there was so little difference present between the crania of the two groups, it was postulated that the C-group were direct descendants of the A-Group. Carlson and Van Gerven (1979), through their examination of previously analyzed Nubian skeletal remains, also supported the *in situ* hypothesis with homogeneity as an underlying premise. Galland et al. (2016) examined craniofacial and mandibular patterns from the Mesolithic to the Meroitic cultural periods—a span of 11,000 years—using 3D geometric morphometric methods and supported the masticatory-functional hypothesis, further suggesting population continuity. As Berry et al. (1967) noted through skeletal and cranial analysis of ancient Egypt and Egypt's neighbors, "At no time are there major discontinuities which might imply replacement of the population on a large scale by a genetically different people" (p. 562).

Van Gerven (1982) analyzed twelve cranial metric variables, from the Meroitic, X-Group, and Christian periods—from the University of Colorado 1964 Expedition to the Sudan—to study differences between Nubian subpopulations from two different geographical areas in *Batn el Hajar* (south of the Second Cataract): Wadi Halfa and Kulubnarti. He felt that while

natural selection and the *in situ* hypothesis had been successful in recent studies, there was still a need to understand the level of influence gene flow had along the Nubian Corridor. He stated:

Recent success in determining the importance of natural selection for craniofacial evolution does not, however, eliminate the need to understand and incorporate the pervasive role of genetic exchange (flow) along the Nubian corridor. Without returning to discredited theories of racial migrations and replacements, gene flow must be considered in any thorough evolutionary analysis. The facts of Nubian geography and history demand this. There is no question that Nubia provided a vital connecting link between the cultures and peoples of the Mediterranean and Egypt to her north and Black Africa to her south. (Van Gerven, 1982: 309)

Van Gerven focused specifically on *Batn el Hajar*, otherwise known as “belly of rock” that was located south of the Second Cataract. Due to its landscape, *Batn el Hajar* was an ideal buffer zone between Egyptian influence and the populations of Upper Nubia, and therefore provided a useful link between Egypt, Upper Nubia, and Lower Nubia. The same pattern of facial reduction over time was observed: longer, narrower palates; a higher, less projecting midface; and shorter mandibles. This lent strong support that populations along the Nile Corridor were related in a clinal pattern. Van Gerven believed this pattern to be evidence of both long-term and short-term changes that were attributed to two sources of variation. The first was temporal, as this reduction pattern had been previously reported for Lower Nubia. The second was geographic and may suggest morphologic convergence due to southward migration. This is supported historically. Egypt had converted to Islam in the 7th century, while their southerly neighbors in Lower Nubia remained as Christian monarchies (Van Gerven 1982; Soler, 2012). However, trade and Egyptian settlement continued along the Nile in Lower Nubia. In the early part of the 14th century, Nubia fell to Muslim raids and invasion and Lower Nubia became an Islamic dependency (Van Gerven, 1982; Soler, 2012). *Batn el Hajar*, particularly Kulubnarti, became a refuge as Lower Nubian Christians fled southwards. Therefore, while a decrease in facial size due to mastication processes were long-term changes, short-term changes occurred due to morphological

convergence from an increase in southward migration from the early to late Christian periods.

Recent research has found more evidence in support of gene flow along the Nile Corridor. Fox (1997) and Krings (1999) both supported the existence of gene flow through mtDNA analysis. However, Fox (1997) related the existence of a south-to-north gene flow rather than north-to-south. Krings (1999) added to this and concluded that north-to-south migrations were either earlier or had a smaller impact in terms of gene flow than later patterns of south to north migration. More recently, Schuenemann et al. (2017) used ancient Egyptian mummy genomes to illustrate an influx of sub-Saharan African ancestry in Egypt after the Roman Period, which the authors attributed to: increased mobility along the Nile River; increased long-distance commerce between sub-Saharan Africa and Egypt; and possibly the trans-Saharan slave trade. In terms of cranial analysis, Godde (2009) found it necessary to analyze populations from both Nubia and Egypt in order to better understand homogeneity. She therefore analyzed 20 cranial nonmetric traits of specimens from multiple sites in both Egypt (such as Badari) and Nubia (such as Kerma) that spanned multiple time periods, including the Christian period. A Mahalanobis D^2 analysis revealed Egyptians and Nubians to have a close affinity with a possible homogeneity between the two populations. Gene flow may account for the homogeneity between the two populations, especially due to the small geographic distance between Egypt and Lower Nubia. Historically, parts of Lower Nubia, such as Kerma, had continuous Egyptian occupation and trade between the two flourished for multiple time periods (Godde, 2009). However, Godde also stressed that this does not rule out the *in situ* hypothesis as common adaptation to a similar environment may also have resulted in cranial similarity.

In terms of Upper Nubia, a recent dissertation from Michigan State University (Vollner, 2016) examined the population history of three medieval Nubian sites, including Mis Island.

Through the analysis of craniometric variance among the three sites, Vollner (2016) found an overall head width decrease over time, but an increase in interorbital breadth. She concluded that the three samples were biologically distinct, but that the overall cranial similarities of the samples supported the *in situ* hypothesis within the Nile River Valley and could be explained by geographic clines. Vollner (2016) also found that the phenotypic variation present was representative of a low rate of external gene flow for the Kulubnarti and Mis Island groups, most likely due to their location and that these samples are primarily small agricultural groups. However, the third site of Gabati may have experienced a small level of variation due external gene flow, possibly from migration due to trade.

As can be seen, cranial-facial changes in Nubia may have occurred over time due to a combination of gene flow and shifts in environment and resources. However, the level to which each contributes to different regions is too difficult to determine due to a long and complicated Nubian history.

Expectations of Macromorphoscopic Traits

Overall the general cranial trends present in African and American Black populations are based on the literature covered above. Over time, slightly different patterns express themselves based on short-term or long-term plasticity and micro-evolutionary processes. Many of the articles described above mainly focus on the use of cranial metric traits and methodologies, or craniometrics, to interpret secular change. The use of nonmetric traits has been less common with respect to this topic (Hefner, 2016 and Spradley, 2006). As the methodology for macromorphoscopic traits has been unstandardized until recently with Hefner's work (Hefner 2007, 2009), the use of cranial macromorphoscopic traits in secular change has largely been

ignored. However, as secular change is evident in morphological characteristics of the cranium in both short and long-term settings, analysis of cranial macromorphoscotics should reflect those traits most commonly used in forensic anthropology. Therefore, it is expected that trait character state will, like previous literature, follow a similar trend of decreasing expression and narrowing facial features through the four population groups. This thesis presents the first time that macromorphoscotics has been used in this capacity.

CHAPTER 3

MATERIALS AND METHODS

To explore patterns of secular change and the frequency of expression and distribution of 17 macromorphoscopic traits among different geographic and temporal populations, data were collected from adult crania representing four skeletal groups (N = 591). These four populations were selected to represent four time periods in African and American Black history: Ancient, Proto-Modern African, Proto-Modern American, and Modern American.

The Proto-Modern African, Proto-Modern American, and Modern American samples were previously collected and analyzed by Hefner (2009) for previous and on-going research. These data were obtained from the MaMD for use in this analysis (Hefner 2016).

Samples

Ancient Sample

The Medieval Nubian (Ancient African) sample consists of native African Blacks from the X-Group and Christian Period classifications (mid-5th to the early 15th centuries AD). Due to the construction of the Merowe Dam, two sites—Cemeteries 3-J-10 and 3-J-11 (n = 128 and n = 277, respectively)—were salvaged from Mis Island, located along the Fourth Cataract of the Nile River (Figure 3-1), by a combined effort of Michigan State University and the British Museum during the 2005 and 2006 field seasons. This collection, on loan to Michigan State University from the British Museum, is currently housed at the Michigan State University Nubian Bioarchaeology Laboratory, East Lansing, Michigan. Numerous research projects, theses, and dissertations have used this collection, including Ginns (2007), Soler (2012), Hurst (2013), and Vollner (2016).

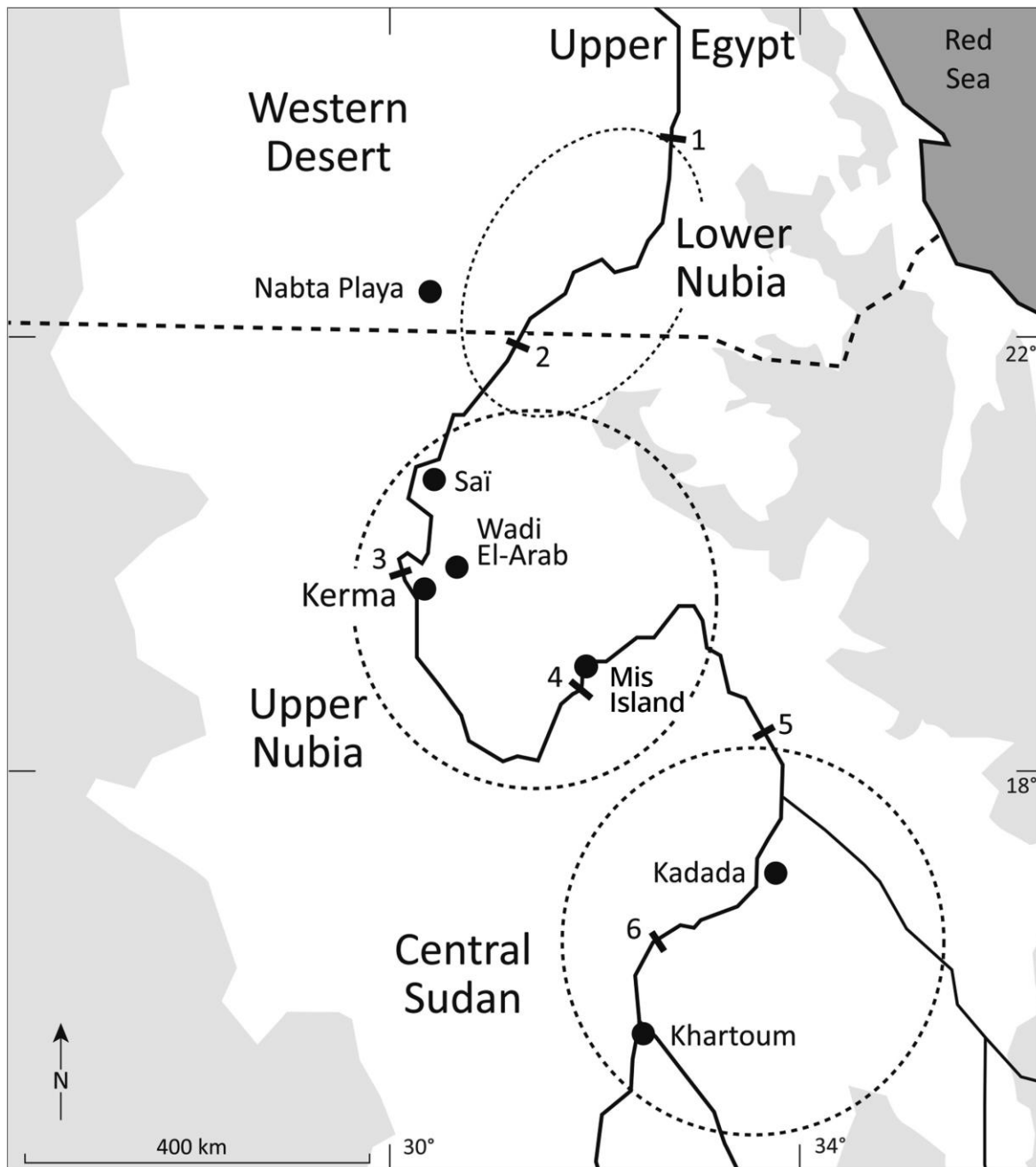


Figure 3-1. Map of Upper Nubia. Adapted from *Quaternary Science Reviews*, 130, Honegger, M., & Williams, M., Human occupations and environmental changes in the Nile valley during the Holocene: The case of Kerma in Upper Nubia (northern Sudan), 141-154, Copyright (2015), with permission from Elsevier. Edited by author to portray the approximate location of Mis Island along the Fourth Cataract.

Research on the MSU Nubian Collection was pioneered by Ginns (2007) and Soler (2012). Ginns (2007) published preliminary site reports on the Mis Island population. The analysis included multiple cemeteries along the Fourth Cataract of the Nile River, although the predominant focus was on Cemeteries 3-J-10 and 3-J-11. Based on these preliminary reports and excavation notes, Soler (2012) created biological profiles, including sex and age, for each individual, as well as inferences concerning the health, mortality, and life practices of this Nubian, Christian population. In Soler's study, sex was determined through a combination of features, such as the analysis of the pelvis, including the subpubic concavity, the ischiopubic ramus, ventral arc, subpubic angle, and the greater sciatic notch; cranial features were used to support these findings. All of the Nubian individuals have been categorized into male, probable male, indeterminate, probable female, or female. Adult age was determined through a combination of fused epiphyses, dental status, and degenerative changes throughout the skeletal remains, including the medial clavicle, iliac crest, pubic symphysis, and auricular surface.

Macromorphoscopic trait data for this sample were only collected from adult crania (≥ 20 years of age) to reduce variability from aging and age-related cranial development. Crania were excluded if they were too damaged to observe character states. Similar to the Proto-Modern and Modern samples (see below) used in this study, males and females in the Medieval Nubian Sample were pooled for analyses. Hefner (2003a) previously found no significant sex differences in macromorphoscopic trait expression, with the exception of post-bregmatic depression.

Proto-Modern African Sample

The Proto-Modern African (East and West Africa) sample consists of Native African individuals with birth years starting in the early 1800s. These individuals are housed at the

National Museum of Natural History (NMNH), Smithsonian Institution in Washington, DC. The sample comprises individuals from East and West Africa ($n = 30$), collected during the 1909 Smith African Expedition, and purchased by the Smithsonian Institution through the efforts of Frederick Muller & Co., Amsterdam, Holland in 1910 (Hefner, 2009).

Proto-Modern American Sample

The Proto-Modern American Black sample ($n = 262$) is a combined sample derived from the American Black samples in the Robert J. Terry Collection and the Hamann-Todd Collection (Hefner, 2009). The Terry Collection is originally from St. Louis, Missouri, as many of the skeletal specimens were obtained from the St. Louis hospital and institutional morgues (Hunt and Albanese, 2005). This collection has been important in anthropological studies, as documentation of each individual exists, consisting of morgue records listing the known age, sex, ethnic origin, cause of death and pathological conditions. The Terry Collection is now housed at the NMNH at the Smithsonian Institution. The Hamann-Todd Collection consists of specimens collected between 1912 and 1938. It is the world's largest documented collection of modern human skeletal remains, and also includes information relative to age, sex, ancestry, and pathology (Hunt and Albanese, 2005). The Hamann-Todd Collection is housed at the Cleveland Museum of Natural History. These two collections were used as they encompass individuals with birth years between the early 1800s and the mid-1900s.

Modern American Black Sample

The Modern American Black sample ($n = 115$) consists of modern American Black data for individuals with birth years from the 1950s to the 1970s. This sample material is from the

William M. Bass Donated Skeletal Collection in Knoxville, TN. This collection was established due to the University's body donation program to conduct research at the Anthropological Research Facility (Marks, 1995). Over 100 bodies are donated per year. As the collection is made up of modern donated cases, the William M. Bass Donated Skeletal Collection is representative of the current living population and has become a major source for studying modern Americans. Each set of remains is well documented with sex, age, ancestry, and health.

Table 3-1. Populations and Sample Sizes for Adult Crania Analyzed.

Population	Sample	Time Period	Sample Size (n)	Collection
Ancient Black	Medieval Nubia			
	3-J-10	1100-1500 AD	64	Michigan State University Nubian Bioarchaeology Laboratory
	3-J-11	300-1400 AD	120	
Proto-Modern African Black	EW Africa	1860s	30	National Museum of Natural History, Smithsonian Institution
Proto-Modern American Black	19th Century American Black	1800-1900s	262	Robert J. Terry Collection Hamann-Todd Collection
Modern American Black	20th Century American Black	1950s - present	115	William M. Bass Donated Skeletal Collection
Total			591	

Data Collection

Macromorphoscopic Traits

To explore macromorphoscopic trait variation among the four samples, 17 macromorphoscopic traits were collected from adult crania using the data entry program Macromorphoscopics (MMS) v. 1.6. Table 3-2 provides the seventeen traits as well as the abbreviations and expression score ranges used throughout the analysis.

Table 3-2. The 17 macromorphoscopic traits collected using MMS v.1.6.

Trait	Code	Score Range
Anterior Nasal Spine	ANS	1 - 3
Inferior Nasal Aperture	INA	1 - 5
Interorbital Breadth	IOB	1 - 3
Malar Tubercle	MT	0 - 3
Nasal Aperture Shape	NAS	1 - 3
Nasal Aperture Width	NAW	1 - 3
Nasal Bone Contour	NBC	0 - 4
Nasal Bone Shape	NBS	1 - 4
Nasofrontal Suture	NFS	1 - 4
Nasal Overgrowth	NO	0 - 1
Orbital Shape	OBS	1 - 3
Post-Bregmatic Depression	PBD	0 - 1
Posterior Zygomatic Tubercle	PZT	0 - 3
Supranasal Suture	SPS	0 - 2
Transverse Palatine Suture	TPS	1 - 4
Zygomaticomaxillary Suture	ZSC	0 - 2
Palate Shape	PS	1 - 4

The approximate location for each of these traits upon the cranium can be viewed in Figure 3-2 through Figure 3-4. These illustrations were obtained from Plemons and Hefner (2016).

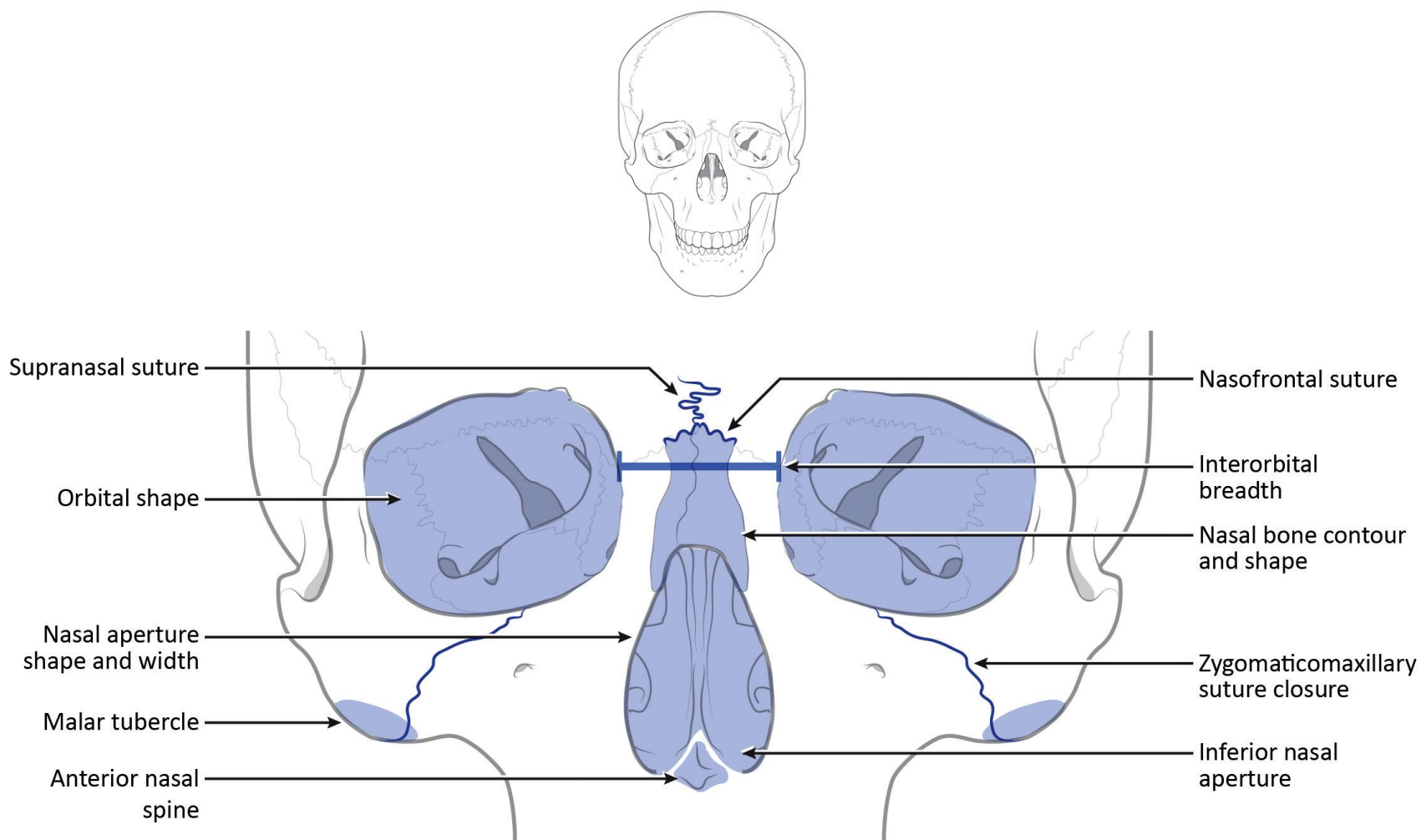


Figure 3-2. Anterior view of a cranium to demonstrate approximate location of macromorphoscopic traits. Obtained from Plemons and Hefner (2016). Reproduced with Permission of Academic Forensic Pathology International (AFPi). Image produced for AFPi under special contract with professional medical illustrator Diana Kryski.

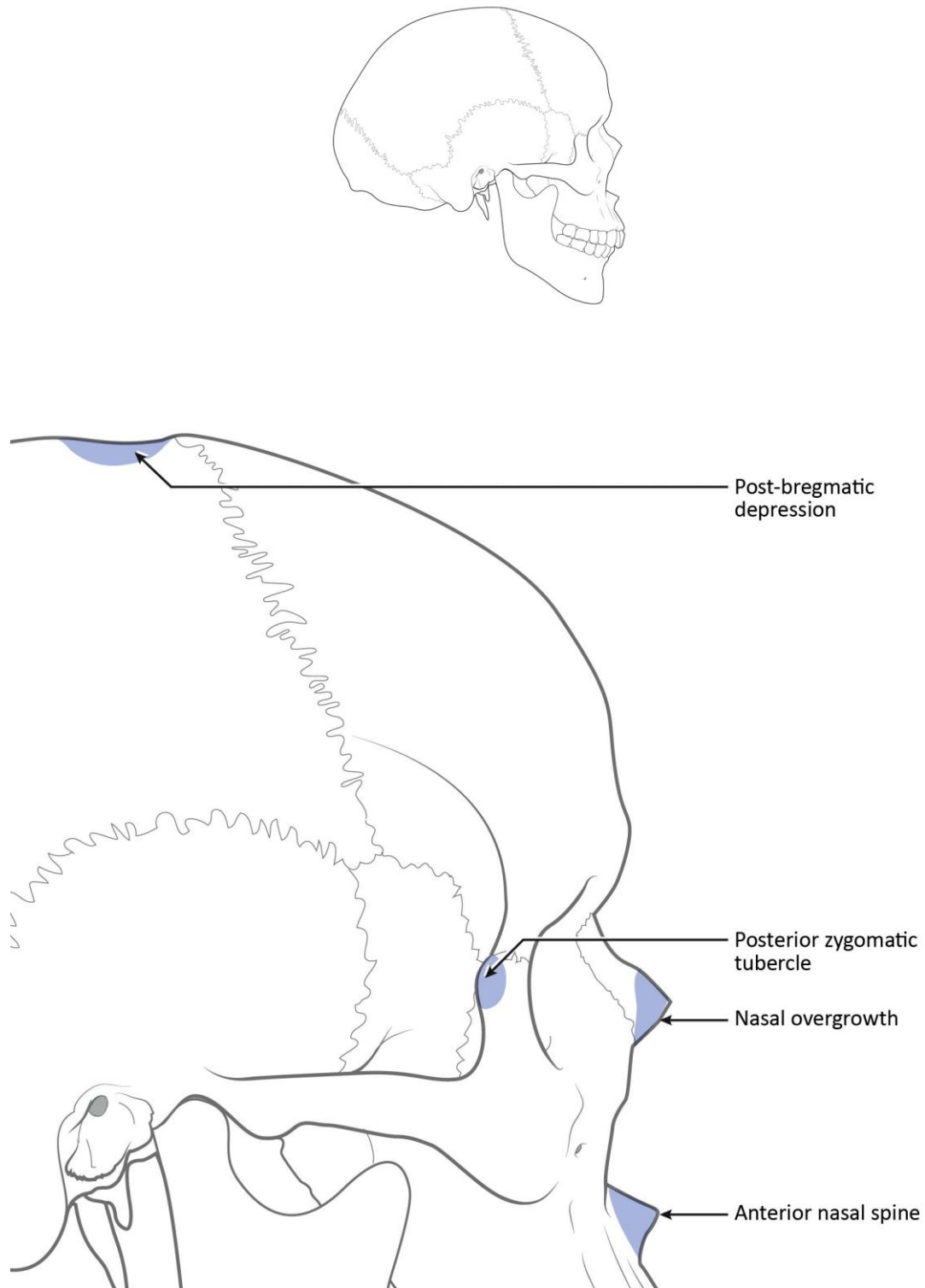


Figure 3-3. Lateral view of a cranium to demonstrate approximate location of macromorphoscopic traits. Obtained from Plemons and Hefner (2016). Reproduced with Permission of Academic Forensic Pathology International (AFPi). Image produced for AFPi under special contract with professional medical illustrator Diana Kryski.

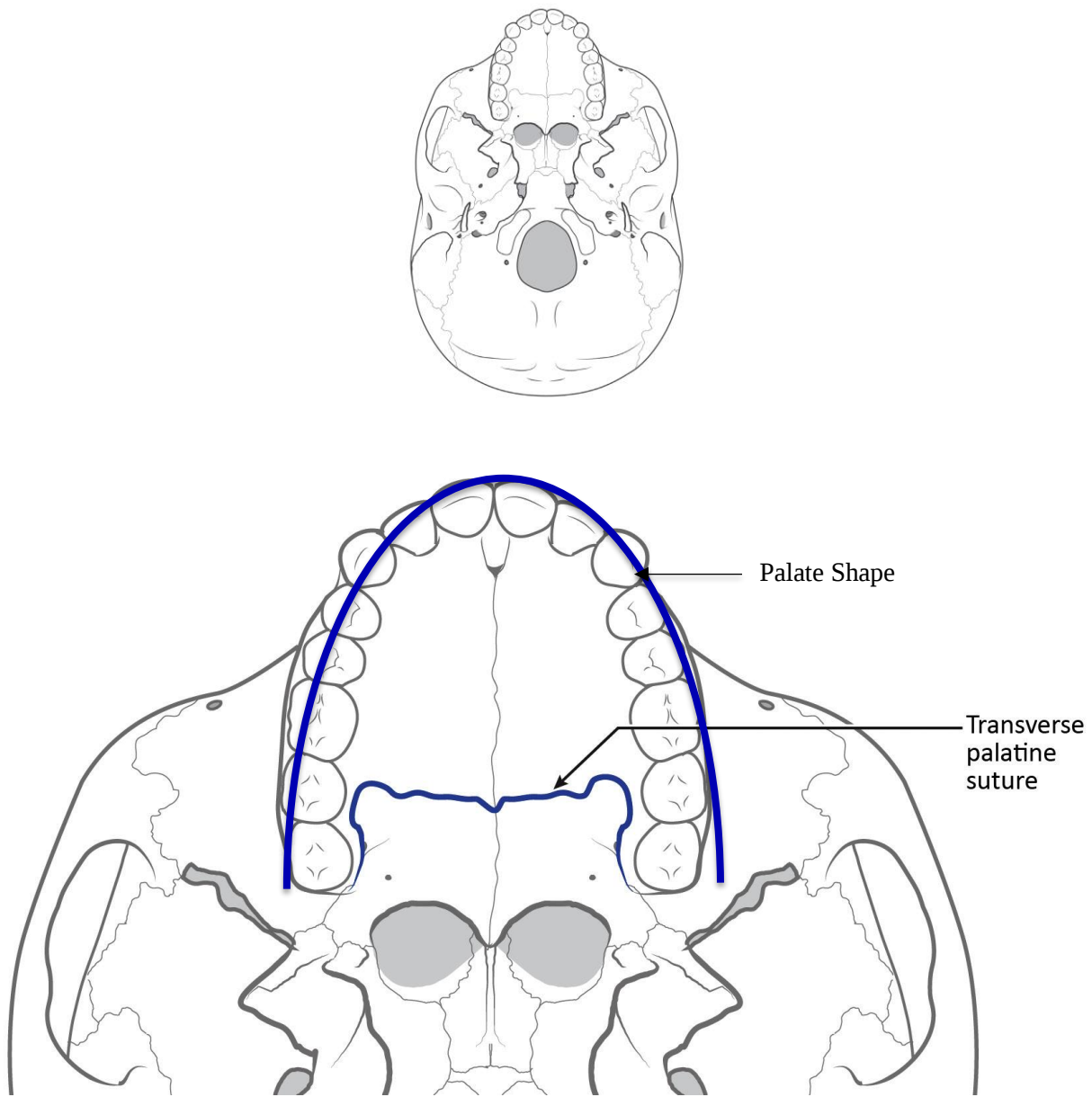


Figure 3-4. Inferior view of a cranium to demonstrate location of macromorphoscopic traits. Adapted from Plemons and Hefner (2016). Edited by author to include Palate Shape. Adapted with Permission of Academic Forensic Pathology International (AFPi). Image produced for AFPi under special contract with professional medical illustrator Diana Kryski.

Data for three of the samples were obtained from the MaMD (Hefner 2016). Therefore, discussion of MMS v.1.6 and data collection is specific to the Medieval Nubian sample. However, the methodology applies to all four samples as the author of this thesis was trained by Hefner prior to data collection.

The software program MMS v.1.6 was developed in 2015 using the previously-established Osteoware program (Osteoware, 2011) developed for the Repatriation Osteology Laboratory, Smithsonian Institution. MMS v.1.6 is still in a beta version, but will be made available to the public in the near future.

A catalogue number designates each box within the MSU Nubian Bioarchaeology Laboratory, and each box contains one set of adult remains. The catalogue numbers were used as the catkey in the MMS v.1.6 program for easy organization, as well as to separate cemeteries 3-J-10 and 3-J-11. All of the catalogue numbers begin with SK followed by a unique numeric identifier. Cemetery 3-J-10 ranges from SK1005 to SK5241; cemetery 3-J-11 ranges from SK1008 to SK3393. Organization for data collection was important as the SK catalogue numbers do not necessarily go in sequential order, and there is an overlap in SK numbers between the two cemeteries. In MMS v.1.6, the overlapped catalogue numbers were designated by an extra space between the SK and the number for cemetery 3-J-11, and the absence of a space for cemetery 3-J-10. The cemetery, sex, and age of each individual was also documented in the provided comment box in MMS v.1.6 to allow appropriate separation in Excel after data collection was complete.

For each cranium, all 17 macromorphoscopic traits were evaluated and scored. The MMS program, a screen-shot of which is provided below (Figure 3-5), provides a detailed definition of each trait, as well as a description of the individual character states and a line diagram of each

(Hefner, 2009). In addition to the MMS v.1.6 program, the author consulted Hefner (2009, 2012) and Wun (2014) for character state descriptions.

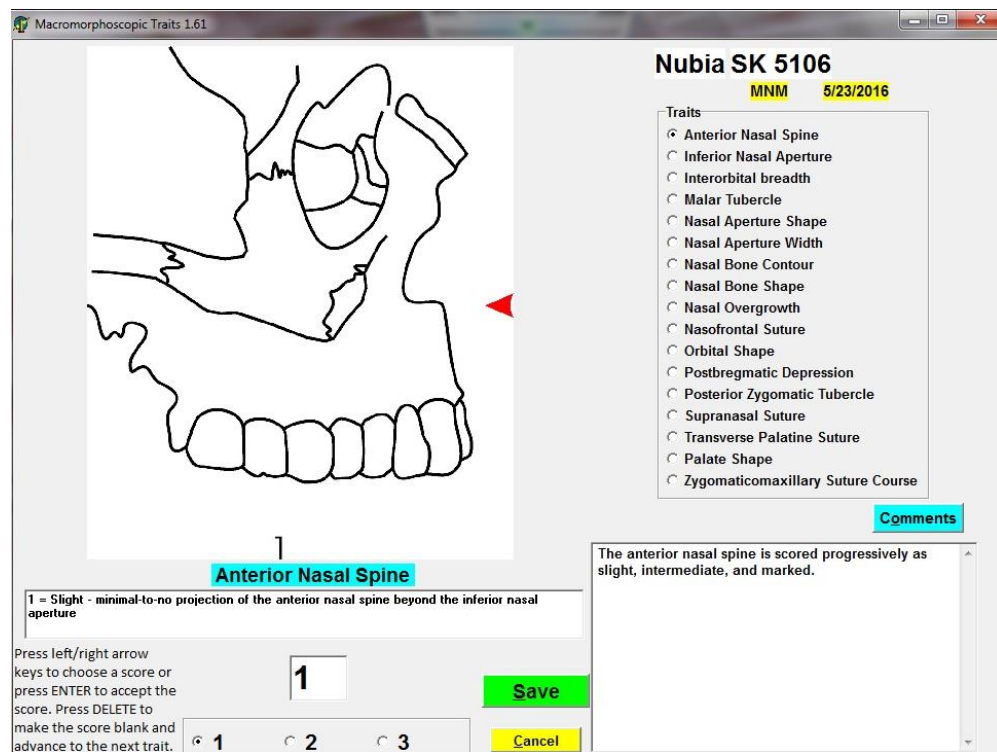


Figure 3-5. Screen-capture of the computer software Macromorphoscopic v.1.6.

Character states represent the various manifestations of each trait, and are scored either relative to the face, or on a gradient scale based on size and morphology. For example, the inferior nasal aperture is scored from 1 to 5, while the orbit shape from 1 to 3. Unobservable traits were not scored and, unless absent, the left side of the cranium was used for consistency. If the left side was absent or damaged, the right was used. Any type of anomalies and/or pathologies affecting the expression of a trait, and any traits that were unable to be scored due to missing or damaged elements were listed in the comments section of MMS. The score of each expressed character state was entered into the MMS program for each cranium. These scores were then exported to an Excel file for statistical analyses.

Each cranium was evaluated once to collect character state expression. However, twenty crania were randomly chosen and re-scored to assess intra-observer error. Random sampling was obtained through Excel.

Character States

The character states for the 17 macromorphoscopic traits included in this study (Table 3-2) are further described in Tables 3-3 through 3-19 below. Sixteen of the character states, line drawings, and descriptions are defined and described in Hefner (2009) as well as in the Macromorphoscopic Module chapter of the Osteoware Software Manual (Hefner, 2012; Osteoware, 2011). Palate shape was included as the seventeenth trait. Data collection and analysis of palate shape has, thus far, only been defined and described by Wun (2014). The trait definition and character states of palate shape were developed by Wun in collaboration with Dr. Joseph Hefner and Dr. Laurel Freas at the Joint POW/MIA Accounting Command Central Identification Laboratory (JPAC-CIL) (Wun, 2014), now the Defense POW/MIA Accounting Agency (DPAA).

Besides the use of the MMS v.1.6 program, the only tools used for analyses were: a contour gauge to determine and assign the appropriate shape of the nasal bone contour; and a ruler to help visualize and score the malar tubercle, the post-bregmatic depression, and the posterior zygomatic tubercle.

Table 3-3. Anterior Nasal Spine (ANS) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

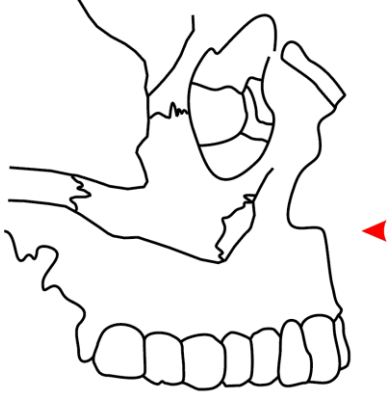
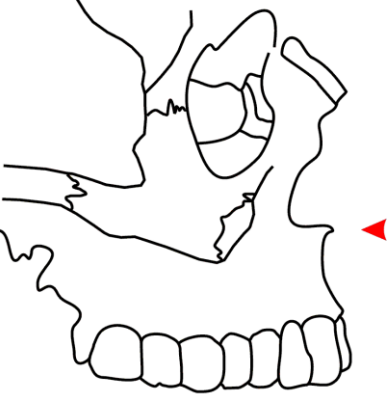
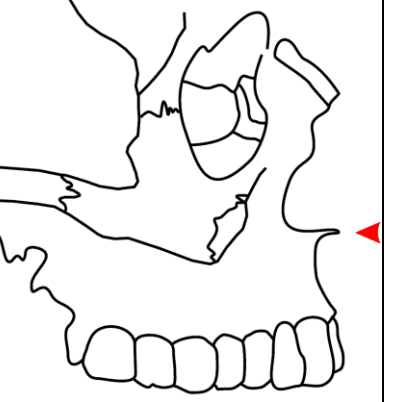
		
1. Slight: minimal-to-no projection of the ANS beyond the INA.	2. Intermediate: a moderate projection of the ANS beyond the INA.	3. Marked: a pronounced projection of the ANS beyond the INA.

Table 3-4. Inferior Nasal Aperture (INA) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

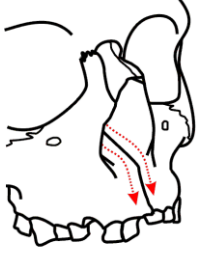
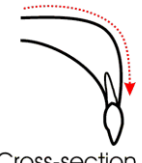
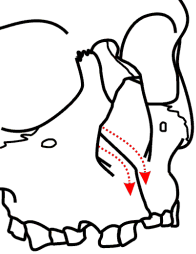
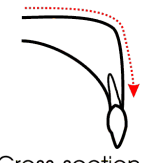
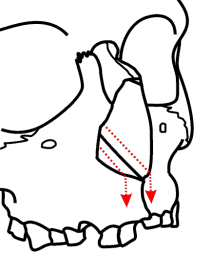
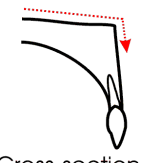
Oblique view  Cross-section 	Oblique view  Cross-section 	Oblique view  Cross-section 
1. Inferior sloping of the nasal floor which begins within the nasal cavity and terminates on the vertical surface of the maxilla, producing a smooth transition.	2. Sloping of the nasal aperture beginning more anteriorly than in INA 1, and with more angulation at the exit of the nasal opening.	3. Transition from nasal floor to the vertical maxilla is not sloping, nor is there an intervening projection, or sill. Generally, this morphology is a right angle, although a more blunted form may be observed.

Table 3-4. (cont'd).

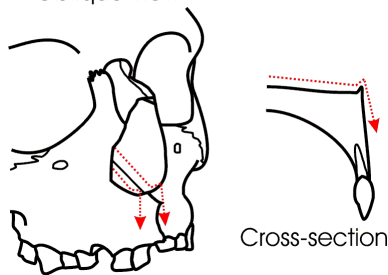
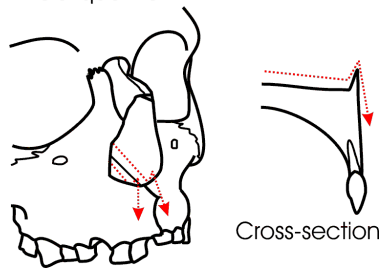
	
4. Any superior incline of the anterior nasal floor, creating a weak (but present) vertical ridge of bone that traverses the inferior nasal border (partial nasal sill).	5. A pronounced ridge (nasal sill) obstructing the nasal floor-to-maxilla transition

Table 3-5. Interorbital Breadth (IOB) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

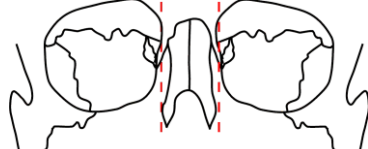
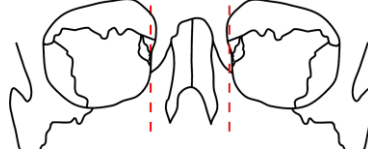
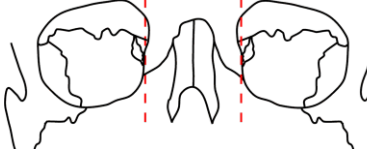
		
1. A narrow IOB.	2. A medium IOB.	3. A broad IOB.

Table 3-6. Malar Tubercle (MT) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

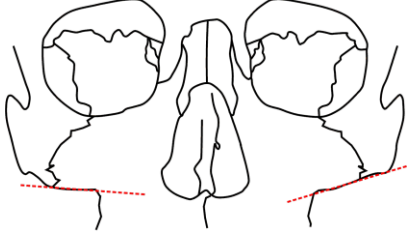
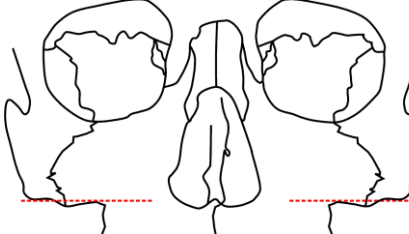
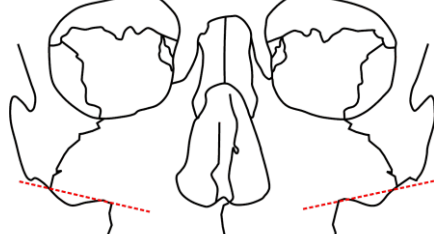
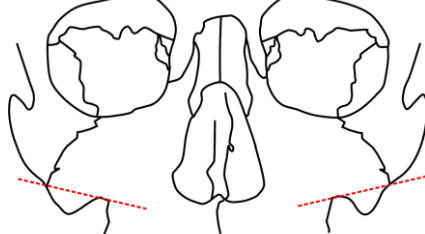
	
0. No projection of bone.	1. A trace tubercle below the ruler's edge (roughly 2 mm or less).
	
2. A medium protrusion below the ruler's edge (roughly 2-4 mm).	3. A pronounced tubercle below the ruler's edge (roughly 4 mm or more).

Table 3-7. Nasal Aperture Shape (NAS) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

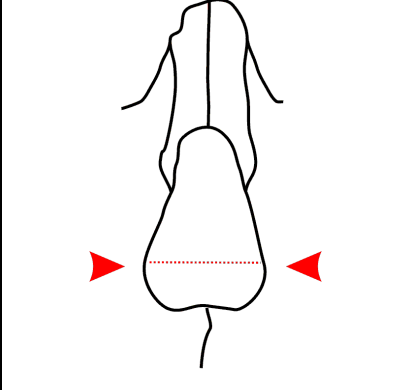
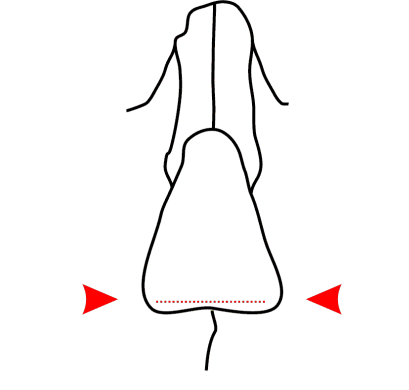
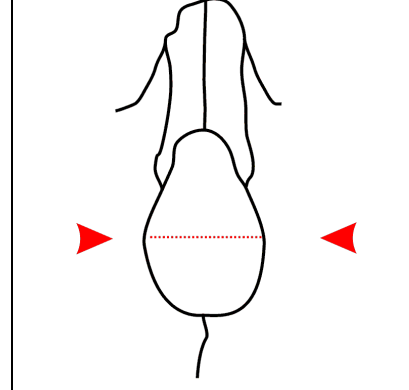
		
1. Teardrop, with lateral projection intermediate to 2 and 3.	2. Bell shape, with greatest lateral projection at the inferior margin.	3. Bowed, with greatest lateral projection at midline.

Table 3-8. Nasal Aperture Width (NAW) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

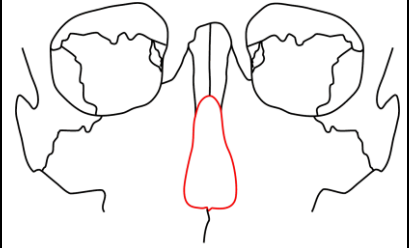
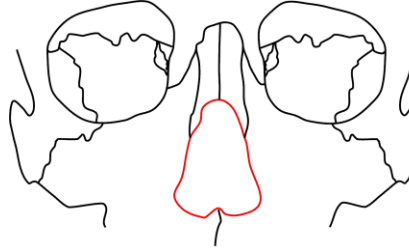
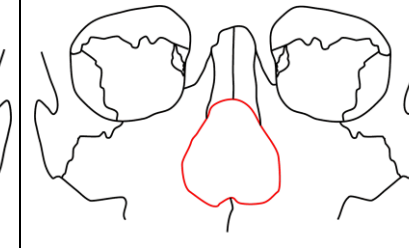
		
1. A narrow NAW.	2. A medium NAW.	3. A broad NAW.

Table 3-9. Nasal Bone Contour (NBC) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

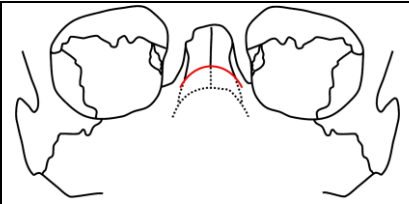
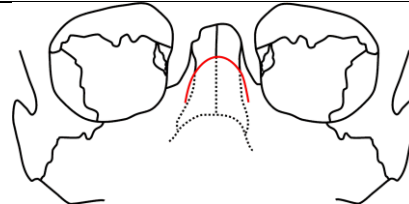
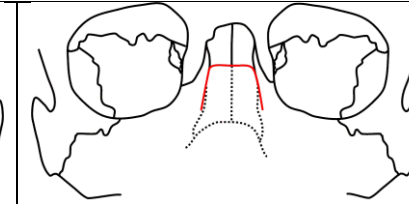
		
0. Low and rounded nasal bone contour.	1. An oval contour, with elongated, high, and rounded lateral walls.	2. Steep lateral walls and a broad (roughly 7 mm or more), flat superior surface "plateau," noted on the contour gage as a flat cluster of needles in the midline.

Table 3-9. (cont'd).

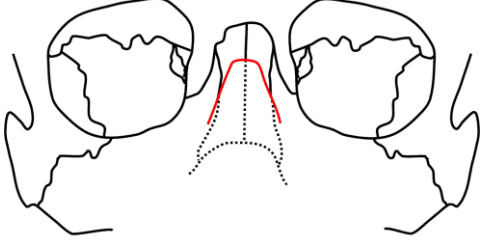
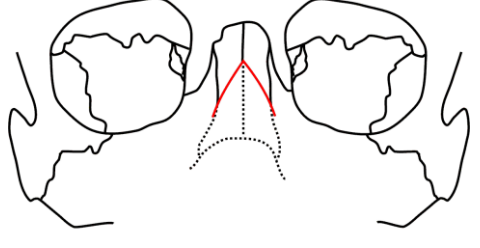
	
3. Steep-sided lateral walls and a narrow superior surface "plateau".	4. Triangular cross section, lacking a superior surface "plateau".

Table 3-10. Nasal Bone Shape (NBS) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

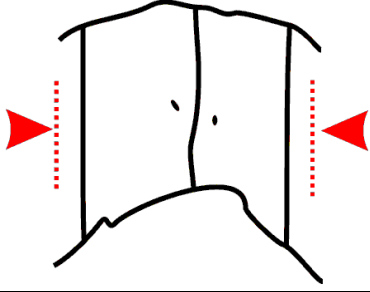
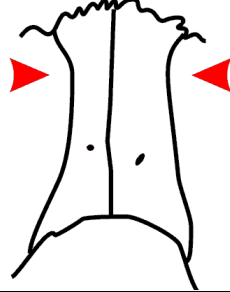
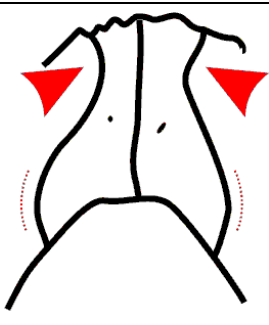
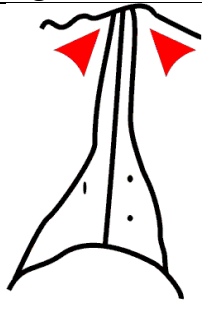
	
1. Nasal bones with no nasal pinch. The nasal bones may be wide or narrow.	2. Nasal bones with a superior pinch and minimal lateral bulging (note: to differentiate a score of 2 and 3, the amount of lateral bulging in the inferior region should be assessed).
	
3. Nasal bones with a superior pinch and pronounced lateral bulging of the inferior region (note: to differentiate between a scored of 2 and 3, the amount of lateral bulging in the inferior region should be observed).	4. Triangular-shaped nasal bones.

Table 3-11. Nasofrontal Suture (NFS) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

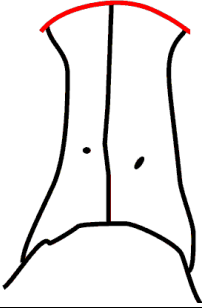
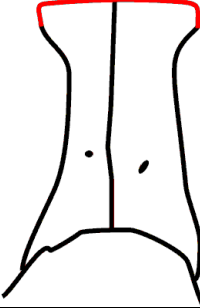
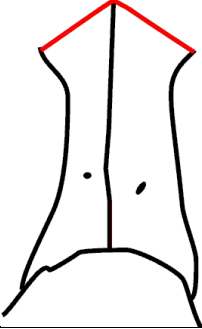
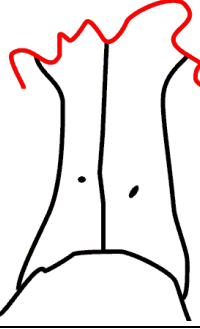
	
1. Nasofrontal suture is round and lacks angles.	2. Nasofrontal suture appears square (approximate right angles at <i>nasale superius</i>).
	
3. Nasofrontal suture appears triangular.	4. Nasofrontal suture is irregular, lacking any definitive shape.

Table 3-12. Nasal Overgrowth (NO) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

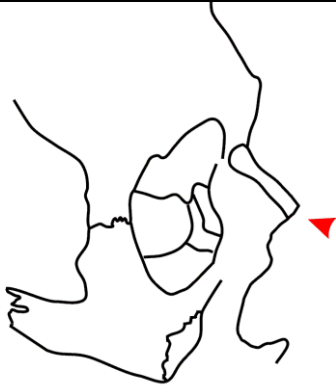
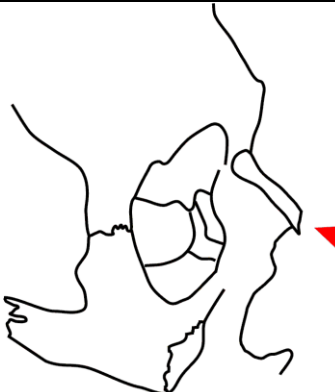
	
0. No overgrowth.	1. Any projection of the lateral border of the nasal bones (at <i>nasale inferius</i>) beyond the maxillary border.

Table 3-13. Orbital Shape (OBS) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

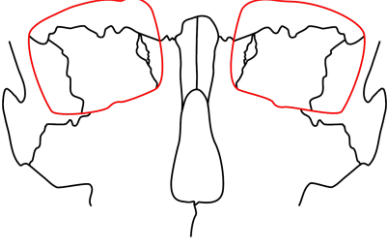
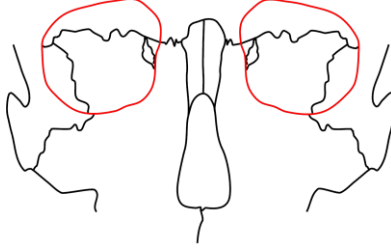
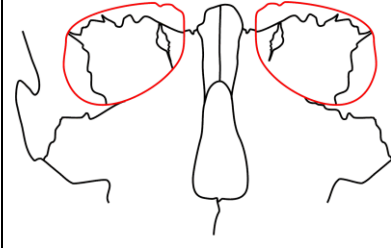
		
1. Rectangular - orbits with horizontal margins longer than the vertical margins, both otherwise parallel.	2. Circular - orbital margin is approximately equidistant from center on all sides.	3. Rhombic - medial border height is shorter than lateral border height.

Table 3-14. Post-Bregmatic Depression (PBD) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

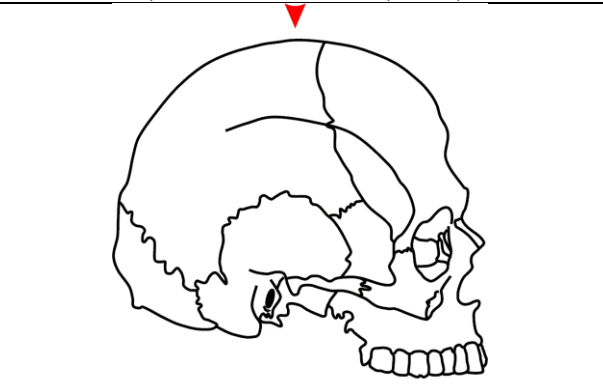
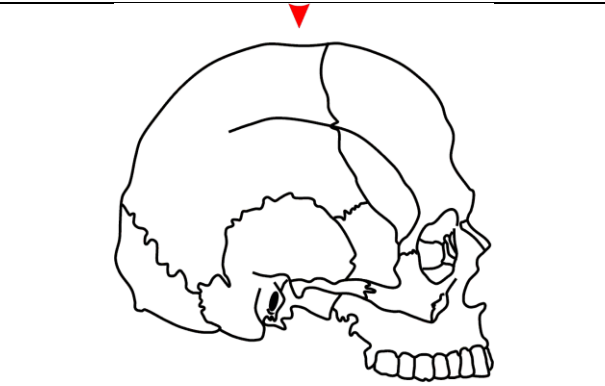
	
0. No depression present.	1. A marked depressed area posterior to bregma along the mid-sagittal plane.

Table 3-15. Posterior Zygomatic Tubercle (PZT) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

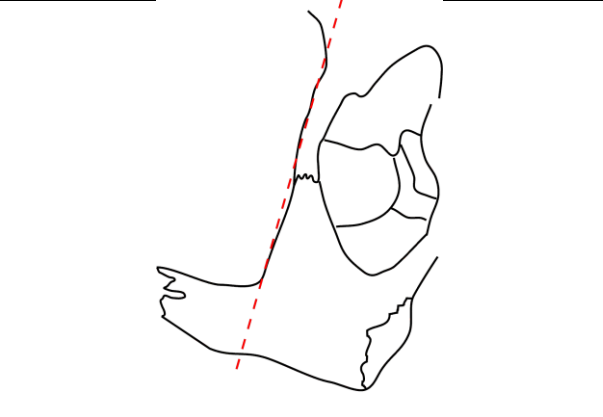
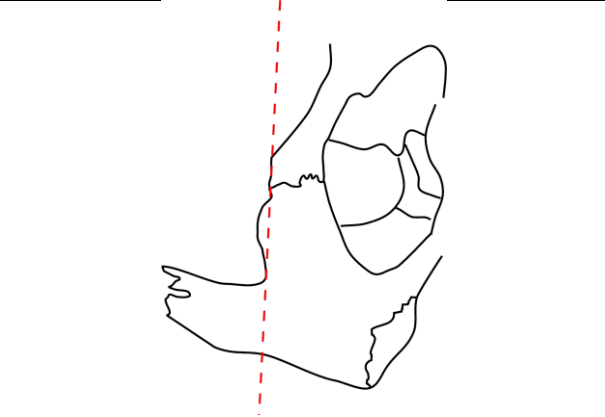
	
0. No projection of bone.	1. A weak projection of bone (< 4 mm).

Table 3-15. (cont'd).

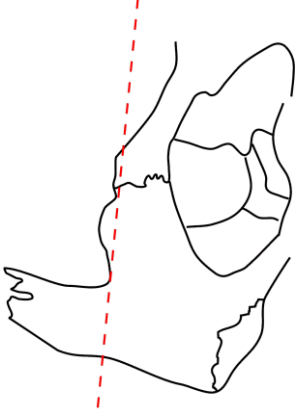
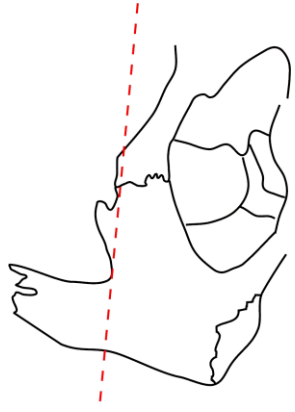
	
2. A moderate projection of bone (approximately 4 to 6 mm).	3. A marked projection of bone (generally >6 mm).

Table 3-16. Supranasal Suture (SPS) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

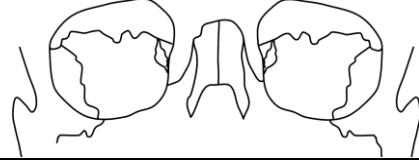
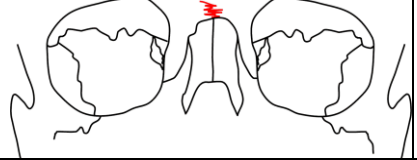
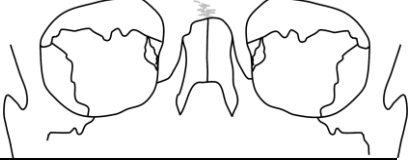
		
0. Obliterated.	1. Open (unfused).	2. Closed (but visible).

Table 3-17. Transverse Palatine Suture (TPS) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

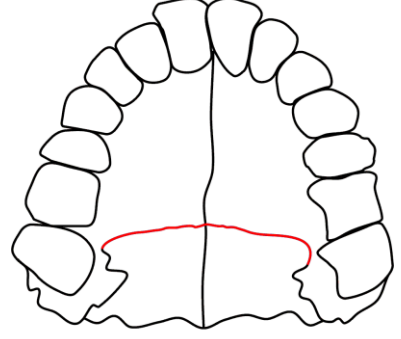
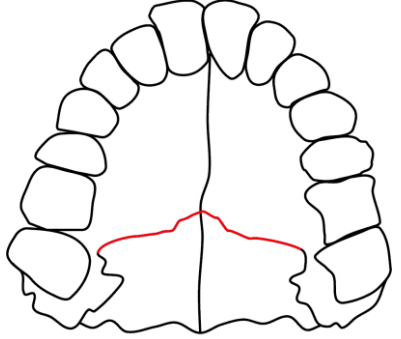
	
1. The suture crosses the palate perpendicular to the median palatine suture, with no significant anterior or posterior deviations. If the right and left halves of the suture do not contact each other at midline, but the suture is otherwise straight, score the suture 1.	2. The suture crosses the palate perpendicular to the median palatine suture, but near this juncture a significant anterior deviation, or bulging, is present.

Table 3-17. (cont'd).

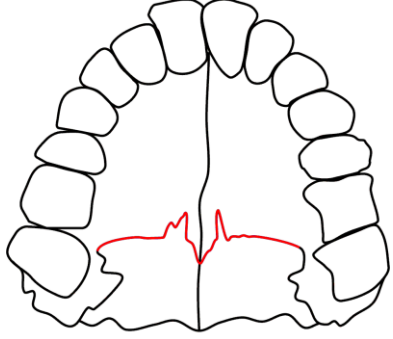
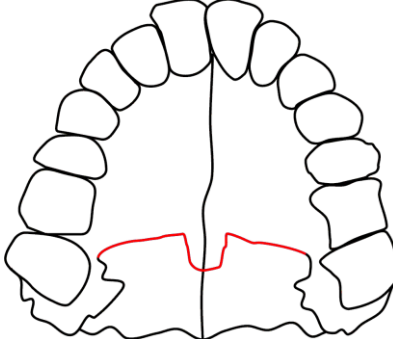
	
3. The suture crosses the palate, but deviates anteriorly and posteriorly (e.g. M-shape) in the region of the median palatine suture.	4. The suture crosses the palate perpendicular to the median palatine suture, but near this juncture a posterior deviation, or bulging, is present.

Table 3-18. Zygomaticomaxillary Suture (ZSC) character states. Restructured from Hefner (2009, 2012) and Osteoware (2011).

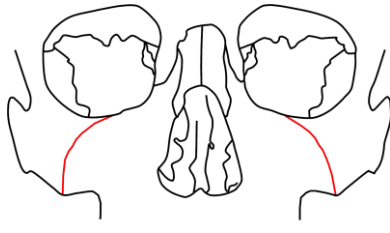
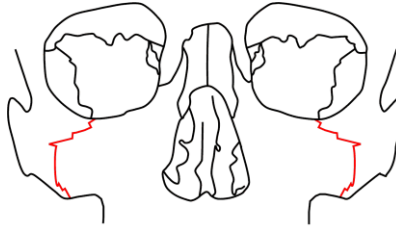
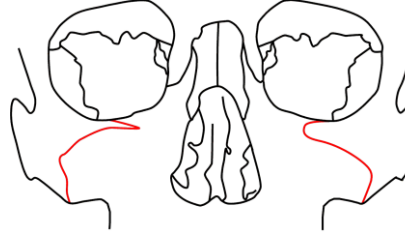
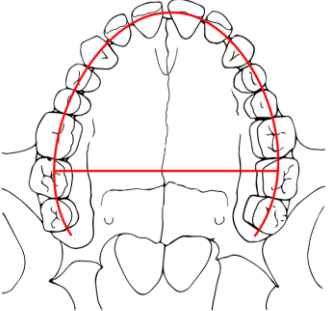
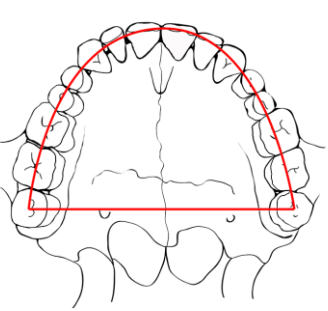
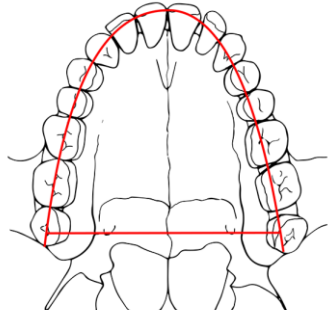
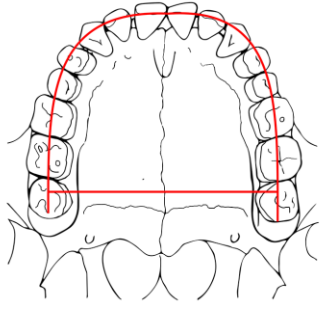
		
0. A suture with no angles and greatest lateral projection at the inferior margin of the malar (note: sutures having greatest lateral projection at the inferior margin, but a slight angle near the midpoint of the suture should be scored as 0).	1. A suture with one angle and greatest lateral projection near the midline.	2. A suture with two or more angles (presenting a jagged and/or S-shaped appearance) with variable greatest lateral projection.

Table 3-19. Palate Shape (PS) character states. Restructured from Hefner (2009, 2012), Osteoware (2011), and Wun (2014).

	
1. Elliptic - Smooth, round curvature of the anterior portion of the palate combined with a mid-arch (ca. M1 and M2) widening relative to M3, contributing to the appearance of constricted (medially-positioned) 3rd molars.	2. Parabolic A - Smooth, rounded curvature of the anterior portion of the palate, combined with an even, gradual flaring of the posterior dentition.
	
3. Parabolic B - Also a smooth, rounded curvature of the anterior portion of the palate, but combined with an even, gradual flaring the posterior dentition. The only distinction is the longer relative length to breadth ratio in Form B.	4. Hyperbolic - Smooth, slightly flattened curvature of the anterior portion of the palate, combined with a straight, more-or-less parallel configuration of the posterior portion of the arch.

Statistical Analyses

Four statistical tests were conducted to assess variation within and between the four populations. These tests included: frequency distribution data of the Nubian crania to determine the range in variation of the traits; correlation coefficients to estimate the relationship between traits within each group; correspondence analysis (CA) to assess the associations and patterns of variation between character states; and, a canonical analysis of the principal coordinates (CAP) to estimate relationships between the samples. The CAP analysis incorporates various steps, including a principal coordinate analysis (PCO) to assess similarities and dissimilarities in the derived distance matrices using the chi-square distance metric. The totality of these analyses facilitates the overall assessment of secular changes between these four populations. Lastly, Cohen's kappa was used to assess intra-observer error.

Two statistical software programs were used to complete the analysis: *R* 3.3.1 and *Statistica* 7.0. *R* provides a variety of separate installable software facilities for data manipulation, calculations, and graphical and plot display. For this analysis, multiple packages were used and the majority of the work was performed in RStudio. *Statistica* was used for the various stages of the CAP analysis.

Frequency Distribution for Nubian Sample

Frequencies of the character states for each trait within the Nubian collection were examined in order to determine the percentage and range in variation of each trait expressed. Comparison through frequency distribution also eliminates blanket statements or expectations concerning the traits within a particular group. For instance, past methodologies of non-metric skull racing has relied on lists of principal traits expected for certain racial attributions (Rhine,

1990). Within his lists, Rhine included the presence of post-bregmatic depression for the cranial identification of American Blacks. However, Hefner (2009) found that less than half (47.2%) of individuals of African ancestry express post-bregmatic depression.

Frequency distribution tables were created for the Nubian sample using *R* 3.3.1. These two-way cross-tabulation tables were created for comparison with the trait frequencies between males and females. Chi-squared goodness-of-fit (χ^2) analyses were also performed to determine if there was a statistically significant ($p < 0.05$) difference between the traits. Frequency distributions for the EW African, 19th century American Black, and Modern American Black samples were formerly collected and published by Hefner (2009). However, Hefner (2009) only performed frequency distribution for 11 traits—ANS, INA, IOB, MT, NAW, NBS, NO, PBD, SPS, TPS, ZS—rather than the 17 used in this study.

Correlation Coefficients for Nubian Sample

Correlation coefficients were calculated to estimate the relationship among the 17 macromorphoscopic traits. Spearman correlation coefficients examined trait associations and tests for trait independence. A correlation plot was also created in *R* 3.3.1 using the *corrplot* package to view these relationships.

While frequency distribution analysis and correlation coefficients were primarily performed for the Nubian sample, the remainder of the statistical tests was performed in conjunction with data from the MaMD (Hefner 2016).

Correspondence Analysis (CA) for All Samples

Correspondence analysis is an exploratory computational method to assess the associations and patterns of variation between states of categorical variability (Greenacre, 2017). It generates independent axes within a plane from the rows and columns of a data matrix. Points within the rows and columns are plotted in a corresponding two-dimensional graphical presentation, also known as perceptual maps (Van de Velden and Takane, 2012; Gower et al., 2010). The results of correspondence analysis, which can be visual or analytical, reveal interdependencies between two variables in a distance matrix (Greenacre, 2006, 2017). Based on frequency distribution, the trait expression scores of individuals or the mean scores of sample groups may be plotted along these axes. This is similar to Pearson's approach to principal components analysis (Pearson, 1901). Pearson stated his approach in terms of finding the "lines and planes of closest fit to systems of points" in Euclidean space (Greenacre, 2006; Pearson, 1901). Therefore, in this study, the points in corresponding multidimensional space represent the frequencies of numeric values for each macromorphoscopic trait character state within the four samples.

Correspondence analyses were performed in *R* 3.3.1 for each macromorphoscopic trait separately. For each trait, cross tabulation tables of trait frequencies within the four samples were calculated to create a table of relative frequencies representing the distance between individual columns and rows. The rows within the matrices represent the character states, and the columns are the four samples in the study. For each macromorphoscopic trait, two plots were created: a symmetrical joint biplot and an asymmetric contribution biplot. Joint display biplots of the row and column profiles were derived from cross tabulation or contingency table data. The biplots are two-dimensional solutions that were obtained by determining the closest plane to the points

in terms of weighted least squares, and then projecting those points onto the plane for visualization (Greenacre, 2006, 2017). Therefore, the dimensionality of the matrix representing trait frequency in terms of population sample was reduced in order to visualize the space in low dimensionality.

In order to properly interpret the symmetric and asymmetric biplots, it is important to understand their structures. The biplots consist of two dimensions. Each dimension (denoted by the axes) of the plot represents a certain percentage of the data variation, otherwise known as inertia. The majority of the inertia scores (explained variation) are typically shown in the first two dimensions (the x and y axes) of the biplot. For analysis, groups that fall closer to one another on the biplots of axes have a greater similarity in their pattern of character state frequency. In contrast, groups that fall farther away from each other on the biplot have lesser similarities in their frequency patterns (Ratliff, 2012; Yelland, 2010). This distance is most easily seen using the symmetric biplots.

The asymmetric joint biplots present additional information as the contribution of each sample to the character state variation is displayed. The character states, which are the principal coordinates, are represented by points while the samples, which are the standard coordinates, are depicted as vectors (arrows drawn from the origin of the map). The distance of the character state points from the centroid are related to the contribution of the sample to that inertia dimension. Points closer to the centroid and the dimensional axis provide a greater contribution to the inertia, while points farther away contribute less. Similarly, the vector lines are closest, in terms of angular distance, to the dimension axis to which they have a higher contribution. Longer vectors have a higher contribution than shorter vectors.

In the asymmetric biplots, color also plays an important role. The character state points vary in size and shade of color in order to illustrate frequency. The larger and darker the point, the more frequently that particular character state was scored. Faint points represent a character state that has been less frequently scored. These points are closest to the vectors that more frequently included this character state score. The vector line color intensity is proportional to the absolute contribution to the total inertia. Darker colors are indicative of a high contribution to the inertia, while a lighter color represents low contribution.

This assessment of similarities and dissimilarities in distance matrices allows a view of the relationships between samples, between character state scores, and between the samples and their most represented character state. This allows a small degree of interpretation for secular change for each individual trait and sample.

Canonical Analysis of the Principal Coordinates (CAP) for All Samples

A canonical analysis of the principal coordinates was performed to estimate relationships between sample groups, to infer levels of secular change, and to determine correspondence between character state manifestations and the population samples. The CAP analyses were performed using *Statistica 7.0*.

A useful technique due to its ability to analyze several sets of data simultaneously; canonical correlation analysis and similar approaches have been the topic of several early studies (Hotelling, 1936; Horst, 1961; Carroll, 1968, Kettenring, 1971). However, Legendre and Legendre (1998) first used canonical discriminant analysis performed on the transformed values of the principal coordinates. Legendre and Legendre (1998: 575) used canonical analysis for numerical ecological studies and defined canonical analysis as “the simultaneous analysis of two,

or eventually several data tables....[It] allows ecologists to perform a *direct comparison* of two data matrices”. They compared this methodology to cluster analysis when clustered results are constrained in order to be consistent with temporal or spatial relationships. Legendre and Legendre pointed out that constrained (ordination) results would be more readily interpretable than the results of unconstrained analysis. This is because clustered results, or the canonical form, are the most comprehensive and simplistic patterns, expressed as a reduced form without the loss of generality.

The CAP method was later advocated and implemented by Anderson (2004) and Anderson and Willis (2003), also for numerical ecological studies (Hefner, 2007, 2016). Anderson and Willis (2003) noted that while Legendre and Legendre (1998) hinted about canonical analysis on the axes obtained from principal coordinate data, they never discussed the advantages of this or examples of how this would be applicable. Anderson and Willis (2003) coined the term “canonical analysis of the principal coordinates” and described it as a flexible constrained ordination method that allows any distance or dissimilarity measure to be used. This means that categorical variables may be transformed (in a sense) into continuous, normally distributed variables useful for identifying patterns in the data in multivariate space.

While the above articles were specific to ecology, Hefner (2007, 2016) indicated that the CAP method offers several advantageous and effective qualities for forensic and biological anthropologists, particularly for classifying and viewing patterns of macromorphoscopic trait data. Hefner (2007, 2016) depicts the CAP method as advantageous due to three factors. The first is that the CAP method is highly flexible, as several distance or dissimilarity measures—such as Euclidean distance and chi-squared distance—may be selected for analysis. Second, the CAP method accounts for correlations within the data. Variables within the data are not automatically

assumed to be independent. Therefore, complex relationships and patterns, such as a combination of group membership, cranial nonmetric traits, and environmental and genetic factors may be better viewed and interpreted. Lastly, unknown individuals can be assigned to a group through a “generalized discriminant analysis based on distances” (Anderson and Robinson, 2003; Hefner, 2007). As categorical variables are transformed into principal coordinates, they can be viewed as continuous. This is useful to forensic anthropologists when dealing with ancestry identification for unknown skeletons using continuous or quasi-continuous structures of a categorical scale (Hefner, 2007).

In this thesis, the CAP method was used to identify patterns in trait expression among the four sample groups. Nonmetric trait response variables were converted to continuous variables, meaning that the variables were converted to a metric measure of similarity and dissimilarity. Through this test, character states that contribute most to overall variance within the samples may be determined. These continuous variables were then converted into principal coordinates for each of the four sample populations, displayed in a distance matrix. The principal coordinates were arranged into a two-dimensional space, allowing this multi-dimension dataset to be portrayed as a single point for each population sample. Therefore, the resulting canonical analysis plot for the four samples is displayed through four points in space.

Similar to correspondence analysis, the canonical plot is a two-dimensional representation of the data in multivariate space. The axes represent the explained variance between the sample groups based on derived factors. The majority of the variance should be explained by the first axis. Also similar to correspondence, samples that fall closer to one another on the canonical plot of axes have a greater similarity in their pattern of character state expression. In contrast, samples that fall farther away from each other on the canonical plot have

lesser similarities in their expression patterns. As group mean scores for character state expression determine the plot, interpretation for secular change between samples is allowed based on overall variation.

Intra-Observer Error

The last statistical test performed was intra-observer error analysis. The macromorphoscopic traits were scored a second time for twenty crania from Nubian cemeteries 3-J-10 and 3-J-11. Intra-observer variability was assessed using Cohen's kappa statistic with quadratic weighting (Cohen, 1960; Cohen, 1968). Cohen's kappa measures the agreement between two observations, while also taking into account the probability that an agreement occurred by chance. Kappa is the proportion of agreement corrected for chance and is scaled to vary from -1 to +1.

Therefore, values closer to zero indicate poor agreement, while higher values (absolute) indicate good agreement. Perfect agreement would be equivalent to a kappa value of 1 (or -1). Cohen's kappa with quadratic weighting is a modification to Cohen's kappa and is calculated using a predefined table of weights that measure the degree of disagreement (Cohen, 1968). The higher the disagreement in the table, the higher the weight applied. Therefore, when using the character states of ANS as an example, a higher weight is applied between character states 1 and 3, than between 1 and 2 or between 2 and 3. The table of weights (w_i) is a symmetric matrix with zeros in the diagonal where there is agreement. Positive numbers are off this main diagonal. Cohen's kappa with quadratic weighting is calculated by:

$$w_i = \frac{1 - i^2}{(k - 1)^2}$$

where i is the difference between categories and k is the total number of categories.

The interpretation of Cohen's kappa has been debated with no set standard on what constitutes good or poor levels of agreement (Hefner, 2007). However, Landis and Koch's (1977) significance values are commonly used interpretations (Table 3-20), and were used for intra-observer error analysis for this thesis. Cohen's kappa was utilized for this study due to its simplicity and availability.

Table 3-20. Kappa Statistic Significance (Landis and Koch, 1977).

Kappa Statistic	Strength of Agreement
< 0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost Perfect

CHAPTER 4
RESULTS: STATISTICAL DETERMINATION OF SECULAR CHANGE

Trait Frequency Distribution

Trait frequency distributions were calculated by applying cross-tabulations using R 3.3.1. The frequency distributions for each of the 17 macromorphoscopic traits are displayed below for the Medieval Nubian sample (Table 4-1). Sex differences were statistically insignificant ($p > 0.05$), with the exception of nasal bone contour, nasal overgrowth, and supranasal suture.

Table 4-1. Frequency distribution of macromorphoscopic traits in Nubian sample (n = 184).

Character State											
Anterior Nasal Spine	1		2		3						
	n	%	n	%	n	%	N				
Male	22	40.7	31	57.4	1	1.9	54				
Female	23	43.4	30	56.6	0	0.0	53				
Inferior Nasal Aperture	1		2		3		4		5		
	n	%	n	%	n	%	n	%	n	%	N
Male	5	6.0	57	68.7	18	21.7	3	3.6	0	0.0	83
Female	9	10.6	49	57.6	24	28.2	3	3.5	0	0.0	85
Interorbital Breadth	1		2		3						
	n	%	n	%	n	%	N				
Male	2	3.5	45	78.9	10	17.5	57				
Female	2	3.3	45	75	13	21.7	60				
Malar Tubercle	0		1		2		3				
	n	%	n	%	n	%	n	%	N		
Male	21	28	40	53.3	13	17.3	1	1.3	75		
Female	27	35.5	39	51.3	10	13.2	0	0.0	76		
Nasal Aperture Shape	1		2		3						
	n	%	n	%	n	%	N				
Male	58	69.0	5	6.0	21	25.0	84				
Female	51	63.8	10	12.5	19	23.8	80				

Statistically significant differences in trait expression are denoted by (*) and accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test.

Table 4-1. (cont'd).

Nasal Aperture Width	1		2		3						
	n	%	n	%	n	%	N				
Male	14	20.9	50	74.6	3	4.5	67				
Female	8	12.3	49	75.4	8	12.3	65				
Nasal Bone Contour *	0		1		2		3		4		
	n	%	n	%	n	%	n	%	n	%	N
Male	17	37.8	22	48.9	4	8.9	1	2.2	1	2.2	45
Female	30	68.2	8	18.2	2	4.5	1	2.3	3	6.8	44
Nasal Bone Shape	1		2		3		4				
	n	%	n	%	n	%	n	%	N		
Male	10	19.6	39	76.5	1	2.0	1	2.0	51		
Female	18	32.1	37	66.1	0	0.0	1	1.8	56		
Nasofrontal Suture	1		2		3		4				
	n	%	n	%	n	%	n	%	N		
Male	29	43.9	25	37.9	0	0.0	12	18.2	66		
Female	23	33.8	20	29.4	2	2.9	23	33.8	68		
Nasal Overgrowth *	0				1						
	n		%		n		%		N		
Male	9		28.1		23		71.9		32		
Female	22		61.1		14		38.9		36		
Orbital Shape	1		2		3						
	n	%	n	%	n	%	N				
Male	51	72.9	16	22.9	3	4.3	70				
Female	46	63.9	19	26.4	7	9.7	72				
Post-Bregmatic Depression	0				1						
	n		%		n		%		N		
Male	34		54.8		28		45.2		62		
Female	37		58.7		26		41.3		63		
Posterior Zygomatic Tubercle	0		1		2		3				
	n	%	n	%	n	%	n	%	N		
Male	5	6.2	33	40.7	34	42	9	11.1	81		
Female	8	9.8	43	52.4	21	25.6	10	12.2	82		

Statistically significant differences in trait expression are denoted by (*) and accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test.

Table 4-1. (cont'd).

Supranasal Suture *	0		1		2				
	n	%	n	%	n	%	N		
Male	1	1.3	12	15.0	67	83.8	80		
Female	10	12.0	3	3.6	70	84.3	83		
Transverse Palatine Suture	1		2		3		4		
	n	%	n	%	n	%	n	%	N
Male	7	13.5	25	48.1	18	34.6	2	3.8	52
Female	8	14.8	30	55.6	13	24.1	3	5.6	54
Zygomaticomaxillary Suture	0		1		2				
	n	%	n	%	n	%	N		
Male	32	43.2	32	43.2	10	13.5	74		
Female	30	40.5	30	40.5	14	18.9	74		
Palate Shape	1		2		3		4		
	n	%	n	%	n	%	n	%	N
Male	6	8.7	22	31.9	36	52.2	5	7.2	69
Female	10	14.9	18	26.9	37	55.2	2	3.0	67

Statistically significant differences in trait expression are denoted by (*) and accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test.

Correlation Coefficients

To estimate the relationship among the 17 macromorphoscopic traits for the Nubian sample, Spearman correlation coefficients were conducted in R 3.3.1. Based on the table data provided below (Table 4-2), a correlation plot was constructed (Figure 4-1).

Significant correlation results were viewed in the following trait relationships: anterior nasal spine with inferior nasal aperture ($r = 0.320$) and nasal aperture width ($r = -0.226$); inferior nasal aperture with interorbital breadth ($r = 0.089$), supranasal suture ($r = -0.073$), transverse palatine suture ($r = 0.002$), and zygomaticomaxillary suture ($r = -0.001$); nasal overgrowth with nasofrontal suture ($r = -0.356$); nasal bone contour with nasal bone shape ($r = 0.294$), and postbregmatic depression with SPS ($r = -0.199$).

Table 4-2. Correlation coefficients for Nubian sample.

	ANS	INA	IOB	MT	NO	NAS	NAW	NBC	NBS	NFS	OBS	PBD	PZT	SPS	TPS	ZSC
ANS	—															
INA	0.32*	—														
IOB	-0.01	0.09*	—													
MT	0.07	-0.03	0.22	—												
NO	0.06	0.22	0.10	-0.04	—											
NAS	0.09	0.11	-0.08	0.06	0.05	—										
NAW	-0.23*	-0.13	0.11	-0.05	-0.10	0.02	—									
NBC	0.15	0.01	-0.13	0.17	0.08	-0.08	-0.16	—								
NBS	0.18	0.13	0.07	0.00	-0.06	-0.10	-0.05	0.29*	—							
NFS	-0.03	-0.05	0.01	0.12	-0.36*	-0.07	-0.05	-0.07	-0.03	—						
OBS	-0.16	0.00	-0.08	0.07	-0.23	-0.08	-0.01	0.00	0.04	0.02	—					
PBD	-0.08	-0.04	-0.06	-0.09	-0.06	-0.09	0.01	-0.09	0.06	-0.08	0.07	—				
PZT	-0.03	-0.07	0.07	0.06	-0.06	-0.09	0.03	-0.08	-0.07	0.11	-0.03	0.00	—			
SPS	-0.06	-0.07*	0.18	-0.03	0.06	0.02	0.05	0.09	-0.05	-0.04	0.09	-0.20*	-0.10	—		
TPS	-0.06	0.00*	-0.30	-0.02	-0.03	-0.04	-0.11	0.00	0.03	0.02	0.05	0.11	-0.09	-0.05	—	
ZSC	0.03	0.00*	-0.30	-0.09	0.05	-0.04	0.07	0.09	0.01	0.01	0.13	-0.13	0.01	-0.10	-0.10	—
PS	0.01	0.07	-0.01	0.09	-0.09	0.04	0.02	-0.02	0.15	0.02	0.07	0.03	0.01	-0.10	0.02	0.11

* are significant at $p < .0500$

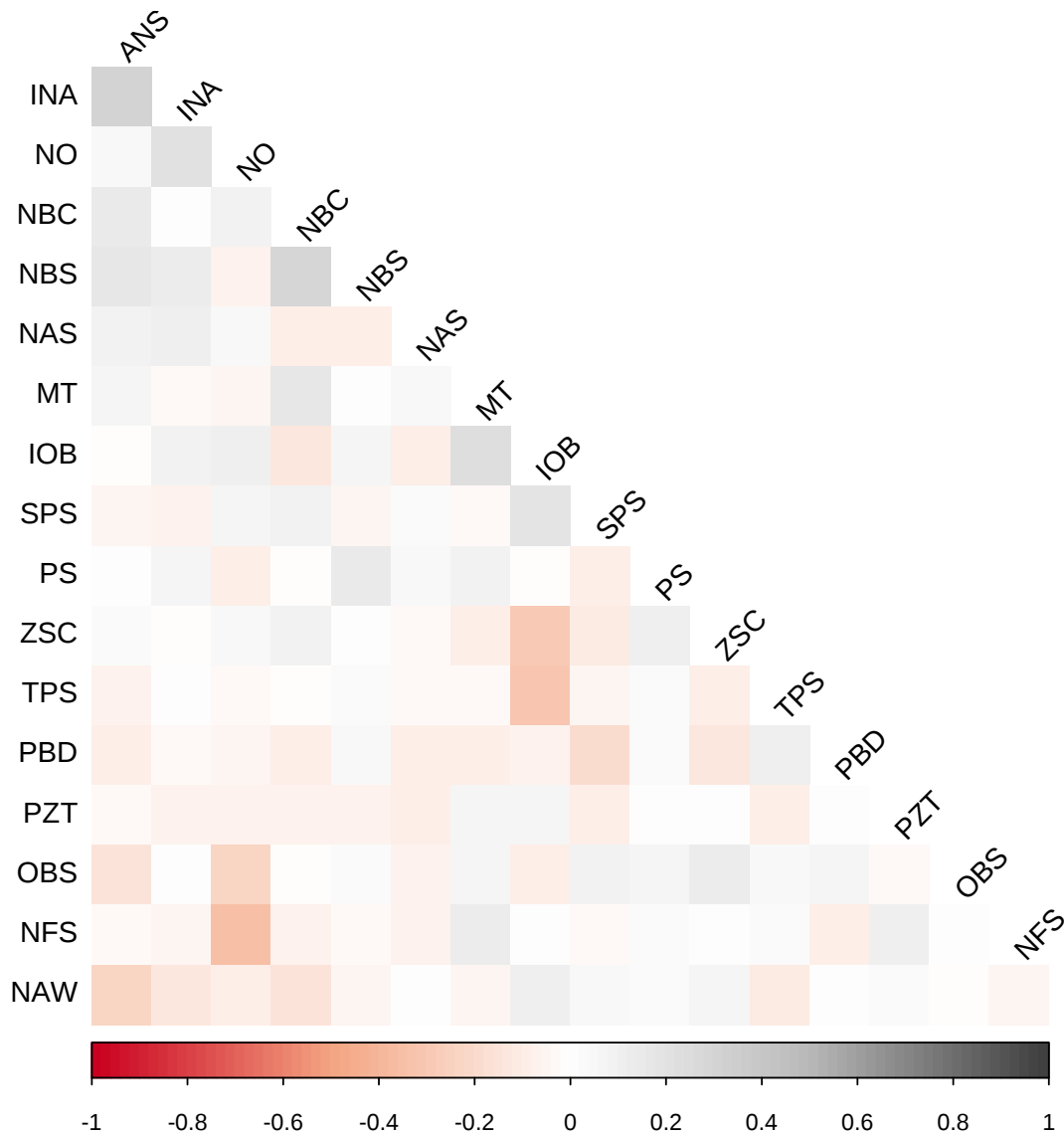


Figure 4-1. Correlation coefficient plot of macromorphoscopic traits in Nubian sample using Spearman correlation coefficient.

The color scale shown in Figure 4-1 above represents the level of correlation between each character state in the Nubian sample. The red end of the spectrum illustrates a negative correlation, while the grey and black represent a positive correlation.

Correspondence Analysis (CA) for All Samples

Two-dimensional graphical presentations were created in R 3.3.1 to visualize mapped patterns and relationships of the 17 non-metric trait character states to each population in multivariate space. Joint biplots were calculated based on frequency distributions for the individual traits, by group. These data are presented in Table (4-3).

Some macromorphoscopic traits were either not collected or were absent for some of the samples. Previous versions of Macromorphoscopies also included expressions that are not present in Macromorphoscopies v.1.6. For instance, Hefner (2007, 2009) collected expression values for NBS (value 0) and ZS (value 3) for the 20th Century American Black population, but these expressions were not collected for the other three groups as these expressions were combined with other expressions as versions of Macromorphoscopies improved.

Differences in macromorphoscopic trait expression between population groups were statistically significant ($p < 0.05$), with the exception of nasofrontal suture ($p = 0.2029$) and postbregmatic depression ($p = 0.8123$).

Table 4-3. Frequency distribution and chi-squared goodness of fit of macromorphoscopic traits between population groups.

Character State											
Anterior Nasal Spine*	1		2		3						
	n	%	n	%	n	%	N				
Nubian	45	41.7	62	57.4	1	0.9	108				
EW African	26	86.7	4	13.3	0	0.0	30				
19 Am. Black	147	57.0	83	32.2	28	10.9	258				
20 Am. Black	67	59.3	38	33.6	8	7.1	113				
ANS $\chi^2 = 40.781$, df = 6, p-value = 3.198e-07											
Inferior Nasal Aperture*	1		2		3		4		5		N
	n	%	n	%	n	%	n	%	n	%	
Nubian	14	8.1	110	63.6	43	24.9	6	3.5	0	0.0	173
EW African	23	76.7	7	23.3	0	0.0	0	0.0	0	0.0	30
19 Am. Black	119	45.4	54	20.6	59	22.5	27	10.3	3	1.1	262
20 Am. Black	4	3.5	16	13.9	48	41.7	42	36.5	5	4.3	115
INA $\chi^2 = 278.05$, df = 12, p-value < 2.2e-16											
Interorbital Breadth*	1		2		3						
	n	%	n	%	n	%	N				
Nubian	4	3.4	91	77.1	23	19.5	118				
EW African	1	3.3	4	13.3	25	83.3	30				
19 Am. Black	30	11.5	103	39.3	129	49.2	262				
20 Am. Black	32	27.8	50	43.5	33	28.7	115				
IOB $\chi^2 = 100.2$, df = 6, p-value < 2.2e-16											
Malar Tubercle*	0		1		2		3				
	n	%	n	%	n	%	n	%	N		
Nubian	48	31.2	81	52.6	24	15.6	1	0.6	154		
EW African	0	0.0	15	50.0	9	30.0	6	20.0	30		
19 Am. Black	15	5.7	120	46.0	80	30.7	46	17.6	261		
20 Am. Black	1	0.9	56	48.7	52	45.2	6	5.2	115		
MT $\chi^2 = 127.67$, df = 9, p-value < 2.2e-16											
Nasal Aperture Shape*	1		2		3						
	n	%	n	%	n	%	N				
Nubian	101	67.3	11	7.3	38	25.3	150				
EW African	0	0.0	0	0.0	0	0.0	0				
19 Am. Black	0	0.0	5	71.4	2	28.6	7				
20 Am. Black	0	0.0	0	0.0	0	0.0	0				
NAS $\chi^2 = 31.701$, df = 2, p-value = 1.307e-07											

Statistically significant differences in trait expression between groups are denoted by (*) and accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test.

Table 4-3. (cont'd).

Nasal Aperture Width*	1		2		3						
	n	%	n	%	n	%	N				
Nubian	23	17.2	100	74.6	11	8.2	134				
EW African	0	0.0	7	23.3	23	76.7	30				
19 Am. Black	9	3.5	111	42.9	139	53.7	259				
20 Am. Black	3	2.6	84	73.0	28	24.3	115				
NAW $\chi^2 = 126.13$, df = 6, p-value < 2.2e-16											
Nasal Bone Contour *	0		1		2		3		4		
	n	%	n	%	n	%	n	%	n	%	N
Nubian	48	53.3	30	33.3	6	6.7	2	2.2	4	4.4	90
EW African	23	76.7	3	10.0	1	3.3	2	6.7	1	3.3	30
19 Am. Black	99	38.7	55	21.5	24	9.4	51	19.9	27	10.5	256
20 Am. Black	24	21.2	42	37.2	21	18.6	19	16.8	7	6.2	113
NBC $\chi^2 = 66.385$, df = 12, p-value = 1.51e-09											
Nasal Bone Shape*	0		1		2		3		4		
	n	%	n	%	n	%	n	%	n	%	N
Nubian	0	0.0	28	25.9	77	71.3	1	0.9	2	1.9	108
EW African	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
19 Am. Black	0	0.0	0	0.0	4	100	0	0.0	0	0.0	4
20 Am. Black	13	17.3	20	26.7	20	26.7	15	20.0	7	9.3	75
NBS $\chi^2 = 62.911$, df = 8, p-value = 1.248e-10											
Nasofrontal Suture	1		2		3		4				
	n	%	n	%	n	%	n	%	N		
Nubian	53	39.0	45	33.1	2	1.5	36	26.5	136		
EW African	0	0.0	0	0.0	0	0.0	0	0.0	0		
19 Am. Black	5	50.0	3	30.0	1	10.0	1	10.0	10		
20 Am. Black	0	0.0	0	0.0	0	0.0	0	0.0	0		
NFS $\chi^2 = 4.6074$, df = 3, p-value = 0.2029											
Nasal Overgrowth *	0				1						
	n	%	n	%	n	%	n	%	N		
Nubian	32	46.4	37	53.6	69						
EW African	20	74.1	7	25.9	27						
19 Am. Black	151	69.3	67	30.7	218						
20 Am. Black	69	60.0	46	40.0	115						
NO $\chi^2 = 13.749$, df = 3, p-value = 0.003267											

Statistically significant differences in trait expression between groups are denoted by (*) and accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test.

Table 4-3. (cont'd).

Orbital Shape*	1		2		3				
	n	%	n	%	n	%	N		
Nubian	98	68.5	35	24.5	10	7.0	143		
EW African	0	0.0	0	0.0	0	0.0	0		
19 Am. Black	4	57.1	2	28.6	1	14.3	7		
20 Am. Black	35	45.5	39	50.6	3	3.9	77		
OBS $\chi^2 = 16.272$, df = 4, p-value = 0.002675									
Post-Bregmatic Depression	0		1						
	n	%	n	%	N				
Nubian	73	57.5	54	42.5	127				
EW African	14	48.3	15	51.7	29				
19 Am. Black	138	55.9	109	44.1	247				
20 Am. Black	20	52.6	18	47.4	38				
PBD $\chi^2 = 0.95446$, df = 3, p-value = 0.8123									
Posterior Zygomatic Tubercle*	0		1		2		3		
	n	%	n	%	n	%	n	%	N
Nubian	13	7.8	79	47.6	55	33.1	19	11.4	166
EW African	0	0.0	2	8.7	13	56.5	8	34.8	23
19 Am. Black	6	2.5	103	42.6	89	36.8	44	18.2	242
20 Am. Black	2	5.3	20	52.6	11	28.9	5	13.2	38
PZT $\chi^2 = 26.901$, df = 9, p-value = 0.001453									
Supranasal Suture *	0		1		2				
	n	%	n	%	n	%	N		
Nubian	11	6.7	15	9.1	139	84.2	165		
EW African	0	0.0	2	28.6	5	71.4	7		
19 Am. Black	55	34.2	12	7.5	94	58.4	161		
20 Am. Black	0	0.0	0	0.0	0	0.0	0		
SPS $\chi^2 = 43.611$, df = 4, p-value = 7.726e-09									
Transverse Palatine Suture*	1		2		3		4		
	n	%	n	%	n	%	n	%	N
Nubian	15	13.9	56	51.9	32	29.6	5	4.6	108
EW African	0	0.0	0	0.0	0	0.0	0	0.0	0
19 Am. Black	0	0.0	6	100.0	0	0.0	0	0.0	6
20 Am. Black	2	3.2	41	65.1	20	31.7	0	0.0	63
TPS $\chi^2 = 13.494$, df = 6, p-value = 0.03583									

Statistically significant differences in trait expression between groups are denoted by (*) and accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test.

Table 4-3. (cont'd).

Zygomaticomaxillary Suture*	0		1		2		3		N
	n	%	n	%	n	%	n	%	
Nubian	63	42.0	63	42.0	24	16.0	0	0.0	150
EW African	0	0.0	10	33.3	17	56.7	3	10.0	30
19 Am. Black	35	13.6	100	38.9	101	39.3	21	8.2	257
20 Am. Black	15	42.9	10	28.6	10	28.6	0	0.0	35
ZS $\chi^2 = 83.471$, $df = 9$, $p\text{-value} = 3.293\text{e-}14$									
Palate Shape*	1		2		3		4		N
	n	%	n	%	n	%	n	%	
Nubian	16	11.4	42	30.0	75	53.6	7	5.0	140
EW African	0	0.0	0	0.0	0	0.0	0	0.0	0
19 Am. Black	0	0.0	0	0.0	0	0.0	0	0.0	0
20 Am. Black	21	27.3	16	20.8	17	22.1	23	29.9	77
PS $\chi^2 = 42.742$, $df = 3$, $p\text{-value} = 2.792\text{e-}09$									

Statistically significant differences in trait expression between groups are denoted by (*) and accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test.

The resulting biplots are displayed below (Figures 4-2 through 4-30). For each trait, two plots are presented: a symmetrical joint biplot and an asymmetric contribution biplot. Within each biplot, the dimensions (denoted by the axes) represent a certain percentage of the data variation, or inertia. For each of the relationships, the variation was explained using only two or three dimensions. Dimension 1 (x-axis) explained the majority of the variation for each trait.

Some of the symmetric and asymmetric biplots—NAS, NBS, NFS, OBS, SPS, TPS, PS—only represent two or three of the samples. The sample most often not represented in the biplots is the East West African sample. Only the symmetric biplot is present for NAS, NFS, NO, PBD, and PS as these are one-dimensional. That is, only two samples or character states are represented and 100% inertia is explained on Dimension 1. However, this correspondence analysis test is built to account for any missing data through listwise deletion, or complete case analysis. Listwise deletion, a classic method for missing data, excludes an entire record

(individual in this case) from analysis if any single value (i.e. character state score) is missing. This method results in less biased results. However, there is the possible limitation of loss of statistical power due to the unused partial data (Graham, 2009; Allison, 2000). This is a minor limitation in the case of this thesis as loss of power is correlated to sample size. Additionally, previous studies (Glynn, 1985; Little, 1992) have shown that listwise limitation produces unbiased regression estimates when the missing data mechanism depends only on the predictor variables (i.e. the population sample), not the response variables (i.e. character state scores). Therefore, listwise deletion is an appropriate method for missing data analysis for this study. The sample size present for each population group concerning each character state scored can be viewed in Table 4-3.

Below is an example of how to read the symmetric and asymmetric biplots present for the anterior nasal spine character state (Figures 4-2 and 4-3).

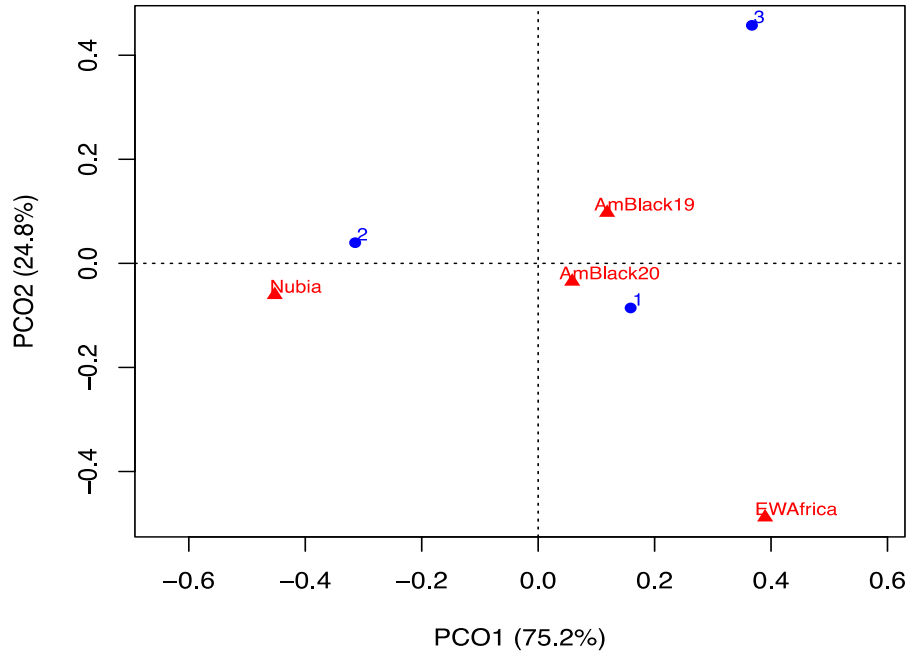


Figure 4-2. Symmetric joint display (biplot) of the row and column profiles derived from contingency table data (Table 4-3) showing distribution of Anterior Nasal Spine character states (columns) and the four samples (rows). Profiles are plotted with respect to the existing principal axes.

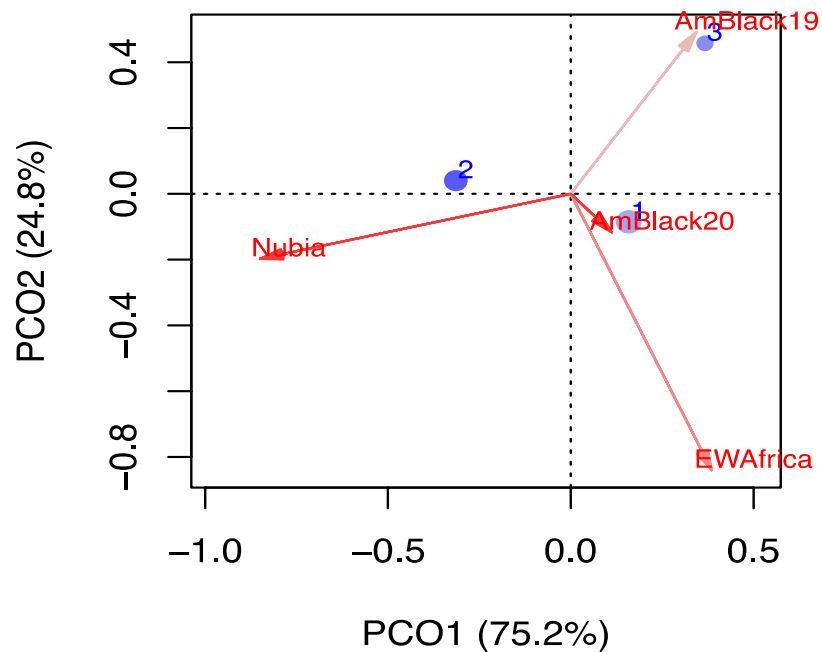


Figure 4-3. Asymmetric joint display (biplot) of the row and column profiles derived from contingency table data (Table 4-3) showing distribution of Anterior Nasal Spine character states (columns) and the four samples (rows). Profiles are plotted with respect to the existing principal axes.

Dimension 1 of the two ANS biplots above explains 75.2% of the inertia. That is, the relative frequency values that reconstructed from the single dimension can reproduce 75.5% of the data variation within the two-way contingency tables. Dimension 2 illustrates that 24.8% of the inertia can be explained. The total inertia was 0.080120.

In the symmetric biplot (Figure 4-2), character states 1 and 2 contribute to Dimension 1, while character state 3 contributes equally to Dimensions 1 and 2. The 19th Century and 20th Century American Black samples are the closest in distance on the matrix. The Nubian sample is closer than the East West Africa Sample to the 20th Century American Black.

In the asymmetric biplot (Figure 4-3), the Nubian sample has a high contribution to the definition of Dimension 1 (proportional to the length of the vector) and therefore a higher contribution to character state 2. Based on the proportionality of color intensity of the lines, and of the points, both the Nubian sample and character state 2 provide a high contribution to the inertia (variability) of the two-way table overall. The 20th Century American Black sample has a low contribution to Dimensions 1 and 2, but a high contribution to character state 1. The sample has a high contribution to the inertia, while character state 1 has a lower presence in the two-way tables than character state 2. The East West Africa sample has a high contribution to Dimension 2 and a lower contribution to the inertia of the character states, though the East West Africa sample was most frequently scored as character state 1. The 19th Century American Black sample contributes highly and equally to Dimensions 1 and 2, but has low contribution to inertia. The 19th Century American Black sample was most frequently scored as character state 3.

Overall, character state 1 was the most represented character state, and was mostly represented by 19th Century and 20th Century American Black samples. Character state 3 was the least frequently scored for the samples.

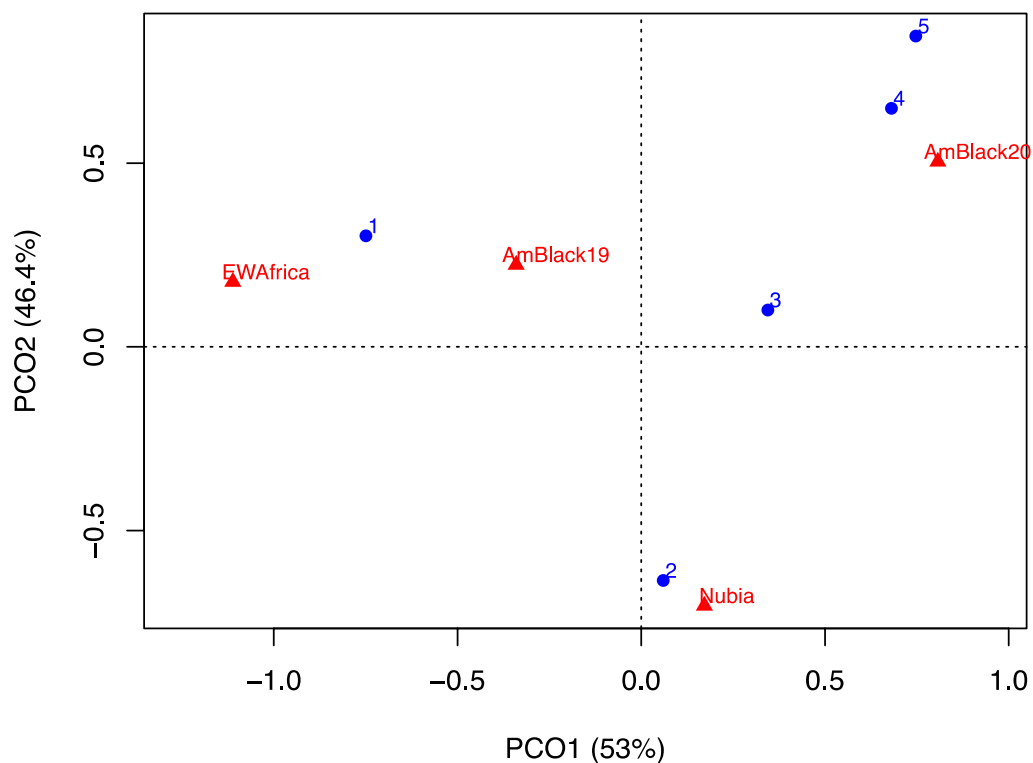


Figure 4-4. Symmetric joint display (biplot) showing distribution of Inferior Nasal Aperture character states and the four samples.

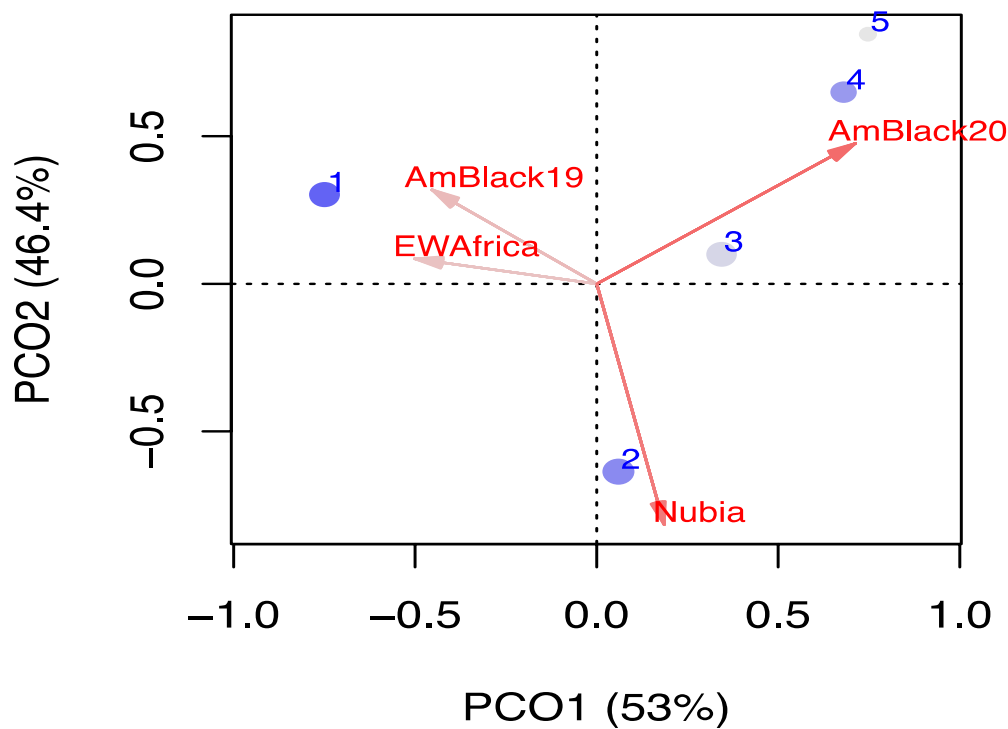


Figure 4-5. Asymmetric joint display (biplot) showing distribution of Inferior Nasal Aperture character states and the four samples.

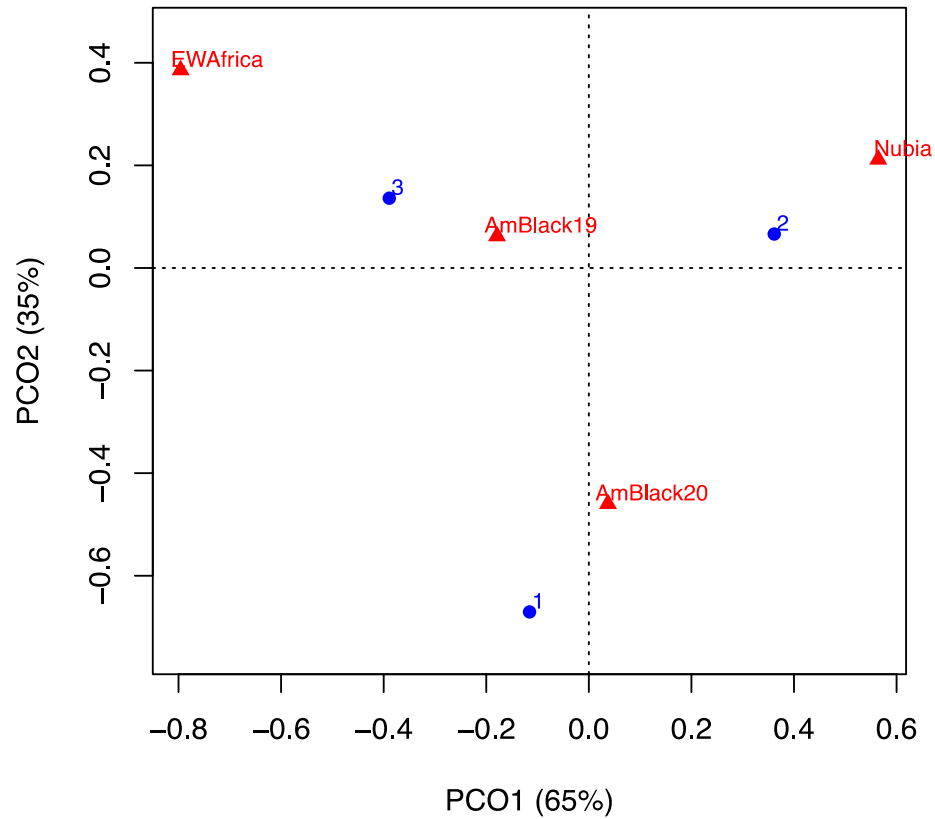


Figure 4-6. Symmetric joint display (biplot) showing distribution of Interorbital Breadth character states and the four samples.

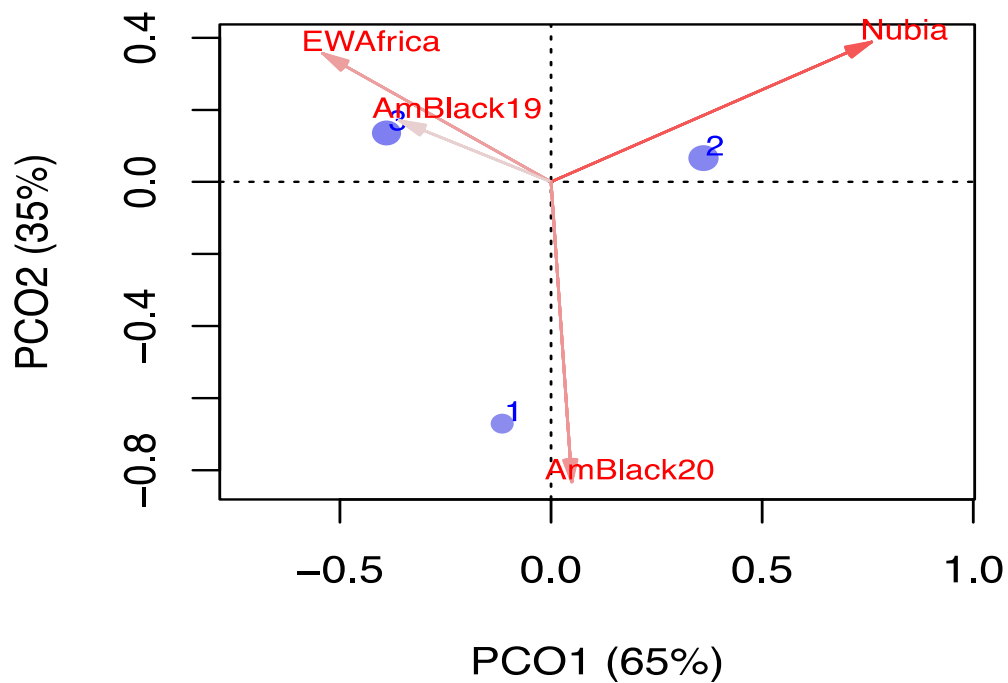


Figure 4-7. Asymmetric joint display (biplot) showing distribution of Interorbital Breadth character states and the four samples.

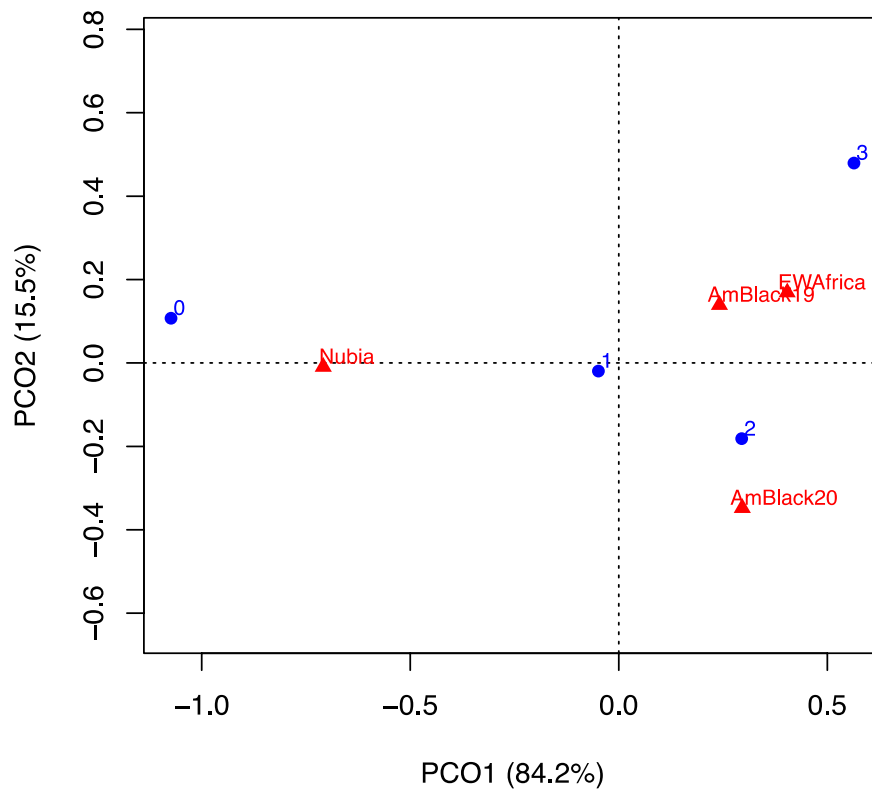


Figure 4-8. Symmetric joint display (biplot) showing distribution of Malar Tubercle character states and the four samples.

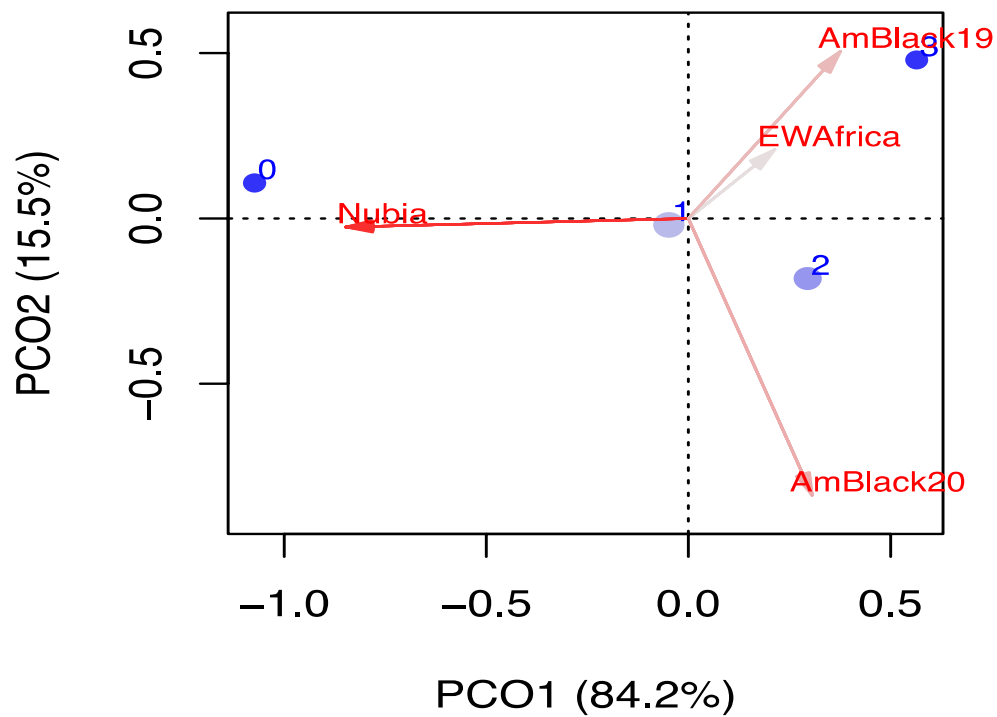


Figure 4-9. Asymmetric joint display (biplot) showing distribution of Malar Tubercle character states and the four samples.

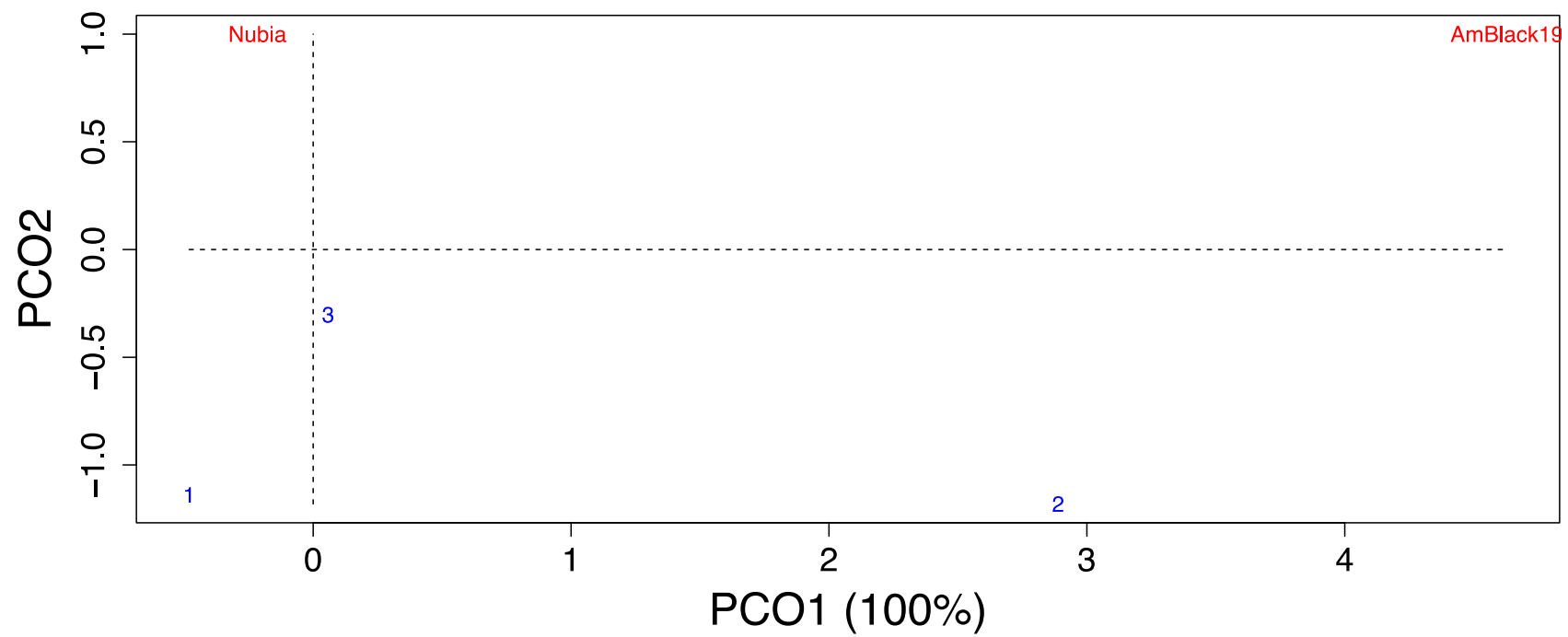


Figure 4-10. Symmetric joint display (biplot) showing distribution of Nasal Aperture Shape character states and the four samples.

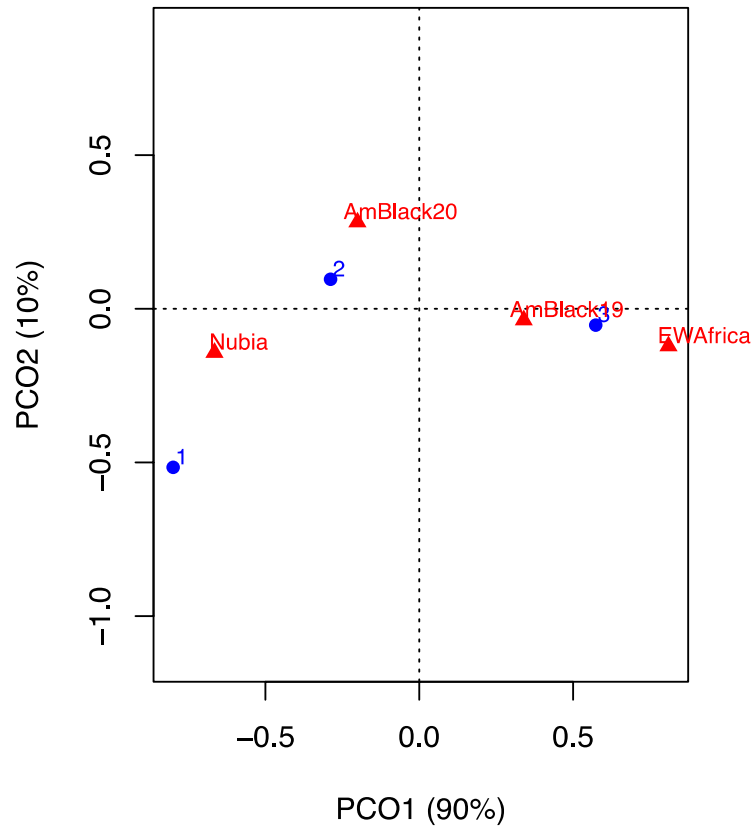


Figure 4-11. Symmetric joint display (biplot) showing distribution of Nasal Aperture Width character states and the four samples.

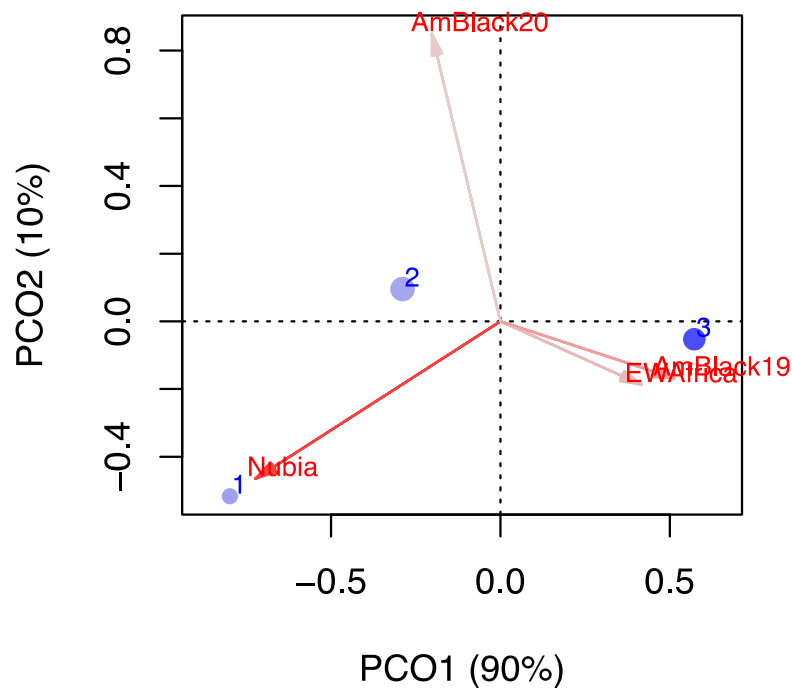


Figure 4-12. Asymmetric joint display (biplot) showing distribution of Nasal Aperture Width character states and the four samples.

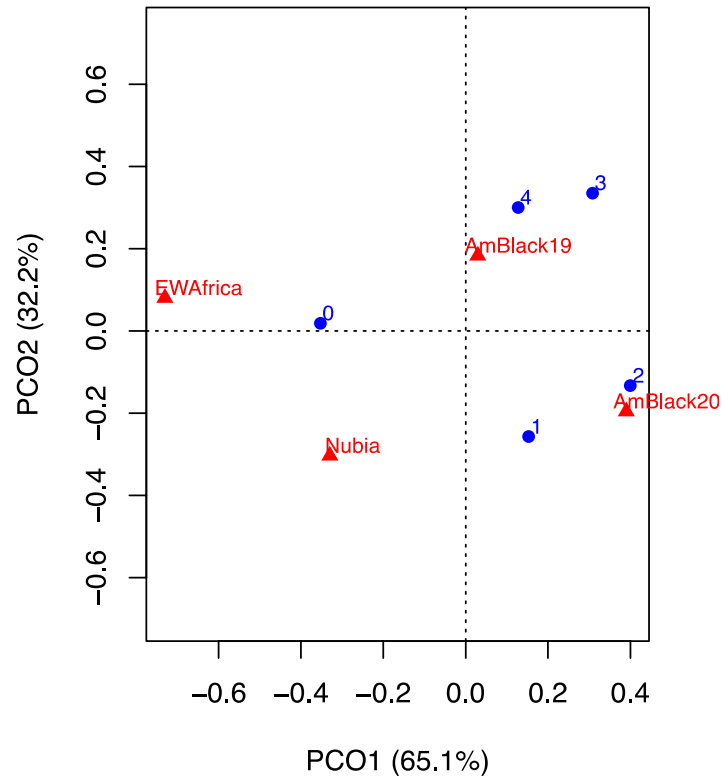


Figure 4-13. Symmetric joint display (biplot) showing distribution of Nasal Bone Contour character states and the four samples.

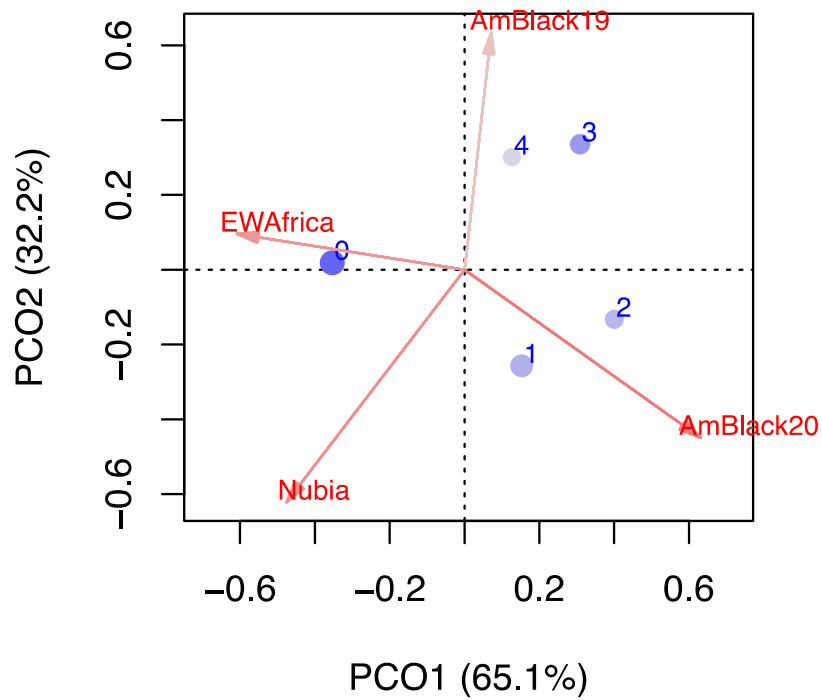


Figure 4-14. Asymmetric joint display (biplot) showing distribution of Nasal Bone Contour character states and the four samples.

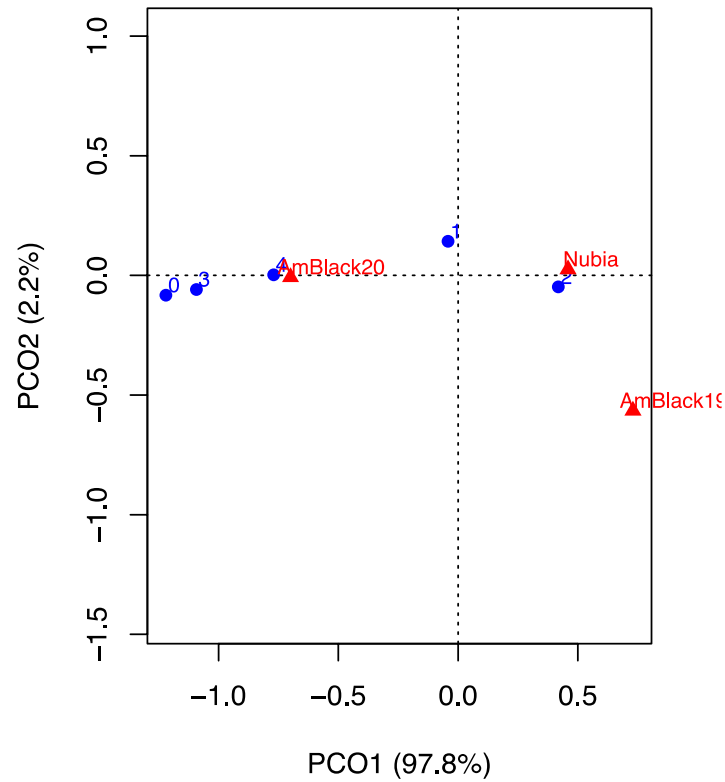


Figure 4-15. Symmetric joint display (biplot) showing distribution of Nasal Bone Shape character states and the four samples.

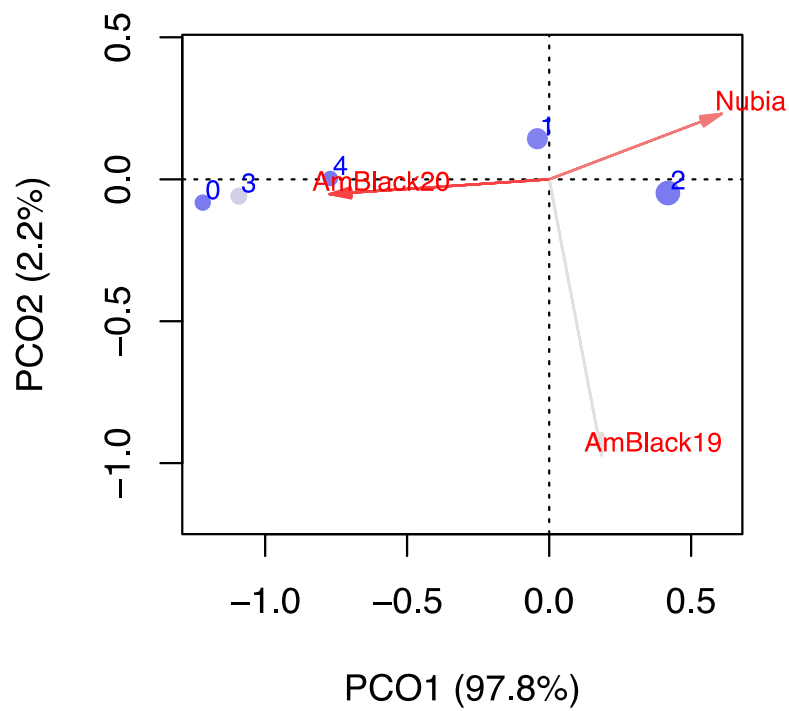


Figure 4-16. Asymmetric joint display (biplot) showing distribution of Nasal Bone Shape character states and the four samples (rows).

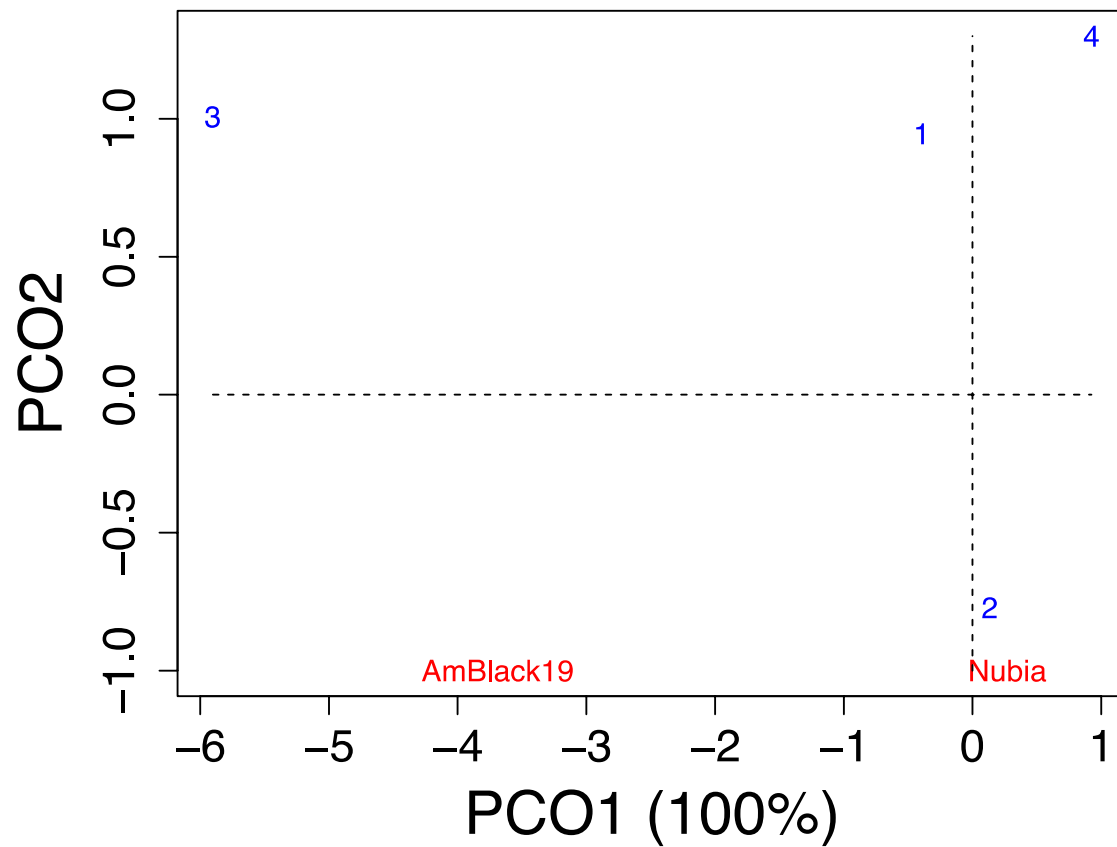


Figure 4-17. Symmetric joint display (biplot) showing distribution of Nasofrontal Suture character states and the four samples.

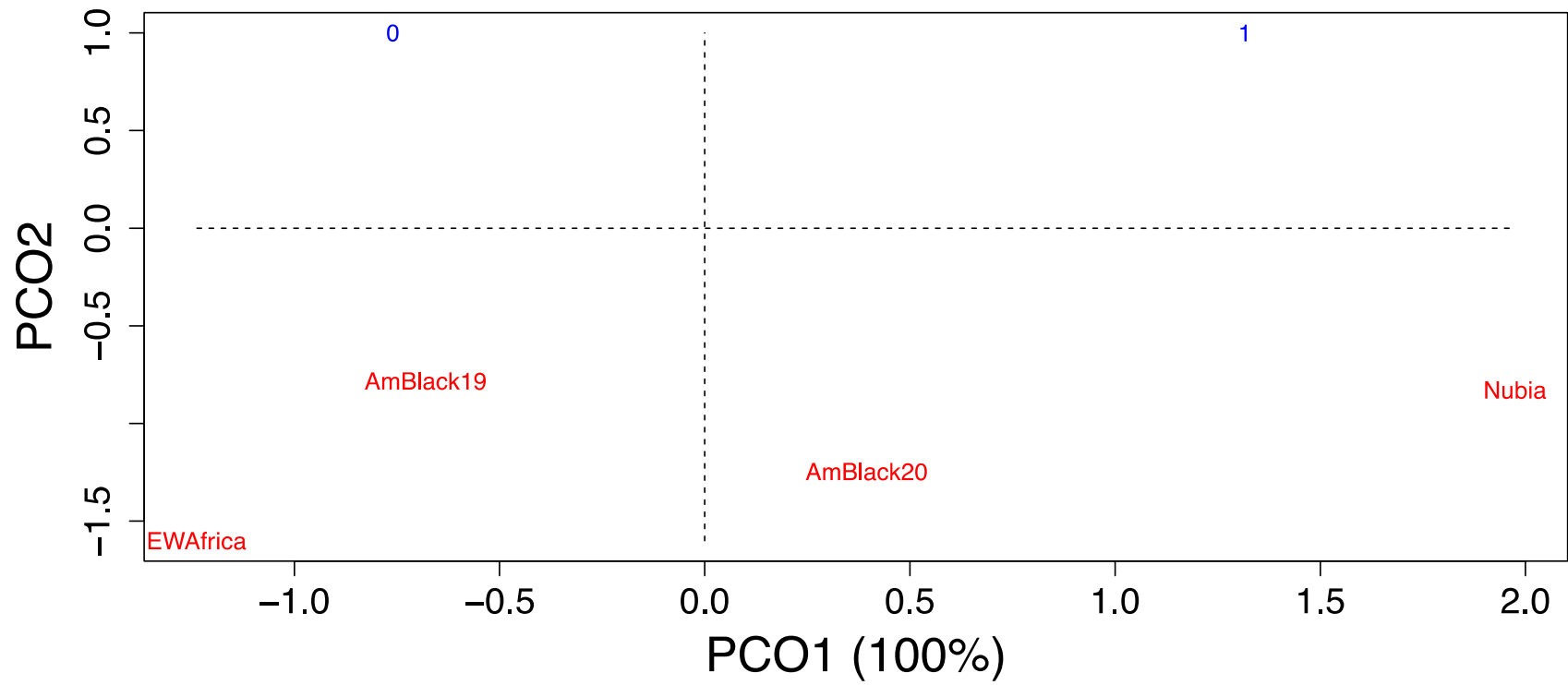


Figure 4-18. Symmetric joint display (biplot) showing distribution of Nasal Overgrowth character states and the four samples.

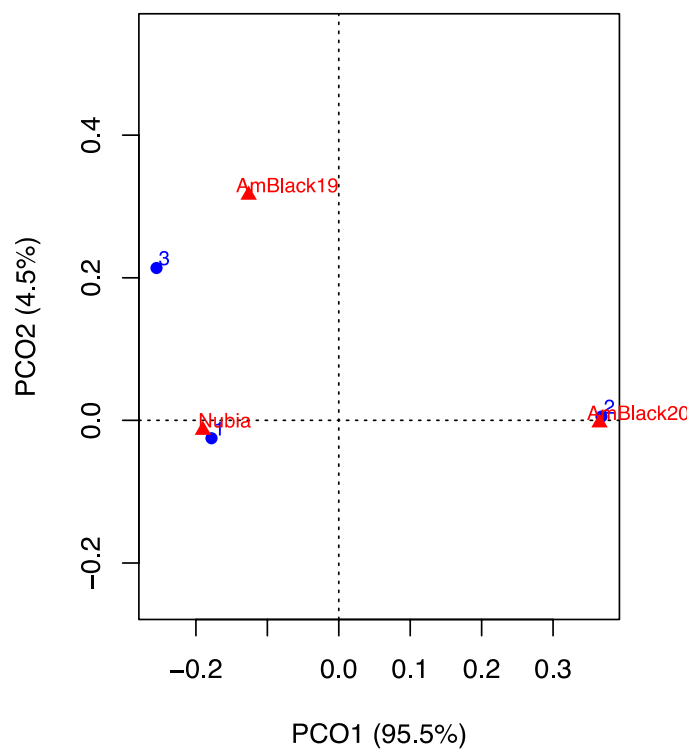


Figure 4-19. Symmetric joint display (biplot) showing distribution of Orbital Shape character states and the four samples.

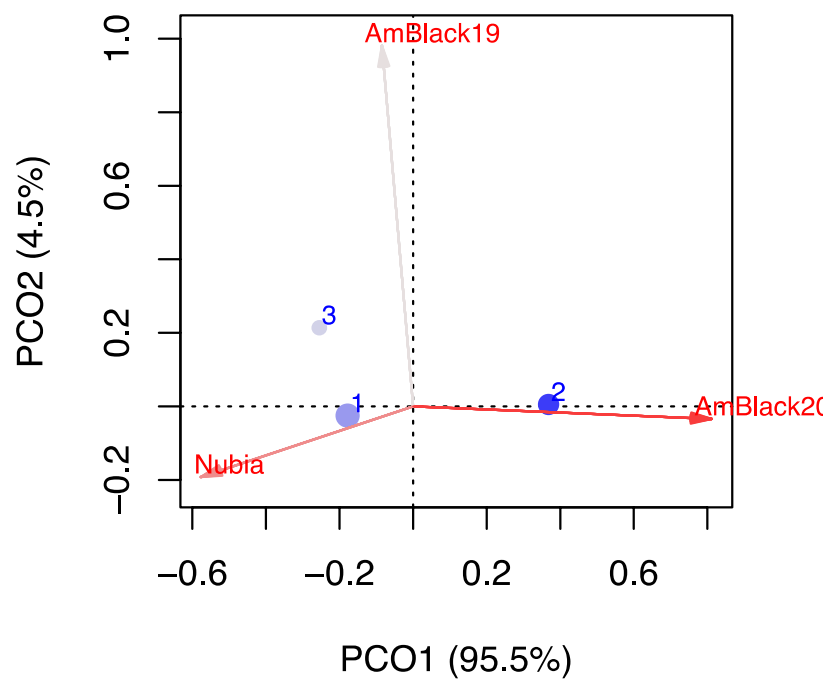


Figure 4-20. Asymmetric joint display (biplot) showing distribution of Orbital Shape character states and the four samples.

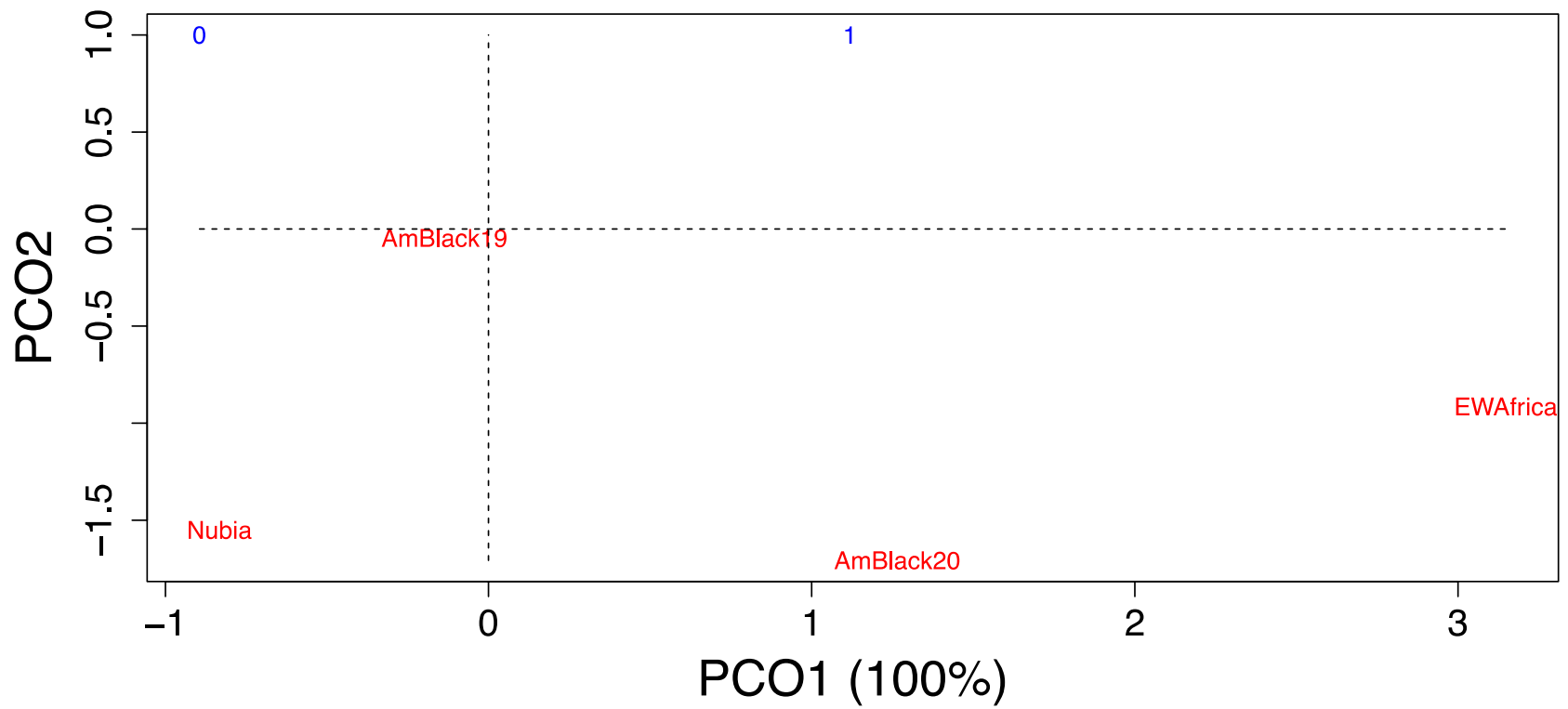


Figure 4-21. Symmetric joint display (biplot) showing distribution of Post-Bregmatic Depression character states and the four samples.

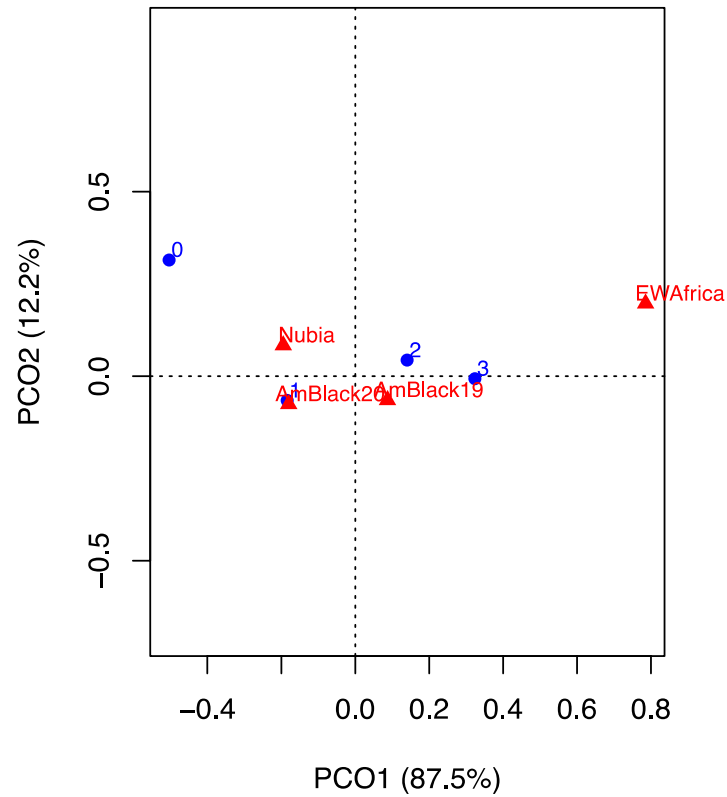


Figure 4-22. Symmetric joint display (biplot) showing distribution of Posterior Zygomatic Tubercle character states and the four samples.

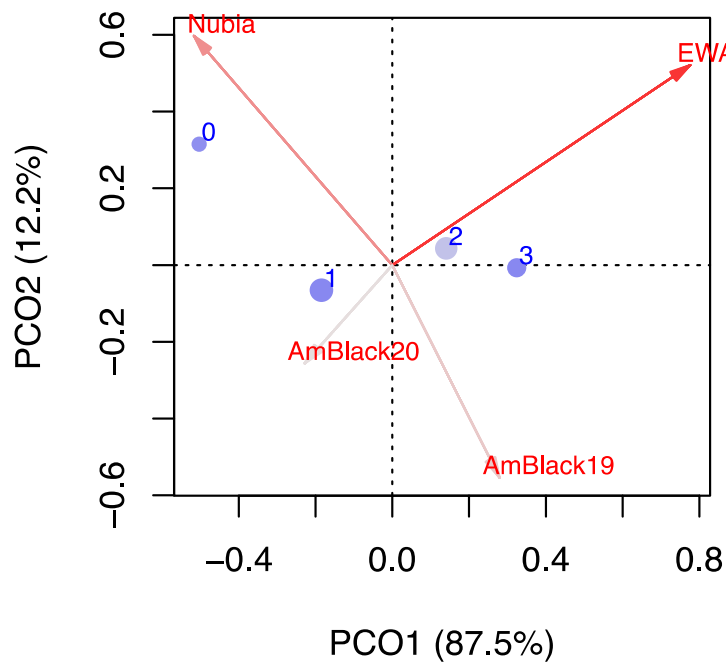


Figure 4-23. Asymmetric joint display (biplot) showing distribution of Posterior Zygomatic Tubercle character states and the four samples.

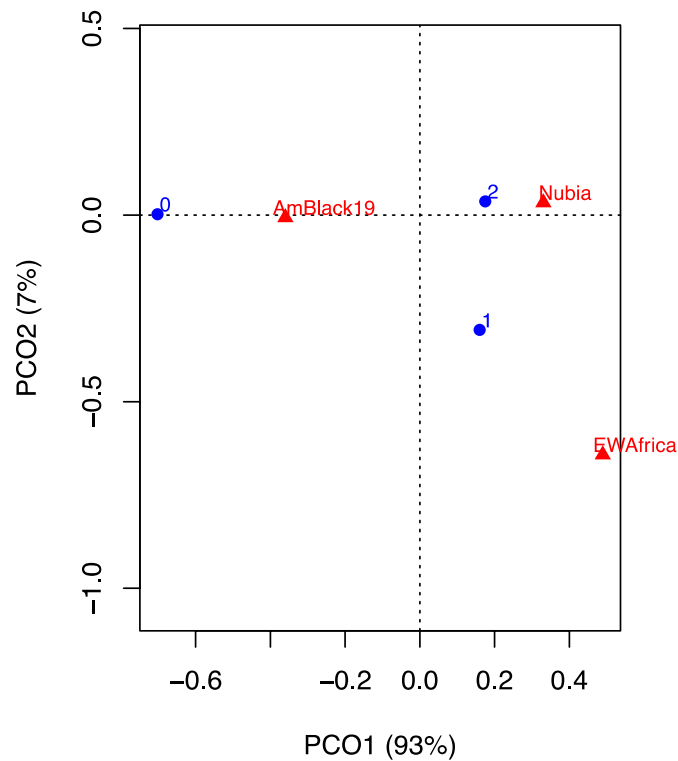


Figure 4-24. Symmetric joint display (biplot) showing distribution of Supranasal Suture character states and the four samples.

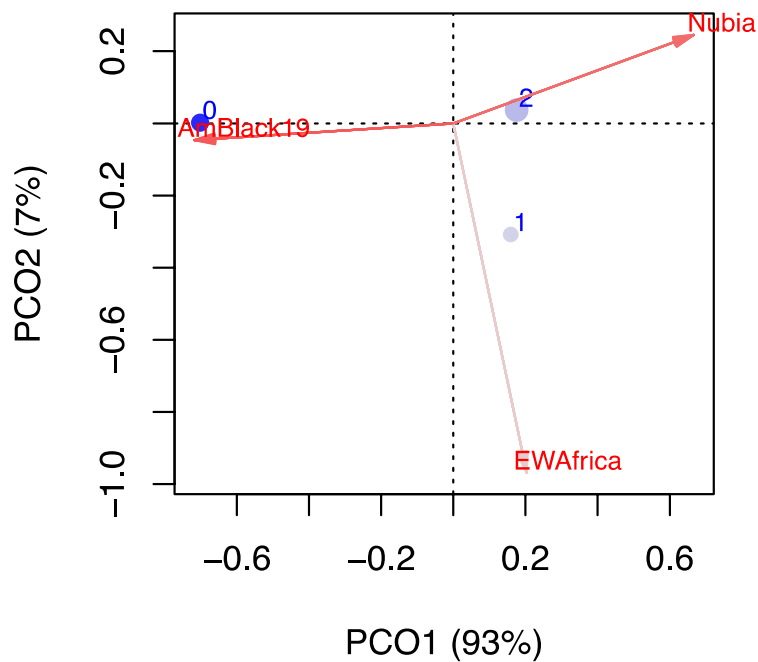


Figure 4-25. Asymmetric joint display (biplot) showing distribution of Supranasal Suture character states and the four.

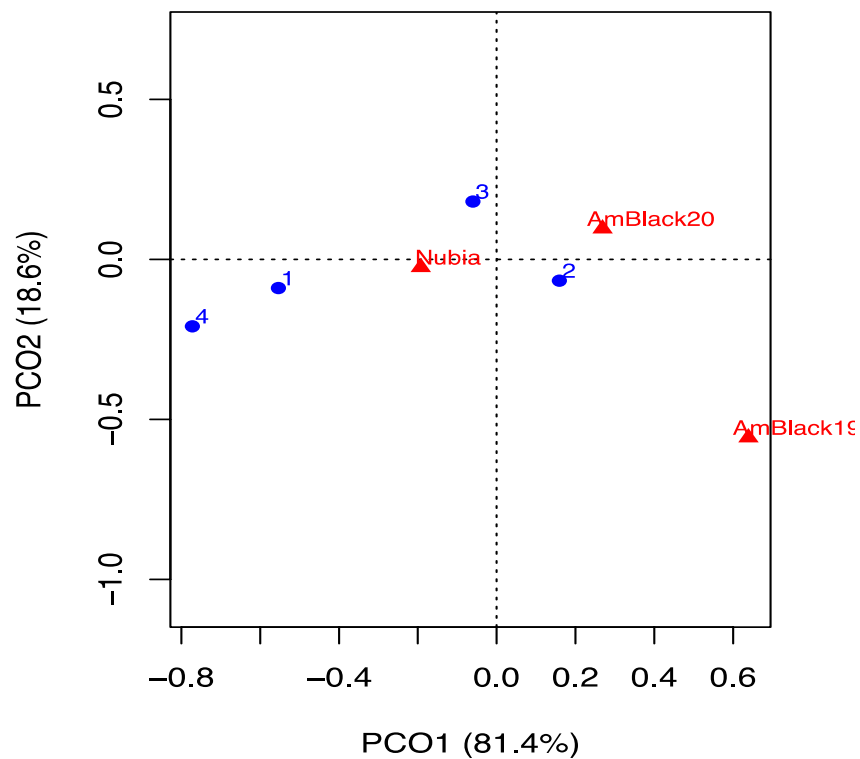


Figure 4-26. Symmetric joint display (biplot) showing distribution of Transverse Palatine Suture character states and the four samples.

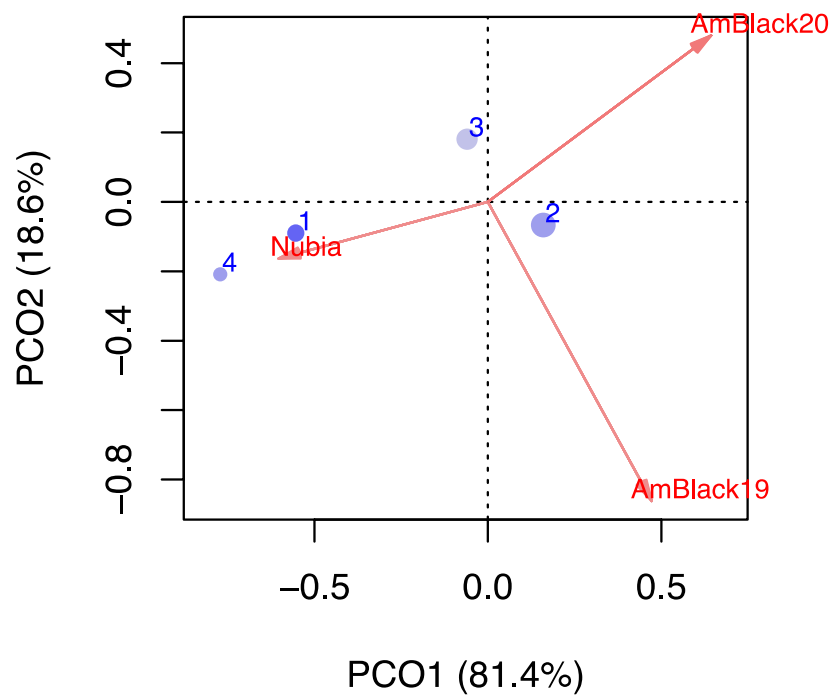


Figure 4-27. Asymmetric joint display (biplot) showing distribution of Transverse Palatine Suture character states and the four samples.

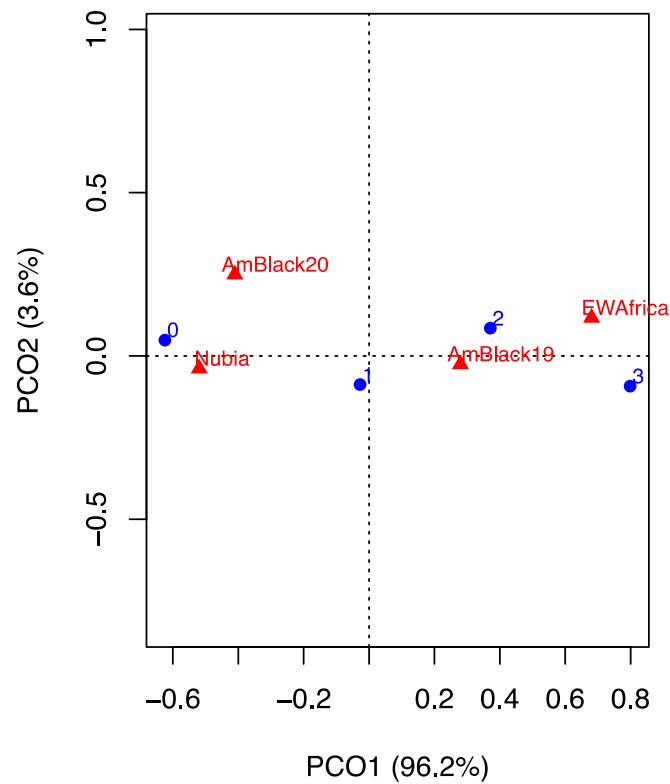


Figure 4-28. Symmetric joint display (biplot) showing distribution of Zygomaticomaxillary Suture character states and the four samples.

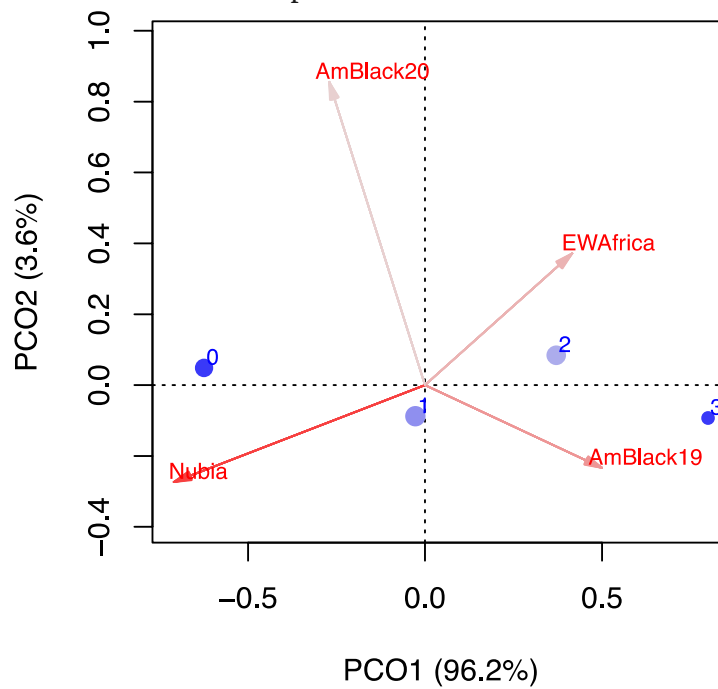


Figure 4-29. Asymmetric joint display (biplot) showing distribution of Zygomaticomaxillary Suture character states and the four samples.

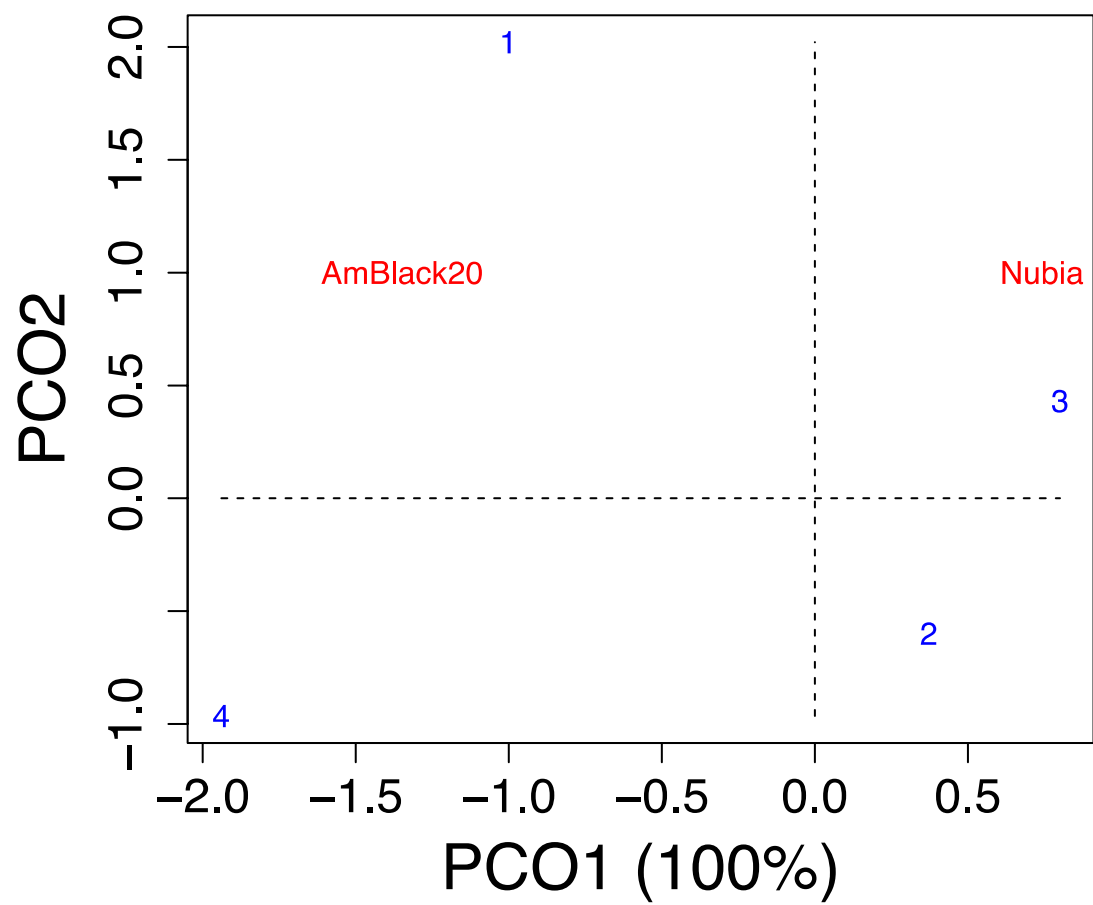


Figure 4-30. Symmetric joint display (biplot) showing distribution of Palate Shape character states and the four samples.

Canonical Analysis of the Principal Coordinates (CAP) for All Samples

Canonical analysis of the principal coordinates was performed to estimate relationships between the sample groups. The resulting tables (Table 4-4 through Table 4-6) and figure (Figure 4-31) are displayed below. As noted for correspondence analysis, the CAP method accounts for any missing data through listwise deletion. The sample size present for each population group in relation to each character state scored can be viewed in Table 4-3.

The nonmetric trait expression variables were converted to factors in order to convert the variables to a metric measure and reproduce inter-correlations among the variables. The factors were clustered into groups, which allowed for group mean scores for each sample.

Table 4-4. Resulting factors and eigenvalues from factor analysis of macromorphoscopic trait expression.

Factor	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	2.161162	24.01291	2.161162	24.0129
2	1.305371	14.50412	3.466533	38.5170
3	1.123765	12.48628	4.590297	51.0033
4	1.006594	11.18438	5.596891	62.1877
5	0.962011	10.68901	6.558902	72.8767
6	0.768731	8.54145	7.327633	81.4181
7	0.587826	6.53140	7.915459	87.9495
8	0.573128	6.36809	8.488587	94.3176
9	0.511413	5.68237	9.000000	100.0000

Table 4-4 shows that a total of 9 factors—ANS, INA, IOB, MT, NAW, NBC, NO, PBD, and ZS—can explain the variable contributions based on correlation. All the eigenvalues, which define the amount or magnitude to which each factor contributes to the total variance within the model, are positive, allowing metric distance measures to be plotted in multidimensional space as eigenvectors. Factor 1 has an eigenvalue of 2.161162 and explains approximately 24% of the variance, which increases with added factor number.

Table 4-5 below displays the eigenvectors, or vectors of a linear relationship, derived from the factor correlation analysis for the nine most contributive macromorphoscopic traits.

Table 4-5. Eigenvectors derived from factor analysis.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9
ANS	-0.497351*	0.052768	-0.203211	0.248334	-0.111385	-0.066282	-0.451927	0.048533	-0.650769
INA	-0.477642*	0.325823*	-0.128667	0.073840	0.080188	-0.093884	-0.360278	0.003902	0.706137
IOB	0.291984	0.509254*	-0.237245	0.370848	-0.158212	0.066243	0.164168	0.636449	-0.012466
MT	0.061102	-0.400484*	-0.547554	0.416060	0.144112	0.538069	0.015801	-0.175499	0.147047
NAW	0.398848*	0.283966	-0.259586	0.265478	-0.110860	-0.467269	-0.080284	-0.620321	-0.023370
NBC	-0.434653*	-0.231049	-0.163301	0.229532	-0.048675	-0.467781	0.672494	0.053666	0.044996
NO	-0.102979	-0.007185	0.555052	0.478583	-0.575320	0.258509	0.049094	-0.199386	0.110604
PBD	0.024592	0.082197	0.422992	0.477715	0.757686	-0.061424	0.002170	-0.005257	-0.087245
ZS	0.276224	-0.574892*	0.070658	0.204517	-0.124991	-0.430264	-0.421489	0.366472	0.183511

The factors are listed in order of variable contribution based on correlation. The higher the absolute values of the eigenvector, the higher the levels of contribution at that factor. For instance, the values denoted with an asterisk (*) for factors 1 and 2 contribute the most to overall inertia. For factor 1, ANS contributes most, while PBD contributes least. For factor 2, ZS contributes most and NO contributes least.

Based upon the factor analysis results (Tables 4-4 and 4-5), principal coordinate analysis was performed. Table 4-6 below displays the resulting principal coordinates axes (columns) for each of the four sample populations (rows).

Table 4-6. Output of principal coordinate analysis for each of the four sample populations based on the 9 factors.

Group	PCO1	PCO2	PCO3	PCO4	PCO5	PCO6	PCO7	PCO8	PCO9
AMBlack19	0.09793	-0.184072	-0.195248	0.096550	0.019942	-0.159062	0.063206	-0.052888	0.030729
AMBlack20	-0.69322	0.649976	-0.164416	0.155404	-0.000412	0.251272	-0.256681	0.024289	0.006682
EWAfrica	1.488354	-0.058108	-0.177535	0.299659	0.021035	-0.050293	0.081607	0.158081	-0.129284
Nubia	-0.570273	0.265737	0.830178	-0.545558	-0.076015	0.410727	-0.098427	0.095386	-0.051331

The principal coordinates (Table 4-6), based on the group mean scores, were plotted into dimensional space with the four population samples, represented by their own individual point (Figure 4-31). Only PCO 1 and PCO 2 were used to plot the population samples. The nine character state factors were also plotted, based on Factors 1 and 2 (Table 4-5) in order to aid in the display and interpretation of the relationship among the population samples based on the expression of these macromorphoscopic traits.

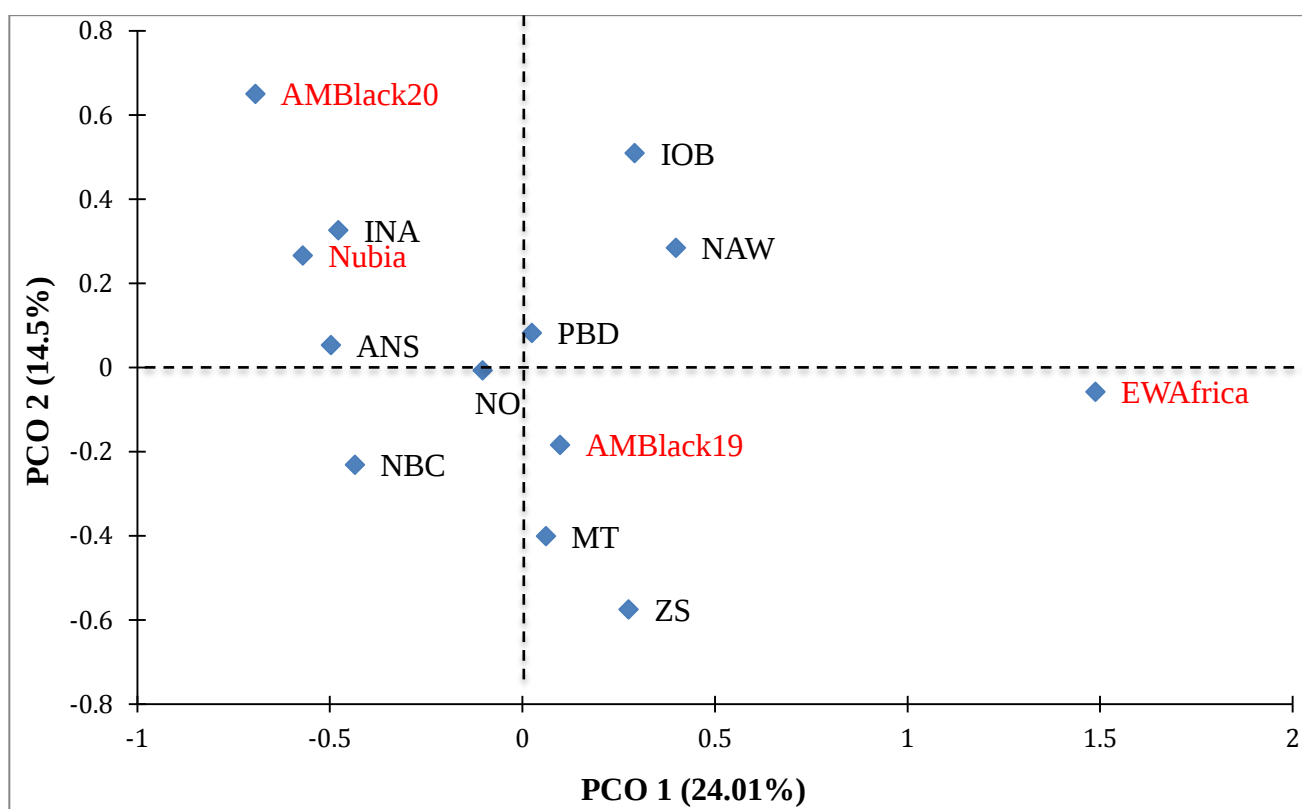


Figure 4-31. A principal coordinate plot displaying the distribution of the four population samples and factors of the character states.

This canonical plot can be read similarly to the correspondence plots. PCO 1 (x-axis) explains 24.01% of the overall variation, while PCO 2 (y-axis) explains 14.5%. The 20th Century American Black sample is closest to the Nubian sample, but most distant from the East West African sample. The 19th Century American Black sample is closest to the East West African sample. The Nubian sample lies between the 20th Century American and the 19th Century American Black samples.

Intra-Observer Error

Table 4-7 below presents the results of the intra-observer error analysis for the Nubian sample data collection. Cohen's kappa with quadratic weighting was used for analysis and interpretation was taken from Landis and Koch (1977). Each of the Cohen's kappa values was determined to be fair or higher. The majority of the values were rated substantial.

Table 4-7. Intra-observer error analysis using Cohen's kappa with quadratic weighting.

Trait	Observed Kappa	Standard Error	.95 Confidence Interval		Significance Magnitude (Landis and Koch, 1977)
			Lower Limit	Upper Limit	
ANS	0.435	0.161	0.119	0.750	moderate
INA	0.537	0.228	0.091	0.984	moderate
IOB *	—	—	—	—	—
MT	0.852	0.144	0.570	1.000	almost perfect
NO	0.769	0.176	0.425	1.000	substantial
NAS	0.696	0.206	0.291	1.000	substantial
NAW *	—	—	—	—	—
NBC	0.321	0.122	0.083	0.559	fair
NBS	0.623	0.296	0.042	1.000	substantial
NFS	0.618	0.235	0.158	1.000	substantial
OBS	0.623	0.289	0.057	1.000	substantial
PBD	0.746	0.139	0.473	1.000	substantial
PZT	0.740	0.264	0.224	1.000	substantial
SPS	0.294	0.253	0.000	0.790	fair
TPS	0.857	0.134	0.595	1.000	almost perfect
ZSC	0.800	0.076	0.651	0.949	substantial
PS	0.468	0.258	0.000	0.973	moderate

* Not calculated due to zero cell frequency beyond limit of the test.

CHAPTER 5 DISCUSSION

Trait Frequency Distribution

For this study, the trait frequency distributions were only calculated for the males and females of the Medieval Nubian sample, as the frequency distributions for the other three samples were previously performed by Hefner (2009, 2016). However, significant differences between the East West African, 19th Century American Black and 20th Century American Black groups were noted at the $p < 0.001$ level with the exception of the MT trait, which did not demonstrate significance.

Frequency distribution was performed for each of the 17 macromorphoscopic traits. Statistically significant differences in trait expression were accepted at the $p < 0.05$ level using the chi-squared goodness-of-fit (χ^2) test. The results for trait frequency distribution are presented in Table 4-1. Therefore, null hypothesis 1—there will be no difference in the frequency of macromorphoscopic traits between males and females in the Nubian sample—resulted in failure to reject. However, while a difference in the frequency of macromorphoscopic expression between males and females were present in the Nubian sample, results show that 14 of the 17 non-metric traits scored were statistically not significant between males and females.

Significant differences were only observed in: NBC ($p = 0.019$); NO ($p = 0.006$); and SPS ($p = 0.002$). Whether significant or non-significant, individuals within the group expressed individual traits at relatively similar frequencies. For the majority of each trait, there was a clear hierarchy of character state for both males and females. For instance, when considering INA as an example, the majority of the group (68.7% males and 57.6% females) expressed character state 2. Following this: character state 3 was expressed by 21.7% males and 28.2% females; character state 1 by 6% males and 10.6% females; character state 4 by 3.6% males and 3.5%

females; and character state 5 by 0% of either sex. This trend is perhaps not that surprising as these individuals are all part of the same population group.

When considering compiled ancestry lists, such as Rhine (1990), and the traditional experience-based approach for estimating ancestry, the expected character states were not expressed as frequently as originally anticipated for this Ancient African population. Overall, the Nubian sample exhibits higher frequencies of the following trait descriptions: an intermediate ANS; a sloped INA; a medium IOB; a trace of an MT; teardrop-shaped NAS; a medium NAW; a circular or oval NBC; a NBS with a superior pinch and minimum bulge; rectangular OBS; a weak PZT; a closed but visible SPS; a TPS with an anterior bulge; and a parabolic PS. However, while these character states were the most frequently displayed in the MSU Nubian collection, trait values still varied. Therefore, the frequency distributions (Table 4-1) suggest that the compiled lists for ancestry ignore a substantial amount of variation within groups. However, this comparison should be made with care, as Rhine's trait list is more for American Black populations, than for an Ancient African population. Rhine (1990) also stated that nonmetric traits are highly variable and continued research on their expression would be necessary for the collection and interpretation of these traits to be more useful.

Correlation Coefficients

Correlation among the 17 macromorphoscopic traits was also only determined for the Ancient Nubian sample. The correlation coefficient table (Table 4-2) and figure (Figure 4-1) reveal that 12 of the 17 traits—ANS, INA, IOB, NAW, NBC, NBS, NFS, NO, PBD, SPS, TPS, and ZSC—had a significant correlation with at least one other trait. Only MT, NAS, OBS, PZT, and PS were not significantly correlated to other variables. ANS significantly correlated with two

other traits, while INA correlated with five other traits. The 12 traits with significant correlations are in concordance with Hefner (2009, 2017) who found that most of the mid-facial macromorphoscopic traits were moderately-to-strongly correlated, and that the majority of shape differences in ancestry are located in the midface, including the upper face, the nasal region, and the orbital borders. According to Hefner (2009), this indicates that the expressions of macromorphoscopic traits are not independent. Therefore, it is reasonable that an underlying genetic basis of these traits and the epigenetic loadings are the result of selective pressures, such as environmental factors or gene flow.

Correspondence Analysis (CA) for All Samples

Correspondence Analysis resulted in symmetric and asymmetric biplots (Figures 4-2 through 4-30) to help visualize the patterns and relationships of the 17 macromorphoscopic traits for each population group. Biplots were calculated based on frequency distributions for the individual traits, by group (Table 4-3). Fifteen of the 17 traits resulted in significant differences ($p < 0.05$) in character state expression among the four population groups. Therefore, CA plots allow a small degree of interpretation of secular change for each individual trait and sample.

There is an overall basic pattern in terms of distance between the samples, and therefore a basic pattern in the most expressed trait character states for each population sample. The symmetric joint biplots follow the same basic trend in terms of distance between the samples. Consistently, the 20th Century American Black sample is most similar to the 19th Century American Black sample, and the 19th Century American Black sample is most similar to the East West African sample. The Nubian sample, interestingly, is often isolated on the biplots and is found either more similar to the 20th Century American Black sample or is equidistant from both

the East West African and 20th Century American Black samples. When all four samples were represented on the maps, the Nubian sample was closer to the 20th Century American Black sample on the ANS, IOB, NAW, NO, PBD, PZT, and ZSC biplots. The majority of these traits are considered mid-facial. The Nubian sample appeared equidistant between the two in the INA, MT, and NBC biplots.

Observing the individual traits and their biplots, other, smaller trends may be observed. The mid-facial traits appear to become smaller over time. However, traits appear to increase in size between the Nubian sample and the East West African sample; remain generally similar between the East West African sample and the 19th Century American Black sample; and decrease in size between the 19th Century American Black sample and 20th Century American Black sample. These shifts in trait expression are most noticeable in ANS, INA, IOB, NAW, NBC, and NBS.

A complete examination of all the traits is not presented here, but an example of interpretation of the symmetric and asymmetric biplots is present for the anterior nasal spine character state (Figures 4-2 and 4-3) in the results section of this thesis. When considering Figures 4-2 and 4-3, a clear pattern can be observed. The Nubian sample most frequently expressed a score of 2, which is an intermediate or moderate projection of ANS. Character state 1, which was a slight minimal-to-no projection of ANS, was the most represented character state and was mostly displayed by the 19th Century and 20th Century American Black samples. Character state 3, a marked pronounced projection, was the least frequently scored.

While similar interpretations for the remaining 16 macromorphoscopic traits are not discussed here, the reader is encouraged to view the CA plots to observe the patterns described above.

Canonical Analysis of the Principal Coordinates (CAP) for All Samples

While the correspondence biplots (Figures 4-2 through 4-30) allowed a small degree of interpretation for secular change for each individual trait and sample, the canonical perceptual map (Figure 4-31) allows an interpretation for secular change between samples based on a culmination of macromorphoscopic trait morphology. This can be viewed through the point separation in space.

In Figure 4-31, the first axis (PCO 1) explains 24.01% of the inertia for the East West African sample and the 19th Century American Black sample. PCO 2 explains 14.5% of the inertia for the Nubian and 20th Century American Black samples. Therefore, PCO 1 and PCO 2 display approximately 38.51% of the variation present among the population samples based on the nine factors displayed in Table (4-4).

In order to interpret the results of CAP, all contributing statistical tests, such as factor analysis and principal coordinate analysis, must be considered simultaneously. The results of the CAP analysis, in conjunction with sample distances in dimensional space, demonstrate the unique cranial morphologies of each population sample, and display a clear secular trend among the four samples. A more thorough understanding of this secular trend may be viewed based on the eigenvalues and eigenvectors (Table 4-4, Table 4-5, Figure 4-31) derived for the nine cranial macromorphoscopic traits that contributed most to the variation among the four samples—ANS, INA, IOB, MT, NAW, NBC, NO, PBD, and ZS. PCO 1 separates the East West African and the 19th Century American Blacks from the Nubians and the 20th Century American Blacks with loadings on ANS (-0.497351), INA (-0.477642), NBC (-0.434653), and NAW (0.398848). PCO 2 also separates East West African and the 19th Century American Blacks from the Nubians and the 20th Century American Blacks, but with loadings on ZS (-0.574892), IOB (0.509254), MT (-

0.400484), and INA (0.325823). Simply, secular change can be easily viewed in Figure 4-31 when the cranial macromorphoscopic traits and the four populations are regarded in relation to the axes. Those traits that are viewed along PCO 1 and to the left of the line designating PCO 2, such as ANS, INA, and NBC, have a negative eigenvalue. This means that they have a smaller size or character state expression in the 20th Century American Black and Nubian population groups (also located to the left of PCO 2). Those traits located to the left of PCO 2, such as IOB and NAW, have a positive eigenvalue and therefore have a greater size or character state expression in the East West African and 19th Century American Black groups. Traits close to the centrum, such as PBD, did not show a significant change in expression. Based on the distance present between the samples and the positioning along the axes, the East West African sample is most similar to the 19th Century American Black sample, and least similar to the 20th Century American Black sample. There appears to be a large difference in macromorphoscopic trait expression between the 19th Century American Black sample and the 20th Century American Black sample. The Nubian sample is most similar to the 20th Century American Black. With an overall view, macromorphoscopic trait size or character state expression decreases when moving from the right side to the left side of the CAP perceptual map.

In order to further demonstrate variability and display the relationship of the populations samples over time based on the expression of the macromorphoscopic traits, an additional canonical analysis was run with a 19th Century American White (n = 60) and a 20th Century American White (n = 60) group. The macromorphoscopic data for these two groups was obtained from MaMD (Hefner 2016). The results are displayed in Figure 5-1.

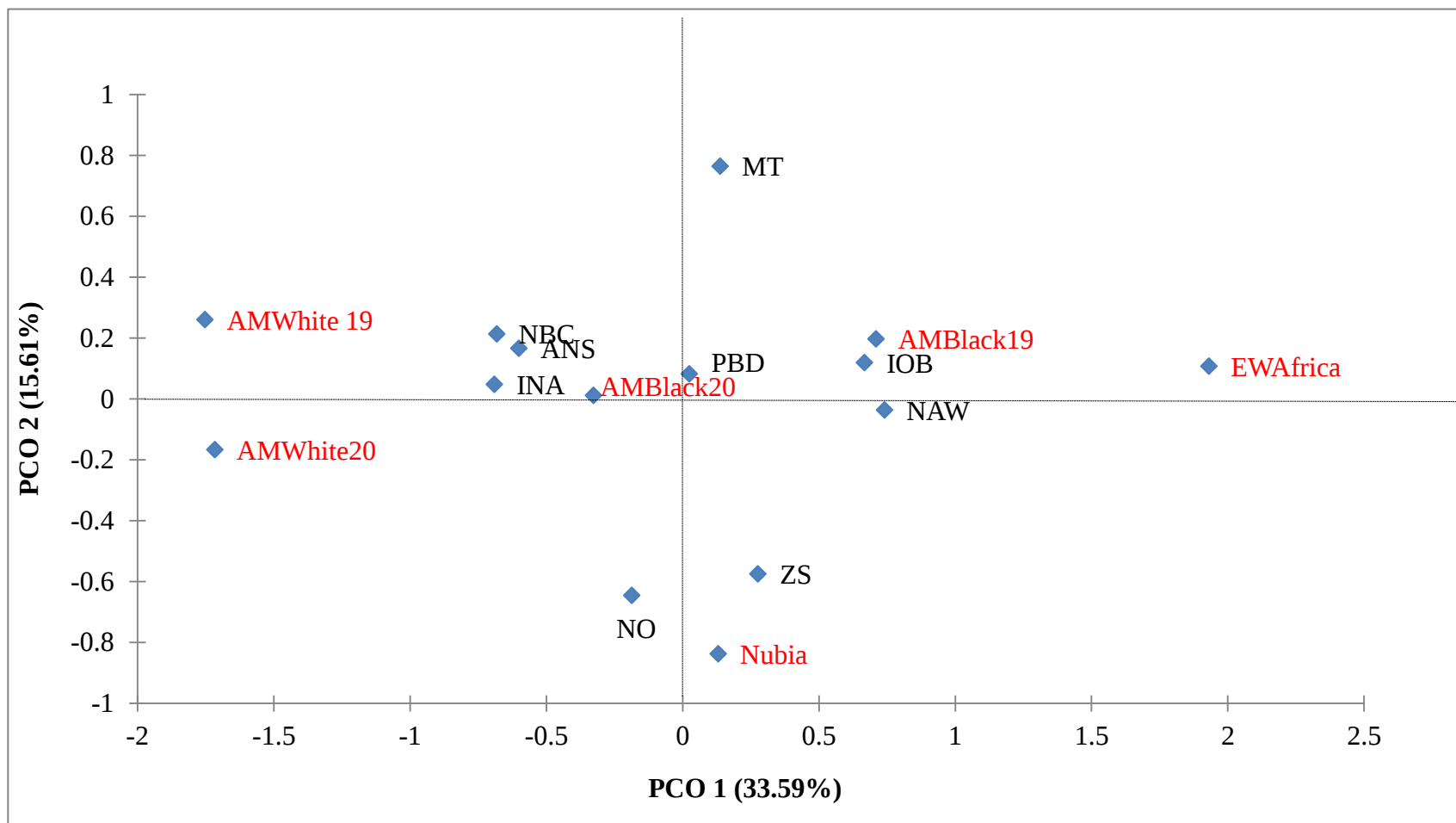


Figure 5-1. A principal coordinate plot displaying the distribution of the four population samples and the two additional groups of 19th Century American White (n = 60) and 20th Century American White (n = 60) with the factors of the character states.

In Figure 5-1, PCO 1 explains 33.59% of the overall variation, while PCO 2 explains 15.61%. In this plot, the same relationship can be viewed among the African and American Black populations as could be seen in Figure 4-31. However, the 20th Century American Black sample is closer to the 19th and 20th Century American White samples than it is to the EW African sample. PCO 1 separates the Nubian sample and the 20th Century American White sample from the remaining four groups with loadings on ANS (-0.600893), INA (-0.690516), IOB (0.666829), NAW (0.741126), and NBC (-0.682187). PCO 2 separates the 20th Century American Black and the 19th and 20th Century American White groups from the Nubian, 19th Century American Black, and EW African groups with loadings on MT (0.764975), NO (-0.644869), and ZS (-0.57489). Based on the distance present between the samples and the positioning along the axes, relationships and differences in macromorphoscopic trait expression may be viewed: EW African is closest to the 19th Century American Black; the 19th Century American Black is closest to the 20th Century American Black; and the 20th Century American Black is closest to the Nubian sample, but is closer to the 19th and 20th Century American White groups than the other African and American Black samples. Again, with an overall view, it is noticeable that secular change is visible among the population groups.

The midface region (ANS, INA, NAW and NBC for Fig 4-31; ANS, INA, IOB, NAW, and NBC for Fig 5-1) is of greatest importance for separating the population groups. As can be viewed by the positioning of the factor points in Figures 4-31 and 5-1, a general narrowing of the nasal aperture width, interorbital breadth, and nasal aperture width has occurred over time. For the midface, a less sloped inferior nasal aperture and a more plateaued nasal bone contour are also observed.

Null hypothesis 2—significant cranial secular change has not occurred in the Native

African and American Black populations over time—was rejected. Alternatively, cranial secular change has taken place in the Native African and American Black populations over time. Secular change has occurred both over the expanse of time of the four sample collections, as well as over short segments of time between each sample. The only group viewed in Figures 4-31 and 5-1 that did not fall within expectations is the Nubian sample, which was expected to fall closest to the East West African group and furthest from the 20th Century American Black.

Interpretations

Secular change, particularly in the midface is present and observable in the four population samples of this study. Short segments of secular change are observable between the East West African group (1800s) and the 19th Century American Black group (1800s – mid 1900s), while a greater segment of time is observable between these two groups and the 20th Century American Black group (1950s – present). It is observed in Figure 4-31 that different macromorphoscopic traits are relevant to these time segments.

Closer in time, the East West African Group and the 19th Century American Black group do not appear to differ heavily in midface traits. However, it is difficult to determine which traits varied greatly between these two groups due to the smaller sample size and the missing data of the East West African group. This absence of facial difference is not surprising when past literature is considered. Jantz and Meadows Jantz (2000), Jantz (2001) and Wescott and Jantz (2005), all of whom analyzed crania through the 18th and 19th centuries, perceived that the noticeable changes in the cranial vault were more evident and significant than changes in the cranial face. However, a significant difference in mid-facial trait expression was viewed between the 19th Century and 20th Century American Black groups (Figure 4-31). This finding supports

and is supported by Spradley (2006), who, through her study of crania involved in the African Diaspora, observed significant changes in the face. Null hypothesis 3—the Modern American Black population will not display significant secular change—was, therefore, rejected (Table 4-3 and Figure 4-31). Alternatively, among the four samples, the Modern American Black displayed the most significant cranial secular change. This is also evident in Figure 5-1, which shows the 20th Century American Black group to be close in distance to the 19th and 20th Century American White groups, particularly in ANS, INA, and NBC. This, therefore, supports Jantz and Meadows Jantz’s (2000) study on secular change: short-term changes involve one or two generations and are a result of environmental changes; and longer-term changes occur due to both environmental shifts and genetic components. Considering these results (Figures 4-31 and 5-1), the collection and analysis of data for Modern American Blacks within the United States is likely relevant, particularly for forensic studies. Secular change has occurred between the 19th Century and 20th Century American Black populations. With the 20th Century American Black group’s proximity to the 19th and 20th Century American White samples, it is likely that these changes are the result of both short and long-term changes resulting from environmental and genetic effects of the African Diaspora. Perhaps temporal comparisons of sub-regions within the United States would reveal trends in particular areas of the country that contribute more to ancestry assessment in forensic anthropology.

The Nubian group does not fit the expected trend in this analysis. As an Ancient Sample (mid-5th to the early 15th centuries AD), the Nubian group was expected to express macromorphoscopic traits most similar to the East West African group, and least like the Modern American Black group. Interestingly, the Nubian group displayed trait expressions most similar to the Modern American Black sample. While there is plenty of archaeological knowledge of

Lower Nubia, there is still very little known about Upper Nubia, where Mis Island is located along the Fourth Cataract. There is a large amount of literature regarding Nubia and its Mediterranean neighbors; however, Vollner (2016) found that due to the isolated nature of Mis Island, external gene flow was likely minimal. Therefore, more work should be performed in this region for a better understanding of the mechanisms of these trends. For future studies, as recommended by Godde (2009), data should be collected and analyzed for cranial macromorphoscopic trait data from populations known to have had higher levels of contact with the ancient Nubians, such as the ancient Egyptians and other populations both from the Mediterranean and along the Nile Corridor. This would help better predict secular trends within that region of the world that may extend to modern-day Sudanese, Egyptians, and other populations of northern Africa and perhaps the Mediterranean.

A brief history of Nubian excavation, the Medieval Nubian Period, and Nubia's role as the gateway to Africa were presented in chapter 2 of this thesis. In relation, the argument of whether cranial variation in Nubia is the result of biological diffusion or *in situ* development was also conferred. Discussion of which is the more likely scenario is beyond the scope of this thesis. What can be relayed, based on the cranial macromorphoscopic trait expression and Figures 4-31 and 5-1, is that cranial-facial changes in Nubia have occurred over time, and that these changes are observable and, in some ways, predictable. These changes may be from gene flow, environmental shifts, or a combination of the two. Perhaps most importantly, this study has demonstrated that macromorphoscopic traits may be utilized to measure secular change in craniofacial morphology.

Intra-Observer Error and Limitations

Table 4-7 presents the results of the intra-observer error analysis. Each of the Cohen's kappa values was determined to be fair ($k = 0.21 - 0.40$) or higher, though the majority was rated as substantial ($k = 0.61 - 0.80$). This suggests very little intra-observer error. The two lowest rated traits were NBC ($k = 0.321$) and SPS ($k = 0.294$). The reasons for these lower scores are unclear, especially for NBC, which utilizes a contour gauge to determine the character state. This error may be due to several circumstances. Simple explanations include: error in recording the scores, or general lack of experience. Data were collected for intra-observer error after initial data collection was completed. Therefore, scores may have changed due to a higher confidence and familiarity in trait expression recognition.

The supranasal suture, which includes determining whether the suture is obliterated, open, or closed but visible, was not considered a hard trait to score. However, it was difficult to assess the character state of this trait with true reliability, as it was often difficult to see. An extra light source was often utilized while holding the cranium at an angle in order to view the presence or absence of this trait. Hefner (2007, 2009) also found this trait difficult to score ($k = 0.468$) and stated that “the difficulty inherent in this trait may suggest dropping it from further analyses, at least until it has been more systematically defined and illustrated.”

Other lower scores, such as the moderate levels of ANS ($k = 0.435$), INA ($k = 0.537$), and PS ($k = 0.468$) were most likely due to increased experience over time. The difficulties with anterior nasal spine cannot be truly explained, as it is a fairly straightforward trait to score. There may have been some difficulty relating the size of a small element to a large element, especially when there was a large amount of damage or fragmentation present in the facial structure. For the inferior nasal aperture, error may also attribute to difficulties in relating the character state to

the line drawing (3-4). As can be seen in Table 4-1, the majority of the Nubian sample was scored as having a score of 1 (6% males, 10.6% females), 2 (68.7% males, 57.6% females) or 3 (21.7% males, 28.2% females). Figure 5-2 displays a larger view of the three line sketches from MMS v.1.6 for the INA character states.

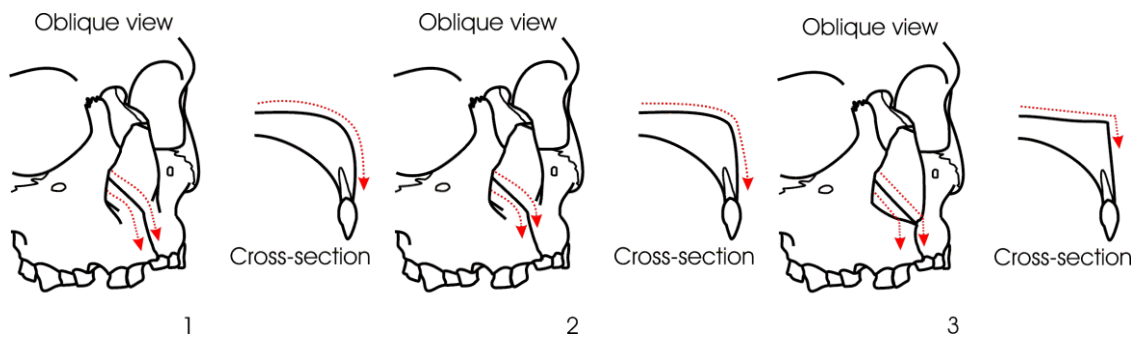


Figure 5-2. The first three character states of inferior nasal aperture. 1 = inferior sloping; 2 = sloping more anteriorly than 1; 3 = no slope. Line drawings and descriptions obtained Hefner (2009, 2012) and Osteoware (2011). See figure 3-3 for more details.

With a lack of experience early on, it is easy to confuse one of these expressions with another, as differences can be slight. Scoring character state 4 and 5 is much simpler as a pronounced ridge or sill is present that transverses the inferior nasal border.

The error in scoring palate shape is the most understandable because this macromorphoscopic trait has only been previously defined and used by Wun (2014). When the author of this thesis first trained in scoring these macromorphoscopic traits, the updated MMS v.1.6 program had not yet been completed. Therefore, the majority of training and practice was performed using the MMS v.1.5, which did not include palate shape. While training with the palate shape occurred before data collection, it was minimal compared to the other sixteen traits. The main difficulty in determining character state was differentiating between character state 1

(elliptic) and character state 3 (parabolic). There are different levels of constriction in the elliptic shape, and this is often difficult to determine when the constriction is slight. Elliptic was also more difficult to determine when the third molar was missing, which was common in the Nubian collection. Differentiating between character state 2 (parabolic A) and character state 3 (parabolic B) is also difficult as they only differ in the level of gradual flaring posteriorly. The line sketches for these three character states are shown below in figure 5-3.

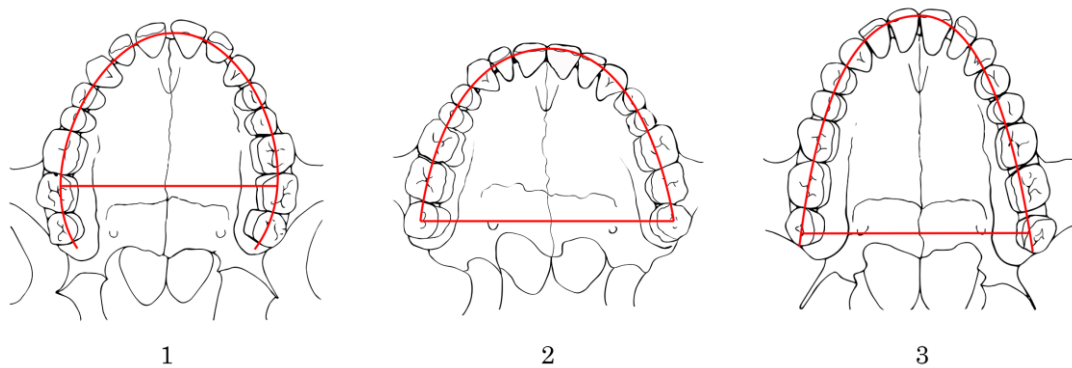


Figure 5-3. The first three character states of palate shape. 1 = elliptic; 2 = parabolic A; 3 = parabolic B. Line drawings and descriptions obtained Hefner (2009, 2012) and Osteoware (2011). See figure 3-3 for more details.

It is recommended that training be completed with crania of various ancestries to become more familiar with the different widths, shapes, and sizes of the palate before applying this knowledge to a study.

While the nasal aperture shape had an intra-observer error rate of substantial ($k = 0.696$), there was some difficulty in scoring this trait. The main confusion stemmed from the definitions and line drawings supplied in MMS v.1.6. The line drawings for the nasal aperture shape are displayed in Figure 5-4 below.

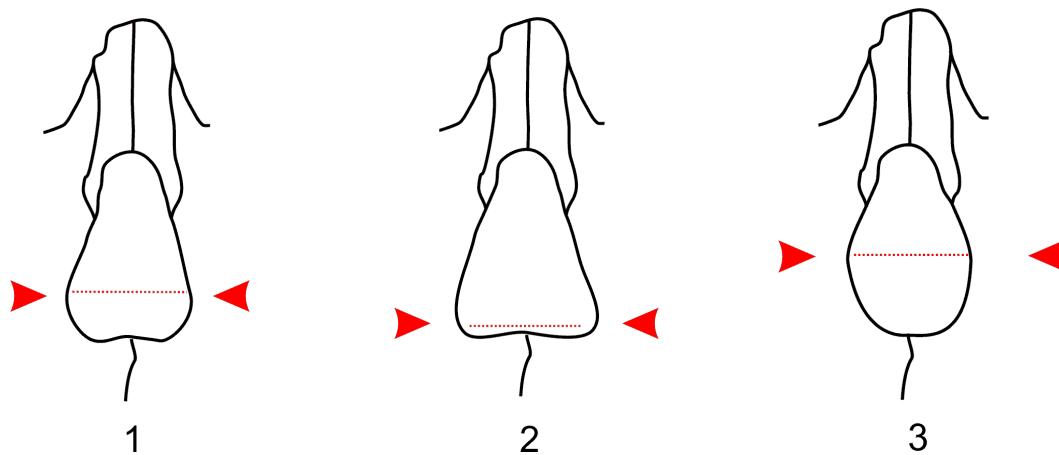


Figure 5-4. The character states of nasal aperture shape. 1 = teardrop; 2 = bell shape; 3 = bowed. Line drawings and descriptions obtained Hefner (2009, 2012) and Osteoware (2011). See figure 3-3 for more details.

The depiction of character state 3 for nasal aperture shape is clear. However, while character states 1 (teardrop) and 2 (bell shape) appear clear in their depictions, they are less so when viewing physical crania. The line drawings are two-dimensional, and therefore do not fully take into consideration the variation of the inferior portion of the nasal border. Within the Nubian collection, a large number of the crania presented smooth and guttered inferior nasal sills. The more anterior part of this sill often dipped so that the posterior border of this sill was in plain view. The lateral borders of the nasal aperture would either curve and continue its course into the anterior sill or it would continue downward and curve more inferiorly. Therefore, the greatest lateral projection was often difficult to decipher depending on the width of the inferior nasal sill. While this possible error in scoring did not strictly affect this study or result in a low intra-observer error, the nasal aperture shape may result in lower intra-observer error in future studies.

The presence of some lower intra-observer error results is not surprising. A recent paper, which was presented as a poster at the 2017 American Academy of Forensic Sciences 69th Annual Scientific Meeting in New Orleans, LA, discussed a fourteen-year intra-observer error

study conducted to understand observer error and experience when analyzing macromorphoscopic traits (Kamnikar et al., 2017; Kamnikar and Hefner, 2017). Results of this test observed four patterns: (1) extreme character expressions were less frequently observed over time; (2) improved technology, such as the contour gauge, produced better defined clusters of trait scores; (3) a trait transposition and smoothing in the original data; and (4) improvement with standardized trait definitions. Overall, it appeared that observer experience played a large role in the intra-observer rate. Over time, the observer appears less likely to score extreme character expressions, whether minimum or maximum score, and is more likely to demonstrate a higher proportion of intermediate scores. Therefore, a moderate level of observer error should be expected as an analyst becomes more familiar with and confident with data collection over time.

Overall, the intra-observer scores presented in Table 4-7 represent a relatively high level of accuracy due to training and standardized trait definitions. The MMS v.1.6 software continues to be updated and improved. With newer technologies and the standardization of data collection strategies, there is potential to further reduce observer differences (Kamnikar et al., 2017; Kamnikar and Hefner, 2017). This study, as well as the past literature, supports that macromorphoscopic traits and their scored character states may help easily and accurately assess ancestry.

While not an intra-observer error, another limitation existed in this study through small sample size for the East West African population group ($n = 30$) and missing data. The missing data are most notable for the following macromorphoscopic traits: NAS, NBS, NFS, OBS, SPS, TPS, and PS. This was handled through listwise deletion, which includes the exclusion of a population group if a value or character state is absent. Missing data is an intrinsic problem in both biological and forensic anthropology due to the fragile nature of osseous material,

particularly due to factors such as taphonomic processes and time (Kenyhercz et al., 2016).

Studies regarding the best analytical method to be used for missing data in macromorphoscopic trait research are currently ongoing (Kenyhercz et al., 2016). While it is felt that listwise deletion appropriately handles missing data for this particular type of analysis, the missing values affected the CA and CAP analyses, especially in light of the missing midfacial character states. However, it should be remembered that cranial variation and population relations should be analyzed using a suite of traits and not one individual trait. Therefore, while methods such as imputation, or the estimation of missing values through the other observed values (Kenyhercz et al., 2016), may have been used to handle the missing data, it was necessary to introduce less bias. Listwise deletion was used, as it is a method that provides unbiased estimates when the missing data depend only on the predictor variables and not the response variables (Glynn, 1985; Little, 1992). Therefore, while these missing data were a limitation, it is not considered to be a major concern in terms of this thesis.

CHAPTER 6

CONCLUDING STATEMENTS

Methods related to ancestry assessment, an integral part of the biological profile determined by forensic anthropologists, have continually developed and improved in recent years. Key to this are the differences in patterns of cranial morphology used to view differences in population groups. The midface is the most prolific area used in ancestry prediction. A view of these patterns holistically, and a knowledge of the frequency of expression and distribution, may aid in a better understanding of human biological variation, as well as lend itself to a more valid and standardized assessment of ancestry. Therefore, research similar to this thesis is necessary and essential to understand the temporal distribution of macromorphoscopic trait expressions, and thus the secular change affecting that distribution.

The goal of this thesis was three-fold: to use cranial macromorphoscopic traits to add to the growing set of data in the statistical assessment of ancestry; to explore the presence of secular change in Native African and American Black populations; and, to assess the ability and potential of macromorphoscopic traits in the determination of the presence of secular trends. Null hypothesis one resulted in failure to reject, and null hypotheses two and three were rejected. Overall, secular change was present among and between the populations, particularly in the midface and nasal region. As with previous research, the trend viewed in macromorphoscopic trait expression was a general narrowing and shortening of the face. Both short-term changes and long-term changes in trait expression were observed. Therefore, the results of this thesis demonstrate that cranial macromorphoscopic traits can, indeed, be used to assess ancestry accurately, can provide error rates in those assessments, and can be utilized to assess population relatedness through an exploration of secular change.

Forensically, the results of this study are important. This thesis not only contributes to a growing database of population trait expression, but also validates the methodology. Hefner's (2009) revised definitions and line drawings of the macromorphoscopic trait character states (Tables 3-3 through 3-19) reduce subjectivity and provide a simple, quick method for data collection and assessment of nonmetric traits. In light of the *Daubert* guidelines and the 2009 NAS Report, there has been a higher demand across forensic science fields for more validation studies, increased standardization, and a higher degree of certainty in research. Therefore, statistical application and the calculation of significance in trait manifestation are essential. Through methods like the CA and CAP analyses, it is possible to further decrease the level of traditional subjectivity in the interpretation of these traits. Using a statistical model, proper weight may be assigned to the importance of a macromorphoscopic trait and, therefore, decreases the emphasis placed on observer experience (Hefner, 2016). As also illustrated by the CAP analyses (Figures 4-31 and 5-1), some nonmetric traits may be more important for correct classifications of ancestry than others, depending on population group. For the four population groups used for this thesis, nine of the seventeen macromorphoscopic traits—ANS, INA, IOB, MT, NAW, NBC, NO, PBD, and ZS—contribute more to a correct assignment. This, again, places great emphasis on the midface region. Therefore, the use of joint distributions, rather than the use of a single trait, optimizes the classification of ancestry.

Data for cranial variation and trends of craniofacial secular change should be collected and studied (Jantz, 2001). In a world of ever-increasing communication, environmental shift, and modes of transportation, human variation and secular change will not abate. As a product of both genetic and environmental components, human crania will react to genetic and environmental

factors and stimulants. Promoting continued study for both past and future secular trends is an important research arena for forensic anthropologists.

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