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A Morphometric Examination of Cranial Vault Modification in the Middle Cumberland Region of Central Tennessee

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A Morphometric Examination of Cranial Vault Modification in the Middle Cumberland

Region of Central Tennessee

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Degree

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Gregory James Wehrman

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ABSTRACT

Cranial vault modification (CVM) is a physical manifestation of intersections between culture and biology. Cultural practices that apply pressure to the head during infancy result in significant reshaping of the skull and can be either intentional or unintentional. Occipital flattening is present among many Mississippian skeletal samples from the Middle Cumberland Region (MCR) of central Tennessee and is thought to be an unintentional result of childcare practices. Traditional methods for CVM classification have concentrated on visual assessment of location and means of flattening; however, this method is subjective. This thesis seeks to evaluate visual assessment of CVM through a morphometric analysis of cranial landmarks using 3D scanning technology. The hypothesis tested is that shape differences among MCR crania correspond to visual assessment of CVM presence. Additionally, morphological variation in cranial shape is examined for sex differences that may correspond to differential cultural practices performed on males and females. Finally, differences in cranial shape variation by site are tested to determine if CVM practices differed within the MCR.

This thesis examines CVM within the Arnold (n=23), Bowling Farm (n=14), and Averbuch (n=47) Mississippian skeletal samples from the MCR. Landmark coordinate data is extracted generated from high-resolution 3D models of MCR crania. A principal components analysis is performed to examine the magnitude and directionality of changes in landmark distributions among individuals. Additionally, discriminant function analysis (DFA) and canonical variate analysis (CVA) is employed in order to evaluate whether variation in cranial landmark locations corresponds with modified and unmodified categories determined by visual assessment, sex, or site membership.

Results indicate that morphological variation exhibited by MCR crania largely correspond to categories determined by visual assessment of CVM. Additionally, there is no morphological distinction by sex among modified crania, indicating that CVM practices were not performed differently between males and females in the MCR. Finally, differences in shape variation among MCR sites are demonstrated and archaeological explanations for those differences are explored. The results of this thesis contribute to a larger body of anthropological literature concerned with Mississippian occupation of the MCR, for which no ethnographic evidence exists.

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CHAPTER 1: INTRODUCTION

The native people who inhabited the Middle Cumberland Region (MCR) of central

Tennessee have fascinated and been a source of mystery to the residents of Nashville ever since

Euro-American settlers first came to the area in 1779 (Ferguson, 1972). The "stone grave

peoples", an early moniker in reference to the ubiquitous burials enclosed with limestone slabs,

left little evidence for historic Americans to reconstruct their history. As a result, many initial

conceptions of these earlier people were steeped in myth. For instance, an early popular idea was

that the area was inhabited by a "race of pigmies", though in reality the graves in question were

of children (Ferguson, 1972; Jones, 1876). Further, early archaeologists classified many of the

individuals from the area as belonging to "the short headed nations" in reference to a distinct

skull shape (Putnam, 1878). We now understand that this skull shape, far from characterizing a

single group, is the result of artificial reshaping of the cranial vault. Though years of archaeology

has described the native history of this region in considerably more practical terms, no

ethnographic sources exist for the Mississippian period residents of the MCR and many

questions remain unanswered regarding their origin, social structure, and why they seem to have

abandoned the region by 1475 CE (Moore and Smith, 2009). This thesis examines cranial

modification, a single aspect of culture in the MCR, and serves as a contribution to the growing

body of anthropological research focused on a further understanding of these Mississippian

Native American societies.

Cranial vault modification (CVM) is a cultural practice that results in permanent

alterations to skull shape. Boasting a wide geographic span, artificial reshaping of the skull has

been practiced in the Americas, Africa, Europe, Asia, Australia, and the Pacific Islands

(Blackwood and Danby, 1955; Dingwall, 1931; Duncan and Hoffling, 2011; Durband, 2008;

Logan et al., 2003; Neumann, 1942; Torres-Rouff and Yoblansky, 2005; Trinkaus, 1982).

Cranial vault modification can be intentional and produce distinct skull shapes, as in Andean

South America, or unintentional as a result of childcare practices like cradleboarding. As an

intersection between culture and biology, anthropologists have been interested in the social

factors that influence CVM, such as ethnic group membership, status, sex, and aesthetic ideals

(Blackwood and Danby, 1955; Knudson and Torres-Rouff, 2009; Weiss, 1962). Particularly

intriguing among interpretations of CVM as a reflection of social identity are those that treat

modification practices as ethnic markers reflective of group membership, examples of which

have linked differences in CVM with the presence of migrant or diasporic groups, female

exogamy, and admixture between historically distinct populations (Knudson and Torres-Rouff,

2009; Logan et al., 2003).

Before interpretations regarding social identity can be made, however, a reliable

classification of skulls into categories that correspond to presence of modification must take

place. Visual assessment of modified crania has traditionally been the predominant method for

classification of CVM, as it is time-efficient and does not require special equipment. Despite

these benefits, visual assessment of CVM has certain limitations. Specifically, the absence of a

single standardized classification system and a disregard for intra-observer error in CVM

classification make visual assessment a relatively subjective method (Clark et al. 2007).

Additionally, many systems that rely on visual assessment of CVM impose stages in an attempt

to consolidate a continuous range of degree of modification within a particular style into a few

discrete categories, thereby ignoring a large amount of morphological variation (Pérez et al.,

2009).

Many classification systems exist to categorize CVM into styles based on different criteria (Allison et al., 1981; Dembo and Imbelloni, 1938; Neumann, 1942). For example, several classification schemes for CVM attempt to categorize crania based on perceived flattening mechanisms (Dembo and Imbelloni, 1938; Dingwall, 1931). Alternately, Allison and colleagues (1981) described styles of cranial modification by cultural affiliation along the coasts of Peru and Chile. Though several variations of classification systems exist, researchers have yet to agree upon a single system as a standard method. Therefore, categories of modification styles determined by these methods can vary between researchers, adding a level of subjectivity to CVM assessment. Additionally, little attention has been paid toward inter-observer error in traditional assessment of CVM (Pérez et al. 2009). This further problematizes how CVM is evaluated, as there is no estimate of confidence in categorical determination between researchers, even if they are using the same classification system.

Furthermore, it is difficult to distinguish between slight cranial modification and natural cranial variation. Within a particular modification style, the degree to which a skull is flattened is dependent on both the amount of pressure exerted on bone and the frequency and duration at which it is applied (Torres-Rouff, 2002; Trinkaus, 1982). Traditional classification, however, does not always take into account varying degrees of CVM, instead conceptualizing discrete categories or stages rather than a continuous spectrum. Disregard for a continuous range of flattening degree can be problematic because it can affect how a cranium is classified in terms of cranial modification. For example, if CVM is present but is of slight degree and visibly difficult to detect, it may be classified as unmodified due to its visual dissimilarity to the typical representation of a particular modification style. Thus, there is a need to quantitatively describe

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morphological variation between modified and unmodified crania in order to account for the continuous variability in degree of flattening.

Many researchers have employed morphometric techniques to describe morphological variation of the skull associated with CVM (Antón, 1989; Cheverud et al., 1992; Frieß and Baylac, 2003; Kuminsky and Tung, 2012; Pérez et al. 2009; Rhode and Arriaza, 2006). Morphometric methods have allowed researchers to assess changes to the cranial vault, base, and face resulting from CVM (Antón, 1989; Cheverud et al., 1992; Frieß and Baylac, 2003; Kohn et al. 1995). Researchers have also used morphometric techniques to examine variation in skull shapes resulting from CVM both within and between groups that practiced modification (Kuzminsky and Tung, 2012; Pérez et al. 2009). Morphometric approaches provide a quantitative description of differences in skull shape that allows researchers a more empirical classification of CVM than traditional visual assessment (Clark et al. 2007). Additionally, by quantifying shape variation through either metric or landmark studies, morphometric methods allow for an evaluation of intra- and inter-observer error that demonstrate the reliability of shape data. Given the aforementioned benefits of quantitative shape analysis, a geometric morphometric approach is used to examine CVM within MCR sites in central Tennessee.

Mississippian occupation of the Middle Cumberland Region dates from around 1000-1475 CE (Moore and Smith, 2009). The MCR describes an area occupied by distinct Mississippian cultures that flourished along the Cumberland River drainage in the Nashville Basin region of central Tennessee and Kentucky (Moore et al., 2006). Cultural characteristics associated with MCR sites include the presence of both platform and burial mounds, shell-tempered pottery, and stone-box graves (Moore et al., 2006). Additionally, skeletal remains excavated from these sites exhibit cranial modification in the form of flattening of the occipital

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and lambdoidal regions of the skull, a modification style that has been described as "probably unintentional" (Neumann, 1942). Given that no direct ethnographic accounts of MCR cultures exist, the archaeological record is our only source of information available regarding this period in Native American history.

This thesis seeks to quantitatively address whether or not differences in cranial landmark variation exist that can be used to differentiate modified skulls from unmodified skulls in the MCR using skeletal assemblages from three sites: Arnold (40WM60), Bowling Farm (40DV426), and Averbuch (40DV60). If a morphological distinction exists, it should be possible to reliably group individuals based on variation in landmark distribution in a way that corresponds to whether a cranium is classified as modified or unmodified through visual assessment. Additionally, it is possible to determine in what ways they differ by examining direction and magnitude of differences in relative landmark loci. If MCR crania can be reliably separated into modified and unmodified categories, morphological variation will be further examined to understand possible cultural differences in modification practices among MCR groups. Since previous researchers have observed that CVM can differ by both sex and group membership (Blackwood and Danby, 1955; Blom, 2005; Dingwall, 1931; Knudson and Torres-Rouff, 2009), this thesis will further test for morphological differences in MCR crania by sex and among sites, as indicated by how reliably morphological data can separate crania along these lines. Therefore, this thesis hypothesizes that morphological differences can be used to (1) reliably classify MCR crania as modified and unmodified, (2) reliably classify MCR crania as male and female, and (3) reliably classify MCR crania by site.

By describing and examining patterns of CVM within MCR samples, the results of this project will contribute to the body of archaeological research concerned with pre-contact Native

American culture and social structure. Such research is important in reconstructing MCR history in the absence of ethnographic accounts. Furthermore, by characterizing CVM using a quantitative method, this project will provide an example of how geometric morphometric approaches can be employed to improve objectivity and evaluate visual assessment of CVM in skeletal samples.

CHAPTER 2: CRANIAL VAULT MODIFICATION RESEARCH

Cranial vault modification (CVM) has long interested anthropologists as an example of culture's influence on human biology. The geographic and temporal span of CVM is quite wide and the interpretations of the practice are similarly varied. Occurrences of CVM have been found in skeletal remains from native groups in Mesoamerica, Andean South America, North America, Pacific Islands, and Australia (Blackwood and Danby, 1955; Dingwall, 1931; Duncan and Hoffling, 2011; Durband, 2008; Logan et al., 2003; Neumann, 1942; Trinkaus, 1982). Bioarchaeological research has largely focused on intentional cranial modification as a means of identity expression, associating CVM with ethnic membership, aesthetic ideals, and status (Blackwood and Danby, 1955; Blom, 2005; Tiesler, 2012). Intentional forms of cranial modification exist in North America along with unintentional modification, such as skull flattening associated with cradleboarding, the cultural practice of binding an infant to a crib or carrier apparatus for the first few years of life (Logan et al., 2003; Neumann, 1942). Since unintentional cranial vault modification can result in considerable variation of cranial shape, it can be difficult to make statements regarding social identity drawn from the cranial modification present in certain North American samples. However, morphometric analyses may be helpful in capturing shape variation between modified and unmodified crania that is not easily observed visually, thereby aiding in classification of CVM.

Cranial Development and CVM Implementation

The bones of the skull can be divided into two general categories: the splanchnocranium, or those bones that make up the facial skeleton, and the neurocranium or those flat bones that cover and protect the brain (Tiesler, 2013). Furthermore, the neurocranium can be divided into

the calvarium, or cranial vault, which encompasses the brain superiorly, laterally, and posteriorly, and the basicranium which supports the brain from below (Schoenwolf et al., 2015). As this thesis is concerned with the bones that surround the brain, particularly the cranial vault, emphasis will be placed on the calvarium and basicranium in discussion of cranial growth and development.

The cranial vault is comprised of dermal bones, or bones formed from direct ossification in embryological mesenchyme (Schoenwolf et al., 2015; Tiesler, 2013). Dermal cranial bones include the frontal, parietal, nasal, and lacrimal bones, as well as the squamous portions of the occipital and temporal bones. These bones do not complete ossification in utero and continue to exhibit plasticity into early life. Plasticity permits the skull to pass through the birth canal without obstruction and allows expansion of the cranial vault accompanying rapid brain growth throughout early childhood (Shoenwolf et al., 2015). The majority of cranial vault expansion occurs within the first two years of life and then expands at a significantly reduced rate (Tiesler, 2013). Though elasticity of the cranial vault bones slows with age, an increase in cranial vault capacity can persist to about 15-16 years of age (Moore et al., 2014).

By contrast, endochondral bone forms from ossification centers that replace cartilage models. In the human skull, endochondral bones form the basicranium and include parts of the occipital surrounding the foramen magnum, as well as the sphenoid and ethmoid bones. Endochondral bone begins to undergo ossification during the seventh week of embryological development and is mostly complete before the dermal bones of the calvarium (Tiesler, 2013). Relatively advanced ossification provides the braincase with a sturdy base and provides structure for important vessels and nerves associated with brain function (Tiesler, 2013).

Plasticity of the human skull during early life has been recognized by different cultures throughout history that have manipulated skull shape through artificial cranial vault modification (Blackwood and Danby, 1955; Dembo and Imbelloni, 1931; Dingwall, 1931; Torres-Rouff and Yablonsky, 2009). Prolonged application of binding, pads, boards, or other flattening apparatuses to an individual's head during infancy can result in significant cranial reshaping (Dingwall, 1931). By restricting the direction of cranial growth, the resulting skull may have a flattened or conical shape. If an apparatus is applied long enough and with sufficient pressure, the bones of the skull become less plastic with age and permanent cranial modification results (Dingwall, 1931). The application of a modification apparatus usually takes place shortly after birth and is halted at around 6 months to 1 year of age (O'Loughlin, 2004).

Modification apparatuses include stones, boards, pads, or textiles and the use of these materials has been generally grouped into two broad modification styles: anteroposterior and circumferential modification (Antón, 1989). Anteroposterior, or tabular, modification results from the prolonged application of one or two flat surfaces to an infant's occipital, frontal, or both regions of the skull (Antón, 1989; Dingwall, 1931). Accordingly, this results in frontal and occipital flattening, though occasionally only occipital flattening is present (Antón 1989). Due to the limitation of growth in both an anterior and posterior plane, the skull compensates by expanding in a superior and lateral direction (Antón, 1989; Tiesler, 2013). A common effect of anteroposterior modification is parietal bulging, which produces a heart-shaped appearance when a skull is viewed superiorly (Antón, 1989; see Figure 1). In terms of occipital flattening, the plane of the occipital can be vertically positioned or more obliquely oriented (commonly referred to as tabular erect and tabular oblique, respectively), with a gradient existing between these forms (Antón, 1989).

Circumferential or annular cranial vault modification results from wrapping an infant's skull with textile or some other type of binding (Dembo and Imbelloni, 1938; Dingwall, 1931). Since growth of the cranial vault is restricted in lateral, superior, and inferior directions, compensatory growth occurs in a supero-posterior direction (Antón, 1989). Circumferentially modified skulls exhibit an elongated conical shape without the parietal bulging characteristic of anteroposterior flattening (Antón, 1989; Dembo and Imbelloni, 1938). Erect and oblique forms of circumferential modification have been observed, similar to tabular modification forms, and are distinguished from each other by the angle at which compensatory growth occurs (Antón, 1989; Dembo and Imbelloni, 1938).
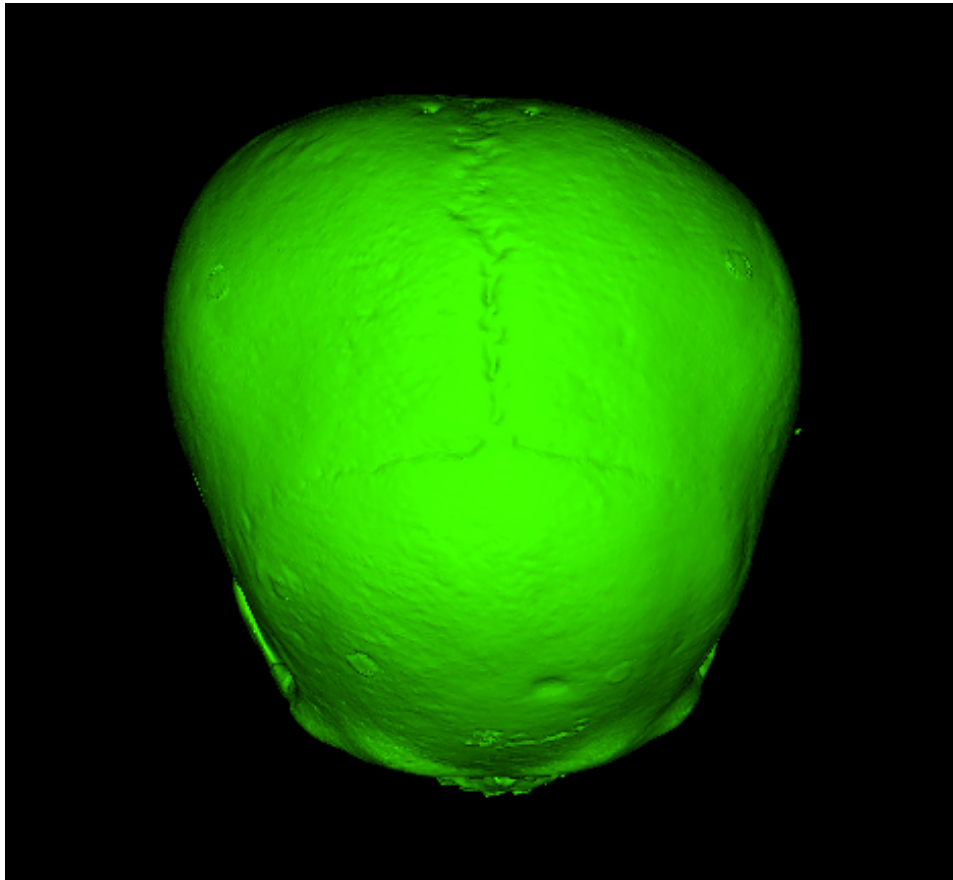
Figure 1: Bowling Farm crania exhibiting parietal bulging as a result of occipital flattening.

Cranial vault modification also results through unintentional habitual actions during infancy. One of the most well known examples of unintentional modification is through the use of cradleboards or cribs. The use of cradleboards has been documented among many North American, Mesoamerican, and South American indigenous groups (Dingwall, 1931). Cradleboards usually consisted of a rigid back piece that could be cushioned with plant fibers, rope or textile straps to secure an infant in the apparatus, and occasionally a hood piece that protected the infant from the elements (Dembo and Imbelloni, 1938; Dingwall, 1931; Tiesler, 2013). The function of a cradleboard was to restrict movement of the infant while still allowing general childcare from caregivers (Tiesler, 2013). Cradleboards could be stationary or portable, the portable style allowing caretakers to carry out tasks without neglecting the infant (Dembo and Imbelloni, 1938; Tiesler, 2013).

An infant routinely restrained in a cradleboard for long periods of time could exhibit posterior flattening as a result of prolonged pressure with the frame of the apparatus (Dingwall 1931; Tiesler, 2013). In addition to posterior flattening, circumferential grooves can be present along the skull where cords or textiles secured the infant's head to the cradleboard. Tiesler (2013) argues that additional intentional cranial modification apparatuses were incorporated into cradleboards in Mesoamerican groups. Two planes of compression were used to produce a modification style, one usually being the backboard and the other either an upper or frontal plane (Teisler, 2013). The resulting pressure expressed a variety of modification styles, usually variants of the tabular classification. Dembo and Imbelloni (1931) argue that the mode of restraint is a factor in the style of CVM resulting from cradleboarding. A tabular erect modification from cradleboarding could be brought about by general bodily restraint, while tabular oblique and annular would result from specific cranial apparatuses (Dembo and

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Imbelloni, 1931). Additionally, asymmetrical flattening may occur from habitual side-biased movement of the child's head within the cradleboard (Tiesler, 2013).

Unintentional flattening of the occipital region can also result from an infant sleeping in a supine position on a relatively hard surface (Dingwall 1931). Bean and Speidel (1923) note that a flattened occiput is a widespread characteristic among Filipinos because of their use of thin bedrolls. More recently, occipital flattening became more common among modern Americans after a 1992 campaign by the American Academy of Pediatrics encouraged parents to put infants to sleep on their backs in hopes of preventing Sudden Infant Death Syndrome (SIDS) (Biggs, 2003).

Social Identity and Cranial Vault Modification

Identity, while a considerably broad term, can be thought of as an individual's conception of their self as well as their position in and relationship to larger social groups (Knudson and Stojanowski 2009). Unlike a person's internalized conception of self, an understanding of one's social context by their relationships to other individuals and groups is more accessible in archaeological and bioarchaeological research (Beaudry et al. 1991). Under the assumption that identity is expressed through material and behavior, archaeological perspectives can examine aspects of identity by engaging with material culture (Conlin Cassela and Fowler 2005). Material culture refers to artifacts, or objects made or altered by humans, and can include tools, clothing, art, as well as human and animal remains. Archaeologists are able to make statements about individual or group identity through consideration of material culture and the context with which it is associated.

It is the skeletal body that is the focus of study in bioarchaeological investigations of identity (Sofaer 2006). At large, bioarchaeology is concerned with the influences of behavior and

environment on biological bodies and the archaeological patterns that this interaction creates (Sofaer 2006). While questions specifically addressing social identity are relatively recent in the field, bioarchaeologists are well suited to examine questions of identity because of an acknowledgement that bodies are both biological and social entities (Knudson and Stojanowski 2009). Additionally, bioarchaeological methodologies offer unique perspectives for indicators of identity, including standard age and sex estimation, stable isotope analysis, biodistance, and genetic analysis (Knudson and Stojanowski 2008, 2009). Some of the forms of identity commonly researched in the field are sex, gender, age, social status, and ethnicity. While much of the research on these facets of identity has been historically studied in isolation, there has been a call for a more integrative multifactorial approach to the subject of identity (Buikstra and Scott 2009).

Because CVM is often viewed as a form of identity expression using the body as media, it has received considerable attention in bioarchaeological research concerned with reconstructing social structure in the past. In particular, CVM among ancient populations has been used to illustrate interactions among ethnic groups (Blom, 2005; Hoshower et al., 1995; Knudson and Torres-Rouff, 2009; Torres-Rouff, 2002). Contrary to the modern racialized usage of the term, the anthropological understanding of ethnicity refers to a more general group membership that is distinguished from other similar groups through differences in appearance or behavior (Barth, 1998). According to Goldstein on diasporic communities, an ethnic group "might be marked by distinctions in practice and activities, and thus by stylistic and practice-based ethnic distinctions" (2005, p. 33). As a cultural practice, CVM is subject to differences in practice, and therefore style, among groups and accordingly can serve as an ethnic marker (Knudson and Torres-Rouff, 2009). Indeed, bioarchaeological research has suggested that CVM

in the Andes and Eurasian steppes functioned in a way that demarcated group membership (Blom, 2005; Knudson and Torres-Rouff, 2009; Torres-Rouff and Yablonsky, 2005; Torres-Rouff, 2002; Torres-Rouff et al. 2015).

Blom (2005) examined cranial modification styles among sites in the Tiwanaku capitol, Tiwanaku Valley, Katari Valley, and Moquegua Valley in the southern Andes. A clear regional pattern of modification style was present: annular modification was dominant in the Katari Valley, tabular modification was the exclusive style in the Moquegua Valley, and both head forms were present in crania from the Tiwanaku capitol and surrounding sites (Blom, 2005). Additionally, temporal continuity in modification style is present in both the Katari and Moquegua Valleys (Blom, 2005). The author argues that the Tiwanaku capitol served as an exchange center where individuals originating from both regions lived and were buried and that distinctions in head form signaled ethnic membership (Blom, 2005).

Other researchers have similarly treated CVM as an ethnic marker to understand the relationship between the Tiwanaku capitol in the Bolivian altiplano and its affiliated sites. Torres-Rouff (2002) used modification styles and mortuary objects to make a case that there was not a physical Tiwanaku presence in San Pedro de Atacama and that the region instead had a more distant cultural affiliation with the capitol. Using multiple lines of evidence, including biogeochemistry and artifact analysis in addition to CVM examination, Knudson and Torres-Rouff (2009) concluded that the individuals interred at the Caspana cemetery site in the Atacama were local but had cultural ties to the altiplano, suggesting either a diasporic group or cultural fission from surrounding sites. Furthermore, variation in CVM styles existed within larger groups in the Andes, possibly distinguishing residential clusters within sites (Hoshower et al., 1995).

Many scholars have postulated that in some societies, differences in CVM style served to distinguish high status groups from the general population (Dingwall, 1931; Weiss, 1962). Particularly in Mayan archaeology, elites and royalty have been depicted with more exaggerated degrees of tabular modification (Teisler, 2013). Bioarchaeological research has largely not been able to corroborate this (Buikstra et al., 2004; Teisler, 1999; Teisler 2012), though certain exceptions in CVM styles appear to be patterned according to status in certain contexts (Teisler, 2013). Cranial vault modification with superior flattening appears to be associated with individuals in elite status burials in the Mayan Classic Period (Teisler, 2012).

Cranial vault modification has also been reported to differ among sexes in certain societies. Ethnographic accounts state that a modified head is attractive to the opposite sex in groups like the Songish in British Columbia or the Arawe in Melanesia (Blackwood and Danby, 1955; Dingwall, 1931). For this reason, Blackwood and Danby (1955) attribute a higher degree of annular modification among female Arawe to a longer period of head-binding during childhood. At several sites in the Atacama region of Chile where tabular styles of modification dominate, females have a much higher frequency of annular modification, which scholars have attributed to a possible practice of female exogamy (Knudson and Torres-Rouff, 2009; Torres-Rouff, 2002). Among many other groups, however, cranial modification does not vary significantly by sex in either presence or style (Blom, 2005; Hoshower et al., 1995; Kohn et al., 1995).

Morphometric Investigations of CVM

In addition to traditional visual assessment of CVM, many scholars have sought to quantify shape differences caused by modification using morphometric analysis. Imbelloni (Dembo and Imbelloni, 1938) proposed that CVM should be accounted for metrically using

standard cranial measurements when classifying and describing modified crania. More recently, geometric morphometric approaches to CVM have utilized sophisticated methods like landmark studies, thin plate splines, and Elliptic Fourier Analysis to describe shape differences among modified and unmodified crania (Boston, 2012; Cheverud et al., 1992; Frieß and Baylac, 2003). More specifically, geometric morphometric research has allowed researchers to examine effects of CVM on the cranial base and face, quantify variation of shape differences in CVM among groups, and providing a quantitative method for classification of CVM (Antón 1989; Clark et al. 2007; Kuzminsky and Tung, 2012; Pérez et al., 2009).

Because CVM primarily results in predictable changes to the cranial vault, early morphometric studies of modified skulls explored the inter-related growth processes between the cranial vault, basicranium, and facial skeleton (Antón, 1989; Teisler, 2013). These studies, however, reached differing conclusions as to the nature of these shape differences (Antón, 1989; Moss, 1958; Oetteking, 1924). To address this ambiguity, Antón (1989) compiled a sample size of 130 crania from coastal and highland Peruvian sites that exhibit anteroposterior, circumferential, and no modification to examine shape differences of the vault, base, and face using traditional cranial measurements. Antón's study found that changes to the vault can be summarized by a shorter, wider vault in anteroposteriorly modified skulls and a longer, narrower vault in circumferentially modified skulls in respect to the unmodified crania (Antón, 1989). Similarly, facial and base widths are larger with anteroposterior type and smaller with circumferential type modification (Antón, 1989). Cranial base angles increase regardless of modification type, though the underlying cause is likely different; circumferential modification produces posterosuperior migration of the frontal region, while anteroposterior modification produces anteroinferior movement of the basion-sella plane (Antón, 1989). The posterosuperior

migration of the frontals in circumferentially modified skulls also results in shallow orbits (Antón, 1989). Across all crania in the study, the nasal region and basion-sella plane orientation are relatively stable (Antón, 1989). This stability suggests that changes to the vault do not affect the inner table of the crania (Antón, 1989). Similar shape differences were demonstrated in subsequent landmark studies between crania exhibiting anteroposterior and circumferential modification (Cheverud et al. 1992; Kohn et al. 1995).

Morphometric analyses have also been employed to classify different types of cranial modification (Clark et al., 2007). Since visual classification of CVM can be subject to high levels of inter-observer error, coupled with discrepancies between different classification schemes, morphometric analysis provides a more objective approach to CVM classification by quantifying shape differences and variation (Clark et al., 2007). Clark et al. (2007) developed a discriminant function based on arc and chord measurements taken along the cranial vault midline of modified and unmodified crania from the Philippines. Among Philippine crania, the discriminant function showed 91.9 % agreement with visual classification, while in a subsequent test of the function on crania from North America, South America, and Australia, the function agreed with visual classification 89.7% of the time (Clark et al. 2007). The function was designed to be conservative so that modified crania could be classified as unmodified, but unmodified crania could not be classified as modified (Clark et al. 2007). The conservative nature of the function is somewhat limiting to its efficacy, however, since it requires that a skull exhibit a significant degree of flattening in order to be considered modified. Kohn and colleagues (1995) used discriminant function analysis in their study on asymmetrical flattening among Hopi cradleboarded crania to classify their sample as modified or unmodified. Slightly flattened skulls

were categorized as both modified and unmodified due to the large range of variation among unintentionally flattened crania (Kohn et al. 1995).

Finally, morphometric approaches have been used to address archaeological questions using cranial modification. For instance, Antón and Weinstein (1999) addressed the proposed close evolutionary relationship between modified fossil Australian *H. sapiens* crania and *H. erectus* crania by examining vault contours. Their results indicate that while fossil Australian frontals are similar to *H. erectus*, their parietals and occipital contours are dissimilar, therefore indicating a more distant evolutionary relationship (Antón and Weinstein, 1999). Kuzminsky and Tung (2012) examined ranges of shape variation among Peruvian crania and suggested that small ranges of variation may be attributed to the presence of a specialist class that implemented CVM practices. Pérez and colleagues (2009) used relative warp analysis to examine temporal and geographical variation of CVM throughout South America in a large-scale study incorporating many different groups. Results indicate continuity in CVM styles in certain regions, while other areas exhibited changes in modification style associated with shifts in subsistence strategies (Pérez et al., 2009).

Summary

Many cultures throughout human history have recognized the morphological effects of CVM and have adopted modification as a cultural practice. Cranial vault modification is caused by a prolonged application of pressure to the cranial vault during infancy while the bones of the skull are still malleable. A modified skull's morphology differs from normal skull shape as a result of flattening where pressure is applied and compensatory growth in directions other than the direction of pressure. Though some cultures have practiced CVM to intentionally produce a

modified skull shape, others have unintentionally produced CVM as a secondary effect of childcare practices.

Anthropological methods for assessing CVM have traditionally relied on visual assessment of skull shape. Several classification systems exist for describing different styles of CVM, but there is no agreed-upon standard system and thus CVM classification may not be comparable among different systems. Morphometric approaches have been used to quantifiably describe shape changes to the cranial vault, base, and face of the skull, as well as to classify different styles of CVM (Antón 1989; Cheverud et al., 1992; Clark et al., 2007; Kohn et al., 1995). An advantage of morphometric approaches to describe CVM is that they can provide morphological information that is not obvious in visual assessment. Given that a range of morphological variation exists from slightly modified to severe modification, this thesis examines whether visual assessment of CVM corresponds to morphological variation of cranial landmark locations.

Archaeological investigations have explored the social dimensions of CVM, including its associations with sex, status, and ethnicity. Dingwall (1931) and Blackwood and Danby (1955) note that the degree of flattening differs in some cultures by sex as a result of aesthetic ideals. Additionally, many researchers have treated CVM as an ethnic marker in that it is a cultural practice that is contextually specific, thereby producing identifiably distinct cranial morphologies among ethnic groups (Blom, 2005; Knudson and Torres-Rouff, 2009; Kuzminsky and Tung, 2012; Torres-Rouff et al., 2015). Therefore, this thesis will examine if cranial morphology resulting from CVM differs by sex and site using Mississippian skeletal samples from the Middle Cumberland Region of central Tennessee.

CHAPTER 3: MIDDLE CUMBERLAND REGION BACKGROUND AND SITE

DESCRIPTIONS

The geotemporal scope of this thesis is the Mississippian period of the Middle

Cumberland Region, sites of which are located along tributaries of the Cumberland River in

central Tennessee and were occupied from about 1000-1475 CE (Moore and Smith, 2009). Since

this period ends prior to European contact, no ethnographic information on MCR societies exists

and reliance must be placed on the period's archaeological record (Ferguson, 1972). The

majority of MCR sites are concentrated in the Central Basin, which is comprised of an elevated

outer basin with rugged terrain and a lower inner basin with smoother terrain (Moore et al.,

2006). Middle Cumberland Region societies were organized into complex chiefdoms, usually in

the form of platform mound centers or nucleated village sites with outlying rural hamlets and

farmsteads (Smith, 1992). Gathered from paleoethnobotanical and zooarchaeological analyses,

Mississippian societies in the MCR followed a subsistence pattern of horticulture, particularly of

maize and beans, supplemented by hunting and gathering of local fauna and wild plant foods

(Ferguson, 1972; Crites, 1984; Smith, 1982; Romanoski, 1984).

Middle Cumberland Region culture is archaeologically unique among Mississippian

societies in both burial practice and ceramic typologies (Moore et al., 2006). It is common that

MCR burials are constructed in the Cumberland Stone Box style, where a burial box, commonly

constructed using limestone slabs, is fitted to the body dimensions of the decedent (Dowd, 2008;

Ferguson, 1972). The calcium carbonate of which limestone is composed has a neutralizing

affect on soil acidity, which may have contributed to bone preservation in MCR burials (Dowd,

2008). Distinct ceramic distributions are also characteristic of MCR sites, including the hallmark

shell-tempered pottery and Nashville negative painted wares (Beahm and Smith, 2013; Moore et

al., 2006). Though negative painted wares occurred elsewhere during the Mississippian period, Nashville negative painted wares are unique to the MCR, and are mostly found in mortuary contexts (Smith, 1992).

Moore and Smith (2009) provide a chronology of the Mississippian period in the MCR and emphasize political and structural shifts that divide the period into five regional periods. Early MCR sites were established by at least 1000 CE and took the form of mound centers and smaller village and hamlet sites (Regional Period I)(Moore and Smith, 2009; Spears et al., 2008). Spears et al. (2008) postulate that the emergence of MCR societies resulted from rapid population growth of local groups, in-migration from extra-local groups, or both. Following an eastward expansion in the Middle Cumberland valley from 1100-1200 CE (Regional Period II), chiefdoms that acted as political centers proliferated from 1200-1325 CE (Regional Period III)(Moore and Smith, 2009). A period of political decentralization occurred from about 1325-1425 CE (Regional Period IV) when smaller sites aggregated into fortified villages, which subsequently experienced a decline in size and number (Moore and Smith, 2009). During this period of political destabilization, extreme levels of conflict and disease affected MCR societies (Fojas, 2012; Moore and Smith, 2009; Worne et al., 2012). Moore and Smith (2009) estimate that the region was abandoned to the point of archaeological invisibility between 1425-1475 CE (Regional Period V). While the exact causes of this abandonment are unknown, the MCR is not unique as rapid Mississippian depopulation occurred throughout the American Bottom and Southeast (Cobb and Butler, 2002).

The three MCR sites used in this thesis are Arnold, Averbuch, and Bowling Farm. These sites are included because they are geographically close to one another, all being located around the Nashville perimeter. Additionally, Arnold and Bowling Farm represent early Mississippian

occupation in the MCR while Averbuch represents a late Mississippian occupation. Thus, the temporal span of these three sites (~1100-1475 CE) encompasses much of the MCR Mississippian period.

Arnold (40WM5)

The Arnold site is a small village site located nine miles south of present-day Nashville along the Little Harpeth River (Moore and Smith, 2009). The site is dated to 1142-1302 CE through radiocarbon dating and features a burial mound and residential structures (Ferguson, 1972; Moore and Smith, 2009). Edwin Curtiss first excavated this site in 1879, sending the partial remains of at least 24 individuals recovered from stone-box graves to the Peabody Museum of Archaeology and Ethnology at Harvard University (Moore and Smith, 2009; Peabody Museum, 2000). The 1879 excavation was focused on the burial mound, with most of the curated remains consisting of crania (Moore and Smith, 2009).

One hundred fifty-seven individuals were later recovered from the site between 1965-1966 by the Southeastern Indian Antiquities Survey (SIAS), an avocational archaeology group, though many of the skeletal remains are fragmentary (Ferguson, 1972). Seventeen residential structures were also excavated, built using wattle-and-daub construction and large posts (Ferguson, 1972). Ferguson (1972) firmly places the site as a Mississippian culture based on house structures, a horticultural subsistence pattern supplemented by hunting and gathering, exclusively Mississippian pottery, and stone-box burial practices. Further, the artifact assemblage at the site suggests little evidence of internal cultural change over the site's occupation, leading Ferguson (1972) to state that Middle Cumberland Culture is a culturally conservative society.

Bowling Farm (40DV426)

The Bowling Farm site is a burial mound site west of Nashville. Located on a low ridge along Richland Creek's eastern bank, Bowling Farm is dated to approximately 1100-1325 CE based on artifact distribution (Moore and Smith, 2009). This site is comprised of five burial mounds and may not have been residential (Putnam, 1878). Frederic Ward Putnam of the Peabody Museum and Major John Wesley Powell of the Smithsonian Institution excavated the five mounds together in 1877, estimating a total range of 600-800 burials with all but one individual being buried in stone-box graves (Moore and Smith, 2009). Remains of 59 individuals from Bowling Farm were recovered and sent to the Peabody Museum (Moore and Smith, 2009).

Putnam and Powell's observations from Bowling Farm were curated by the Peabody Museum and serve as the only substantial record of archaeological excavation at the site (Moore and Smith, 2009). In these field notes, Putnam speculates that the Bowling Farm mounds probably served as a burial site for a nearby residential settlement, archaeological evidence of which having been destroyed by land cultivation (Putnam, 1878). Mortuary artifacts recovered from graves were sparse, though Putnam notes that many of these may have been perishable (Putnam, 1878). Pottery fragments, stone tools, and other artifacts found within the mound were placed over the graves as offerings or memorials (Putnam, 1878).

Based on artifacts and skeletal material recovered at Bowling Farm, Putnam speculates a "very probably reception into the tribe of persons of another nation" (Putnam, 1878). His main argument for this is the presence of two distinct skull shapes, which he dubs "short headed" and "long-headed" (Putnam, 1878). The "short headed" crania were identified as local based on other observations from MCR excavations that feature similar skull shapes (Putnam, 1878). Putnam bolsters this argument with evidence from non-local artifacts that suggests a wide geographic

span for intertribal contact, such as a chisel made of non-local Mill Creek chert from southern Illinois and beads made from shells found along the southern Atlantic coast (Moore and Smith, 2009; Putnam, 1878). Interestingly, recent biodistance analyses of skeletal assemblages from the MCR seem to support Putnam's conjectures, indicating that Bowling Farm was an outlier among other MCR sites (Vidoli, 2012).

Averbuch (40DV60)

Averbuch, a large nucleated village site located north of Nashville, was surveyed in 1975 by the Tennessee Division of Archaeology and fully excavated by the University of Tennessee beginning in 1977 (Berryman, 1981; Reed, 1984a). Recent radiocarbon dates indicate that occupation at Averbuch began in 1265-1380 CE and ended in 1440-1475 CE (Cobb et al., 2015). The site had a relatively short occupation span of 70-205 years (Cobb et al., 2015). The site features a large settlement, cemetery, and palisade complex (Berryman, 1981). Based on paleoethnobotanical remains, corn was the main staple of diet at Averbuch, supplemented with beans, hickory nuts, and wild flora and fauna (Crites, 1984). Though excavation mostly focused on the burial component at Averbuch, 22 structures were excavated as well as portions of the palisade surrounding the village (Reed and Klippel, 1984). A total of 645 graves were excavated, yielding an estimated 887 individuals recovered (Berryman, 1981).

Given the large sample size that the recovered skeletal assemblage provides, Averbuch has been one of the more studied sites in the MCR (Berryman, 1981; Eisenberg, 1986; Fojas, 2012; Vidoli, 2012). Much of the attention Averbuch has received has focused on the evidence for high frequencies of disease and trauma, possibly indicating that the site experienced continual episodes of conflict (Berryman, 1981; Berryman, 1984; Fojas, 2016; Worne et al., 2012). The presence of a palisade and evidence of structural burning further support the hypothesis that

conflict, or at least a threat thereof, was present at Averbuch (Reed, 1984b). Additionally, one of the cemeteries at Averbuch is superimposed by a palisade, indicating a temporal component to cemetery use at the site for potential intra-site analysis (Berryman, 1981).

Summary

The Mississippian occupation of the Middle Cumberland Region flourished in central Tennessee from approximately 1000-1475 CE (Moore and Smith, 2009). MCR culture was distinct in mortuary practice and pottery styles like negative painted wares. The three sites included in this thesis' sample are Arnold, Bowling Farm, and Averbuch. Arnold and Bowling Farm are roughly contemporaneous early MCR sites, while Averbuch is a later MCR site. Many crania from these three sites exhibit CVM in the form of posterior flattening of the occiput, possibly the result of unintentional practices related to childcare (Neumann, 1942). Since a continuous range of flattening degree is present among modified crania, it can be difficult to visually distinguish slight flattening from unmodified crania. Therefore, morphometric analyses will be performed to evaluate visual classification of CVM within the MCR based on differences in cranial landmark locations among MCR sites.

CHAPTER 4: MATERIALS AND METHODS

Crania from the Arnold (40WM5), Bowling Farm (40DV426), and Averbuch (40DV60) skeletal assemblages was examined morphometrically to quantify shape differences between modified and unmodified crania, as well as shape differences that may exist between males and females and among sites. Inter-observer error of visual CVM was assessed to evaluate the consistency of CVM classifications between multiple observers. Coordinate data for six cranial landmarks was extracted from 3-D scans and subsequently standardized for size, orientation, and position using a generalized Procrustes analysis (GPA). A principal components analysis (PCA) was then performed to describe morphological variation among modified and unmodified individuals. Discriminant function analyses were performed to determine how well morphological differences correspond to sex and site. Additionally, inter-site shape variation between all three sites was examined using a canonical variate analysis (CVA).

Sample Selection

The sample size for the current study is comprised of 84 crania from a variety of osteological collections associated with three Mississippian sites from the MCR in central Tennessee (Table 1). The Arnold sample is comprised of two skeletal collections consisting of individuals recovered during Putnam's 1879 excavation and individuals recovered during the 1965-1966 Southeastern Indian Antiquities Survey (SIAS) excavation. These collections are curated at the Peabody Museum of Archeaology and Ethnology in Boston, MA and at Vanderbilt University in Nashville, TN, respectively. The Bowling Farm skeletal collection is also curated at the Peabody Museum. The Averbuch collection is curated at the Archaeological Research Laboratory through the University of Tennessee in Knoxville, TN. Crania from the

aforementioned collections exhibit differing degrees of lambdoidal or occipital flattening. The distinction between occipital and lambdoidal flattening is a difference in the plane of flattening, with occipital flattening being in a more or less vertical plane and lambdoidal flattening occurring at an anteriorly directed angle (Figure 2). Such a pattern of flattening is consistent with CVM that results from prolonged contact between a hard surface and an individual's posterior skull during infancy and has traditionally been associated with cradleboarding by archaeologists (Kohn et al., 1995; Logan et al., 2003; Neumann, 1942).

The main criterion for inclusion of individuals in this study's samples is completeness of the cranial vault. Individuals were included if preservation of the cranium was sufficient for extraction of the landmarks discussed below. The samples were previously estimated for sex and age by researchers other than the author following standard methods outlined in Buikstra and Ubelaker (1994) (Vidoli, personal communication; Tung, personal communication). Both sex and age estimation methods are based on pelvic and cranial features (Buikstra and Ubelaker, 1994). Individuals aged below 16 years were excluded due to their underrepresentation in this thesis' samples. Both male and female individuals are included in the samples (Table 1).

Visual Assessment of CVM:

Each skull was scored for CVM based on visual assessment using the methods outlined by Buikstra and Ubelaker (1994: 160-163). An individual's cranium was placed in Frankfort horizontal and scored for presence or absence of CVM based on visual inspection and whether the modification style is tabular, circumferential, or other. If present, the orientation of flattening (occipital and lambdoidal in this sample) was recorded. Finally, asymmetrical flattening was recorded if present. CVM designations resulting from visual assessment were evaluated by a discriminant function analysis to determine whether visual observation of CVM

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Table 1: Osteological Collections and Sample Sizes.

Collection Name	Collection Location	Number of Individuals	Estimated Sex			Number of Modified Individuals*	% modified*
			F	M	I		
Arnold	Harvard University, Cambridge, MA. Vanderbilt University, Nashville, TN.	23	10	11	2	22	95.7%
Averbuch	University of Tennessee, Knoxville, TN.	47	20	24	3	41	87.2%
Bowling Farm	Harvard University, Cambridge, MA.	14	7	7	0	6	42.9%
Total Sample Size		84	37	42	5	66	81.5%

* modification determined by author through visual assessment following Buikstra and Ubelaker (1994).
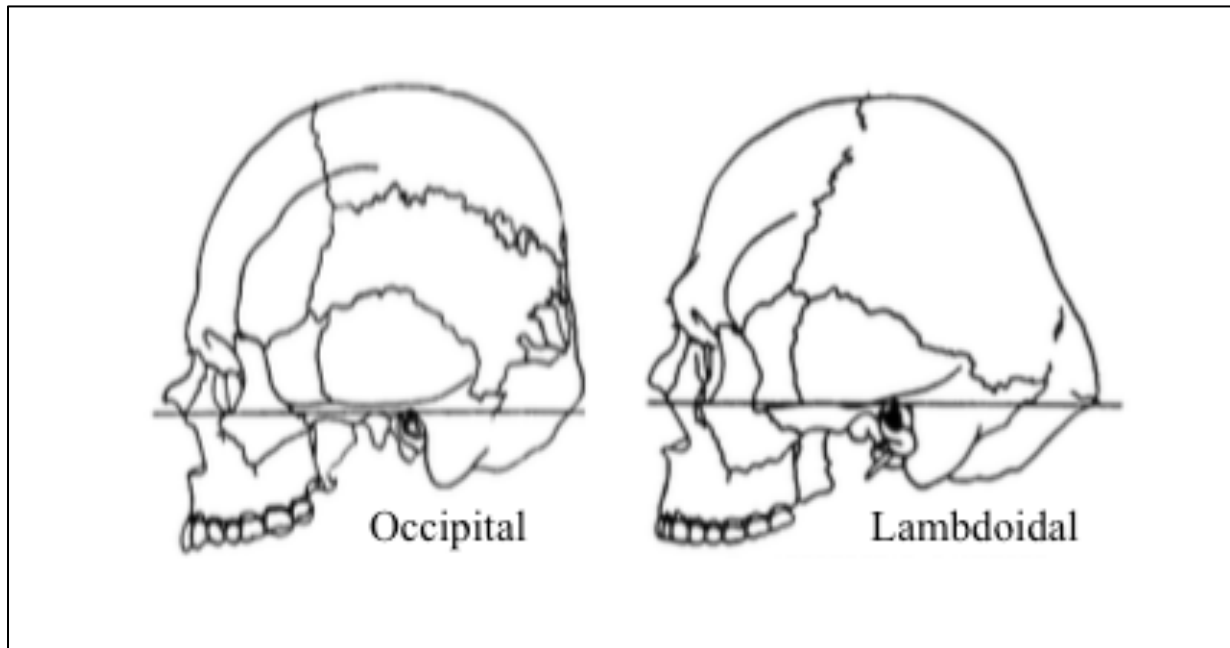
Figure 2: Occipital and lambdoidal flattening of the skull (adapted from Neumann, 1942).

corresponds to quantifiable morphological differences in cranial vault shape. Using visual assessment of CVM, the counts and percentages of modified individuals by site are listed in Table 1.

Landmark Extraction:

To assess differences in cranial morphology among modified and unmodified crania, three-dimensional data were collected from the same crania that were assessed visually using a NextEngine 3D Desktop Scanner (NextEngine, Inc., 2010; Model 2020i). Three-dimensional scans produce models with high resolution that capture cranial shape data. The high-resolution scans offer a curatorial function for preserving shape data for fragmentary remains or those awaiting repatriation. For each skull, two 360° scans were performed in wide-range focus in order to encompass the entire skull. Each 360° scan was partitioned into eight divisions, meaning each skull was scanned at eight equally spaced points of the scanner's revolution. A neutral image capture and a setting of 1,900 points per inch^2 were used to attain high resolution for each scan. Each cranium was oriented in an upright position for one 360° scan and was placed on its side for a second 360° scan in order to acquire shape data from the entire surface of the skull. The two scans were subsequently aligned using ScanStudio 2.0.2 (NextEngine, Inc., 2010) and fused to produce a single scan that was then used for landmark extraction.

Standard cranial landmarks are based on shared common features of a skull (i.e. the juncture of two sutures, the most posterior point along the midline, etc.). Therefore, the relative location of landmarks can be directly compared among individuals in order to assess morphological difference between modified and unmodified crania. Bookstein (1991) identified three types of landmarks. Type 1 landmarks are points where three structures meet in space, Type 2 landmarks are apices of a curve, and Type 3 landmarks are extremal points of

measurements (Bookstein 1991). Examples of Type I landmarks include the juncture of cranial sutures, like at bregma or lambda. Type II landmarks are maxima or minima of curves, like mastoideale, the maximum point of curvature of the mastoid process. Both glabella and euryon are Type III landmarks, as their definition is relative to maximum cranial height and breadth, respectively. Type 1 landmarks are preferred to Type 2 landmarks, which are preferred to Type 3 landmarks when considering biological relevance and error associated with identification (Bookstein 1991). Coordinate data from cranial landmarks was extracted from the high-resolution scans using ImageJ 3D Viewer (Version 1.49v; Rasband, 2015), an image-processing program. All coordinate data were collected in millimeters.

Six cranial landmarks were used in the current study: bregma, lambda, left and right euryon, and left and right asterion (Table 2; Figure 3). The landmarks are described following Howells (1973). Based on visual assessment of CVM within the sample, MCR crania exhibit posterior flattening without accompanying frontal flattening. Therefore, cranial landmarks of the posterior skull were selected to examine shape differences of the posterior vault. In addition to landmarks situated along the midline of the cranium (bregma, lambda), lateral landmarks were included to account for shape differences occurring at the sides of the skull (euryon, asterion). Lambda, left asterion, and right asterion were selected to account for shape differences of the posterior skull as a result of posterior flattening. Bregma was selected to describe shape differences related to increased cranial height resulting from CVM. Euryon was chosen to describe shape differences associated with parietal bulging. Despite euryon being a Type III landmark, it is one of the only cranial landmarks that may account for shape differences in the parietal bone. In sum, the cranial landmarks included in the present study encapsulate posterior cranial vault shape.

Table 2: Cranial Landmark Descriptions.

Landmark	Type	Description
Asterion (L/R)	I	The junction of the temporal, occipital, and parietal bones on each side.
Bregma	I	The posterior border of the frontal bone in the median plane.
Euryon (L/R)	III	The widest point of the skull in a transverse plane.
Lambda	I	The junction of the occipital bone with the parietals in the median plane.
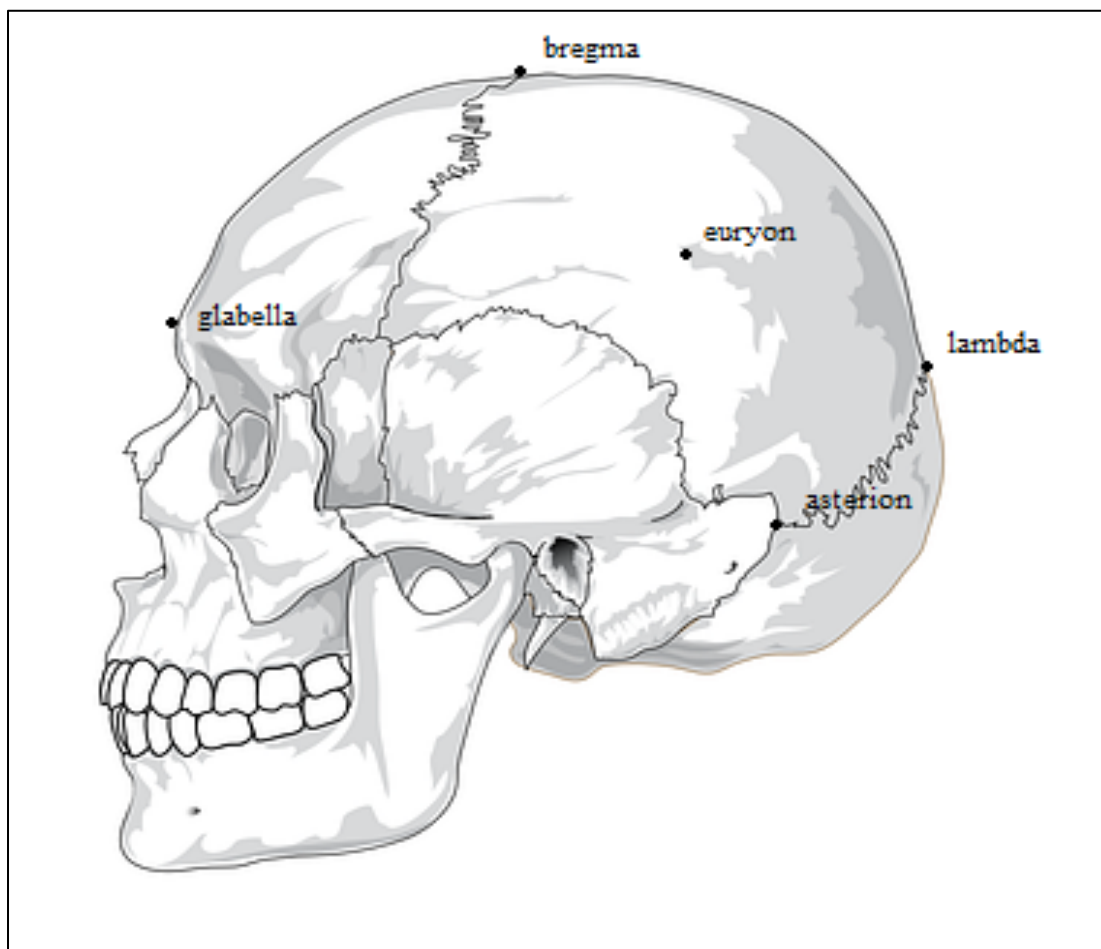
Figure 3: Locations of Selected Cranial Landmarks.

Measures of Inter-observer Error in Visual Classification of CVM:

An assessment of inter-observer error was performed to assess repeatability of visual assessment of CVM following Buikstra and Ubelaker (1994). A second researcher, Giovanna Vidoli, previously assessed CVM for 17 of the MCR crania included in this thesis' sample from 2006-2008 as part of a large-scale analysis of MCR sites (Vidoli, 2012). Vidoli's previous assessments allow for comparison of CVM classifications generated by herself and the current author. Since the previous researcher's data includes only modified crania, the consistency of classifications for occipital and lambdoidal flattening was compared. Given the small sample size, a Fisher's exact test was performed in R (R Core Development Team, 2012) to determine if relative frequencies of recorded occipital and lamdoidal flattening are significantly different between observers, indicated by a *p*-value less than 0.05. Additionally, the percent agreement between observers was presented.

Statistical Analyses:

All morphometric statistical analyses were performed using MorphoJ (Version 1.06d; Klingenberg, 2011). MorphoJ is a statistical program that performs various morphometric analyses on both coordinate and measurement data. The following analyses were used to explore differences in relative landmark loci: generalized Procrustes analysis (GPA), principal components analysis (PCA), canonical variate analysis (CVA) and discriminant function analysis (DFA). By using the methods above, the major directions of morphological variation among crania can be identified and individual crania will be placed into categories based on these shape differences. If the resulting categories reflect presence or absence of CVM comparable to gross visual assessment, then the first hypothesis of this thesis will be supported. The second and third

hypotheses will be accepted if morphological variation can reliably categorize crania by sex and site, respectively.

In order to compare landmark configurations, it is necessary to transform raw coordinate data into a common reference space via translation, scaling, and rotation (Slice 2005). Generalized Procrustes analysis is a least-squared method that seeks to minimize differences between landmark configurations while maintaining morphometric integrity (Bookstein, 1991; Slice 2005; Zelditch et al. 2012). Rohlf and Slice (1990) provide the following summary of the steps of a GPA: 1) the centroid of each landmark configuration is translated to the origin of a coordinate space (translation); 2) the landmark coordinates are divided by the centroid size (scaling); and 3) a reference landmark configuration is chosen, around which subsequent configurations are rotated in order to minimize the sum of squared distances between corresponding landmarks (rotation). Respectively, the point transformations standardize the effects of position, size, and orientation so that the remaining variation in landmark distribution will be attributed to shape (Bookstein 1991; Gower 1975; Zelditch et al. 2012). Generalized Procrustes analysis is applicable when more than two landmark configurations are to be fitted in a common coordinate space, as is necessary when dealing with skeletal samples containing many individuals (Slice 2005). In GPA, the first landmark configuration acts as the reference configuration upon which all subsequent configurations are iteratively superimposed in order to determine the overall mean (Slice 2005). The superimposition process is then repeated to fit the configurations around the resulting centroid estimate until the decrease in summed squared differences among landmarks is negligible (Slice 2005). For the purposes of the current study, a GPA was performed to translate, scale, and rotate the raw coordinate data associated with each

cranium to standardize the position, size, and orientation of each suite of landmarks so that shape differences can be compared among individuals.

Principal components analysis was employed to assess the magnitude and directionality of shape differences among crania. Principal components analysis transforms variation from potentially correlated variables into uncorrelated principal components (PCs), which act as axes that describe the majority of the variation within a sample (Zelditch et al. 2012). The first principal component (PC1) explains the majority of the variation, while the second principal component (PC2) describes the most remaining unexplained variation possible under the constraint that it is orthogonal to the first principal component. The process is repeated until all of the variation within a sample has been explained by principal components. In PCA, the number of variables equals the number of PCs, and each subsequent PC describes a diminishing portion of the total variation compared to that PC's predecessor. Principal components analysis is ideal for simplifying and visualizing the main factors influencing variation among coordinate data (Zelditch et al. 2012). In the context of this thesis, principal components will indicate which landmarks exhibit the most variation within the sample and how these axes of variation result in morphological differences between modified and unmodified crania.

Principal component loadings describe the relationship between the original variables and the new principal component (Zelditch et al., 2012). Magnitude of landmark variation is represented by the absolute value of each PC loading, with higher values indicating larger magnitude. Directionality along a given principal component axis is represented by whether a PC score is positive or negative. PC loadings will be presented to quantitatively demonstrate magnitude and direction of cranial landmark variation among modified and unmodified crania. While the PC loadings provide information regarding magnitude and directionality of shape

changes in landmark locations, lollipop graphs allow for visual representation of these changes.

In a lollipop graph, major axes of shape differences are described using straight lines. The

"head" of a lollipop represents the mean shape of a given landmark, while the "stick" represents

the shape change in units of 0.1 Procrustes distance along the PC in question. While lollipop

graphs visually represent the axes along which major shape differences at landmarks are

occurring, it should be stressed that lollipops do not specify the directionality of shape changes

from unmodified to modified or vice versa. For example, the head will not necessarily

correspond to a modified state shape and, similarly, the tail end does not necessarily correspond

to the shape of an unmodified state. Instead, these graphs summarize the general directions of

variation in landmark location. The correspondence of shape differences at landmarks with

presence of cranial modification will be discussed in Chapter 6.

Lastly, the Procrustes coordinates were subjected to discriminant function analysis (DFA)

in order to assess whether the shape changes described by PCA can be used to differentiate

between modified and unmodified crania. Discriminant analyses seek to describe group

separation based on reduced independent variables, called discriminants, and to assess the

magnitude of that separation (Timm 2002). In the context of this thesis, the DFA will attempt to

predict a categorical variable (modified/unmodified classification) within the pooled sample

using continuous variables (Procrustes coordinates derived from cranial landmarks). Using

standard methods outlined by Buikstra and Ubelaker (1994), the skulls were previously assessed

for presence of modification, allowing group membership to be known a priori based on visual

assessment. Discriminant function analysis, however, separates crania into modified and

unmodified categories based on shape differences, thereby evaluating the accuracy of visual

assessment. The DFA used leave-one-out cross-validation to evaluate the probability of

misclassification, providing more realistic results in regard to the DFA's ability to assess separation between modified and unmodified skulls. The results generated by the DFA include the number of correctly and incorrectly classified individuals in each category, as well as a T-square statistic and associated *p*-value to assess the difference of means between groups (Klingenberg, 2011). A *p*-value less than 0.05 indicates a significant difference between multivariate group means of modified and unmodified skulls.

A discriminant function analysis was also performed using sex as a classifier in order to evaluate skull shape differences related to sex. Sex differences were examined using a pooled sample of both modified and unmodified individuals, as well as subset of only modified individuals. A subset of only unmodified individuals was not examined for sex differences due to small sample sizes and because possible morphological variation is expected to be unrelated to CVM if present. If sex differences are apparent within the pooled sample, it may be indicative of a difference in frequencies of modification between the sexes. Sex differences among modified individuals may indicate a difference in implementation of CVM related to differential aesthetic ideals according to biological sex (Blackwood and Danby, 1955).

Canonical variate analyses (CVA) were performed to examine variation in landmark locations among sites. Canonical variate analysis is a data simplification method similar to PCA, in that both methods describe variation in multivariate data along new axes corresponding to major directions of variation, called canonical variates in CVA, and both have an orthogonal constraint for describing variation between these axes (Campbell and Atchley, 1981; Zelditch, 2012). The major difference between these two methods is that CVA examines morphological variation among groups while PCA examines morphological variation among individuals

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(Zelditch, 2012). Additionally, the number of CVs that describe variation in CVA is equal to the number of groups examined minus one (Campbell and Atchley, 1981).

Two CVAs were performed in this thesis to examine cranial shape variation among all three sites at once and to display this variation graphically. The first CVA includes both modified and unmodified individuals while the second only includes modified individuals. The CVA that includes crania regardless of CVM presence is performed to indicate differences in frequency of modified individuals among sites, while the CVA that includes only modified individuals is performed to examine differences in degree of flattening among sites. Mean CV scores for each site will be calculated in order to describe how shape variation differs among sites and lollipop graphs displaying directions of variation in landmark location based on intersite shape differences are provided for both CVAs. Additionally, pairwise comparisons of sites will be performed using a total of six separate DFAs to evaluate whether crania can be effectively classified by site based on morphological variation in cranial shape. Three DFAs will be performed including both modified and unmodified individuals, while an additional DFAs will be performed including only modified individuals. Differences in cranial shape by site would be reflective of difference in CVM practice performed on individuals buried at a given site. Such differential practices may include an absence of practices resulting in CVM or differential degrees of flattening among sites.

CHAPTER 5: RESULTS

Morphometric analyses were performed to examine variation in landmark location among MCR crania in order to evaluate whether morphological variation can be used to reliably categorize crania as (1) modified or unmodified, (2) male or female, and (3) by site. The results of the PCA indicate that unmodified crania exhibit a more homogenous range of shape variation than modified crania along PC1 and PC2. Additionally, shape differences among individuals described by PC1 and PC2 show major directions of variation at lambda, asterion, and euryon. Discriminant function analysis results for both sex comparisons produced low correct classification percentages. Finally, intersite comparisons indicate that individuals in Bowling Farm and Arnold are driving site-specific variation along CV2, resulting in negative mean CV scores compared to Averbuch, while Bowling Farm's mean CV score for CV1 is more positive than both Arnold and Averbuch. The DFAs that examined both modified and unmodified crania for site classification indicate that Bowling Farm can be reliably separated from Arnold and Averbuch, but that a pairwise comparison of Arnold and Averbuch does not result in high correct classification percentages. The DFAs that examined only modified individuals resulted in a moderate correct classification between Arnold and Bowling Farm and between Bowling Farm and Averbuch, but lower correct classification percentages are reported for the pairwise comparison between Arnold and Averbuch.

Results for Inter-observer Error:

The contingency table showing the number of visual classifications of lambdoidal and occipital flattening between the two observers is presented in Table 3. The Fisher's exact test resulted in a p-value of 0.443, indicating that the relative frequencies for classification of

occipital and lambdoidal flattening were not significantly different between the two observers'

visual assessments. Agreement in visual assessment of modified crania as having either occipital

or lambdoidal flattening was 72.2% between observers.

Table 3: Contingency Table for Interobserver Error in Classification of Flattening Type Among
Modified Crania.

	Observer 1	Observer 2
Occipital Flattening	15	12
Lamdoidal Flattening	3	5

Principal Components Analysis:

A principal components analysis was performed in this study in order to simplify the

shape variation of cranial landmarks within the pooled sample, describing this variation in terms

of directionality and magnitude. The first four principal components (PC1-PC4) describe a

cumulative 70.19% of the total variance within the sample (Figure 4). The first PC accounts for

29.93% of the variance, the second PC accounts for 18.86%, the third PC accounts for 11.61%,

and the fourth PC accounts for 9.80% (Figure 4). The remaining 7 principal components describe

diminishing proportions of the shape variation among crania (Figure 4). Given the higher

proportion of shape variation described by PC1-PC4, emphasis will be placed on these four

principal components for describing the major differences in landmark position within the pooled

MCR sample, which is reflective of overall shape variation among both modified and

unmodified skulls.
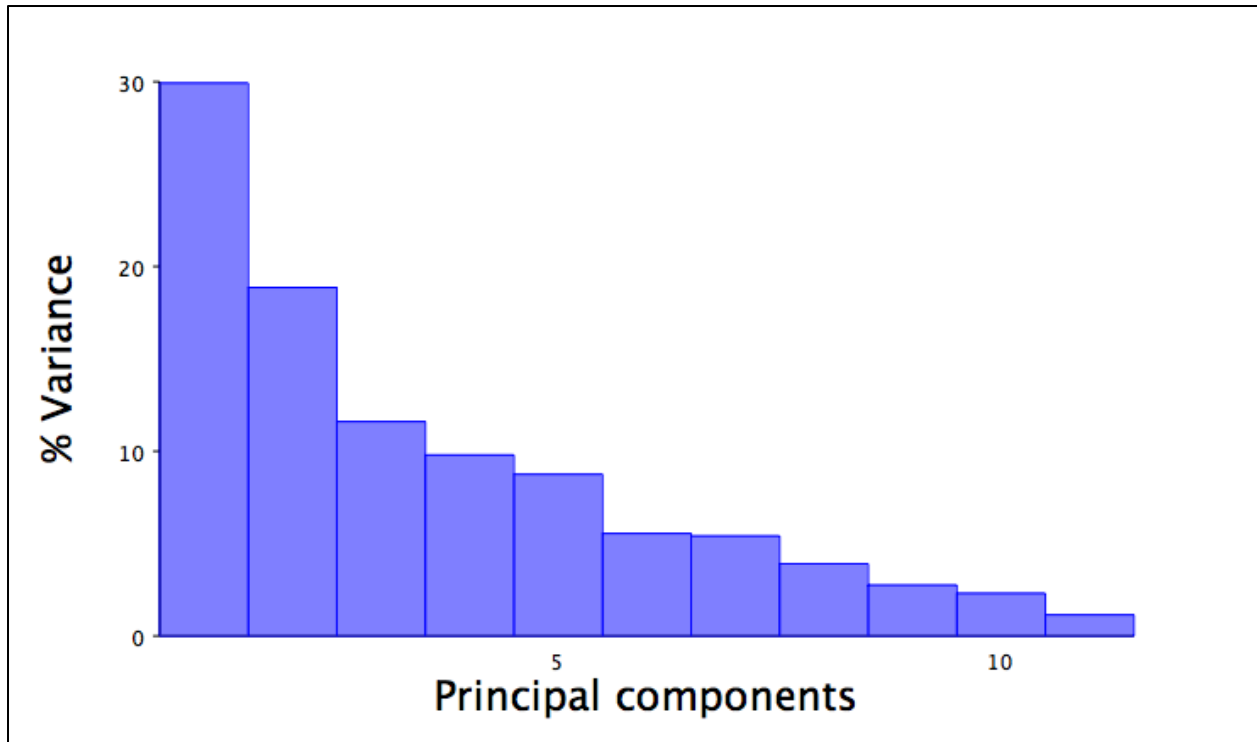
Figure 4: Partition of Variance by Principal Component.

The variation in landmark position among crania is summarized in Table 4 and graphically represented in Figures 5-12. Table 4 describes shape variation by principal component loadings, which quantitatively describe how each landmark is behaving along a principal component axis with respect to the coordinate data.

Figures 5-12 show lollipop graphs for a visual representation of shape differences described by PCs 1-4. Figures 5, 7, 8, and 11 show posterior views of the shape differences at each landmark, while Figures 6, 8, 10, and 12 show lateral views. The posterior views present the equivalent of a skull viewed posteriorly and slightly superiorly (see Figure 4). The lateral views present the equivalent of a left lateral view of a skull, also oriented slightly superiorly, with the posterior aspect oriented toward the right (see Figure 5).

Figure 4: Posterior Orientation of Cranium as in Lollipop Graphs (red circles indicate cranial landmarks).
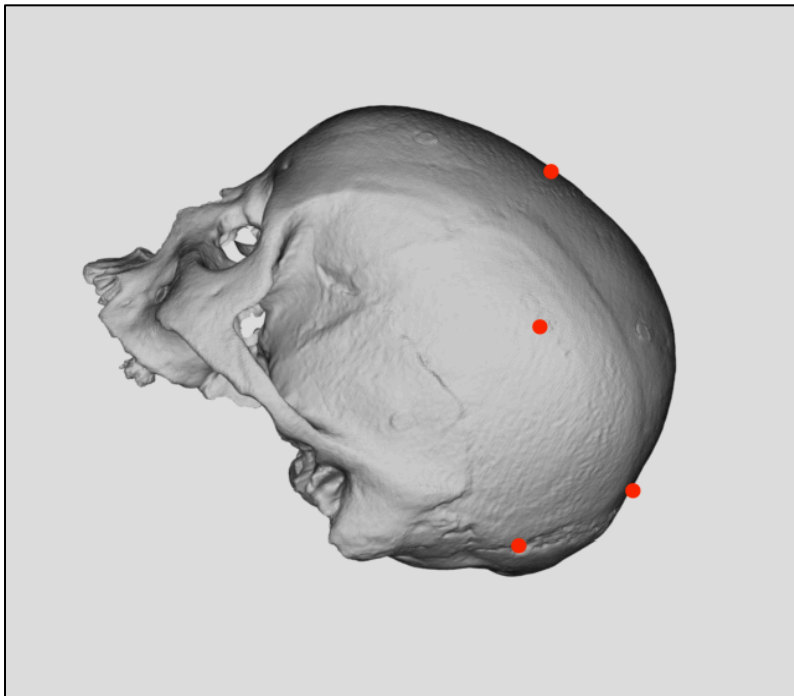
Figure 5: Lateral Orientation of Cranium as in Lollipop Graphs (red circles indicate cranial landmarks).

Table 4: PC Loadings by Cranial Landmark.

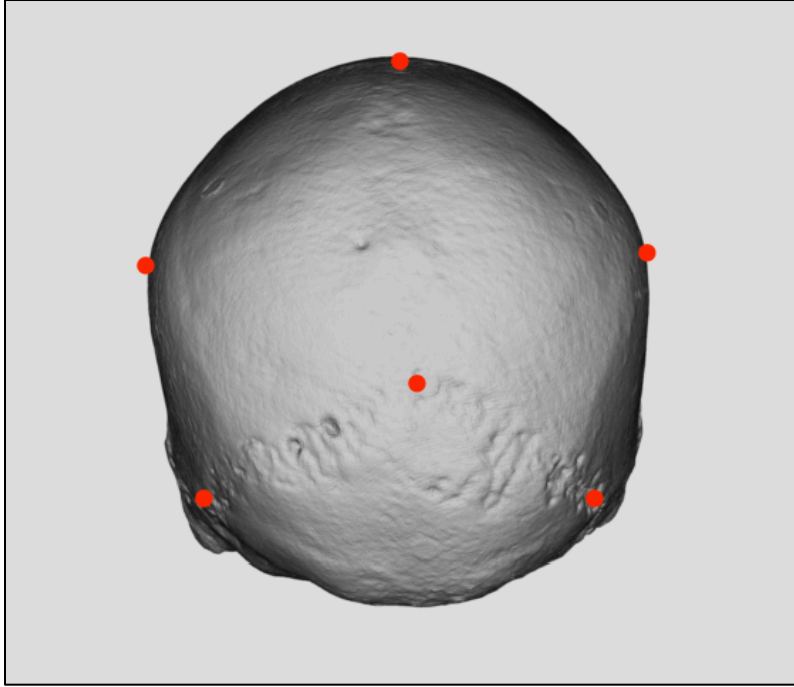| Landmark	Coordinate Axis	PC1	PC2	PC3	PC4
Bregma	x	-0.03713	-0.112863	0.204407	-0.016484
	y	0.024563	-0.180624	-0.105431	-0.344224
	z	-0.284949	-0.411856	-0.305158	0.011343
Lambda	x	-0.02719	-0.034547	-0.018552	0.253231
	y	-0.439653	0.627261	0.270535	0.10925
	z	0.439805	0.089769	0.017398	0.077012
L Asterion	x	-0.038818	0.177543	-0.405716	0.039343
	y	0.011836	-0.056774	-0.109337	-0.414895
	z	-0.295043	0.120103	-0.23853	0.301405
R Asterion	x	0.163763	0.06257	-0.065095	0.015087
	y	0.089187	0.067659	-0.438315	-0.078607
	z	-0.391942	-0.096126	0.229463	-0.202609
L Euryon	x	0.133159	0.206365	0.102982	-0.250384
	y	0.109394	-0.347402	0.398907	0.377391
	z	0.238231	0.09372	0.307332	-0.357749
R Euryon	x	-0.193784	-0.299066	0.181974	-0.040792
	y	0.204672	-0.11012	-0.016359	0.351085
	z	0.293898	0.20439	-0.010506	0.170598

The major shape differences described by PC 1 occur at lambda. Landmark location differences at lambda are directed inferiorly (Figure 5). Minor differences in landmark location occur at euryon in an anterior and lateral direction, bregma in a posterior and superior direction, and asterion in a posterior direction (Figures 5 and 6). Major shape differences described by PC2 are occurring at lambda, bregma, and euryon (Figures 7 and 8). Principal component 2 shows that the majority of landmark location variation occurs at lambda superiorly and anteriorly, at bregma posteriorly, and at euryon laterally and inferiorly (Figures 7 and 8). Major shape differences described by PC 3 occur at asterion, and euryon (Figures 9 and 10). Left asterion shows variation in landmark location in a medial direction, while right asterion shows variation in a posterior direction (Figures 9 and 10). Left euryon exhibits variation in landmark location in a superior direction, while right euryon is directed medially and at a lower magnitude than left euryon (Figures 9 and 10). Major shape differences described by PC 4 occur at left asterion, bregma, and euryon (Figures 11 and 12). Both bregma and left asterion exhibits variation in an inferior direction, while right asterion exhibits variation in a posterior and inferior direction (Figures 11 and 12). Variation in landmark location at euryon is directed superiorly for both left and right euryon, though right euryon is directed more anteriorly than left euryon (Figures 11 and 12).

In addition to describing shape changes associated with each cranial landmark, the principal components analysis shows how each skull scores on orthogonal principal component axes using a scatter plot. Scatter plots are useful for providing a summary view of shape differences between categorical groups within a sample and the variance in shape present in each group. Each point in these plots represents an individual, and the points are placed based on their PC score for PC 1 and PC 2 (Figure 13) and PC 3 and PC 4 (Figure 14). Figures 13 and 14
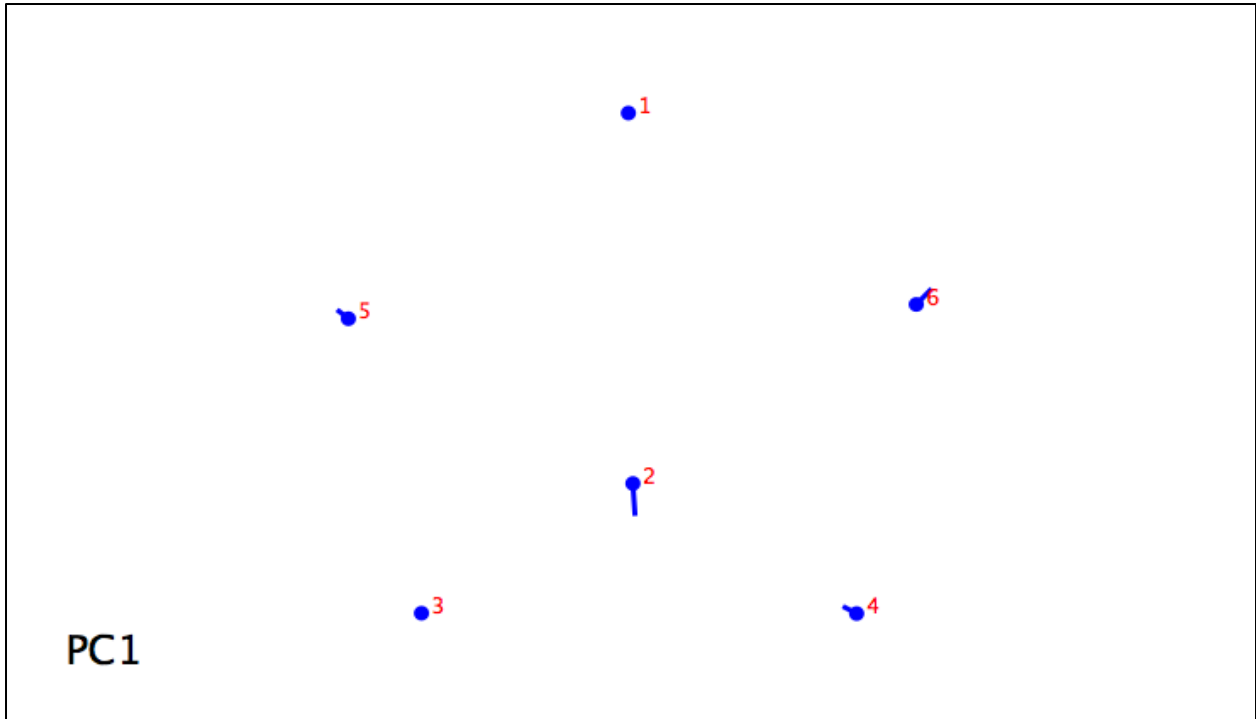
Figure 5: Shape plot of PC1, superior view (1 = bregma, 2 = lambda, 3 = left asterion, 4 = right asterion, 5 = left euryon, 6 = right euryon).
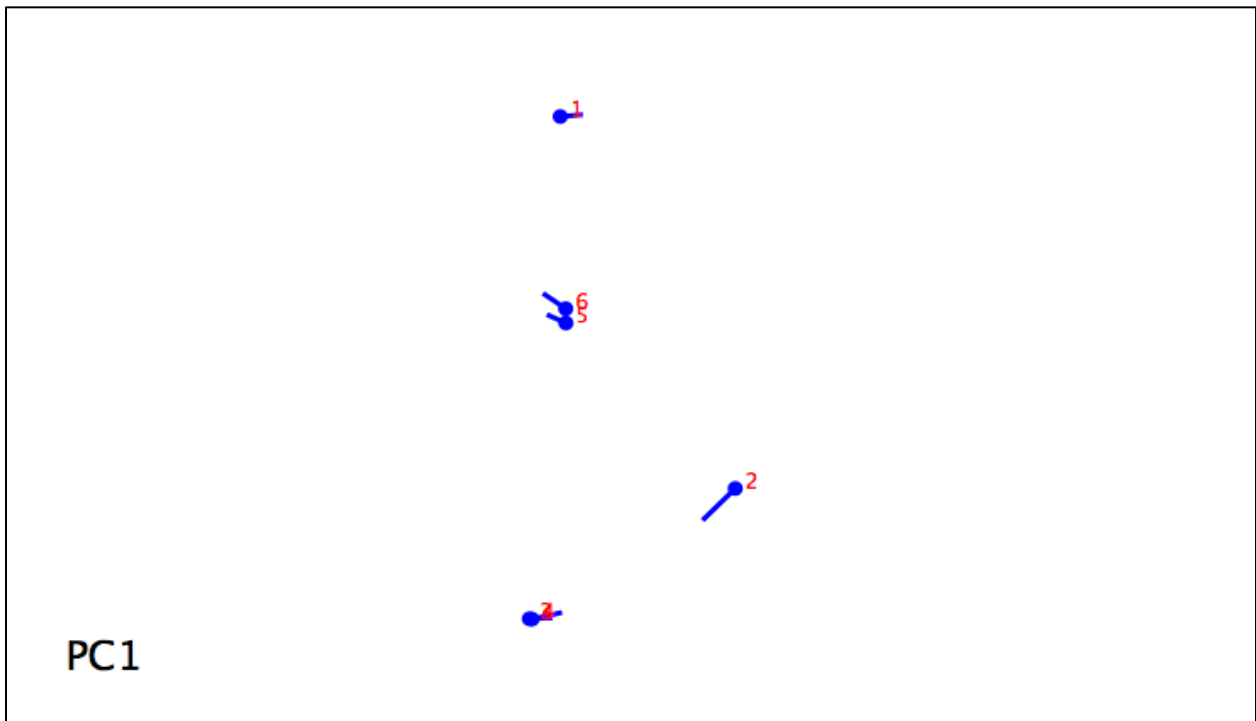
Figure 6: Shape plot of PC 1, lateral view (see Figure 4 caption for number key).
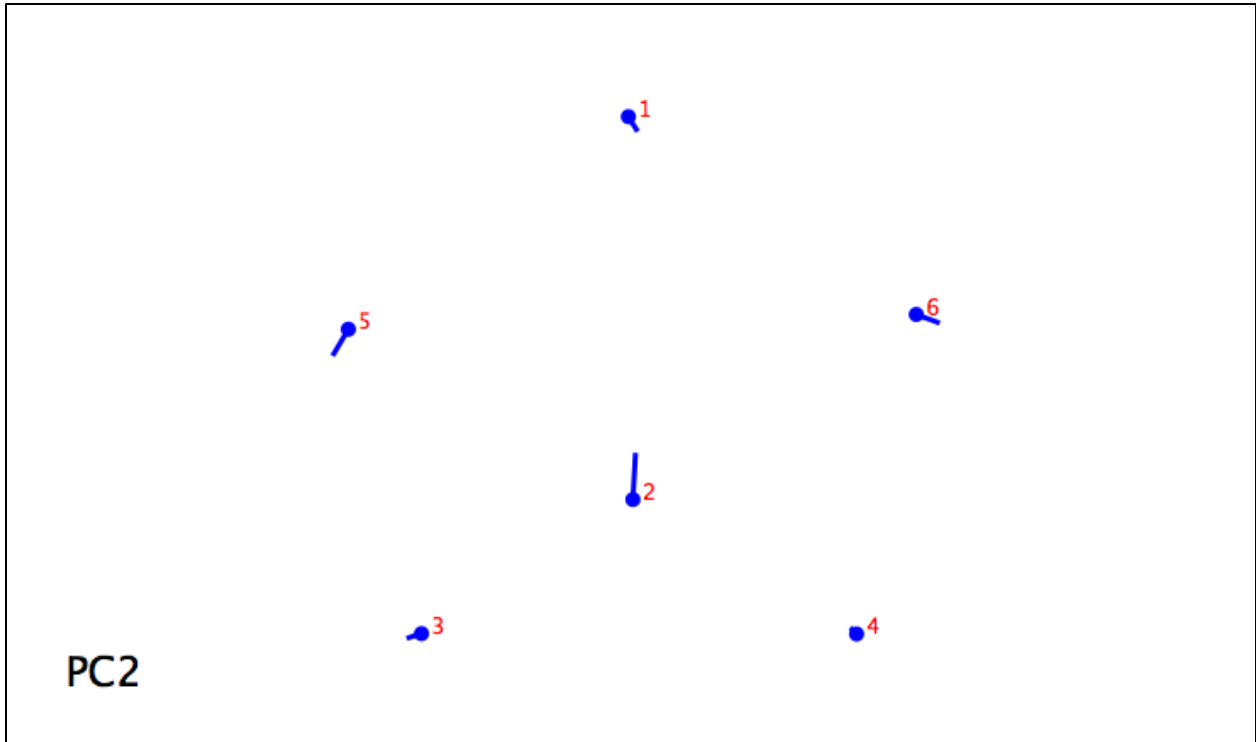
Figure 7: Shape plot of PC 2, superior view (see Figure 4 caption for number key).
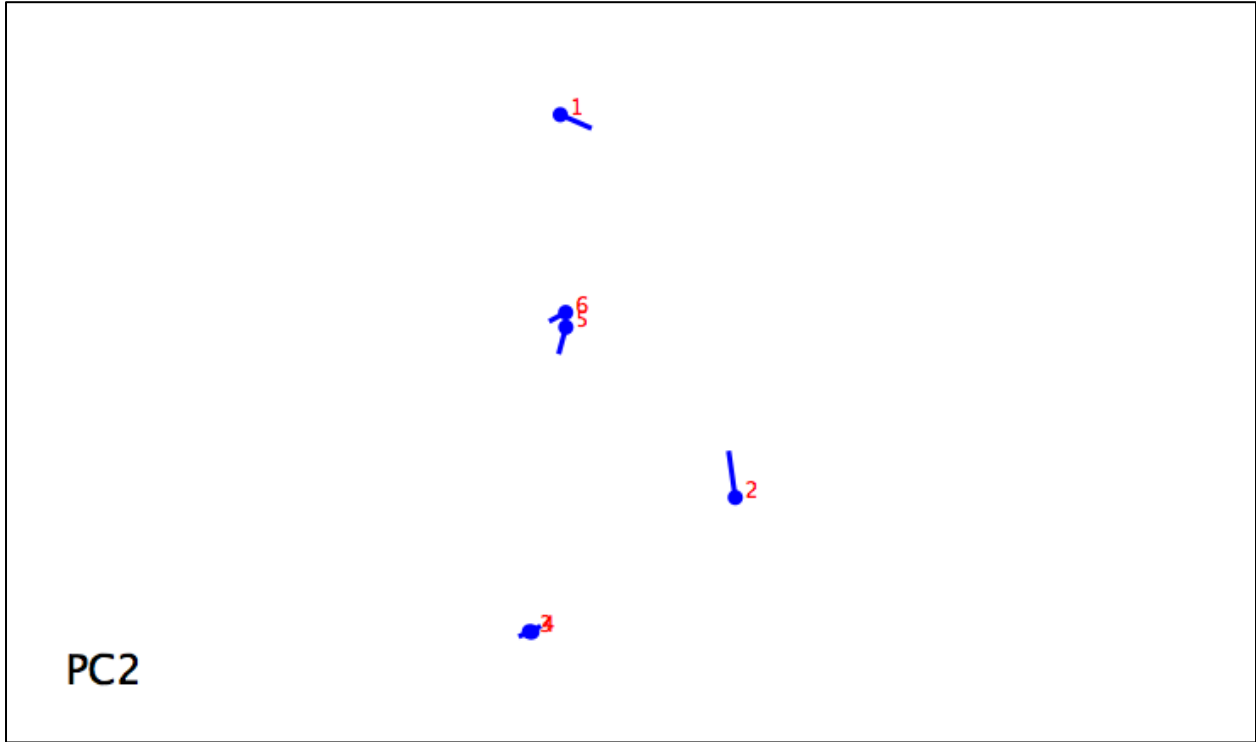
Figure 8: Shape plot of PC 2, lateral view (see Figure 4 caption for number key).
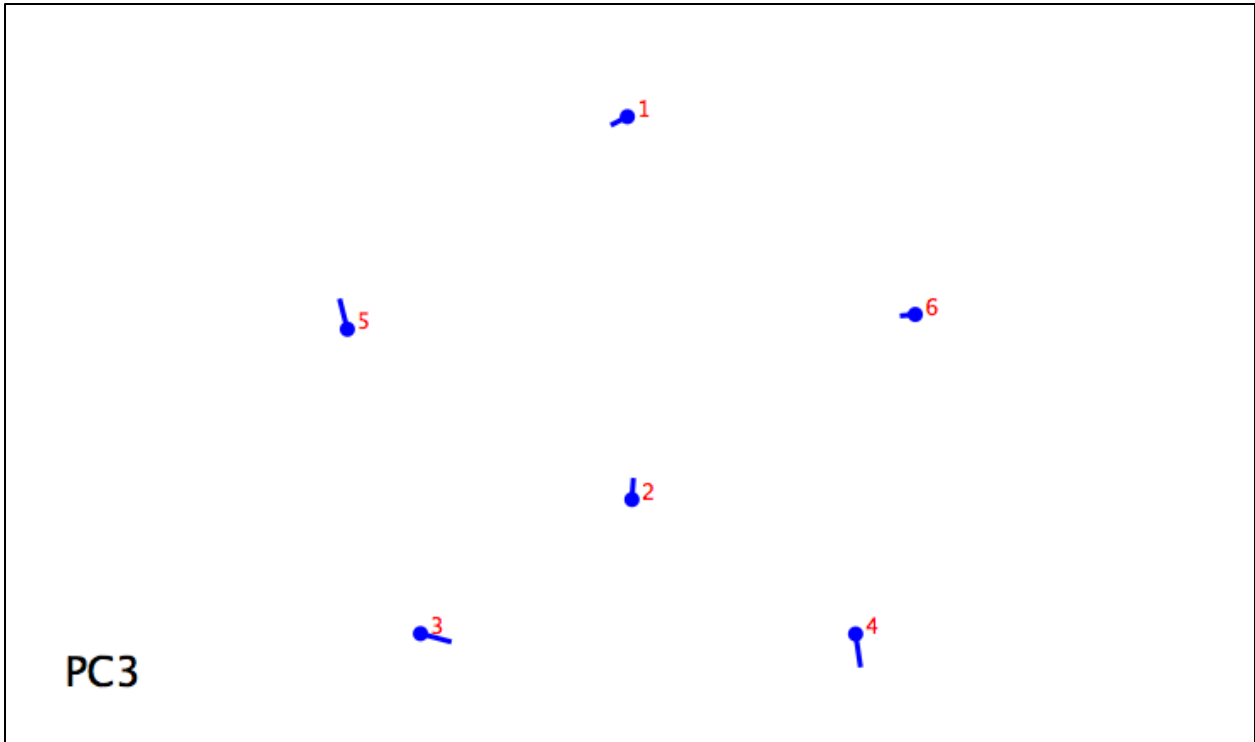
Figure 9: Shape plot of PC 3, superior view (see Figure 4 caption for number key).
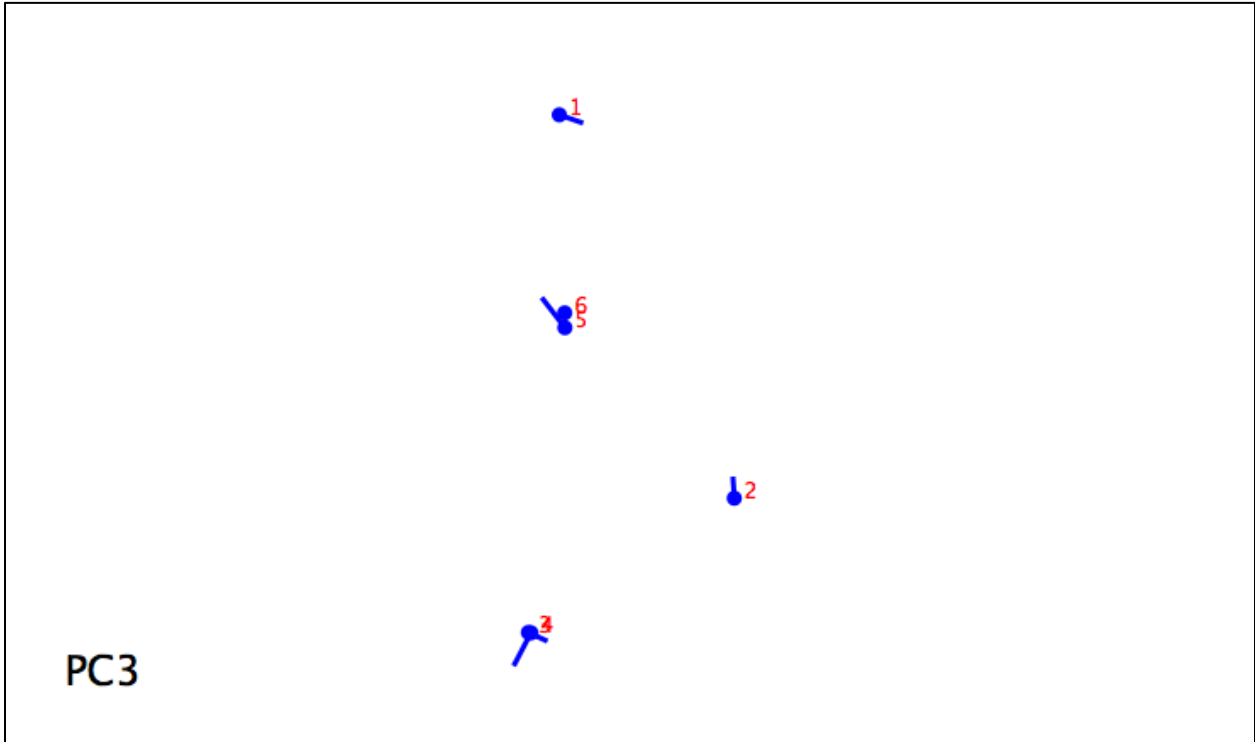
Figure 10: Shape plot of PC 3, lateral view (see Figure 4 caption for number key).
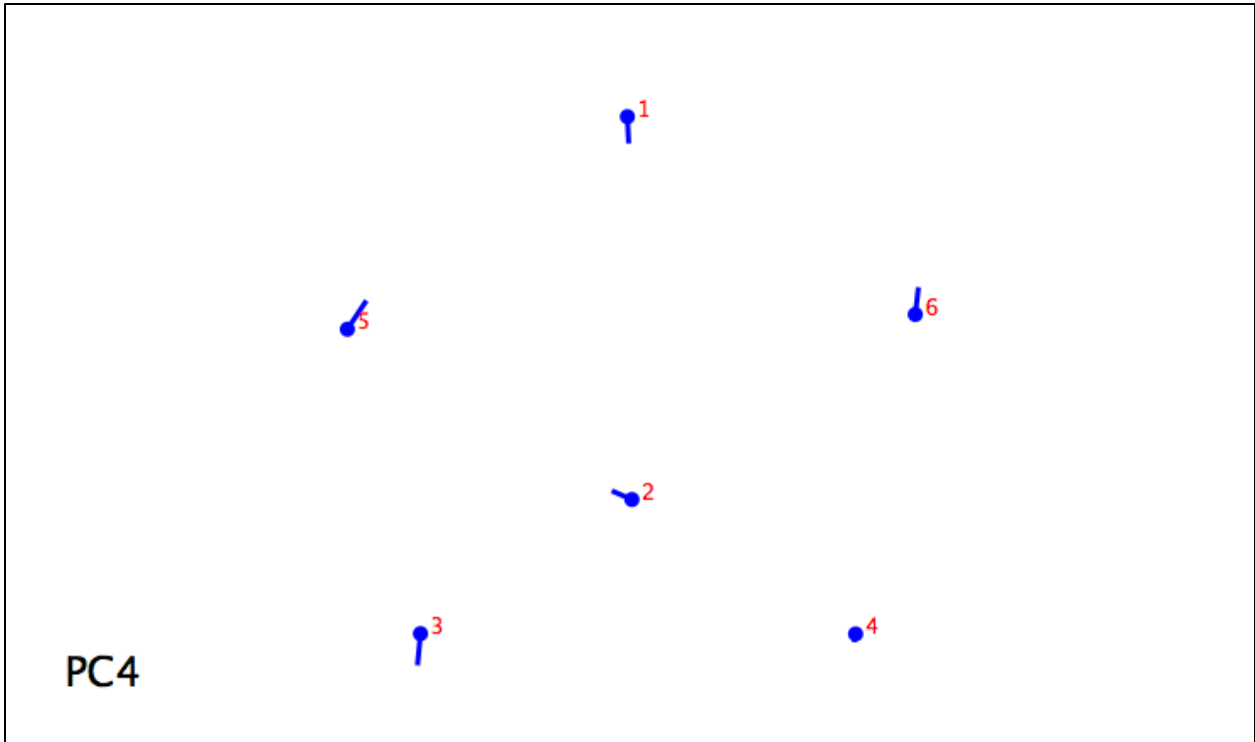
Figure 11: Shape plot of PC 4, superior view (see Figure 4 caption for number key).
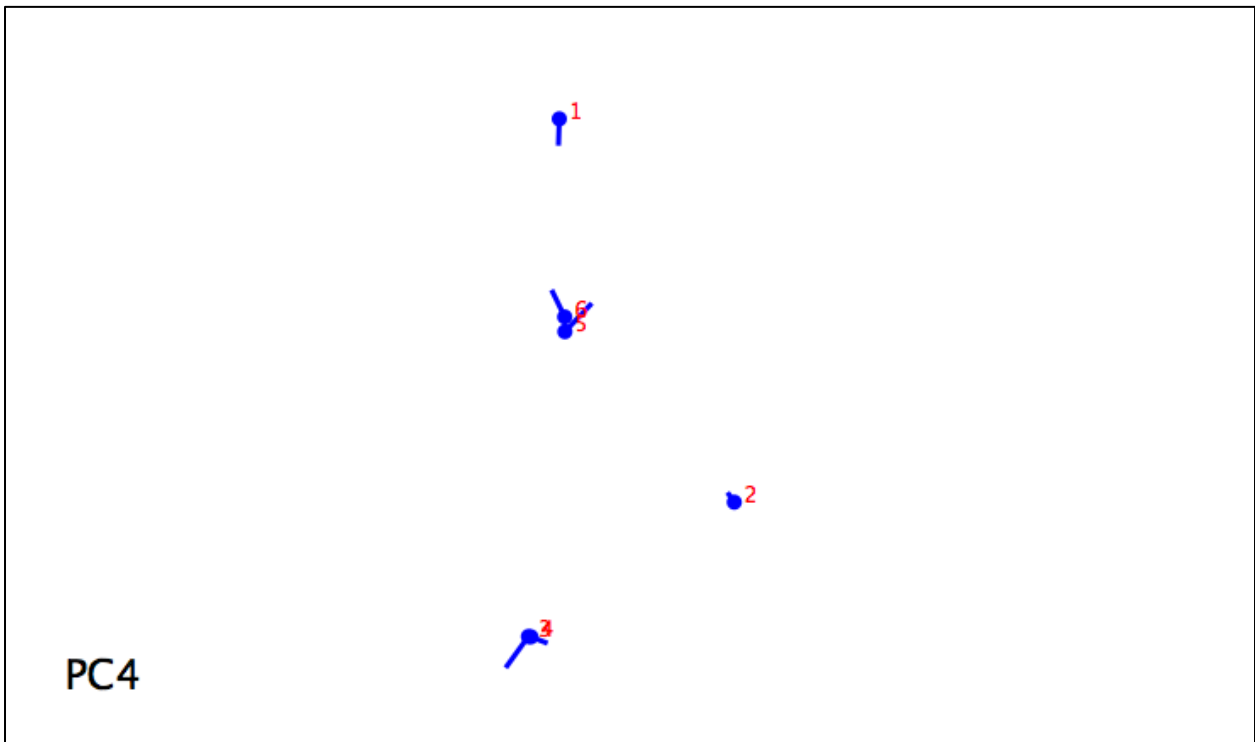
Figure 12: Shape plot of PC 4, lateral view (see Figure 4 caption for number key).

demonstrate the shape differences among unmodified and modified skulls within the sample of this study. Equal frequency ellipses (Pr = 0.90) were drawn based on whether the skull was visually classified as unmodified or modified in order to summarize the distribution of skulls in each category. The scatter plot for PC 1 and PC 2 indicates that modified skulls have considerably more shape variation than unmodified skulls, with unmodified skulls clustering based on higher PC scores for PC 1 and PC 2 (Figure 13). Additionally, ellipses corresponding to each category's shape variation overlap, indicating that the ranges of shape variation for modified and unmodified skulls are not entirely distinct (Figure 13). Figure 14 shows the scatter plot for PC 3 and PC 4 and indicates that the variations between unmodified and modified crania are not distinct, with the variation expressed by unmodified crania encompassed by that of modified crania.

Discriminant Function Analysis by Presence of Modification

A discriminant function analysis (DFA) was performed in order to determine whether or not shape differences among modified and unmodified crania could be used to separate skulls into categories that are consistent with those determined using traditional visual assessment of cranial modification. Results of the discriminant function analysis for categorization of modified or unmodified crania are presented in Table 5. Results indicate a significant difference in group means between modified and unmodified classifications ($T^2 = 74.51$; $p < 0.0001$). The DFA successfully classified 82.7% of the crania (67/81) into the correct group based on shape differences (Table 5). Fifty-four out of 66 modified crania (81.8%) were correctly classified while 13 out of 15 unmodified crania (80.0%) were correctly classified (Table 5).
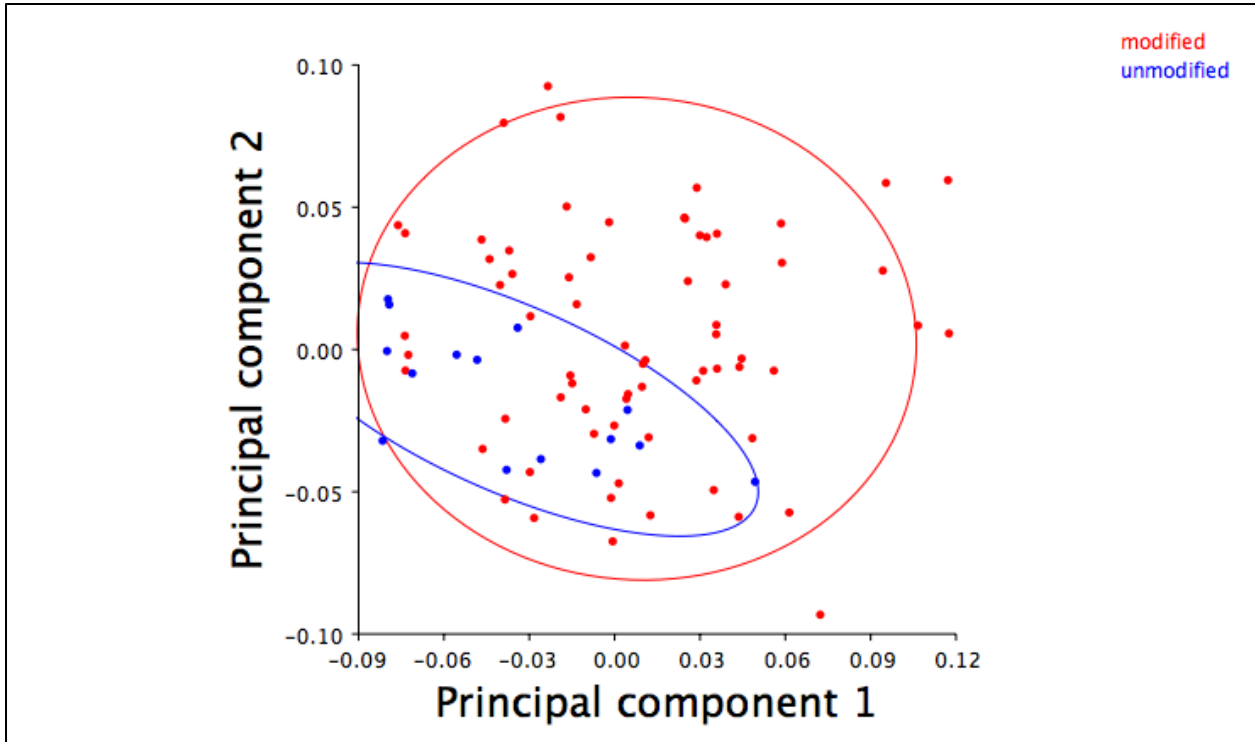
Figure 13: Scatter plot showing PC scores for individual crania along PC 1 and PC 2.
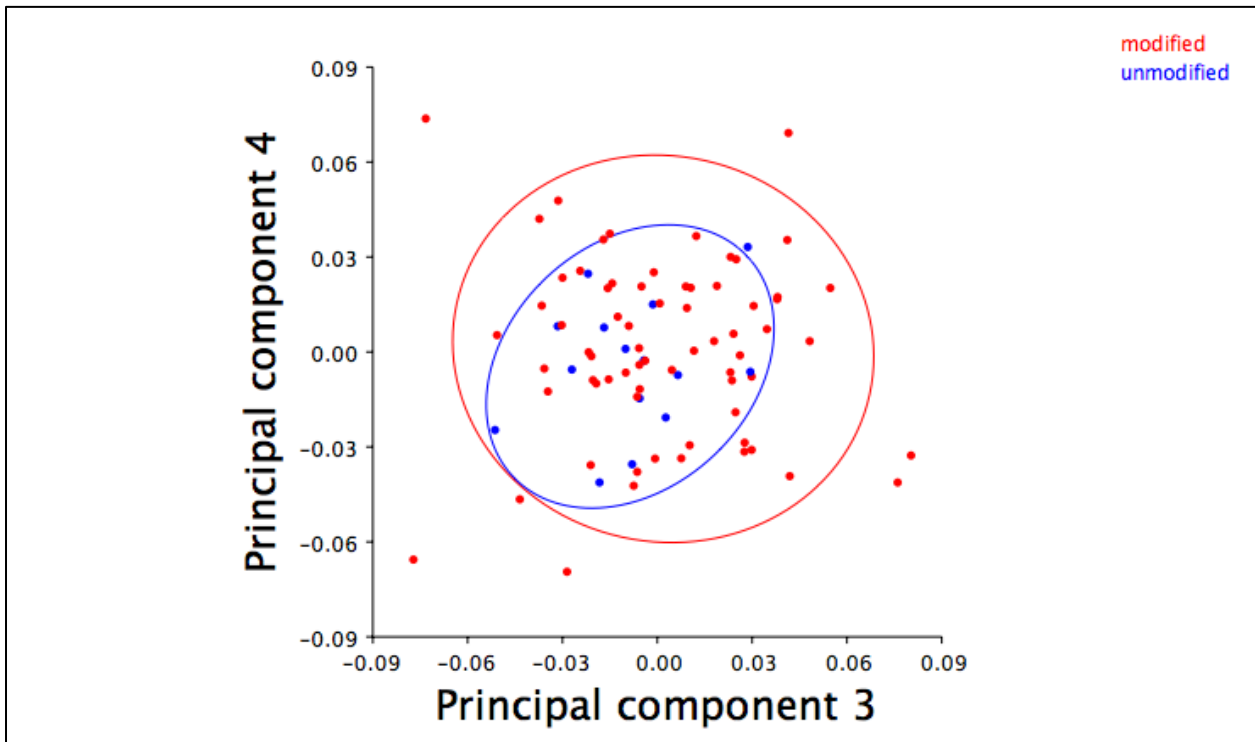
Figure 14: Scatter plot showing PC scores for individual crania along PC 3 and PC 4.

Table 5: Results for Discriminant Function Analysis by Modification Presence/Absence.

		Into Group		
From Group	Total Number	Modified	Unmodified	% Correct
Modified	69	58	11	84.1%
Unmodified	15	4	11	73.3%
Total Correct: 69 out of 84 (82.1%) Cross-validated.				

Discriminant Function Results by Sex

Table 6 provides the results of the DFA performed to classify MCR by sex regardless of presence of modification using variation of landmark locations on the cranial vault. A significant difference in group means between the sexes is demonstrated ($T^2 = 55.96$; $p = 0.0006$). The DFA correctly classified 59.3% of the crania by sex (Table 6). Twenty-three out of thirty-six crania belonging to females were correctly classified (63.8%) while 25/40 crania belonging to males were correctly classified in (62.5%) (Table 6).

The results of the DFA that evaluated classification of only modified crania by sex using morphological variation are presented in Table 7. The DFA resulted in a significant difference in group means between modified females and males ($T^2 = 44.60$; $p = 0.0098$). The DFA correctly classified 58.1% of modified crania by sex (Table 7). Eighteen out of 33 modified females were correctly classified (54.5%) while 18/29 modified males were correctly classified (62.1%) (Table 7).

Table 6: Results for Discriminant Function Analysis by Sex.

		Into Group		
From Group	Total Number	Female	Male	% Correct
Female	37	25	12	63.8%
Male	42	16	26	62.5%
Total Correct: 51 out of 79 (64.6%) Cross-validated.				

Table 7: Results for Discriminant Function Analysis by Sex for Modified Crania

		Into Group		
From Group	Total Number	Female	Male	% Correct
Female	33	18	15	54.5%
Male	29	11	18	62.1%
Total Correct: 36 out of 62 (58.1%) Cross-validated.				

Canonical Variate Analysis and Discriminant Function Results by Site

The results of the CVA performed to examine shape variation by site including both modified and unmodified crania are presented in Figure 15 and Table 8. The first CV describes 68.00% of the variance among sites, while CV2 describes 32.00% of the variance. Similarities in mean CV scores are evident among the three sites, with Arnold and Averbuch having negative mean CV scores along CV1 and Arnold and Bowling Farm having negative mean CV scores along CV2 (Table 8). These similarities are reflected in Figure 15, which shows similar expression of Arnold and Averbuch along CV1 and similar expression of Arnold and Bowling Farm along CV2.
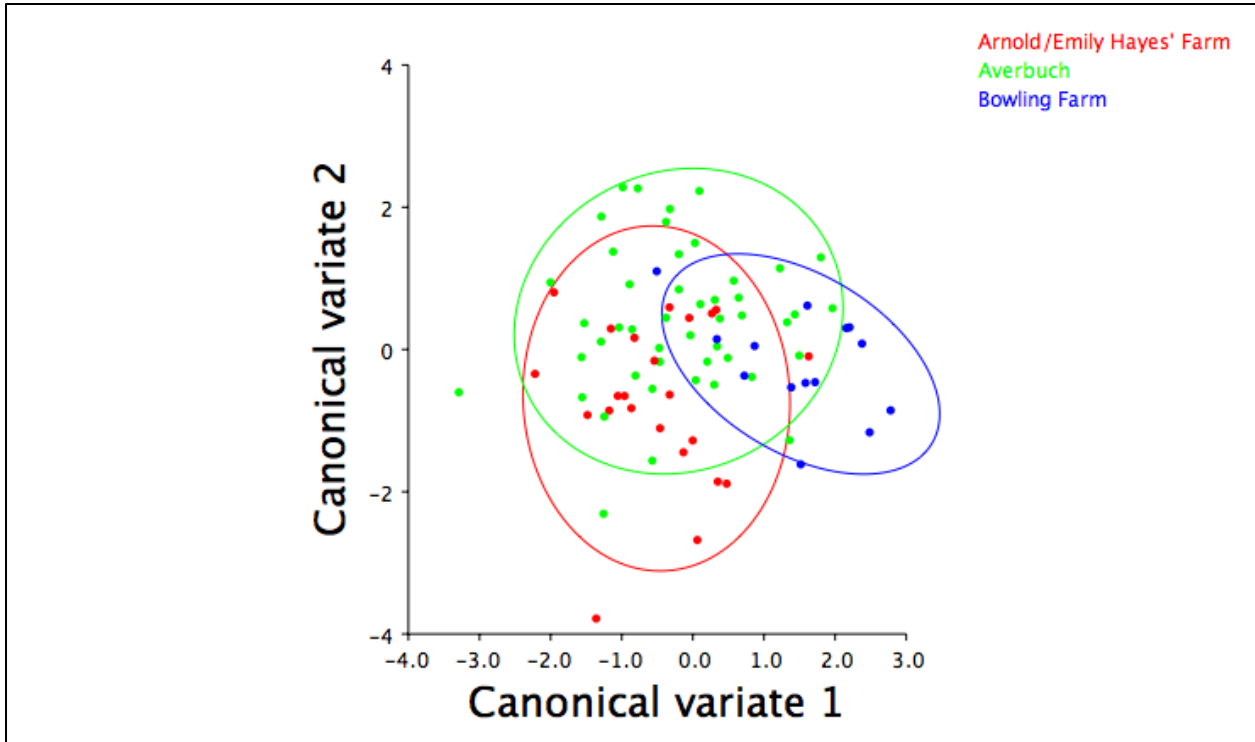
Figure 15: Scatter plot showing CV scores for individual crania (modified and unmodified) along CV1 and CV2.
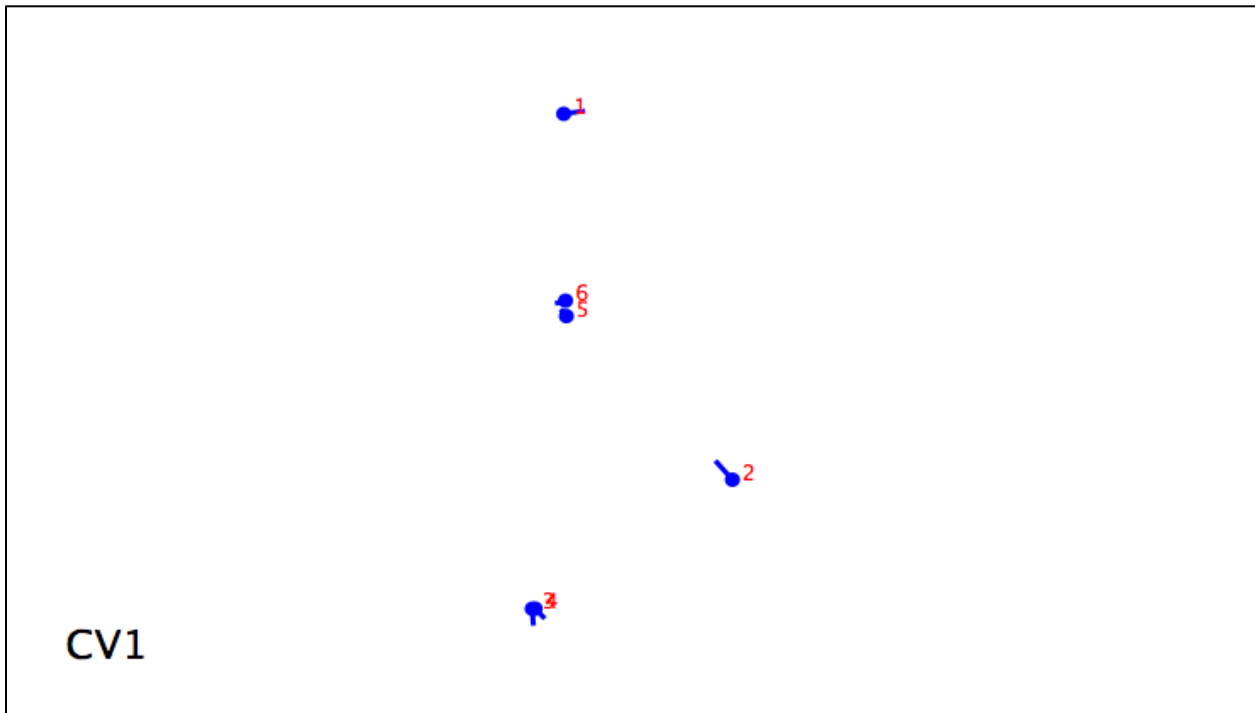
Figure 16: Shape plot of CV1 from CVA including modified and unmodified individuals, lateral view (see Figure 4 caption for number key).

Table 8: Mean CV Scores by Site Using Modified and Unmodified Crania.

Site	Mean CV Score (CV1)	Mean CV Score (CV2)
Arnold	-0.512	-0.688
Averbuch	-0.201	0.398
Bowling Farm	1.512	-0.204

The CVA including both modified and unmodified individuals also provides graphical representation of shape differences among sites (Figure 16). The lollopop graph for CV1 (lateral view) shows that lambda exhibits shape variation anteriorly, bregma exhibits variation superiorly, and left and right asterion exhibit variation posteroinferiorly (Figure 16). The lollipop graph showing the posterior view of shape differences did not indicate major variation in landmark location, and was therefore not included.

The results of the three DFAs performed to evaluate classification by site using morphological variation and including both modified and unmodified individuals are presented in Tables 9-11. The DFA indicates a significant difference in group means between Arnold and Bowling Farm ($T^2 = 204.60$; $p < 0.0001$) and between Averbuch and Bowling Farm ($T^2 = 43.93$; $p = 0.0122$). No significant difference is detected between Averbuch and Arnold ($T^2 = 26.36$; $p = 0.1418$). Between Bowling Farm and Arnold, the DFA correctly classified 91.4% of crania, with 14/14 (100%) correctly classified into Bowling Farm and 18/21 (85.7%) correctly classified into Arnold (Table 9). Between Bowling Farm and Averbuch, the DFA correctly classified 70.0% of the crania, with 10/14 (71.4%) correctly classified into Bowling Farm and 32/46 (69.6%) correctly classified into Averbuch (Table 10). Finally, between Averbuch and Arnold, the DFA

Table 9: Results for Discriminant Function Analysis by Site Using Modified and Unmodified Crania (Arnold/Bowling Farm).

		Into Group		
From Group	Total Number	Arnold	Bowling Farm	% Correct
Arnold	23	20	3	87.0%
Bowling Farm	14	3	11	78.6%
Total Correct: 31 out of 37 (83.7%) Cross-validated.				

Table 10: Results for Discriminant Function Analysis by Site Using Modified and Unmodified Crania (Averbuch/Bowling Farm).

		Into Group		
From Group	Total Number	Averbuch	Bowling Farm	% Correct
Averbuch	47	33	14	70.2%
Bowling Farm	14	3	11	78.6%
Total Correct: 44 out of 61 (72.1%) Cross-validated.				

Table 11: Results for Discriminant Function Analysis by Site Using Modified and Unmodified Crania (Arnold/Averbuch).

		Into Group		
From Group	Total Number	Arnold	Averbuch	% Correct
Arnold	23	14	9	66.7%
Averbuch	47	22	25	53.2%
Total Correct: 39 out of 70 (55.7%) Cross-validated.				

correctly classified 58.2% of crania, with 12/21 (57.1%) correctly classified into Arnold and 26/46 (58.7%) correctly classified into Averbuch (Table 11).

The results of the CVA performed to examine shape variation by site including only modified individuals are presented in Figure 17 and Table 12. The first CV describes 56.07% of the variance among sites and the second CV describes 43.93% of the variance. Arnold and Averbuch have more similar mean CV scores along CV1 than Bowling Farm, while mean CV scores along CV2 are dissimilar among all sites. For CV2, Arnold and Bowling Farm both have negative mean CV scores while Averbuch has a positive mean CV score (Table 12). The CV plot displaying shape variation by site indicates that while Arnold, Averbuch, and Bowling Farm all overlap, certain individuals are contributing to variation with more negative scores along CV2 from Arnold and Bowling Farm (Figure 17).

Since the sites separate mostly along CV2, the graphical representation of variation in landmark location described by CV2 for the CVA including only modified individuals is presented in Figures 18 and 19. In the same orientations as the lollipop graphs generated by the PCA, Figure 18 shows a lateral view while Figure 19 shows a posterior view. Variation at lambda is expressed in an anterior and inferior direction (Figure 18). Right and left euryon show variation in superior, anterior, and medial direction (Figures 18 and 19). Variation at left and right asterion is in a posterior direction (Figure 18).

The results of the three DFAs performed to evaluate classification by site using morphological variation and including only modified individuals are presented in Tables 13-15. The DFA indicates a significant difference in group means between Arnold and Bowling Farm ($T^2 = 49.13$; p = 0.0326). There is no significant difference between Averbuch and Arnold
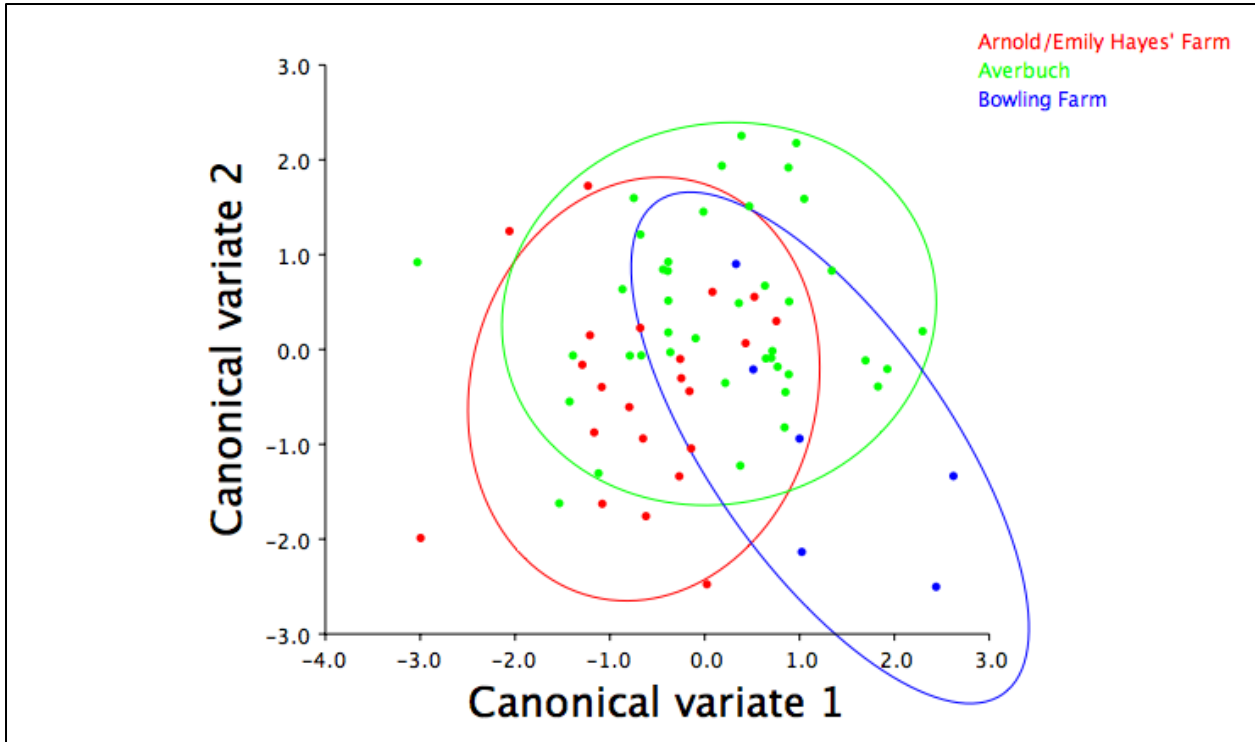
Figure 17: Scatter plot showing CV scores for individual crania (modified) along CV1 and CV2.
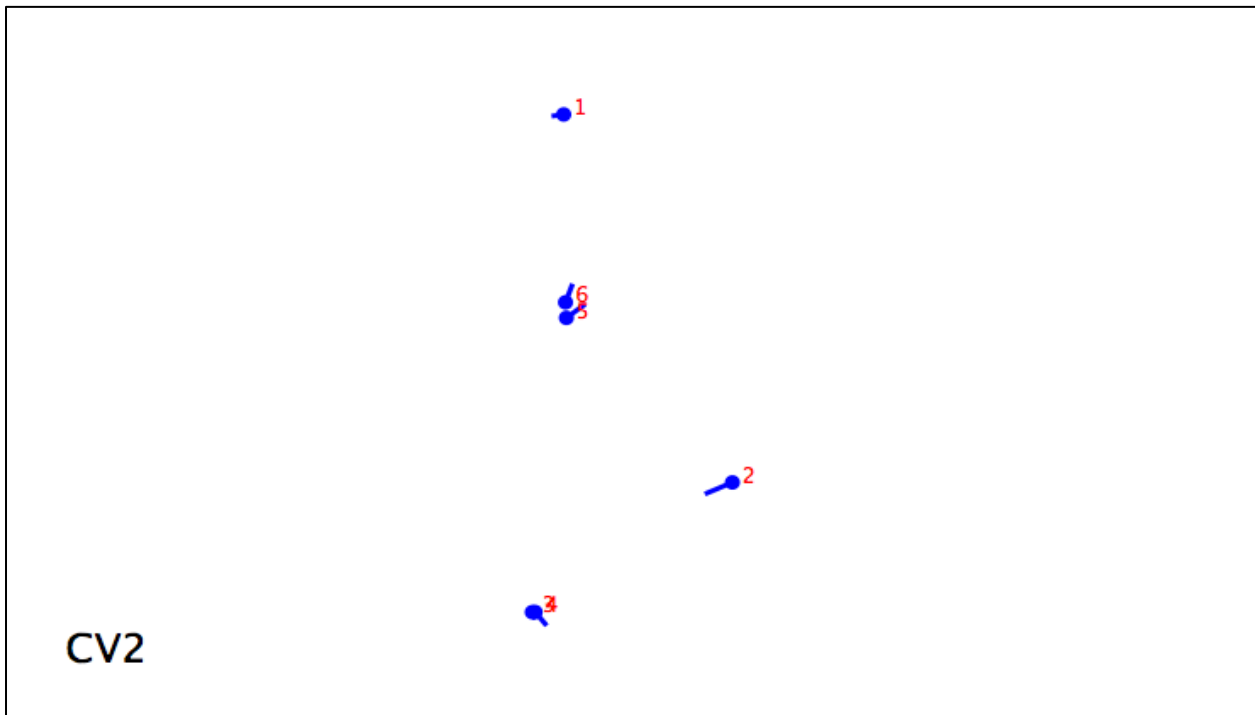
Figure 18: Shape Plot of CV1 from CVA including only modified crania, lateral view (see Figure 4 caption for number key).
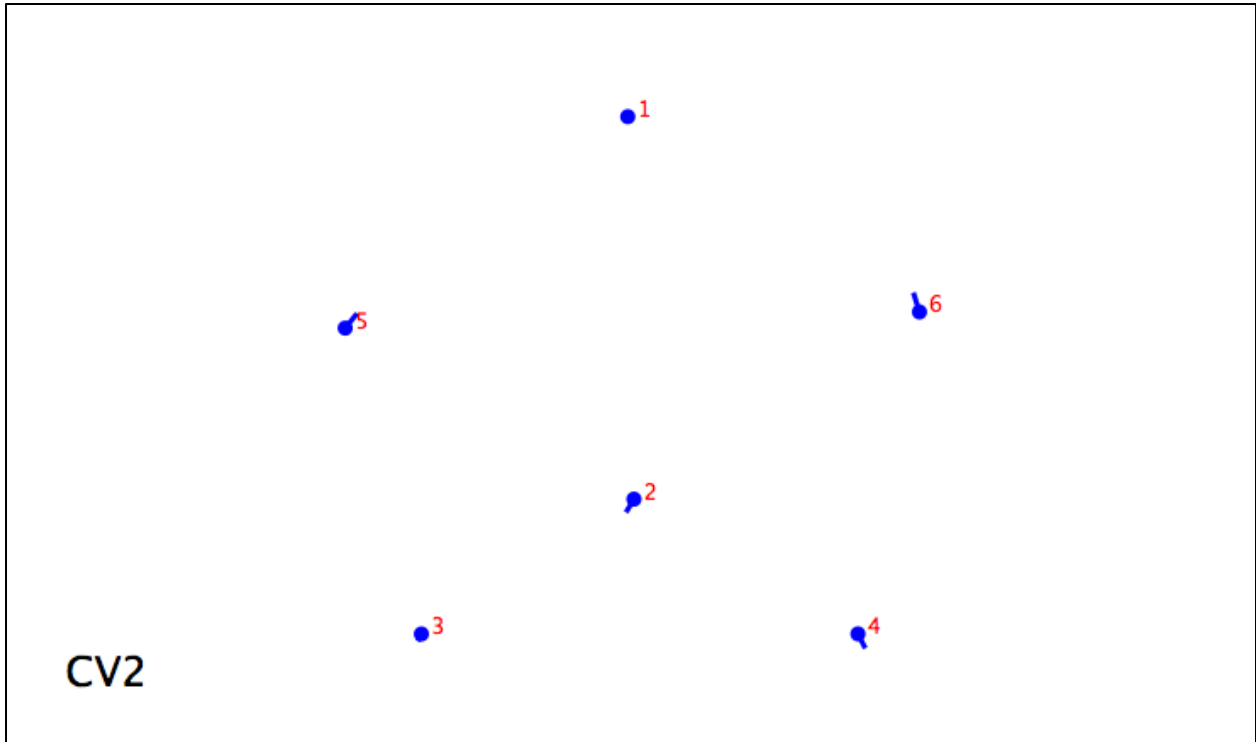
Figure 19: Shape plot of CV1 from CVA including only modified crania, posterior view (See Figure 4 caption for number key).

Table 12: Mean CV Scores by Site (modified only).

Site	Mean CV Score (CV1)	Mean CV Score (CV2)
Arnold	-0.642	-0.417
Averbuch	0.151	0.375
Bowling Farm	1.321	-1.037

Table 13: Results for Discriminant Function Analysis by Site Using Modified Crania (Arnold/Bowling Farm).

From Group	Total Number	Into Group		% Correct
		Arnold	Bowling Farm	
Arnold	22	17	5	77.3%
Bowling Farm	6	2	4	66.7%
Total Correct: 21 out of 28 (75.0%) Cross-validated.				

Table 14: Results for Discriminant Function Analysis by Site Using Modified Crania (Averbuch/Bowling Farm).

From Group	Total Number	Into Group		% Correct
		Averbuch	Bowling Farm	
Averbuch	41	28	13	68.3%
Bowling Farm	6	2	4	66.7%
Total Correct: 32 out of 47 (68.1%) Cross-validated.				

Table 15: Results for Discriminant Function Analysis by Site Using Modified Crania (Arnold/Averbuch).

From Group	Total Number	Into Group		% Correct
		Arnold	Averbuch	
Arnold	22	12	10	54.5%
Averbuch	41	16	25	61.0%
Total Correct: 37 out of 63 (58.7%) Cross-validated.				

($T^2 = 17.23$; $p = 0.2463$) or between Averbuch and Bowling Farm ($T^2 = 17.63$; $p = 0.2950$).

Between Bowling Farm and Arnold, the DFA correctly classified 75.0% of crania, with 4/6 (66.7%) correctly classified as Bowling Farm and 17/22 (77.3%) correctly classified as Arnold (Table 13). Between Bowling Farm and Averbuch, the DFA correctly classified 68.1% of the crania, with 4/6 (66.7%) correctly classified into Bowling Farm and 28/41 (68.3%) correctly classified into Averbuch (Table 14). Finally, between Averbuch and Arnold, the DFA correctly classified 58.7% of crania, with 12/22 (54.5%) correctly classified into Arnold and 25/41 (61.0%) correctly classified into Averbuch (Table 15).

CHAPTER 6: DISCUSSION

Results indicate that MCR crania can be reliably categorized as modified and unmodified based on morphological differences, thus signaling agreement with visual assessment of CVM. Morphological differences did not efficiently categorize crania as male or female using both modified and unmodified as well as only modified crania. Therefore, CVM practices were not performed differently on children based on biological sex. Intersite comparisons indicate that Bowling Farm crania exhibit morphological variation differently from Arnold and Averbuch due to a high frequency of unmodified crania at Bowling Farm compared to the other two sites. This high frequency may be due to the presence of nonlocal individuals who did not perform CVM practices. Finally, morphological differences are detected for both Arnold and Bowling Farm and may be the result of dissimilar ranges of variation in the degree of flattening among sites. However, these shape differences may not be reliable given Bowling Farm's small sample size of modified individuals.

Inter-observer Error

Results from the Fisher's exact test indicate no significant difference in the relative frequencies of visual assessments of occipital and lambdoidal flattening between observers. However, the percent agreement between observers was 72.2%, suggesting that there was a substantial amount disagreement between observers in terms of whether a modified cranium had occipital or lambdoidal flattening. This inconsistency in CVM assessment is an example of the subjectivity associated with visual assessment of CVM. Given this subjectivity, it is important to evaluate inter-observer error for visual assessment methods in order to establish reliability of

classification. Additionally, supplementing visual assessment with morphometric methods to quantify shape differences may further aid in classification of CVM.

Variation in Cranial Vault Shape due to Presence/Absence of CVM

The results from the PCA performed on the aggregate MCR sample indicate directionality and magnitude of variation in relative landmark location (Figures 5-12). It must be reiterated for the purposes of interpretation, however, that while the lollipop graphs show directionality in the axes of variation, they do not specify which extreme of a range of variation is due to cranial modification or absence thereof. In other words, while the ends of each lollipop represent the extremes of landmark location, they cannot be interpreted as the "head" representing unmodified cranial variation and the "stick" representing modified variation, or vice versa. Thus, these lollipop graphs describe directionality of the axes of variation in landmark location, not direction of landmark location along such axes toward a modified or unmodified skull shape.

Results from the PCA indicate that major shape differences exist in the sample based on differences in location at lambda, bregma, asterion, and euryon (Figures 5-8). The lollipop graphs for PC1 and PC2 indicate that lambda exhibits variation in both an anterior direction and along the superoinferior axis, bregma exhibits variation in a posterior direction, asterion exhibits variation in a posterior direction, and that euryon exhibits variation laterally and inferiorly (Figures 5-8). The possible causes of variation at bregma, lambda, asterion, and euryon will be discussed separately. Variation in landmark location expressed by PC3 and PC4 appears to be more sporadic, with the paired euryons and asterions showing variation in differing directions and midline landmarks like bregma and lambda showing variation in lateral directions (Figures 9-12).

The directions of variation in landmark location at lambda and euryon are likely a product of CVM. Cranial vault modification that involves pressure applied to the posterior skull results in flattening of the occipital region and that pressure can cause in compensatory growth in the form of parietal bulging (Antón, 1989; Figure 20). When the occipital is flattened, it is expected that the location of lambda would move anteriorly, as the data in this thesis demonstrates (Figures 5 and 6). Figures 5 and 6 also demonstrate that lambda's location moves superiorly with occipital flattening. Additionally, since occipital pressure would produce compensatory growth either anteriorly, laterally, or superiorly in the parietals, it is intuitive that euryon's direction of landmark location variation with flattening is directed laterally (Figures 5-8). The directionality of changes at euryon is consistent with parietal bulging, with the widest point of the cranial vault being shifted anteriorly and laterally with compensatory growth of the parietals. It is important to remember, however, that euryon is a Type III landmark and is therefore not as biologically meaningful as Type I and II landmarks (Bookstein, 1991). As such, the variation expressed at euryon may easily be a product of the inconsistency in location of the landmark, which can be extracted from a relatively large range on the skull (Ross and Williams, 2008). Error associated with this difficulty in landmark location at euryon may be responsible for the differing directions of variation shown in Figures 9-12.

The scatter plot shown in Figure 13 displays the overall shape variation for each skull along PC1 and PC2. The crania, represented by individual points in the scatter plot, were color coded to indicate presence or absence of modification based on visual assessment of CVM. The scatter plot indicates that unmodified crania exhibit a more homogenous expression of shape variation than do modified crania, as unmodified crania generally cluster with lower values for each PC in the lower left corner of the plot (Figure 13). While unmodified crania demonstrate a
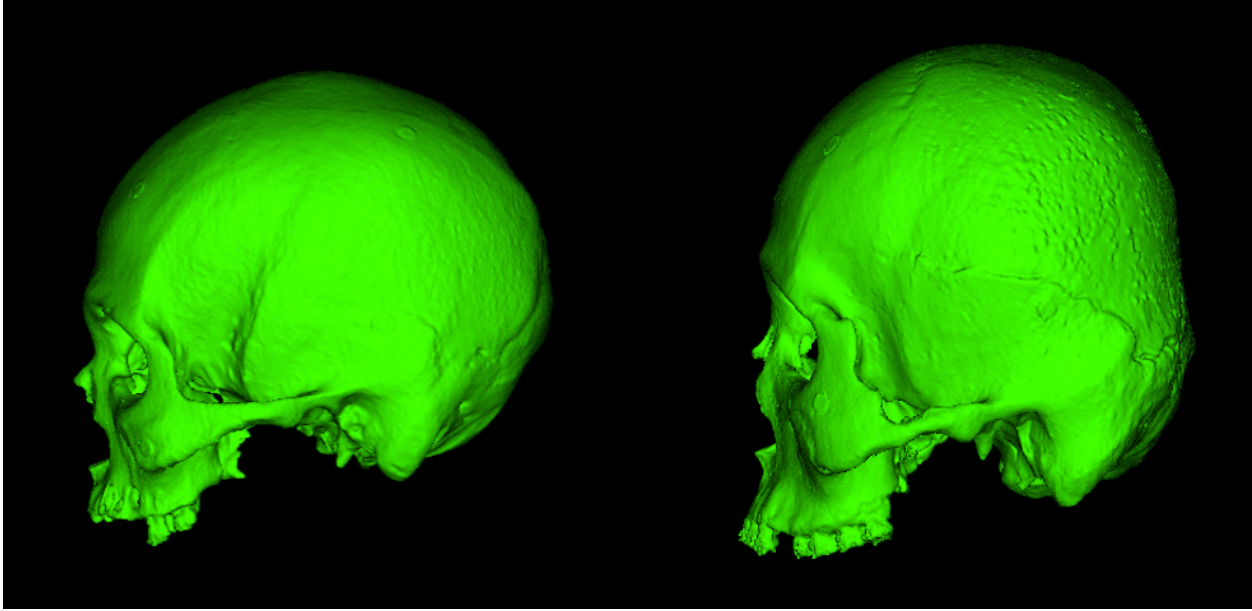
Figure 20: Unmodified cranium (left, from Averbuch) and modified cranium (right, from Arnold).

more confined range of shape variation than modified crania, their ranges of variation are not distinct and instead overlap (Figure 13). Such an overlapping of variation suggests that unmodified crania and crania with slight modification may have similar landmark configurations and thus plot similarly along PC1 and PC2.

A lack of morphological distinction between modified and unmodified crania is also shown in the DFA results that attempted to classify modified and unmodified crania based on cranial shape (Table 5). The DFA classified crania into modified and unmodified well, with an 82.1% correct classification for modified and unmodified crania (Table 5). However, a correct classification percentage of 100%, reflecting a clear distinction in shape between modified and unmodified crania, is precluded based on the fact that a continuous range of flattening from unmodified to significantly modified is present in this sample. Therefore, the hypothesis that modified and unmodified crania can be reliably distinguished based on morphological differences is accepted.

The scatter plot for overall shape variation along PC3 and PC4 is presented in Figure 14. The range of variation for modified crania wholly encompasses the range of variation expressed by unmodified crania and both categories of crania have a similar distribution of points, indicating similar ranges of variation along PC3 and PC4 (Figure 14). Since no distinction in the variation between modified and unmodified crania is shown by their behavior along PC3 and PC4, these principal components do not characterize variation in landmark location that can be attributed to differences in shape between modified and unmodified crania. Given this, it is unlikely that the major shape differences among landmarks described by PC3 and PC4 are attributable to shape differences resulting from the presence or absence of CVM (Figures 9-12).

Possible factors contributing to the shape differences described by PC3 and PC4 are simple error in landmark location, as discussed earlier, or asymmetrical flattening. Asymmetrical flattening was recorded for 18 individuals in the overall sample (12 individuals exhibit left-biased asymmetry, 6 exhibit right-biased asymmetry). It is possible that the differing directions of variation in landmark location described by PC3 for left and right asterion, as well as for left and right euryon, is a result of asymmetrical flattening, which would essentially shift one side of the posterior crania anteriorly in relation to the other side. Such a contralateral shift in lateral landmarks may explain the differing directions of variation in landmark location.

Variation in Cranial Vault Shape by Sex

The results for the DFA classifying crania by sex based on morphology of the cranial vault indicate that there is no meaningful morphological difference in vault shape between males and females when the sample included both modified and unmodified individuals (Table 6). The pooled DFA did not adequately classify crania into sex categories, with a 64.6% correct classification percentage (Table 6). Additionally, the DFA that tested classification of modified

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males and females by vault shape did not classify crania by sex adequately, with a 58.1% total correct classification (Table 7). These DFA results by sex suggest that males and females were just as likely to undergo modification. Additionally, since there is not a strong distinction in shape variation among modified crania, CVM practice in the MCR did not differ based on the sex of the child, or at least not enough to result in significant morphological differences in cranial vault shape. Therefore, the hypothesis that distinct morphological differences in vault shape exist between sexes is rejected as no sex differences were detected among MCR crania that might be indicative of differential CVM practices observed elsewhere (Blackwood and Danby, 1955; Dingwall, 1931).

Variation in Cranial Vault Shape by Site

A CVA was performed to examine shape differences in cranial morphology between Averbuch, Arnold, and Bowling Farm using both modified and unmodified crania (Table 8; Figures 15 and 16). Arnold and Averbuch have similar expression of variation in landmark locations along CV1, while Arnold and Bowling Farm have similar expression of variation along CV2 (Table 8; Figure 15). Since CV1 describes 72.07% of the shape variation among sites, this indicates that major differences in cranial morphology exist between Bowling Farm and the other two sites (Table 8; Figure 15). Shape differences indicated by the lollipop graph of CV1 demonstrate that lambda expresses variation anteriorly, bregma exhibits variation superiorly, and left and right asterion exhibits variation posteroinferiorly (Figure 16). These shape differences are associated with differing morphologies between modified and unmodified crania: an anterior shift of the occipital associated with posterior flattening occurs concurrently with compensatory growth superiorly.

Additionally, three separate DFAs were performed to assess whether morphological variation of the cranial vault can be used to distinguish crania from the Averbuch, Arnold, and Bowling Farm skeletal samples using pairwise comparisons (Tables 9-11). The DFA between Bowling Farm and Arnold classified the crania by site very well (83.7%), while the DFA attempting to classify Bowling Farm and Averbuch resulted in a moderate 72.1% correct classification (Tables 9 and 10). A 55.7% correct classification is reported for the DFA between Arnold and Averbuch, indicating that shape differences in the cranial vault are not much better than chance at categorizing the crania by site (Table 11). Along with the distinct expression of Bowling Farm along CV1, the high percentage of correct classification between Bowling Farm and Arnold, and to a lesser extent between Bowling Farm and Averbuch, is a result of a much lower frequency of modified skulls present in the Bowling Farm sample (42.9%) compared to Arnold (95.7%) and Averbuch (87.2%) (Table 1).

In addition to inter-site comparisons including modified and unmodified crania, a CVA and three pairwise DFAs were performed using only modified crania to determine if differences in degree of flattening exist among Arnold, Averbuch, and Bowling Farm (Figure 17-19; Tables 12-15). The CVA indicates that while Arnold and Averbuch have more similar mean CV scores than Bowling Farm along CV1, the mean CV scores are different among all three sites along CV2 (Table 12). The scatter plot of CV scores for modified crania among sites demonstrates that while all sites overlap to an extent, the ranges of variation for Bowling Farm and Arnold deviate from that of Averbuch, indicating that the variation in cranial landmark location may be useful in classifying crania by site (Figure 17). Shape differences identified among sites in the modified-only CVA indicate similar directions of variation as those between modified and unmodified individuals (Figures 18 and 19). Posterior flattening of the occipital would result in variation at

lambda, left asterion, and right asterion along an antero-posterior axis along with variation at lambda superiorly, while compensatory growth would explain the medial and anterior directions of variation at left and right euryon (Figures 18 and 19). The 75.0% correct classification for the DFA between Arnold and Bowling Farm and the 68.1% correct classification for the DFA between Averbuch and Bowling Farm indicate moderate separation based on morphological data (Tables 13 and 14). Meanwhile, the DFA between Arnold and Averbuch resulted in a 58.7% correct classification, indicating that classification between these two sites is not much better than chance (Table 15). The moderate correct classification rates from the Arnold/Bowling Farm and Averbuch/Bowling Farm DFAs may indicate that the degree of flattening at Bowling Farm is quantifiably different from that present at either Arnold or Averbuch. However, it should be noted that only six individuals were visually classified as modified in the Bowling Farm sample and that this small sample size may not be representative of the range of variation among modified individuals from the site. Furthermore, the small sample size of modified individuals at Bowling Farm means that if one more or one less crania was correctly classified for the site in the above DFAs, the correct classification percentage would be either significantly higher or lower, respectively. Therefore, statements of much confidence cannot be made regarding modified cranial shape variation among sites due to the small number of modified crania at Bowling Farm.

The fact that the Bowling Farm sample has significantly more unmodified crania than Arnold, and that the DFA categorizes crania by site with high correct classification percentage in a pairwise comparison of Bowling Farm and Arnold, is interesting given that the two sites are roughly contemporaneous and geographically proximate. The frequency of unmodified crania in the Bowling Farm sample compared to Arnold indicates a difference in CVM practice,

specifically a lack thereof, for a subset of the Bowling Farm sample. Putnam (1878) noticed this relatively large presence of "long-headed" individuals during excavation at Bowling Farm and speculated that these particular individuals were non-local people incorporated into the community. Other evidence of interactions with non-local groups at Bowling Farm include the presence of non-local mortuary artifacts, like a chisel made of Mill Creek chert and shells native to the southern Atlantic coast (Putnam, 1878). Non-local mortuary artifact assemblages are not necessarily indicative of non-local individuals within the community, as these artifacts could be a result of trade. However, Vidoli (2012) conducted biodistance analyses of several MCR sites and her results indicated that Bowling Farm was an outlier compared to the other sites. Together, this evidence is suggestive of the presence of non-local individuals, though the reasons for their presence at Bowling Farm are unclear.

Bowling Farm is one of the earlier Mississippian sites in the MCR, so a heterogeneous community could be the result of early coalescence in the region (Vidoli, 2012). It is also possible that these non-local individuals are part of a migrant or diasporic community at Bowling Farm, as Knudson and Torres-Rouff (2009) suggested for an explanation of different modification styles at the Caspana cemetery in northern Chile. While a more direct analysis of the unmodified individuals at Bowling Farm and their relatedness to local groups is necessary to confirm that they are non-local, the incidence of unmodified crania could be an example of the presence or absence of modification as an ethnic marker based on cultural distinctions in the practice of CVM. In other words, since these possible nonlocal individuals whose skull was not flattened as a child had a distinct cranial morphology compared to other occupants at Bowling Farm, a cultural difference in this practice would be visibly identifiable during life. A possibility to consider, however, is that Bowling Farm's sample size is fairly low (n=14) and the high

proportion of unmodified crania could be a result of sampling bias. Given this, interpretation of the presence of unmodified crania at Bowling Farm is speculative.

Summary

The results of the PCA indicate that major shape differences among MCR crania are consistent with posterior flattening and consequent parietal bulging. Additionally, the scatter plot of PC scores along PC1 and PC2 indicate that cranial morphology between modified and unmodified is not distinct, and instead a continuous range of flattening exists between these morphologies. No sex differences in variation of landmark location were detected, indicating that CVM practices were not performed differently between males and females in the MCR as is seen elsewhere (Blackwood and Danby, 1955; Dingwall, 1931). Finally, site differences in cranial morphology show that Bowling Farm has substantially less modified crania than Arnold or Averbuch, possibly indicating the presence of nonlocal individuals who were not subjected to CVM practices. Intersite comparisons of only modified individuals show that Bowling Farm exhibits a different range of variation in flattening than Arnold or Averbuch, but the small sample size of modified individuals at Bowling Farm does not allow for meaningful interpretations to be made regarding this variation.

The posterior flattening without accompanying frontal flattening is consistent with CVM produced by cradleboarding. Though the use of cradleboarding cannot be ascertained conclusively without physical evidence of such apparatuses within the MCR, a cradleboard was present in the archaeological assemblages at the Newt Kash Shelter, an Early Woodland rock shelter in eastern Kentucky (Claassen, 2011). While the presence of a cradleboard at Newt Kash is certainly not substantial evidence for the practice during the Mississippian occupation of the MCR, it does demonstrate that cradleboard use was not foreign in the area. Cradleboards were

used for protection and transport of an infant and allowed mothers to carry out daily tasks while tending to their child (Densmore, 1979). Additionally, cradleboards allowed for ease of transport when travelling long distances (Densmore, 1979). In the context of the MCR, cradleboards may have allowed mothers to continue to participate in subsistence labor, food preparation, craft production, and other tasks while also caring for a child (Claassen, 2011; Thomas, 2001; VanDerwarker and Wilson, 2016). If the posterior flattening exhibited by MCR crania is indeed caused by cradleboarding, the use of a cradleboard seems to be a fairly ubiquitous practice in the lives of MCR Mississippians given the high prevalence of modified crania in both Arnold and Averbuch.

CHAPTER 7: CONCLUSION

The primary goal of this thesis was to provide a more empirical method for assessing CVM within archaeological skeletal samples through morphometric analysis of cranial vault shape. To that end, the results indicate that while classification of morphological variation of modified and unmodified crania largely corroborates visual assessment, a range of slight modification still exists that is difficult to distinguish from unmodified crania. Bioarchaeological questions were also addressed, such as differences in the expression of modification by site and sex. Among the MCR sites examined, there is no morphometric evidence of differential modification practices by sex. The large proportion of unmodified crania at Bowling Farm, however, may indicate the presence of a non-local group. Though further analysis is necessary, the case of Bowling Farm may be indicative that CVM (or lack thereof) can serve as an ethnic marker that can be used to distinguish groups during the Mississippian period in the MCR. Since no ethnographic accounts exist for Middle Cumberland Mississippian societies, the results of this thesis contribute to ongoing archaeological reconstruction of MCR history.

Several limitations to this study should be noted. First, low sample sizes hinder statistical power for analyses involving that subset of the overall sample. One glaring example is the low number of unmodified individuals in this thesis's overall sample (n=15). To address this, further MCR samples should be included in order to increase representation of unmodified individuals. Additionally, certain site sample sizes, like Bowling Farm (n=14) are low. For this thesis, fragmentary cranial remains, coupled with low recovery rates for Arnold and Bowling Farm, limited sample sizes since all landmarks examined needed to be present. Secondly, landmark studies examine morphological differences by comparing variation of landmark configurations, but such point data captures only a small amount of morphology of the cranial vault.

Furthermore, the cranial vault does not have many reliable landmarks that can be used to study shape differences compared to the basicranium and facial skeleton. All Type I landmarks that exist for the cranial vault were used in this thesis, as well as Type III landmarks like euryon. Other possible landmarks like opisthocranion and metopion are Type III landmarks. As discussed before, Type III landmarks are generally avoided since they are difficult to locate, contribute to high intra-observer error, and are not biologically meaningful (Bookstein, 1991).

Future morphometric examination of CVM may involve a more comprehensive analysis of cranial vault morphology. An alternative research design could implement thin plate splines (TPS) as the morphometric analysis of cranial vault shape. Thin plate splines are conceived as infinitely thin, flat plates that are bent to conform to a target surface (Bookstein, 1989; Stoyanova et al., 2015). An algorithm is then used to model the minimum bending energy to match said surface. In the context of CVM research, bending energies can be compared using surface scans of the occipital region that may correspond to the presence or absence of CVM. A preliminary expectation of such a study would be that TPS applied to flattened occipitals would require a lower bending energy than those applied to unmodified occipitals. Since thin plate splines use entire surfaces for analysis, not just points or linear measurements, their application to CVM research may allow for morphometric examination of subtler shape variation caused by modification. Additionally, since a TPS method does not require the presence of al

Bioarchaeological investigations of CVM are often concerned with the practice's cultural dimension and how differences in modification can reflect some aspect of social structure for past populations. Intuitively, accurate CVM classification must come first. The research design of this thesis evaluated the morphological basis for visual assessment of CVM, the most common method of CVM classification, and further explored archaeological implications of CVM in the

MCR. A similar research framework can be adopted for examination of other groups in order to

understand how cranial modification is related to social identity and societal structure in the past.

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VITA

Greg Wehrman received a B.A. in Anthropology from the University of South Carolina in 2014. During his undergraduate career, he conducted research on skeletal samples from post-medieval London and subsequently wrote his undergraduate honor's thesis on health disparieties from the same period. Upon graduation, he was accepted as a graduate student under Dr. Dawnie Steadman at the University of Tennessee studying skeletal biology and bioarchaeology. There, he worked as a Graduate Teaching Assistant in the Department of General Biology and the Department of Ecology and Evolutionary Biology. Greg has conducted historical archaeological fieldwork in northern Virginia and bioarchaeological fieldwork in St. Croix, USVI. He intends to remain at the University of Tennessee to pursue his doctorate degree in biological anthropology.