FLUCTUATING ASYMMETRY AS A MEASURE OF DEVELOPMENTAL INSTABILITY IN ARIKARA BIOARCHAEOLOGICAL ASSEMBLAGES

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By
MARK BEARY

Dr. R. Lee Lyman, Dissertation Co-Advisor
Dr. Todd VanPool, Dissertation Advisor

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The undersigned, appointed by the dean of the Graduate School,

have examined the Dissertation entitled

FLUCTUATING ASYMMETRY AS A MEASURE OF DEVELOPMENTAL INSTABILITY IN ARIKARA BIOARCHAEOLOGICAL ASSEMBLAGES

Presented by Mark Beary

A candidate for the degree of

Doctor of Philosophy

And hereby certify that, in their opinion, it is worthy of acceptance.

Dr. R. Lee Lyman

Dr. Todd VanPool

Dr. Daniel Wescott

Dr. Mark Flinn

Dr. Michael Glascock

DEDICATIONS

To my parents, Kathleen and Charles Miller, for all their love and support.

To my father, Lawrence T. Beary, in memoriam.

To the Sahnish (Arikara) people, past and present,

teenikutuhnaa'iitUxù'. As best as I could tell it.

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ABSTRACT

Fluctuating asymmetry (FA) has been advanced as a tool for investigating the developmental instability of human populations and has more recently found its way into bioarchaeological investigations. The research presented here seeks to build upon those investigations and determine whether specific measures of FA can provide meaningful insight into the developmental instability of past Arikara populations represented in archaeological variants of the Coalescent tradition. Specifically, cranial morphometric, cranial nonmetric, and post-cranial metric measurements have been used to determine if meaningful patterns in the magnitude of FA across variants of the Coalescent tradition can be detected.

The data that form the basis of this research originate from skeletal assemblages excavated from numerous Arikara archaeological sites along the Missouri River in South Dakota. These assemblages were selected for this study because they represent a single, culturally and genetically affiliated population that can be examined over the course of several centuries during which time the Arikara experienced variability in environmental and social stressors—the suspected cause of developmental instability. Moreover, several of these skeletal assemblages provide rather large samples, which is ideal when assessing FA in order to avoid the possible influences of small samples such as sampling error.

Three approaches to data collection and analysis are included in the study. Patterns of FA were assessed for nonmetric traits of the cranium and metric traits of the post-cranial skeleton. In addition, three-dimensional craniometric data were assessed for fluctuating asymmetry through the applications of Euclidean Distance Matrix Analysis (EDMA).

A hypothesis for the relative ordering of the magnitude of FA was developed based on archaeological/ethnohistorical information regarding potential social stressors, prior studies that have examined the health of the Arikara, and information regarding the changing climatic conditions during the four variants of the Coalescent tradition. The hypothesized ordering of the magnitude of FA, from least to greatest, is: Post-Contact Coalescent, Extended Coalescent, Initial Coalescent, and Disorganized Coalescent. However, the results do not fully support this ordering. While the Disorganized Coalescent did display rather high magnitudes of fluctuating asymmetry in certain measures and dimensions, the Post-Contact Coalescent was found to represent some of the highest magnitudes of fluctuating asymmetry, especially for the craniometric measures.

If fluctuating asymmetry is indeed a suitable measure of developmental instability, then the major implication of this study is that a reevaluation of the Coalescent variants may be in order. Specifically, the Post-Contact coalescent may not have been a period of fluorescence and prosperity for the Arikara as has been described elsewhere. Alternatively, it may be that these archaeological variants do not provide an appropriate chronological resolution for assessing fluctuating asymmetry within this population.

CHAPTER 1: INTRODUCTION

Assessing stress among prehistoric peoples has been a focus of bioarchaeologists for many years (e.g., Goodman et al. 1984, 1988; Schell 1997; Klaus and Tam 2009; Ice and James 2012; Klaus 2014). Throughout this time, various methods and measures have been explored as tools for investigating the human response to stress, whether it originates extrinsically or intrinsically, from skeletal remains. More recently, the biological phenomenon of fluctuating asymmetry has been advanced as one such measure which may be used as an indicator of environmental stress among peoples of the past (e.g., Perzigian 1977; Teul et al. 2002; DeLeon 2007; Gawlikowska et al. 2007; Hoover and Matsumura 2008; Barrett et al. 2012).

Fluctuating asymmetry (FA) has been suggested to be a measure of developmental instability in biological organisms and its use as an analytical tool has gained in popularity over the past several decades (e.g., Perzigian 1977; Trinkaus 1978; Palmer and Strobeck 1986; Palmer 1994, 1996; Gangestad and Thornhill 1999; Flinn et al. 1999; Auerbach and Ruff 2006; DeLeon 2007; Gawlikowska et al. 2007; Zachos et al. 2007; Barrett et al. 2012). The fact that biological organisms tend to deviate from perfect bilateral symmetry to variable degrees has led to a proliferation of research utilizing FA as a tool for understanding developmental instability. However, problems in FA analyses remain persistent and some fundamental questions about the nature of FA remain unanswered. Efforts to resolve these issues require ongoing evaluation of how we develop and frame hypotheses, but also new methods and perspectives on how we measure and evaluate the effects of environmental perturbations on populations of organisms. To that end, this research adds to the limited body of FA research within bioarchaeology and, in doing so, adds a valuable perspective to the scientific community investigating the utility of FA analyses as a means to document physiological stress in populations of organisms.

Approaches to measuring FA have traditionally utilized metric (continuous) and nonmetric (discrete) skeletal traits or a combination of both. Both measures have their advantages and drawbacks and many indices of FA have been developed that, likewise, are more or less appropriate in particular experimental scenarios (see Palmer and Strobeck 1986, Palmer 1994). New methods, both of data collection and data analysis, have recently found their way into FA evaluations of prehistoric samples. Specifically, the collection of three-dimensional coordinates from human crania and the application of Euclidean Distance Matrix Analysis to these data represent a new approach that can be compared against traditional measurements and statistical computations. Ideally, these analytical methods would be tested on skeletal series which are well defined archaeologically and for which prior bioarchaeological research has defined well-supported presumptions about the nature of environmental and social stressors on that population over time. In North America, one of the best skeletal series to satisfy these characteristics belongs to the Arikara skeletal assemblages that were predominately recovered during the large salvage archaeology programs of the River Basin Surveys (RBS) (see Banks and Czaplicki 2014 for the history of the RBS).

Prehistorically and historically, the Arikara were a people of the northern Plains, specifically South Dakota, who resided in villages along the Missouri River. The Arikara and their ancestors have been characterized as having belonged to four archaeological variants of the Coalescent cultural tradition (in temporal order): Initial Coalescent (IC), Extended Coalescent

(EC), Post-Contact Coalescent (PCC) and Disorganized Coalescent (DC). These four variants that comprise the Coalescent tradition are generally taken to span approximately A.D. 1300 to A.D. 1845. Because of the massive salvage archaeology programs conducted under the RBS of the 1950s and 1960s, a large number of Arikara cemeteries/burials, which recovered large numbers of individual interments, were excavated from sites dating within this time span. These skeletal collections, through an analysis of FA, afford us the opportunity to evaluate how culture, ecology, and biology articulate and influence each other in a single population over time.

The present study is an inquiry into the relationship between late prehistoric and early historic Arikara developmental instability, as measured by FA, and the environmental and social stress these people experienced during the archaeological variants of the Coalescent tradition. The primary purpose of this investigation is to determine if previously established notions about the magnitude of environmental and social stress experienced during these Coalescent variants is consistent with the rank ordering of developmental instability, measured as the magnitude of fluctuating asymmetry, within these archaeological variants. A secondary goal of this research is to determine whether specific measures of FA are better suited to provide insight into the developmental instability of past populations. Specifically, cranial morphometric, cranial nonmetric, and post-cranial metric measurements will be tested to determine if statistically significant results demonstrate a causal relationship between environmental and social stressors and the magnitude of FA across the variants of the Coalescent tradition.

The chapters that follow cover the basic premises of fluctuating asymmetry, review our understanding of the Arikara from prehistoric times up to the historic period, and investigate how FA might be used to better understand how these people responded to their ever-changing environment (both physical and social). Chapter 2 provides an overview of FA as a biological phenomenon and discusses how researchers have attempted to use it to answer questions about developmental instability and stress. Chapter 3 discusses the Arikara and their ancestors during the time they inhabited the Missouri River trench in what is today South Dakota. This discussion is based primarily on what has been gleaned from the archaeological record during the twentieth century. Chapter 4 is an overview of the materials utilized in this research. The data that form the basis of this research originate from skeletal assemblages excavated from numerous archaeological sites along the Missouri River in South Dakota; discussions of each of these sites and our current understanding of their position in prehistory are provided. Moreover, because the Coalescent archaeological variants are being utilized to assign relative magnitudes of stress to these assemblages, it is important to evaluate how these archaeological sites have been assigned to their respective variants; such evaluation is provided in Chapter 4. Chapter 5 discusses the analytical methods I employed to measure, assess and interpret the magnitude of FA, from three-dimensional coordinate, metric, and nonmetric traits derived from various regions of the skeleton. Chapter 6 provides the results of the FA analyses conducted on the cranial nonmetric, post-cranial metric, and craniometric datasets. Finally, Chapter 7 concludes with my interpretation of the results as they relate to our understanding of the Arikara, the social and physical environments within which they existed, and the utility of the FA measures to add to our understanding of environmental stress and developmental instability among the Arikara. Ultimately, the more we learn about which measures of FA work best with bioarchaeological skeletal samples, the better equipped we become at utilizing this tool to interpret the past.

CHAPTER 2: FLUCTUATING ASYMMETRY

Bilateral symmetry, the property of having symmetrical halves, is so pervasive in animals that it is often taken for granted. Most phyla of the Kingdom *Anamalia* are subsumed under the subregnum of *Bilateria*. Phyla not included in *Bilateria* include *Porifera* (sponges), with no symmetry, in addition to *Cnidaria* (jellyfish, coral, and anemone) and *Ctenophora* (comb jellies), which have radial symmetry (Boorman and Shimeld 2002). However, even bilateral organisms tend to show some level of asymmetry in their structures. For example, the internal organs of many complex animals can show a significant degree of asymmetry in terms of their placement. However, placing these internal inconsistencies aside we see that members of *Bilateria* are all related because their bodies are organized around anteroposterior and dorsoventral axes with the left and right sides reflected around the midline (Boorman and Shimeld 2002:1004). However, even at this level, many organisms deviate from perfect bilateral asymmetry in distinct ways.

The term *fluctuating asymmetry* was coined by Ludwig (1932) and later included, along with directional asymmetry and antisymmetry, in Van Valen's (1962) description of three categories of deviation from perfect symmetry. Van Valen (1962:126) described fluctuating asymmetry as "asymmetry that results from the inability of organisms to develop in precisely determined paths." How closely an organism follows these precisely determined paths has been termed *developmental precision* (Palmer 1996). *Developmental instability* (or *developmental noise*) refers to random variations, at the molecular and cellular level, in an organism's developmental processes that keep it from achieving perfect symmetry (Palmer

1996; Hallgrímsson 2002). Conversely, *developmental stability* (or *developmental homeostasis*), refers to processes that buffer against developmental noise and create a “tendency for development to follow the same trajectory under identical genetic and environmental conditions” (Willmore and Hallgrímsson 2005:191). Note that developmental stability and instability refer to an organism’s processes of growth and development as they occur under identical genetic and environmental conditions. However, *canalization* refers to “the ability of a structure to develop along a predetermined path in a variety of environments” (Palmer 1996:519).

As Willmore and Hallgrímsson (2005:192) indicate, quantifying developmental stability is impractical because it amounts to measuring a lack of variation arising from perturbations within an organism. Therefore, assessing developmental stability (the target variable) is accomplished by measuring developmental instability by means of FA (the measured variable). FA is a population-level measure, characterized by minor deviations from symmetry among individuals, which are random with regard to side and normally distributed about a mean of zero (Van Valen 1962).

Analysis of the FA of bilaterally paired features or elements has been offered as a method for assessing developmental stability among populations (e.g., Livshits and Kobyliansky 1991; Palmer 1994, 1996) and, concomitantly, as an indicator of developmental instability arising from environmental and genetic stressors (Markow 1995; Leung and Forbes 1997; Møller and Swaddle 1997). However, all of these supposed associations are debatable, with some authors arguing for a strong relationship between FA and developmental stability (e.g., Sciulli et al. 1979; Pankakoski 1985; Freebairn et al. 1996) and others reporting quite the opposite (e.g., Hallgrímsson 1993; Bjorksten et al. 2000).

Anthropologists have analyzed FA of both living human populations (Harris and Nweeia 1980; Noss et al. 1983; Kieser 1992; Kieser and Groeneveld 1994; Flinn et al. 1999) and skeletal assemblages (Jolicoeur 1963; Perzigian 1977; Doyle and Johnston 1977; Noss et al. 1983; Albert and Greene 1999; Gawlikowska et al. 2007). As with studies of other organisms, the ambiguity of results has plagued anthropological analyses and has led some to the perhaps obvious conclusion that the relationship between FA and developmental stability is not always straightforward owing to the interactions of genetic and environmental factors (Saunders and Mayhall 1982). Despite the conflicting results found in a wide array of studies from disparate fields of investigation, some skeletal biologists and bioarchaeologists have pursued FA as a means of investigating developmental instability (DI). Ultimately, the confirmation of a meaningful FA-DI relationship would give archaeologists another tool for elucidating how specific environments, or environmental changes, influenced past human populations.

Approaches to FA analysis in bioarcheology are reminiscent of investigations that have sought to establish biological affinity and distance between populations based on analysis of morphological (metric and nonmetric) traits of the skeleton (e.g., Conner 1990; Konigsberg 1990). The underlying assumption of those studies has been that morphological traits are polygenic and therefore provide a window into the microevolutionary mechanisms operating on populations (Buikstra et al. 1990; Tyrrell 2000). However, to date, these studies suffer from a lack of research aimed at determining the level of heritability of studied traits (Tyrrell 2000) and, therefore, the degree that the environment plays in determining their expression.

Somewhat conversely, a major underlying assumption of studies of FA as a measure of developmental instability is that departures from symmetry within an individual should not be heritable (Palmer and Strobeck 1992). Furthermore, analysis of FA must cope with the fact that stressors giving rise to increases in FA can be either intrinsic (genetic) or extrinsic (environmental) and, most likely represent some combination of the two. Thus, though there are parallels for both types of studies, there are also intersections at which information gleaned from one approach may give direction to research in the other.

2.1.1 Types of Asymmetry

According to Van Valen (1962), directional asymmetry (DA) occurs whenever a majority of individuals exhibits greater development of a character on one side of the plane of symmetry than on the other (Van Valen 1962). When conceived in terms of a population, directional asymmetry includes deviations that diverge significantly from a mean of zero when asymmetry is measured as the difference between right and left sides (Hallgrímsson 2002). Antisymmetry refers to a less common situation where asymmetry is present but the side that is larger is variable (Van Valen 1962). In a population, antisymmetry includes deviations from symmetry that exhibit a bimodal distribution (Hallgrímsson 2002). The final type of asymmetry is fluctuating asymmetry (FA); it represents the inability of organisms to develop in “precisely determined paths” and is “undoubtedly ubiquitous” (Van Valen 1962:126). In a population, FA is characterized by random deviations from symmetry that are normally distributed in frequency about a mean of zero.

Palmer (1996) provides an informative overview of FA and the terminology associated with FA research. He notes that it is important to bear in mind that FA implies nothing definitive about causation. Rather, *developmental noise* refers to any processes “whose random variation during growth tends to cause a structure to depart from its ideal for a particular genotype and environment” (Palmer 1996:519). The “ideal,” which is most likely never achieved, is perfect symmetry, this being what makes measures of FA a seductive analytical variable, because it establishes a baseline from which deviations can be measured. FA, therefore, arises from the interaction of developmental noise and developmental stability. Furthermore, and perhaps most importantly, FA offers a measure of *developmental precision*, that is, how closely an organism approaches its ideal for a particular genotype and growth environment (Palmer 1996). One might consider symmetry the null model of development, and FA the real result, with individually distinct empirical manifestations.

Much has been written about FA, as well as its causes and effects. In biology, FA has been advanced as a powerful variable that reflects the health, quality, or developmental stability of organisms (Palmer 1996). Palmer notes that while the potential usefulness of measures of FA has led to considerable attention, its "uncritical application has also engendered much skepticism" (Palmer 1996:518). Clearly, FA cannot be everything to every researcher; however, the seemingly simple measurement of FA has resulted in a proliferation of eyebrow-raising studies (e.g., Gangestad and Thornhill 1998; Martin et al. 1999). Nevertheless, when used with care and consideration of confounding variables, "fluctuating asymmetry offers a unique tool for quantitative comparisons of developmental precision among a wide variety of organisms and traits" (Palmer 1996:518).

The fact that FA offers a measure of developmental precision is of critical importance. As many researchers have illustrated, FA appears to correlate with a variety of stresses. These stresses can be grouped into two categories: “environmental, or extrinsic, stresses (temperature extremes, food shortage, pollution, pesticides, parasite load, and population density) and genetic, or intrinsic, stresses (inbreeding, hybridization, chromosomal abnormalities, mildly deleterious recessive genes, disruption of gene balance)” (Palmer 1996:523). Typically, studies have concluded that the greater the stress, the greater the magnitude of FA.

One potential problem in studies of asymmetry is related to quantifying and comparing relative magnitudes of asymmetry. The ideal from which asymmetry is measured is perfect symmetry; however, populations of perfectly symmetrical organisms do not exist. Therefore, we must ask what magnitude of asymmetry is needed before it is considered unusual? As Palmer (1996:524) notes, “only if the level of fluctuating asymmetry of a putatively stressed population lies significantly far from the background level of fluctuating asymmetry in unstressed populations can biologists answer this question with much confidence, and few studies have adequately sampled natural or unstressed populations.” That being said, in a single population over time, assessing relative magnitudes of FA at different times may prove meaningful for determining relative degrees of environmental stressors.

Aside from this, there are other concerns related to the requirements of the sample to be researched. Obviously, when attempting to determine the magnitude of FA within a skeletal series, the necessity of a sample consisting of left and right skeletal elements of *individuals* is of great importance. A commingled assemblage, therefore, represents a challenge to applications of FA analysis. Additionally, taphonomic agents that influence skeletal remains can impact the measurements necessary to proceed with asymmetry studies. Some taphonomic agents may distort traits or osteometric dimensions, whereas others may destroy them. The lack of anthropometric landmarks, or even anatomically complete skeletal elements, can obviously be very detrimental to studies of asymmetry.

Yet, bioarchaeologists, despite their own unique set of challenges, would appear to be in a position to offer a rather unique view of FA analysis given their long temporal perspective. In this view, FA analysis of archaeological assemblages is not a simple application of a biological concept to anthropological questions. Rather, anthropologists have much to offer other fields of scientific inquiry concerned with using FA as an indicator of developmental stability. Given enough information about a past population, archaeologists are able to construct hypotheses about how intrinsic and extrinsic factors would have combined to affect the developmental stability of past peoples. These hypotheses can then be tested and ultimately provide evidence to either support or refute claims of a causal relationship between FA and developmental stability. And, while aiding in determining the future standing of FA analysis, archaeologists also stand to benefit directly from pursuing FA investigations. If the link between FA and stress is found to be sufficient to provide meaningful data regarding developmental stability, then archaeologists will have gained another means of capturing information about the role of stress in human development and evolution. Moreover, bioarchaeologists may also find that investigations of FA can help shed light on larger theoretical questions of archaeological significance. One example would be issues related to the well-known osteological paradox (Wood et al. 1992). In the classic conundrum of this paradox, those individuals displaying skeletal indicators of stress (e.g., Harris lines, skeletal lesions) can actually be interpreted to be among the healthier individuals of a given population, precisely because they survived long enough to develop these skeletal responses to stress and disease. Therefore, Wood et al. (1992) indicated that archaeologists need to search for ways to better assess the *frailty* of prehistoric populations. As an alternative to skeletal lesions arising from disease, FA carries no connotation about the cause of an individual's death and can be measured in all individuals, both healthy and ill at the time of death. Furthermore, FA is useful as a population level indicator, meaning that it may ultimately lend itself as a proxy for population frailty. Ultimately, if FA analysis proves useful in measuring developmental stability of prehistoric population, then it may also serve to construct hypotheses regarding other theoretical issues current in bioarchaeology.

Bioarchaeologists wanting to utilize FA analysis to better understand diachronic developmental instability in past populations should seek research samples, the constituent skeletons of which, have: (1) genetic affiliation over time; (2) a relatively well-known archaeological chronology for assessing relative magnitude of FA between time periods; and (3) reasonably well preserved skeletal elements arising from (4) large samples of non-commingled individuals.

Chapter 3 will review the archaeological variants of the Coalescent tradition and, in doing so; will review the prevailing notions about the magnitude of environmental and social stress experienced during these variants. Chapter 4 will describe the archaeological sites from which the skeletal assemblages utilized in this study originate and identify to which Coalescent variant a particular site or cemetery is assigned. These samples will then be used to investigate the relationship between late prehistoric and early historic Arikara developmental instability and the environmental and social stress these people experienced during these periods. Chapter 4 will also discuss the specific measures (cranial morphometric, cranial nonmetric, and post-cranial metric) of FA examined in this investigation. These three categories of osteometric data will be tested to determine if the patterns in the magnitude of FA across variants of the Coalescent tradition can be correlated with the hypothesized rank ordering of the magnitude of environmental and social stress during these variants. In addition, these data may also indicate whether specific measures of FA are better suited to provide insight into the developmental instability of past populations.

CHAPTER 3: THE ARIKARA

Although some of the dates have been slightly modified with more recent research, Lehmer's (1971:33) classification of traditions and variants within the Middle Missouri subarea (Table 3-1) continues to be the scheme utilized by most archaeologists today (e.g. Wood 1998, Krause 2001). A brief review of the development of the archaeological taxonomy of this region is provided in Appendix 8.1.

Table 3-1. Lehmer's (1971) cultural traditions and variants of the Middle Missouri subarea.

Major Cultural Tradition	Tradition	Variant	Dates
Plains Village	Coalescent	Disorganized	1780 – 1862
		Post-Contact	1675 – 1780
		Extended	1550 – 1675
		Initial	1400 – 1550
	Middle Missouri	Terminal	1550 – 1675
		Extended	1100 – 1550
		Initial	900 – 1400

Following Lehmer (1971), the late prehistoric and early historic Arikara chronology can be divided into four chronologically sequent cultural variants: Initial Coalescent (IC), Extended Coalescent (EC), Post-Contact Coalescent (PCC), and Disorganized Coalescent (DC). The prehistoric period is comprised of the Initial and Extended Coalescent horizons; the Post-Contact and Disorganized Coalescent periods comprise the historic period. Significant events and archaeological characterization of each horizon are described below.

3.1 Coalescent Climatic Conditions

In 1965, archaeologist David Baerreis and climatologist Reid Bryson published their classic work on climatic episodes and the dating of the Mississippian cultures. In this work, Baerreis and Bryson (1965) laid out a sequence of distinct climatic episodes, which they felt were both biotically and culturally significant. The earliest of their climatic episodes germane to this study is termed the Neo-Atlantic and is given the timeframe of A.D. 800 – 1250. During the Neo-Atlantic, subtropical anticyclones brought an influx of moist tropical air into the Great Plains, providing abundant rains and allowing the extension of maize agriculture into the region by the Upper Republican people of the Central Plains tradition (Baerreis and Bryson 1965). However, around A.D. 1250, a change in atmospheric circulation patterns created zonal flow, or airflow along latitudinal lines, that allowed Pacific air to flow across the North American Cordillera, resulting in diminished rains in the northern Plains (Baerreis and Bryson 1965). This pattern, which lasted from A.D. 1250 until approximately A.D. 1450, is a period Baerreis and Bryson (1965) referred to Pacific I. The arid conditions of the Pacific I episode were damaging to corn farmers of the Central Plains who were forced to seek better conditions or more arable land elsewhere. Beginning around A.D. 1450 and lasting until around A.D. 1550, the more favorable Pacific II episode was characterized by warm and moist conditions. However, about A.D. 1550, the westerlies and polar vortexes shifted southward, likely bringing cooler summers and shorter growing seasons to the upper Midwest (Baerreis and Bryson 1965). This episode, referred to as the Neo-Boreal by Baerreis and Bryson (1965), lasted until approximately A.D. 1880.

Lehmer (1970) felt there was good congruence between the climatic episodes laid out by Baerreis and Bryson (1965) and the culture history that he had developed for the Middle Missouri valley. Figure 3-1 is an adaptation from Lehmer's (1970) original chart illustrating the relationship he envisioned between these climatic episodes and the cultural variants of the Coalescent tradition. The adapted version presented here includes updated starting and ending dates for the Coalescent variants. In a fashion similar to Lehmer (1970), Ehrenhard (1972) also postulated that these climatic episodes were correlated with cultural movements of the Coalescent peoples into and along the Missouri River trench. Wendland's (1978) review of the patterns of human occupation of North American during the Holocene focuses on the impact of the climatic episodes. Here again, the author (Wendland 1978) focuses on the impact of the climatic episodes identified by Baerreis and Bryson (1965) on the livelihood and movement of people on the Great Plains. What all of these investigations share is the utilization of the Baerreis and Bryson (1965) climate episodes and the idea that more favorable conditions (i.e. warm and moist) existed during the Neo-Atlantic and Pacific II episodes, whereas more arid conditions existed during the Pacific I episode and generally cooler conditions prevailed during the Neo-Boreal episode.

In describing the climatic context of bioarchaeological assemblages originating from the Northern Plains, Blakeslee (1994) questions the ways in which the Baerreis and Bryson (1965) climatic sequence has been "used and abused by archaeologists" (Blakeslee 1994:12). Nevertheless, even Blakeslee (1994) confines his discussion of climate sequencing to the Baerreis and Bryson (1965) approach since so many archaeological interpretations from the Northern and Central Plains are based on it.

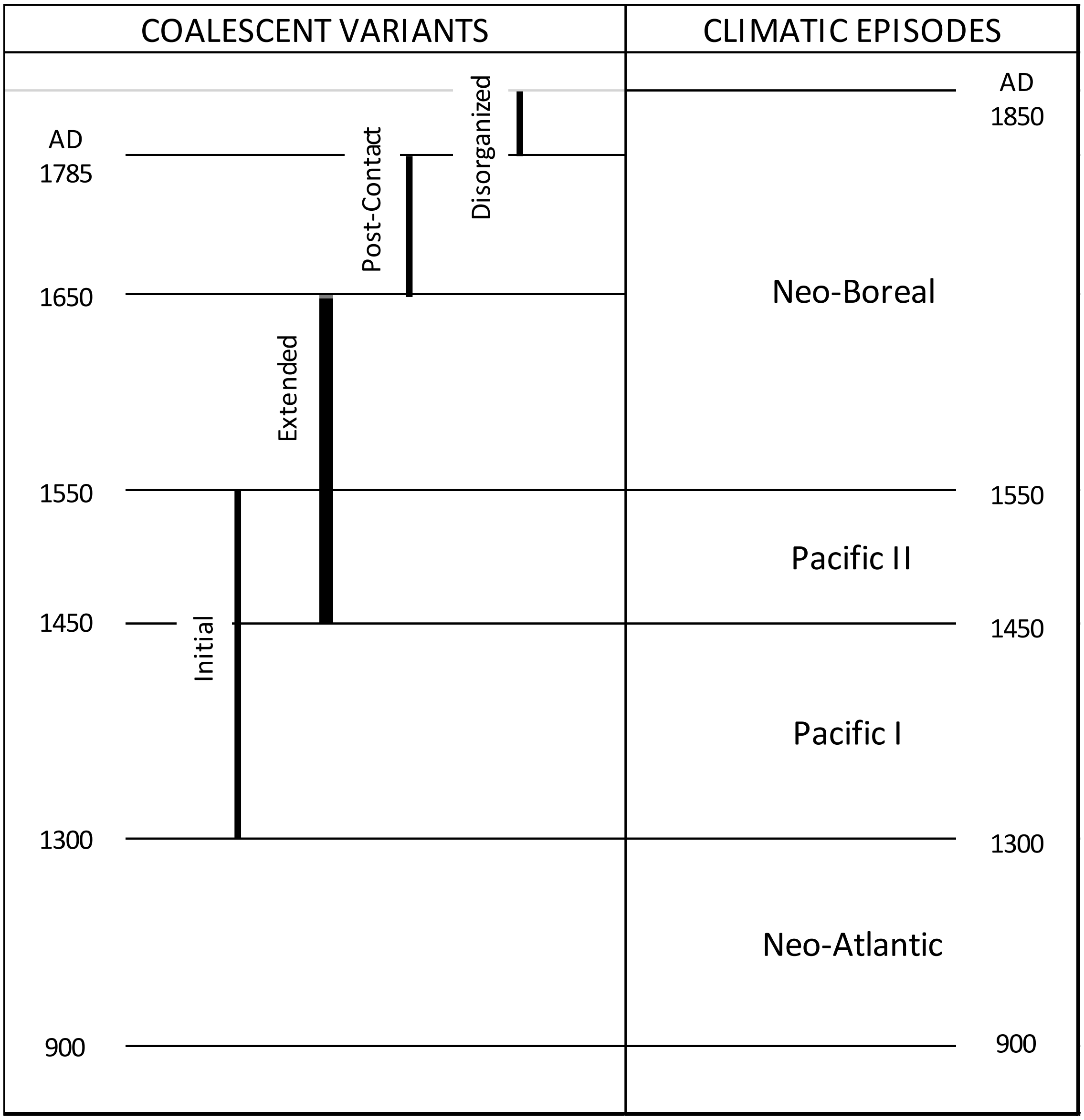

Figure 3-1. Chart illustrating the relationship between climatic episodes and cultural variants. (Adapted from Lehmer 1970)

Despite Lehmer's (1970) acceptance of the climate episodes in relation to the culture history he had developed for the Middle Missouri region, it is important to bear in mind that Baerreis and Bryson (1965) were not focusing their attention specifically on that region within South Dakota. In addition, other terms such as the "Medieval Climate Anomaly" (MCA) and the "Little Ice Age" (LIA) have commonly been used (see Graham et al. 2007 as one example) to describe broad (both temporally and spatially) climatic trends. In comparison to the Baerreis and Bryson (1965) episodes, the Medieval Climate Anomaly would coincide closely with the Neo-Atlantic, and the Little Ice Age would cover the Pacific and Neo-Boreal episodes.

More recent investigations (e.g. Dean and Schwalb 2000; Fritz et al. 2000; Clark et al. 2002; Laird et al. 2003; Brown et al. 2005; Graham et al. 2007; Grimm et al. 2011; Stambaugh et al. 2011; Harden et al. 2015) have provided higher resolution assessment of climatic variability on a more regional scale. Characteristic of these types of paleoclimatic studies is the use of proxy measures to indirectly infer other aspects (e.g. aridity, precipitation, temperature) of the past climate.

Dean and Schwalb (2000) utilized various proxy measures (e.g. magnetic susceptibility, stable isotope measurements, estimates of mineral content) when analyzing sediment cores from Pickerel Lake, SD to assess Holocene climatic change in the Northern Great Plains. The authors discuss aridity cycles over the past 2000 years and draw similarities to other lake studies in the region. They conclude that century-scale cycles in aridity and aeolian activity were dominate climatic features of the Northern Great Plains during the past 2000 years and further posit a possible connection between these cycles and solar activity (Dean and Schwalb 2000).

Grimm et al. (2011) conducted a high-resolution study of climate across the Holocene by examining various proxy measures (i.e. sediment mineralogy, pollen, and charcoal) of climate changes at Kettle Lake, ND. Their chronology of Kettle Lake sediments is based on 53 AMS radiocarbon dates. These authors divide the Late Holocene into three zones, the oldest division is 1460 – 900 cal yr BP (490 – 1050 AD) and is drier and had two severe droughts. It is followed by a wet period with little variance from ~900 – 600 cal yr BP (1050 AD – 1350 AD) that appears to roughly correspond with the Medieval Climate Anomaly. Following this and during the final division, the climate appears to cycle more strongly with more severe droughts than during the preceding interval (Grimm et al. 2011).

Fritz et al. (2000) produced another proxy study in which they examined hydrologic variation in the Northern Great Plains during the past two millennia. These authors utilized reconstructions of lake-water salinity at decadal resolution over the past 2000 years when comparing North Dakota lakes. Their data show frequent shifts between high and low salinity (as a proxy for arid and moist periods, respectively) at Moon Lake, Coldwater Lake, and Rice Lake (Fritz et al. 2000). Results from these three North Dakota lakes suggest severe droughts, equal to or greater in magnitude than those experienced during the Dust Bowl period, were a common occurrence during the last 2000 years.

In a somewhat similar study, Laird et al. (2003) provide an analysis of high-resolution sediment cores from six lakes on the Canadian and northern U.S. prairies. Like Fritz et al. (2000), their results show that droughts of varying intensity and frequency have been common in this region for at least the last two millennia (Laird et al. 2003). However, they also note that a major shift in climate occurred between AD 1000 and 1300 in the northern prairies of the United States after centuries of relative stability (Laird et al. 2003). Of the six lakes these authors focus on in their analysis, the one closest to the Middle Missouri area examined in this study is Coldwater Lake located near the border between South Dakota and North Dakota. It is worth noting that the climatic pattern seen at Coldwater Lake is essentially the opposite of the other two U.S. Northern Plains lakes examined (Moon Lake and Elk Lake). Interestingly, the climatic patterns described at Coldwater Lake conforms rather well to the Baerreis and Bryson (1965) climatic sequence by indicating wetter conditions up to A.D. 1300, followed by a shift to drier conditions.

Like the Laird et al. (2003) analysis of Coldwater Lake, Harden et al. (2015) also examined Late Holocene climatic conditions at a location not far removed from the Middle Missouri area. Their study examined flood probabilities during the past 2000 years within the Black Hills of South Dakota. The chronology of these floods was developed from 99 radiocarbon dates derived from organic materials recovered from within these flood episode deposits (Harden et al. 2015). Their analysis revealed three distinct episodes of frequent 100-year floods that occurred during the past two millennia. The second of these episodes dated to A.D. 900-1290 and the third dated to A.D. 1410 to present (Harden et al. 2015). The authors acknowledge the second episode correlates very well with the Medieval Climatic Anomaly. And, although the authors do not mention it, the time period between their second and third flood episodes (A.D. 1290 – 1410) approximates the timing of the more arid Pacific I climatic episode.

Since the work of Baerreis and Bryson (1965), many other studies utilizing more modern proxy measures and techniques which allow for higher resolution of climatic trends have taken place (e.g. Dean and Schwalb 2000; Fritz et al. 2000; Clark et al. 2002; Laird et al. 2003; Brown et al. 2005; Grimm et al. 2011; Stambaugh et al. 2011; Harden et al. 2015). Of course, higher resolution does not always equal greater clarity and this is especially the case when examining regional and localized climatic trends during the Late Holocene in the northern Great Plains. But amongst these higher resolution investigations, a couple studies geographically bracket the Middle Missouri region examined in this study. In their analysis, Laird et al. (2003) examined

Coldwater Lake, ND, which is situated northeast of this study's geographic region of interest. Harden et al. (2015) focused on the Black Hills of South Dakota, located to the southwest of the study area. Interestingly, the climatic patterns described at these two geographic locations appear to reaffirm the broader climatic patterns and episodes as described by Baerreis and Bryson (1965) and utilized by Lehmer (1970). Therefore, these original climatic episodes are maintained here and used to discuss climatic conditions during the variants of the Coalescent tradition.

3.2 Initial Coalescent (A.D. 1300 to 1550)

The Coalescent tradition takes its name from the combination of cultures thought to have merged when Central Plains populations migrated into the Middle Missouri region and blended with Middle Missouri cultural traditions. This period of initial cultural coalescence is represented by roughly a dozen sites around the Big Bend region, located between modern-day Chamberlain and Pierre, SD.

It has been suggested the influx of Central Plains peoples into the Middle Missouri region resulted from drought conditions in the Central Plains (Lehmer 1954a; Wedel 1961). These drier conditions are believed to have resulted when the favorable agricultural conditions of the Neo-Atlantic climatic episode were interrupted by changes in climatic patterns circa A.D. 1250 (Baerreis and Bryson 1965). This timing is also coincident with the most severe multidecadal drought during the past millennium, which occurred during the period of 1229 – 1248 (Stambaugh et al. 2011). The onset of the Pacific I climatic episode made maize horticulture increasingly difficult and ultimately forced Central Plains peoples from their homelands north into the Missouri River trench where river bottomland soils may have provided some initial relief from their hardships (Zimmerman and Bradley 1993) (but see Blakeslee 1993 for an alternative explanation as to why these people might have migrated to the Middle Missouri region). Patrick Key's (1983:106) craniometric analysis of Plains Indians supported this population movement model by noting a strong temporal trend in cranial morphological complexes, specifically an increase in facial height and lowering of the cranial vault, beginning with the Nebraska and St. Helena Phases of the Central Plains Tradition and continuing through Coalescent Tradition Arikara skeletal series.

Lehmer (1971:111-115) notes similarities and differences of Initial Coalescent sites relative to both Central Plains and Middle Missouri Traditions. A blending of cultural traits from both cultural traditions is apparent throughout Initial Coalescent material culture. Further, whereas Initial Coalescent houses were more like those of the Central Plains Tradition, cache pits within them were more similar to those of the Middle Missouri Tradition. Additionally, much like Central Plains sites, Initial Coalescent sites contained widely spaced houses laid out in seemingly random fashion. However, one distinctive feature of Initial Coalescent sites lacking in Central Plains sites are the elaborate ditch and palisade fortification systems surrounding villages. This combination of widely dispersed, low density per acre houses enclosed by massive fortification systems has led to the assertion that the fortifications were built subsequent to the initial establishment of the villages (Lehmer 1971; Zimmerman 1985; Zimmerman and Bradley 1993).

Krause (2001:210) notes that important limitations to these villages would have followed from their practice of floodplain agriculture. Specifically, these large villages would have required heavy use of unimproved land and unmanaged faunal resources that would have led to declining yields over time (Krause 2001:201). Zimmerman and Bradley (1993) attempted to model Initial Coalescent populations during this period and found competition for arable land and wild resources to be a likely factor underlying the evidence of warfare at Initial Coalescent villages.

While it is clear that Initial Coalescent peoples felt the need to defend themselves against aggression, what is less clear is the identity of the aggressors. Zimmerman and Bradley (1993) argued internecine warfare arose from within the Initial Coalescent villagers after populations grew and resources ran thin. This seems plausible given that the prior Extended Middle Missouri occupants of this area appear to have moved further north just prior to the influx of Central Plains peoples (Lehmer 1971:105-107). However, Caldwell (1966) and Lehmer (1971) argued the amelioration of the Pacific I climatic episode in the 1400s led to attempts of Extended Middle Missouri peoples to repopulate their previously held territory. Nevertheless, it is obvious that in addition to the subsistence pressure Initial Coalescent peoples felt, they were pressured by other inhabitants of the region. And, while the ultimate causes of warfare are not certain, it is not hard to imagine a link between limited resources and ongoing conflict. Ultimately, as Krause (2001:202) notes, nutritional deprivation exhibited by the skeletons at the Crow Creek Massacre site "may perhaps be taken as a measure of the human cost of maintaining a concentrated population in the face of the natural and social environment of the times."

Notable Initial Coalescent sites include Arzberger (39HU6), Talking Crow (39BF3), Black Partizan (39LM218), and Crow Creek (39BF1). Of these, only Crow Creek is represented in this study.

3.3 Extended Coalescent (A.D. 1450 to 1650).

Members of this variant began dispersing across the landscape and constructing small, mostly unfortified settlements that appear to have been occupied for relatively short periods of time (Krause 2001:202). Lehmer (1971:151) indicates that although the Extended Coalescent variant witnesses an explosive expansion and dispersal of local populations, any growth in population during this variant is not to the extent suggested by the numerous Extended Coalescent sites since many appear to have been occupied for only short periods of time. Interestingly, the fortifications found at Extended Coalescent sites seem to exist primarily at the northern and southern periphery of this variant's geographic range (Lehmer 1971). Additionally, population distribution over a larger geographic area might have eased subsistence pressures associated with the Initial Coalescent. However, there is some evidence to suggest Extended Coalescent peoples were not free from hardships. Lehmer (1970) suggested periodic food shortages occurred because of climatic change associated with the Neoboreal climatic episode at approximately A.D. 1500. The degree or extent of the shortages is not known; however, it seems unlikely they were as significant as those suspected to have occurred during the Initial Coalescent.

Sites, or specific cemeteries of sites, which have been assigned to the Extended Coalescent and included in this investigation include Mobridge (39WW1) Feature 1, Mobridge

(39WW1) Feature 3, Anton Rygh (39CA4), Sully (39SL4) Cemetery D, Sully (39SL4) Cemetery E, and Swan Creek (39WW7).

3.4 Post-Contact Coalescent (A.D. 1650 to 1785).

The Post-Contact Coalescent is defined by the presence of European trade goods in the archaeological record. Jantz and Owsley (1986:16) suggest this is "a period of [cultural] florescence, particularly during the early part." Furthermore, Lehmer (1970) suggests the effects of the Neoboreal subsided during this time, which subsequently led to better yields in agriculture and hunting endeavors. In contrast to Extend Coalescent settlements, Post-Contact Coalescent settlements were relatively large and occupied for long durations (Jantz and Owsley 2001:16).

Sites, or specific cemeteries of sites, assigned to the Post-Contact Coalescent and included in this investigation include Nordvold 2/3 (39CO32/39CO33), Nordvold 1 (39CO31), Mobridge (39WW1) Feature 2, Cheyenne River (39ST1), Indian Creek (39ST15), Leavitt (39ST215), Buffalo Pasture (39ST216), Larson (39WW2), Sully (39SL4) Cemetery A, and Sully (39SL4) Cemetery B.

3.5 Disorganized Coalescent (A.D. 1785 to 1845).

The Disorganized Coalescent is characterized by widespread epidemics, which frequently depleted the population. Following the work of others (Wedel 1956, Lehmer and Jones 1968, Lehmer 1971), Jantz and Owsley indicated this was a period of "internal and external conflict, sociopolitical deterioration and disastrous food shortages" (Jantz and Owsley 1984:16). The severely deteriorating health conditions and social upheaval of the Arikara are recorded in the ethnohistorical accounts of Tabeau, a chronicler who resided with the Arikara throughout some of these ordeals (Abel 1939). Information on specific epidemics gathered by Rogers (1990) (Table 3-2) attests to the hardships faced by the Arikara people during the final years of the Post-Contact Coalescent and throughout the duration of the Disorganized Coalescent. The Leavenworth Site (39CO9) is the only site included in this investigation representative of the Disorganized variant of the Coalescent tradition.

Date	**Epidemic**	**Reference**
1772-1780s	Three possible	Hyde 1952:33
1780-1782	Possible Smallpox	Stearn and Stearn 1945:46-48, 75-77, 130-131
1801-1802	Possible Smallpox	Stearn and Stearn 1945: 46-48,75-77, 130-131
1818-1819	Possible Smallpox	Stearn and Stearn 1945: 78
1837	Smallpox	Abel 1932: 124, 127
1846	Measles	United States 1847:290
1851	Cholera	Hewitt 1937: 69, 72-73, 76-77
1856-1857	Smallpox	United States 1857: 127

Table 3-2. Dates of epidemic diseases afflicting the Arikara (Rogers 1990:82).

Descriptions of the four cultural horizons defined within the Coalescent tradition, and their chronological alignment with fluctuating climates, migrating human populations and inexplicable (to the Arikara) population depletion from introduced diseases, provide a framework from which hypotheses can be formed. What follows is a proposal for how relative levels of environmental stress might be inferred from an analysis of fluctuating bilateral asymmetry.

3.6 The Arikara and Fluctuating Asymmetry

The prehistoric and historic past of the Arikara people has been documented by means of archaeological investigations and ethnohistorical accounts. Knowledge of the Arikara's past allows the development of hypotheses about the relative magnitude of fluctuating asymmetry, as measured by skeletal traits and dimensions, which might be detected between the Coalescent variants. The Initial Coalescent period would have been a rather trying time for the Arikara as they were expanding into territory occupied by other groups. Competition for resources would have developed and the presence of fortifications indicate that competition threatened to escalate to hostilities. The Extended Coalescent appears to represent a time when the Arikara had established themselves in the Middle Missouri region and were capable of dispersing across the landscape and constructing new settlements. Fewer fortifications during the Extended Coalescent suggest the Arikara had established themselves as a presence in the region. However, many of the sites from this variant show evidence of short occupations that may not have allowed for or required defensive structures. This variant witnessed the beginning of the Neoboreal period, the cooler climatic conditions of which may have led to abbreviated growing seasons and subsequent food shortages. These food shortages may have led to the creation of many sites of short occupation, each serving as a seasonal camp.

Some authors (e.g., Jantz and Owsley 1984) suggest the Post-Contact Coalescent represents a period of growth and well-being for the Arikara. This assessment seems to run counter to the experiences of many Native American groups who suffered from the effects of warfare, displacement and disease after the arrival of Europeans. However, Lehmer (1970:172) describes the third quarter of the eighteenth century as being a time of prosperity and cultural elaboration. It appears the devastating effects of disease were delayed among the Arikara until the earliest of several successive epidemics struck around 1780. Subsequently, the Disorganized Coalescent was characterized by widespread disease, increasing pressure from nomadic horse tribes, and economic competition and disruption from white settlers, which lead to a near complete social breakdown and forced the Arikara to band together with their neighbors, the Mandan and Hidatsa, as a means of survival.

Jantz and Owsley (1984) utilized long bone growth variation among Arikara skeletal series to assess health and nutritional status during the Extended, Post-Contact and Disorganized Coalescent. Their study was based on the long bones of children between approximately 0.5 and 11.9 years of age from ten different samples of Arikara skeletal groups. The ontogenetic age of the individuals, as determined by dentition, was regressed on bone length to model longitudinal growth and to model cross-sectional growth of the skeletal population (Jantz and Owsley 1984).

Health and nutritional status was assessed on the basis of two factors: climate and European contact. Given the lack of direct European contact during the Extended Coalescent, the main focus during this variant was the onset of the cooler climatic conditions of the Neoboreal episode, which began around 1550 A.D. (Jantz and Owsley 1984:16). Jantz and

Owsley (1984) reference Lehmer's (1970) argument that, given cooling temperatures during the Neoboreal, the Arikara faced a shortened growing season and, therefore, increased likelihood of periodic food shortages. Moreover, the archaeological trend during this period is towards smaller villages, with little refuse and small cache pits, all suggesting shortened occupations (Lehmer 1970).

Jantz and Owsley's (1984) argument that the Post-Contact Coalescent was a period of cultural florescence is supported by amelioration of the Neoboreal, which provided stability in agricultural production (Lehmer 1970). Unlike the Extended Coalescent, Post-Contact Coalescent villages show evidence of long-term habitation, including increases in cache pit size and number (Lehmer and Jones 1968). In addition, Jantz and Owsley (1984) suggest introduction of the horse circa 1715 would have increased the bison hunting range of the Arikara and afforded them even more nutritional resources. Overall, their expectation was that the Post-Contact Coalescent was a favorable time in the health and nutritional status for the Arikara.

By contrast, the Disorganized Coalescent had all the hallmarks of a period of poor health and nutritional status. Jantz and Owsley's (1984) cite several sources to demonstrate the hardships brought on by numerous epidemic diseases and the sociocultural deterioration that followed partial collapse of the Arikara means of subsistence. The once populous Arikara were severely depleted in number and much more susceptible to raids from other Plains populations. Given all these problems, Jantz and Owsley (1984) expected to see growth impairment of Disorganized Coalescent children.

Despite a few inconsistencies, the overall pattern anticipated by Jantz and Owsley (1984) appears to be confirmed in their results. Although the bones of children in the Extended and Post-Contact Coalescent variants start out very similar, growth among Post-Contact Coalescent children was accelerated, resulting in longer bones during the Post-Contact variant. Oddly, bone lengths during the Disorganized Coalescent actually begin slightly longer; however, bone growth then decelerates relative to the other variants, culminating in final bone lengths mostly intermediate to the Extended Coalescent and Post-Contact Coalescent. While initial bone lengths for the Disorganized variant are somewhat perplexing the overall trend for improved growth of Post-Contact Coalescent children over Extended Coalescent children and, likewise, the growth deceleration of Disorganized Coalescent children appear to support the hypotheses drawn from the joint impacts of climate and European contact.

Given what is known both archaeologically and ethnohistorically about the Arikara and, given the results of Jantz and Owsley's (1984) prior analysis, it is reasonable to assume the Post-Contact Coalescent was the period of highest nutritional and health status. Conversely, it is easy to conceive the Disorganized Coalescent as the variant being assigned the lowest nutritional and health status. The Extended Coalescent, by default, should be intermediate to the Post-Contact Coalescent and the Disorganized Coalescent. Jantz and Owsley (1984) did not consider the Initial Coalescent because skeletal remains associated with that variant are scarce. However, if measurement from Initial Coalescent skeletons could be included, it may be reasonable to rank the nutritional and health status of the Extend Coalescent peoples slightly higher than the Initial Coalescent. This assessment is based on the aforementioned reliance of

Initial Coalescent peoples on floodplain agriculture and the regional tensions demonstrated by the presence of fortifications at initial Coalescent sites.

It is worth noting that at least one other investigation into the fluctuating asymmetry patterns of the Arikara has been conducted prior to this study. Storms (2009) examined the fluctuating asymmetry patterns of skeletal epiphyseal unions to determine if significant differences in levels of enivonmental stress could be detected between pre-contact, contact and post-contact Arikra populations. Storms (2009) utilized samples from the Mobridge, Larson and Leavenworth sites; her results did not demonstrate statistically significant differences between these groups. Nevertheless, if FA is an indicator of developmental instability, then the assessment of fluctuating asymmetry of the populations existing during these cultural variants should reflect their relative magnitudes of stress. The highest magnitude of FA should be detected in the Disorganized Coalescent and the lowest in the Post-Contact Coalescent (Table 3-3).

Table 3-3. Hypothesized FA magnitude by archaeological variant.

Coalescent Variant	Dates	Relative FA Magnitude (1 = highest, 4 = lowest)
Initial Coalescent	1300 – 1500 A.D.	2
Extended Coalescent	1450 – 1650 A.D.	3
Post-Contact Coalescent	1650 – 1785 A.D.	4
Disorganized Coalescent	1785 – 1845 A.D.	1

If the various measures (craniometric, post-cranial metric, and cranial nonmetric traits) selected for analysis in this study are, in fact, adequate for revealing statistically significant differences in FA among these Coalescent variants, then we should expect the rank ordering of their FA magnitudes to follow relative ordering displayed in Table 3-3.

Analysis of FA among these Arikara variants may reflect the levels of stress indicated by the archaeological and ethnohistorical records or, conversely, it might suggest a slightly different interpretation requiring a reassessment of environmental conditions during these periods.

CHAPTER 4: MATERIALS

This chapter provides an overview of the materials utilized in this research. The data that form the basis of this research originate from skeletal assemblages excavated from numerous Arikara archaeological sites along the Missouri River in South Dakota. These assemblages were selected for this study because they represent a single, culturally affiliated and presumably genetically related population that can be examined over the course of several centuries during which these peoples experienced variability in environmental stressors. Moreover, several of these skeletal assemblages provide rather large samples, which is ideal when assessing FA.

Table 4.1 provides an overview of the archaeological sites from which the samples are derived. This is followed by a discussion of each site and our current understanding of its chronology. Because the Coalescent archaeological variants are being utilized to assign relative magnitudes of stress to these assemblages, it is important to evaluate how these archaeological sites are being assigned to their respective variants.

Finally, I describe in detail the specific datasets or samples utilized to investigate FA of nonmetric traits, craniometric measures, and post-cranial dimensions.

Site Name	Site Number	Variant/Cultural Affiliation	Dates	Source
Crow Creek	39BF11	IC, Campbell Creek Phase	1300-1400 AD	Johnson 2007
Mobridge F1/F3 (Stirling's Cemetery 1)	39WW1	EC		
Anton Rygh	39CA4	EC		
Sully D	39SL4	EC	1550-1700 AD	Johnson 2007
Sully E	39SL4	EC		
Swan Creek	39WW7	EC, Akaska Phase		
Nordvold 2/3	39CO32/ 39CO33	PCC		Billeck et al. 2005
Mobridge F2	39WW1	PCC		
Nordvold 1	39CO31	PCC, Le Beau Phase	1650-1785 AD	Johnson 2007
Cheyenne River	39ST1	PCC, Bad River Phase	1700-1750 AD	Johnson 2007
Indian Creek	39ST15	PCC, Bad River Phase	1700-1750 AD	Johnson 2007
Leavitt	39ST215	PCC, Bad River Phase	1700-1750 AD	Johnson 2007
Buffalo Pasture	39ST216	PCC, Bad River Phase	1750-1785 AD	Johnson 2007
Larson	39WW2	PCC, Le Beau Phase	1750 – 1785	Jantz 1973
Sully A	39SL4	PCC		
Sully B	39SL4	PCC		
Leavenworth	39CO9	DC, Historic Arikara	1798-1832 AD	Johnson 2007

Table 4-1. Overview of archaeological sites utilized in this study. IC = Initial Coalescent, EC = Extended Coalescent, PCC = Post-Contact Coalescent, DC = Disorganized Coalescent

4.1 Archaeological Sites

The purpose of this section is partly to inform the reader of the nature of the sites from which the study samples are derived; it also elucidates the sometimes-problematic task of assigning a particular site, or even a specific cemetery within a site, to a particular cultural affiliation or taxonomic unit. As originally conceived, this research intends to use the *variant* as the taxonomic unit by which the Coalescent peoples will be compared to assess levels of FA between them. As the following site summaries show, the archaeological task of assigning sites and cemeteries to specific variants is not always straightforward. Nevertheless, a concerted effort has been made to evaluate site reports when they exist (e.g., Bass 1965, Bass 1966a, Bass 1966b, Bass 1967), field notes when site reports do not exist (e.g., Sigstad and Sigstad 1973), and the numerous related research publications spawned from the excavations and investigations of these skeletal assemblages.

4.1.1 Crow Creek Site (39BF11)

The Crow Creek Site is located in Buffalo County, SD on the eastern bank of the Missouri River, situated on the first and second terraces above the confluence of Crow Creek and Wolf Creek (Kivett and Jensen 1976). This large village was protected by a trench that was originally up to six feet in depth and, in places, twenty feet in width; the trench included ten bastions (Sigstad and Sigstad 1973). The village was defensively secured by means of the massive trench on the north and east aspects of the site and by the steep ravines of Crow Creek to the south and the Missouri River cut bank to the west.

The Crow Creek Site has major cultural components that date to both the Initial Middle Missouri and the Initial Coalescent. William H. Over visited the site in 1918 and described it in his field notes accompanied by a map illustrating the trench with bastions and several visible house depressions (Sigstad and Sigstad 1973). Over noted the defensive trench is the widest and deepest of all of those known to exist in South Dakota (Sigstad and Sigstad 1973). According to his notes, Over conducted very limited test excavations in one of the house depressions to determine that the house floor was contemporaneous with some visible debris eroding from the western cut bank (Sigstad and Sigstad 1973).

Figure 4-1. Aerial photograph of the Crow Creek Site (39BF11). MRBS photograph 39BF11-7, courtesy W. Raymond Wood.

Due to concerns about possible impacts from rising waters in anticipation of the construction of the Fort Randall Dam, the site was formally excavated for the first time during summer field seasons of 1954 and 1955. Excavations during these years were conducted as a joint venture between the U.S. National Park Service and the Nebraska State Historical Society and the work was supervised by Marvin F. Kivett, then Museum Director of the Nebraska State Historical Society (Kivett and Jensen 1976).

The fortifications at Crow Creek were not limited to the defensive ditch described above. Kivett and his excavation crew also uncovered evidence of an inner ditch within the village area that had been completely in-filled with village debris to the point that it was no longer visible from the ground surface (Kivett and Jensen 1976). Excavations revealed that this inner ditch had been accompanied by an extensive stockade that presumably ran along its entire length (Kivett and Jensen 1976). Additionally, a small fortification ditch is also visible on the extreme southern boundary of the site. Interestingly, no evidence of a palisade could be found along the massive outer defensive ditch. Willey and Emerson (1993) suggest a possible explanation for abandonment of the inner ditch and construction of the outer ditch was growth of the village population. Indeed, several house depressions are located between the two ditches. However, it would appear that if a palisade was planned for the outer ditch, it was never realized as the village was destroyed before the fortification could be completed.

Renewed attention was brought to the Crow Creek Site in 1978 when Robert Alex discovered human skeletal remains eroding out of a region where the outer ditch intersected the western cut bank (Willey and Emerson 1993). Alex contacted the Corps of Engineers and the Crow Creek Sioux Tribal Council to initiate a plan to excavate, analyze and rebury the skeletons; however, before the work commenced, looters dug into the eroding bone bed exposing the remains of nearly fifty individuals (Willey and Emerson 1993:227). The contract to excavate the remainder of the bone bed was awarded to the University of South Dakota and, during the final four months of 1978, the remains of nearly 500 individuals were recovered from a commingled bone bed within the ravine (Willey and Emerson 1993:231).

Excavation of the bone bed and examination of the skeletal elements revealed the deceased had all been murdered and mutilated. These Initial Coalescent people had been the victims of an enemy raid that decimated the village population. Moreover, taphonomic traces indicate the dead had been left to decompose on the surface for some time prior to being collected and deposited in the ditch. Interestingly, the bone bed had been capped by a layer of clay that must have been laboriously brought up from the river floodplain to cover the remains (Willey and Emerson 1993:237). Willey and Emerson (1993:237) believe deliberate burial of the remains of the dead within the ditch suggests some of the villagers escaped the onslaught only to return later to bury the less fortunate.

The skeletal remains recovered from the Crow Creek site were only available for analyses for a few short months, with most work taking place between January and March of 1979 before the remains were turned over to the Crow Creek Sioux Reservation for reburial in August 1981 (Willey and Emerson 1993). Nevertheless, during the short window of time, a tremendous amount of data was collected from the remains, which allowed paleodemography, paleopathology, and craniometric affinity studies to be conducted. Available for use in the present study was a database of nonmetric cranial traits; see Section 4.3 for details on these data.

4.1.2 Mobridge Site (39WW1)

The Mobridge Site is located in Walworth County, SD on a high bench overlooking the Missouri River trench, approximately one and one-half miles north of the city of Mobridge. The site is on the east bank of the river nearly opposite the mouth of the Grand River on the western side.

Three burial areas have traditionally been recognized at the Mobridge Site. In 1932, William Duncan Strong produced a detailed map (Figure 4-2) of the site identifying the three cemeteries, which have subsequently become referred to as Features 1, 2 and 3. Feature 1 was identified as a small hill located west of the village, Feature 2 was a large hill located approximately 200 – 300 yards south of the village, and Feature 3 was a small knoll also west of the village and approximately 100 yards south of Feature 1 (Bass 1970).

Mobridge was first excavated by William H. Over of the University of South Dakota in 1917 and again in 1920. The 1917 excavations were conducted over the course of a few days during which time several refuse heaps were excavated and six skeletons were recovered from a natural mound below the village and west toward the railroad track (Sigstad and Sigstad 1973:299). The overall size of the refuse heaps led Over to believe the site had been occupied for a considerable amount of time. However, he also noted the presence of some copper trade goods within the middens. These two points led Over to believe the village had been occupied by both early and late period Arikara inhabitants (Sigstad and Sigstad 1973:301).

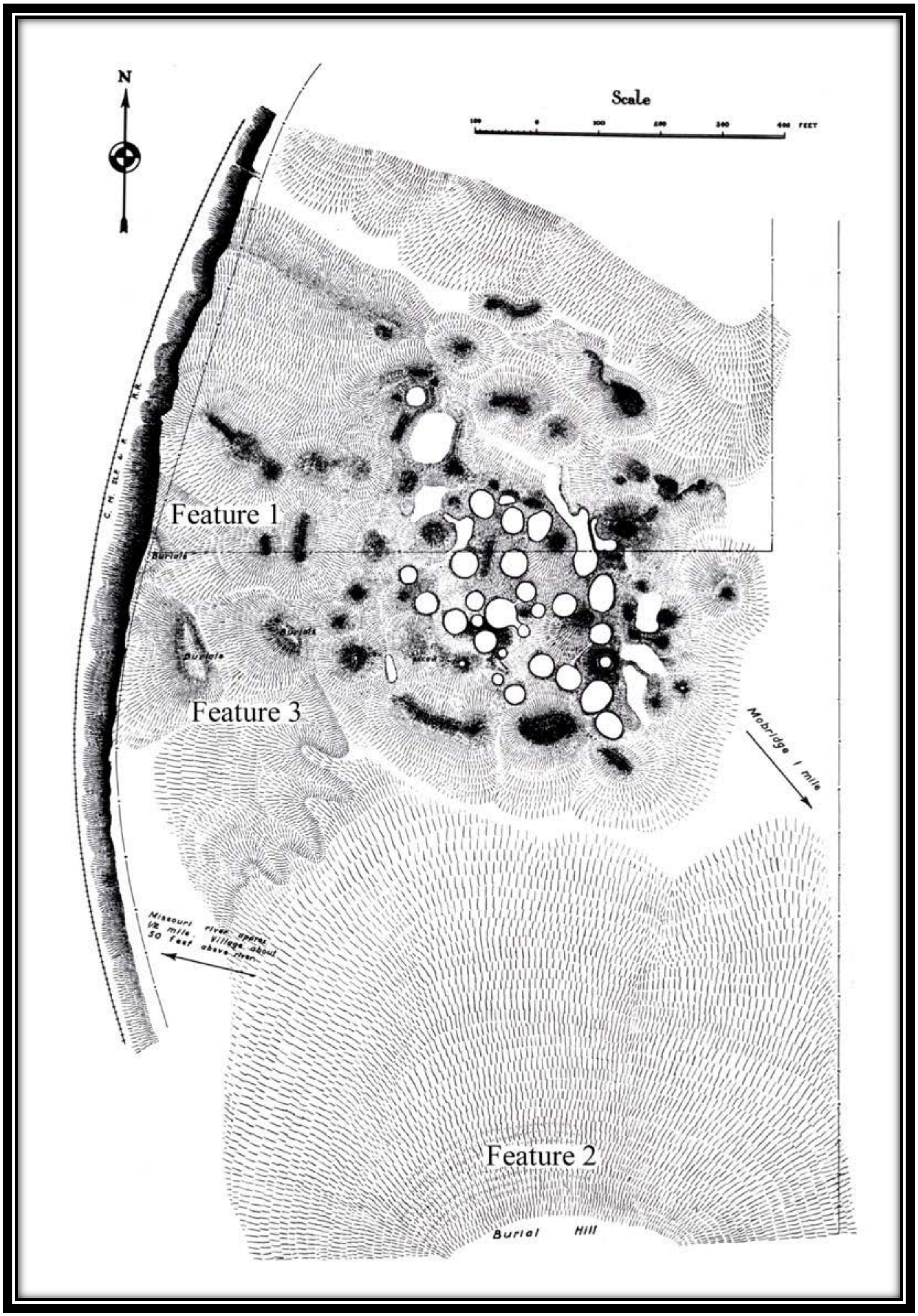

Figure 4-2. William Duncan Strong's 1932 map of the Mobridge Site (39WW1) (National Anthropological Archives, Billeck et al. 2005:161).

Over’s 1920 excavations spanned four weeks, during which time 53 graves were opened within a cemetery on a higher hill south of the village (Sigstad and Sigstad 1973:301). From these graves, Over noted that eight skeletons and 65 skulls were saved. Over also noted that within this cemetery many of the burials were intrusive, an aspect that reaffirmed to him that his prior supposition about successive occupations at Mobridge had been correct (Sigstad and Sigstad 1973).

From descriptions Over provided (Sigstad and Sigstad 1973:299), it is clear his 1920 cemetery excavations took place in Feature 2. Of the burials Over recovered in 1917, he only noted they came from a natural mound below the village, toward the railroad tracks (Sigstad and Sigstad 1973:299). However, as indicated by Billeck et al. (2005:162), William Duncan Strong’s journal entries (Strong 1924 – 1962) regarding his visit to the site in 1931 and 1932 indicate Over had excavated in Feature 1.

The next individual to excavate at Mobridge was Matthew W. Stirling, who was serving as the assistant curator of ethnology at the National Museum. Stirling conducted excavations at four sites in the vicinity of Mobridge, SD, during June of 1923. Cemeteries were partially excavated at all four sites although their designation was only given as Cemetery 1, Cemetery 2, Cemetery 3 and Cemetery 4. Although some brief notes were published, a formal report never followed. However, in 1955 with the support of Stirling and William Duncan Strong, Waldo Wedel publish his study of the materials Stirling had collected some 30 years prior. Wedel (1955) was able to conclude Stirling’s Cemeteries 1, 2, 3 and 4 were associated with the sites of Mobridge (39WW1), Nordvold 2/3 (39CO32/39CO33), Nordvold 1 (39CO31) and Leavenworth (Lewis and Clark Site) (39CO9), respectively.

Although Wedel (1955) was able to associate Stirling's Cemetery 1 with the Mobridge Site, there has always been a fair amount of controversy regarding the feature from which Stirling recovered burials. The uncertainty arises from Stirling's own field notes (Stirling 1923) in which he indicated the cemetery he excavated was "located about 300 yards *north* [emphasis added] of the village [site], on the crest and slope of the bluff overlooking the river" (Wedel 1955:86). Wedel (1955), referencing William Duncan Strong's 1932 map of the village and burial areas, noted the lack of an identified northern burial location. He presumed that, unless Stirling was in error regarding the direction of the village relative to the area where he excavated, Strong's map did not include this fourth burial location. Billeck et al. (2005:162) also reference Stirling's field notes (Stirling 1923) and point out Wedel (1955) seemingly overlooked the following sentence in which Stirling stated: "It [Stirling's Cemetery 1] has been partially excavated by Mr. Over for the University of South Dakota." Billeck et al. (2005) place significance on this presence of Over's prior excavations, noting Over was known to have excavated burials in (presumably) Feature 1 (1917 excavations) and also Feature 2 (1920 excavations). On the basis of this information, Billeck et al. (2005) suggest the most likely explanation for this confusion is that Stirling incorrectly noted the direction and, instead, actually excavated in the cemetery 300 yards *south* of the village, where Over had previously excavated within Feature 2. However, Billeck et al.'s (2005) inference regarding the location of Stirling's excavations based on the presence of prior excavations by Over would also appear to similarly overlook comments made by Over in his own field notes. In summarizing his 1920 excavations within Feature 2, Over noted: "The graves followed a line that bisected the crest of the hill (see map). Forty other places were dug into that proved not to be graves, so that it is unlikely that we missed many here. Efforts were made to find other burying grounds *on higher land surrounding the village* [emphasis added], but all were failures" (Sigstad and Sigstad 1973:302). Therefore, it is entirely possible Over also conducted test excavations on the bluff north of the village. Strong's 1932 map, although not specifically noting burials to the north, does show the rising bluff north of the village. Moreover, Over's notes describe the village as being located within "a wide shallow draw" (Sigstad and Sigstad 1973:299) indicating higher-elevation lands surrounded the village to the south, east and north. When Over describes his effort to locate other burials on higher land surrounding the village, it seems clear he is not describing efforts within Feature 2 because his crew had already dug forty test excavations in that region which did not produce graves. Is it possible Over dug test excavations atop the northern bluff and did not locate any burials, only to have Sterling excavate nearby three years later and identify eleven graves containing the remains of forty individuals? If we use Over's results from his excavations in Feature 2 as a guide, then it seems possible. On the basis of forty, non-burial producing test excavations within Feature 2, Over surmised that "it is unlikely that we missed many here" (Sigstad and Sigstad 1973:302). The inaccuracy of this statement becomes apparent when confronted with the results of Bass' excavations during the 1970 field season when his crew recovered an additional 90 individuals and felt confident this number represented only one-quarter to one-tenth the total number of burials present within Feature 2 (Bass 1970:2). Moreover, the 1971 excavations of Feature 2, directed by T. Dale Stewart and Douglas Ubelaker, uncovered the remains of an additional 334 individuals (Billeck et al. 2005).

The question regarding where Stirling excavated burials is important because Mobridge is a site that exhibits long occupation and is believed to have components representing both the Extend Coalescent and Post-Contact Coalescent. Following the 1968 – 1970 field seasons, Bass felt he had established the temporal sequencing of burial areas at Mobridge (39WW1) and Feature 2 was "probably the last burial area used by the inhabitants of the Mobridge Site" (Bass 1970:1). In his dissertation regarding the craniometric relationships among Plains Indians, Key (1983) assigned the burials from Sterling's Cemetery 1 to the Extended Coalescent. However, in her dissertation regarding craniometric variation among the Arikara, McKeown (2000), citing personnel communication with Billeck, choose to include Sterling's burials within Feature 2 and assigned them to the Post-Contact Coalescent.

Given the scant field notations of Over and Stirling and the lack of any solid provenience information regarding Stirling's burial excavations, a consideration of associated artifacts recovered from the graves he excavated would be the next logical point of inquiry for identifying the chronological variant they may belong within. However, here again, the answer is not clear. Wedel (1955:87-89) provides Stirling's brief description of each grave and the skeletal remains and associated artifacts within. Grave offerings were relatively few. Grave 2 contained "some red paint and also two stone balls, each about an inch in diameter," also "[o]ne of the male skulls rested upon a large piece of buffalo skull" (Wedel 1955:88). In Grave 3, Stirling noted "[a] few glass beads were scattered about the head of the infant" (Wedel 1955:88). Within Grave 8, Stirling indicated "[t]he skull of one of the males was discolored by copper, but this had evidently taken place before burial" (Wedel 1955:89). Grave 9 included "some flint chips and a potsherd" (Wedel 1955:89). And, finally, Stirling's description of Grave 11 noted "[i]n the hand of one of the males was a funguslike mass (tinder?) in which was embedded a white arrowhead (by the knee)" (Wedel 1955:89).

McKeown (2000:59) used the presence of the glass beads in Grave 3 and the possible copper staining on the skull in Grave 8 to suggest the burials could date to the Post-Contact Coalescent. Wedel (1955:87) acknowledged the presence of the direct or indirect trade goods (i.e. glass beads and copper), but felt the "scarcity of grave goods of any kind, as compared to the relatively large quantities recovered at the other nearby burial sites worked, suggests an earlier time period for Cemetery 1."

Perhaps a more compelling line of inquiry regarding the temporal placement of Stirling's excavated burials can be found in the craniometric investigation undertaken by Owsley (1981). Utilizing discriminant function analysis, Owsley (1981) compared both the Over and Stirling recovered skeletal collections to later skeletal assemblages originating from Features 1, 2 and 3. Owsley's (1981) findings demonstrate crania recovered from Stirling's excavations group with Features 1 and 3, whereas crania recovered during Over's excavation primarily group with Feature 2. Owsley's (1981) analysis is compelling because Over's field notes clearly indicate he had, in fact, excavated within Feature 2 during his 1920 field season. Moreover, the few crania in Over's sample that didn't group closely with Feature 2 showed more resemblance to Feature 1 – the area where Over is presumed to have excavated during his 1917 field season. Given the lack of provenience information in Stirling's own field notes and the inconclusive assessment of the associated grave goods, the most compelling line of evidence concerning the temporal association of the burials recovered by Stirling would be Owsley's (1981) analysis which indicates these crania do not group with Feature 2 and are much more similar to those crania recovered from Features 1 and 3. Clearly, Owsley's (1981) analysis does not indicate Stirling's burials were recovered from either Feature 1 or 3, rather it indicates these individuals were morphologically more similar to those individuals recovered from those areas. Since Feature 2 is generally regarded as being a later (Post-Contact Coalescent) cemetery and Features 1 and 3 are taken to be earlier (Extended Coalescent) burial areas, the burials recovered by Stirling during his 1923 excavations will be regarded here as most likely having a temporal association with the Extended Coalescent.

4.1.3 Nordvold 2/3 (39CO32/39CO33)

The name Nordvold has been given to three different sites all within close proximity to one another in Corson County, SD. The Nordvold Sites are located about three miles north of the Mobridge Site (39WW1), on the west side of the Missouri River trench where Oak Creek flows into the river (Wedel 1955).

Matthew W. Stirling excavated at the site during the summer of 1923 when he visited and excavated at other sites in the vicinity. As previously described, Stirling excavated at four sites that year and labeled the sites and associated cemeteries as Site/Cemetery 1, Site/Cemetery 2, Site/Cemetery 3, and Site/Cemetery 4. Wedel (1955:89) examined Stirling's notes and was able to determine that Site 2 referred to a large occupation area that was actually comprised of two separately recognized sites, Nordvold 2 (39CO32) and Nordvold 3 (39CO33). Wedel (1955) also consulted with William Duncan Strong who indicated he believed the two villages to be of differing ages – Nordvold 2 being an earlier prehistoric or protohistoric Arikara site and Nordvold 3 being protohistoric or historic (Wedel 1955:89). The cemetery Stirling's labeled "Cemetery 2" was located just east of Nordvold 2. However, Wedel (1955:89-90) was unable to determine if the burials excavated by Stirling belonged to Nordvold 2 or

Nordvold 3. It is also, therefore, possible the cemetery contains burials belonging to both Nordvold 2 and Nordvold 3 and, because of this, it has become commonplace to refer to this cemetery as Nordvold 2/3.

Key (1983) used a sample of crania form the Nordvold 2/3 cemetery in his analysis and assigned these individuals to the Extended Coalescent. Others (e.g., McKeown 2000; Wescott and Cunningham 2006) have also assigned the Nordvold 2/3 cemetery to the Extended Coalescent. Conversely, Billeck et al. (2005) indicate that assigning Nordvold 2/3 to the Extended Coalescent is incorrect, noting many of the graves within the cemetery contain historic trade goods. Billeck et al. (2005) note "although some burials may date to the Extended Coalescent, most appear to date to the Post-Contact Coalescent" (Billeck et al. 2005:121). Because of this, and for the purpose of this research, individuals from the Nordvold 2/3 cemetery are considered to belong to the Post-Contact Coalescent.

4.1.4 Anton Rygh Site (39CA4)

The Anton Rygh Site, or more commonly Rygh Site, is a multi-component site located in Campbell County, SD on the east bank of the Missouri River, north of the mouth of the Grand River. The site is located on the first terrace, approximately 40 – 50 feet above the floodplain. The Rygh Site is situated almost directly across the Missouri River from the Lewis and Clark Village Site (Leavenworth Site – 39CO9); however, as Knudson et al. (1983:25) indicate, the site was apparently not occupied when the Lewis and Clark expedition passed by as they made no mention of its presence.

William H. Over mentioned the Rygh Site in his field notes and, although the date of Over's visit to the site is not mentioned, it likely took place between 1915 – 1917 when he visited other sites in the vicinity. Over noted the presence of an apparent "moat" and various large refuse heaps at Rygh, but he was not able to discern the remnants of lodge depressions on the ground surface (Sigstad and Sigstad 1973:19). Although he carried out no excavations at the site, his notes show he believed the site to likely be affiliated with the prehistoric Arikara.

Rygh was first excavated by William Duncan Strong and his field crew in 1932 when they dug several test trenches through middens and house pits (Knudson et al. 1983). Based on some of the early artifact recoveries and the overall surface appearance of the site (large refuse heaps and an irregular fortification ditch), Strong felt the site could have belonged to prehistoric Mandan (Knudson et al. 1983:213).

Alfred Bowers first visited Rygh in 1929 while mapping sites in the region. His first excavations at the site took place in 1947 when he secured samples of ceramic sherds for his doctoral dissertation (Knudson et al. 1983). Bowers' limited 1947 excavations also led him to believe the site had been inhabited by early Mandan.

In 1957, 1958, 1959 and 1963, Bowers, then with the University of Idaho, carried out excavations at Rygh on behalf of the National Park Service as part of the River Basin Surveys (Knudson et al. 1983). Bowers and his crews were conducting salvage archaeology in the face of impending inundation by the rising Oahe reservoir. Thus, the main goal was recovery and little initial analysis accompanied these efforts. A site report published by Knudson et al. (1983) details the excavations and recovered artifact assemblages, but offers little interpretation of the site. By the authors' own admission (Knudson et al. 1983:8), the report was primarily written to fulfill the 1958 contract with the National Park Service. However, what these later excavations made clear was that Rygh was a multi-component site and the latest component of these, according to Bowers (Knudson et al. 1983:218), appeared to be associated with inhabitants whose material culture closely approximated the Arikara of the Lewis and Clark Village Site.

Skeletal remains from Rygh were recovered during all years of excavation. Remains recovered during William Duncan Strong's 1932 excavations and remains recovered during Bowers' 1958 and 1959 field seasons are currently curated at the National Museum of Natural History (Billeck et al. 2005). Additional skeletal remains were recovered by William M. Bass during visits to the site in 1965, 1966 and 1969. The recoveries took place while Bass and his crew were excavating at nearby sites and frequently checking on the partially inundated Rygh site for skeletal remains exposed by wave action. Through these additional efforts, Bass managed to recover at least an additional 34 burials during the 1965 and 1966 field seasons, as well as ten more burials during his visit to the site in 1969. Based on his experience excavating numerous other burials at Arikara sites in the region, Bass felt the burial practices at Rygh were indicative of Arikara inhabitants (Knudson et al. 1983:302). In a similar fashion, in 1971, T. Dale Stewart and Douglass Ubelaker of the Smithsonian Institution recovered four additional individual skeletons eroding out of an embankment at Rygh (Billeck et al. 2005).

Because of the multicomponent nature of Rygh and because some of the earlier components included cultural trait frequencies reminiscent of Mandan sites in North Dakota, there has always been a struggle to assign prehistoric tribal affiliation. As Knudson et al. (1983:202) discuss, the introduction of Lehmer's (1954) Middle Missouri archaeology framework allowed some resolution. Bowers, utilizing Lehmer's (1954) model, assigned the earliest component (Rygh I) to the pre-Mandan Extended Middle Missouri variant and the later components (Rygh II – V) to the Arikara Extended Coalescent and Post-Contact Coalescent variants (Knudson et al. 1983:202). Bowers indicated burials recovered from his excavations at the site came from the Rygh II and Rygh III occupations (Knudson et al. 1983:226), placing them within the Extended Coalescent.

Lehmer (1971) and Johnson (2007) both designated two Arikara components at Rygh; the early component was assigned to the Extended Coalescent and the later component to the Post-Contact Coalescent (Billeck et al. 2005). In an appendix written to accompany the Knudson et al. (1983) report, Bass discussed additional remains he recovered from Rygh during the 1965, 1966 and 1969 field seasons. Bass (Knudson et al. 1983) noted the presence of Arikara burial customs, such as interments with the head placed in a northern direction and the presence of wood coverings, as evidence of an Arikara affiliation at Rygh. It was Bass' impression Rygh represented a protohistoric Arikara site but one where "very little European influence was felt during the occupation" (Knudson et al. 1983:302).

Rygh site individuals utilized in this study originated from Bowers 1958 excavations, Bass' recoveries in the 1960's and the salvage recoveries of Ubelaker and T. Dale Stewart in 1971. These individuals are assigned to the Extended Coalescent.

4.1.5 Buffalo Pasture Cemetery (39ST216)

The Buffalo Pasture Cemetery (39ST216) is adjacent to the Buffalo Pasture Site (39ST6) village, which is located on the west bank of the Missouri River in Stanley County, SD. The village site was situated between two deep ravines and a deep trench surrounded the earth lodge village. William H. Over visited the Buffalo Pasture village, performing excavations in some of the middens (Sigstad and Sigstad 1973:247). Over does not indicate the date of his visit to Buffalo Pasture, but it likely took place between 1917 – 1918, when he visited several other sites in Stanley County.

In 1939, Albert C. Spaulding of Columbia University oversaw excavations of one earth lodge feature, associated cache pits, and a section of the palisade (Lehmer and Jones 1968:5). In 1952, Franklin Fenenga directed further excavations at the village site on behalf of the River Basin Surveys. These excavations included four houses, associated cache pits, and investigations of the palisade and fortification ditch (Lehmer and Jones 1968:5). None of these excavations revealed more than one component at the site; however, superimposition of various features at the site demonstrates a relatively long and continuous occupation (Lehmer and Jones 1968:48).

None of the above mentioned excavations at the Buffalo Pasture village included work within the associated cemetery (39ST216) which apparently had not been located at the time. However, Lehmer and Jones (1968), citing Howson (1941), indicate William Duncan Strong had visited the site in 1931 and examined skeletal remains of a female eroding out of the dry wash ravine south of the village site (Lehmer and Jones 1968:46-47). The remains displayed copper staining and near a skull were found copper wire hair ornaments (Lehmer and Jones 1968:47). Although Lehmer and Jones (1968) and Wedel (1982) indicate a single individual was recovered, Billeck et al. (2005:296) indicate the remains of three individuals were collected by Strong and sent to the National Museum of Natural History.

Richard P. Wheeler indicated to Lehmer and Jones (1968) that, in 1955, the area just to the south of this ravine was excavated by power shovels to create fill for the construction of Oahe Dam (Lehmer and Jones 1968:47). At that time, at least 15 human burials were disturbed by the excavation company and these remains were later handed over to Wheeler (Lehmer and Jones 1968:47). Wheeler noted that, although several attempts were subsequently made to identify *in situ* burials at the Buffalo Pasture cemetery, none were successful (Lehmer and Jones 1968).

In an appendix of Lehmer and Jones (1968:107), Bass discussed his examination of the skeletal materials recovered from the cemetery. Bass noted the remains of 25 individuals had been turned over to the RBS staff and, on the basis of the demographic profile of these individuals, the cemetery appeared to be from a settlement community (Lehmer and Jones 1968:107-108). Owing to the nature of the recovery, very few associated artifacts were available. However, Bass indicated a portion of a buffalo robe with small brass beads was recovered (Lehmer and Jones 1968:108). Utilizing a laboratory of the Federal Bureau of Investigation, the beads were found to have been produced from alloy of copper and zinc indicating their Euro-American origin (Lehmer and Jones 1968:108).

Occupation of the Buffalo Pasture site occurred during the Bad River phase of the Post-Contact Coalescent. Lehmer and Jones (1968) indicate contact period artifacts recovered from the village were comprised of glass beads, metal (including gun parts), other European manufactured items, and horse bones (1968:98). Lehmer and Jones (1968:98) denoted two subphases of the Bad River phase, and they ascribed the Buffalo Pasture Site (39ST6) to the latter (Bad River 2). Lehmer and Jones (1968:98) estimated the dates of this subphase to AD

1740 – 1795. Johnson's (2007:153) ceramic ordination analysis agrees with the subphase ordering of Lehmer and Jones (1968).

Figure 4-3. Aerial photograph of the Buffalo Pasture Site (39ST6). MRBS photograph 39ST216-55, courtesy W. Raymond Wood.

4.1.6 Cheyenne River Site (39ST1)

The Cheyenne River site is a fortified earth lodge village located on the west side of the Missouri River, just south of the mouth of the Cheyenne River in Stanley County, SD. William H. Over visited the site on two different occasions, once in 1917 and once in 1920. Upon his 1917 visit, Over noted the site was eroding into the Missouri River and approximately one-third of the village had already slumped toward the river. This slumping was somewhat recent as Charles DeLand had visited the site in 1900 and had noted, "[t]here is a continuous and deep ditch all around the village, including the river side" (DeLand 1906:547). During Over's first visit, he noted the fortification ditch was incomplete as it had slumped with a portion of the village into the river. Over described pottery fragments collected from the surface of the village as "typical Arikara pottery" (Sigstad and Sigstad 1973:250).

During Over's visit in 1920, he discovered an associated cemetery on a ridge southeast of the village. Over excavated the remains of nine individuals from eight graves. The bodies of the adults were in a flexed position and had been covered with slabs of cedar or cottonwood, a typical mortuary practice of the Arikara (Sigstad and Sigstad 1973).

Paul L. Cooper visited the site in 1948 to conduct initial archaeological surveys on behalf of the River Basin Surveys and subsequent excavations directed by Waldo Wedel took place in 1951, 1955 and 1956 (Billeck et al. 2005). Wedel divided the site into three different areas. Area 1 included the fortified village area previously described. Located nearby, Area 2 and Area 3 were unfortified regions that contained both rectangular lodges of the Middle Missouri tradition and circular lodges belonging to the Post-Contact Coalescent (Billeck et al. 2005:264). Area 3 also contained the cemetery region where, in 1955, Wedel directed the excavation of 55 graves (Billeck et al. 2005).

Although an Extended Middle Missouri component and an Extended Coalescent component have been identified at the site, the cemetery within Area 3 and the fortified village of Area 1 have been assigned to the Post-Contact Coalescent (Billeck et al. 2005). This assignment is made on the basis of mortuary practices and associated artifacts, which included glass and metal (Jantz 1972:24). Johnson notes the site dates to the middle of the Bad River phase with an approximate age of 1725 AD. (Johnson 2007:152).

Figure 4-4. Aerial photograph of the Cheyenne River Site (39ST1). MRBS photograph 39ST1-103, courtesy W. Raymond Wood.

4.1.7 Indian Creek Site (39ST15)

The Indian Creek Site is located in Stanley County, SD on the west bank of the Missouri River, just north of Indian Creek on the first terrace above the floodplain. The site was first surveyed as a part of the River Basin Surveys in 1948 (Lehmer and Jones 1968). In 1951, during construction of a railroad to access the planned Oahe Dam, a cemetery was discovered about 60 – 70 yards west of the village area (Lehmer and Jones 1968:64). Disturbed remains were collected by construction workers and given to Paul Cooper of the RBS (Billeck et al. 2005:307). In the same year, Donald Lehmer excavated two additional burials in this area (Lehmer 1954a).

Lehmer and Jones (1968) indicate two components are present, the earliest belonging to the Extended Middle Missouri and the most recent belonging to the Post-Contact Coalescent. The Post-Contact Coalescent assignment is based on the burial pattern in the cemetery, the ceramic wares, and the presence of metal artifacts of native manufacture (Lehmer and Jones 1968:72). The Post-Contact Coalescent component at the Indian Creek Site is assigned to the Bad River 1 phase (Lehmer and Jones 1968:92).

4.1.8 Larson Site (39WW2)

The Larson Site is located in Walworth County, SD, approximately two miles southeast of the town of Mobridge, on the east bank of the Missouri River. The site is comprised of a fortified village and associated cemetery situated on a high terrace overlooking the river valley (Owsley et al. 1977). The site has been assigned to the Post-Contact Coalescent Le Beau phase (Lehmer 1971) with associated approximate occupation dates of 1750 – 1785 (Jantz 1973).

Excavations at Larson, conducted by the RBS, were directed by Alfred W. Bowers during 1963 and 1964 and further excavations were carried out by J. J. Stephenson in 1966 (Owsley et al. 1977). Over the course of field seasons from 1966 to 1968, the cemetery was excavated by field crews from the University of Kansas directed by William M. Bass. The cemetery excavations yielded a total of 621 individuals; the remains of 71 additional individuals were recovered from the living floors of the village lodges (Owsley et al. 1977). Throughout the course of the RBS excavations of the village area, three lodges were excavated in their entirety while an additional ten lodges were trenched; of these, more than fifty percent had skeletal remains on their floors, many exhibiting trauma and burning indicative of warfare (Owsley et al. 1977).

Owsley et al. (1977) undertook a demographic and osteological analysis of the Larson site to determine if the cause of the unburied remains within the village was intertribal warfare. Analysis revealed the majority of skeletal remains recovered from the village area showed signs of scalping, dismemberment and mutilation (Owsley et al. 1977). Additionally, demographic analysis indicated the cemetery mortality profile was dominated by high mortality rates for infants and small children, whereas the mortality profile of individuals recovered from the village showed a predominance of adolescents and young adults (Owsley et al. 1977). Overall, the evidence recovered from the Larson Site reveals relatively short occupations, and populations reduced over time to a point where defenses were easily overcome and the population was decimated by intertribal warfare.

4.1.9 Leavitt Site (39ST215)

The Leavitt Site is a multicomponent site located on the west bank of the Missouri River in Stanley County, SD. The site was first discovered in 1954 when road construction activities in the region exposed several burials from the cemetery (Lehmer and Jones 1968:49). Richard P. Wheeler made initial investigations of the site that year and returned the following year to complete more extensive excavations of both the village and cemetery areas. Wheeler's excavations revealed the village site was affiliated with the Extend Coalescent; however, on the basis of the associated artifacts, the cemetery clearly dated to the later Post-Contact Coalescent (Lehmer and Jones 1968:49). Therefore, it appears the cemetery is actually affiliated with the Post-Contact Coalescent Phillips Ranch Site (39ST14) which is located approximately 700 feet north-north-west of Leavitt (Lehmer and Jones 1968:49).

4.1.10 Nordvold 1 (39CO31)

Nordvold 1 is located in close proximity to the other Nordvold sites, Nordvold 2 (39CO32) and Nordvold 3 (39CO33), in Corson County, SD. Nordvold 1, an earth lodge village surrounded by a defensive ditch, is located a few hundred yards northeast of Nordvold 2 (Wedel 1955). Similar to Nordvold 2 and Nordvold 3, Matthew W. Stirling excavated at Nordvold 1 during the summer of 1923, a site and associated cemetery he referred to as Site 3 and Cemetery 3. As he did with the other sites Stirling investigated that year, Wedel (1955) examined Stirling's notes and was able to determine "Site 3" referred to the site that has become known as Nordvold 1 (39CO31).

The cemetery associated with Nordvold 1 is smaller than that of Nordvold 2/3. Stirling's notes indicated burials were few in number, which he attributed to the hard and rocky ground of the ridge upon which the cemetery is located (Wedel 1955:95). Although Stirling's notes display confidence the Nordvold 1 cemetery was more recent than the Nordvold 2/3 cemetery, Wedel (1955:96) was uncertain given the associated artifacts did not appear to support that conclusion. However, William Duncan Strong indicated to Wedel artifacts recovered from the surface of the village area were more closely related to those recovered at the historic Leavenworth Site than they were with those recovered from Nordvold 2/3. Johnson's (2007) chronological sequencing of Le Beau phase sites supports the placement of Nordvold 1 within the Post-Contact Coalescent. More specifically, he indicates that “Nordvold 1 is assumed to be the last Le Beau phase village and is assigned the date of AD 1785” (Johnson 2007:144).

4.1.11 Sully Site (39SL4)

The Sully Site (39SL4), sometimes referred to as the Fort Sully Village, is located in Sully County, SD on the high table land of the east bank of the Missouri River directly across Sully Creek from where old Fort Sully (39SL45), a U.S. military post, was once located (Sigstad and Sigstad 1973:288). William H. Over visited the site in the early 20th century, although his field notes do not indicate exactly when this visit took place. Over’s visit was short (“less than one day”) and only minimal excavation took place (Sigstad and Sigstad 1973:289). In his brief description of the site, Over notes the village was not fortified but it was very large, including evidence of numerous lodges and four or five larger ceremonial lodges (Sigstad and Sigstad 1973:288). Over indicates during his visit the “burying ground was not located” (Sigstad and Sigstad 1973:289).

Alfred Bowers conducted excavations of the village and cemetery portions of the site during the field seasons of 1930 and 1931, recovering remains of 49 individuals (Bowers 1940).

Visits to the Sully Site by members of the RBS from 1948 to 1950 resulted in the recommendation of further investigations which eventually culminated in large scale excavations, under the direction of Robert L. Stephenson, commencing in 1956 (Billeck et al. 2005:357). Stephenson’s excavations focused on the village area, but he was joined in 1957 by William M. Bass who oversaw excavations in the cemetery locations (Billeck et al. 2005:359).

Five burial locations, external to the village, were identified at the Sully Site; Bass labeled these as Cemeteries A, B, C, D and E. Cemeteries A, B, D and E are located to the northeast of the village and are centered at approximately the midpoint of the village along its longitudinal axis. Following a line that runs east from the village’s eastern border, Cemetery D is approximately 100 feet from the village, followed by Cemetery E and Cemetery A, which are approximately 600 feet and 1000 feet from the village’s boundary, respectively. Cemetery B is located approximately 400 feet south of Cemetery A. Isolated from the other cemeteries is Cemetery C, which is located approximately 500 feet from the southeastern most boundary of the village area and close to the terrace edge (see Figure 4-5). Bass (1965) considered Cemetery C to be a scaffold burial location and did not associate it with the other Sully cemeteries (Bass et al. 1971:135). Table 4-2 provides an overview of the cemetery areas, the archaeological feature designations within each, and the number of burials recovered from those areas.

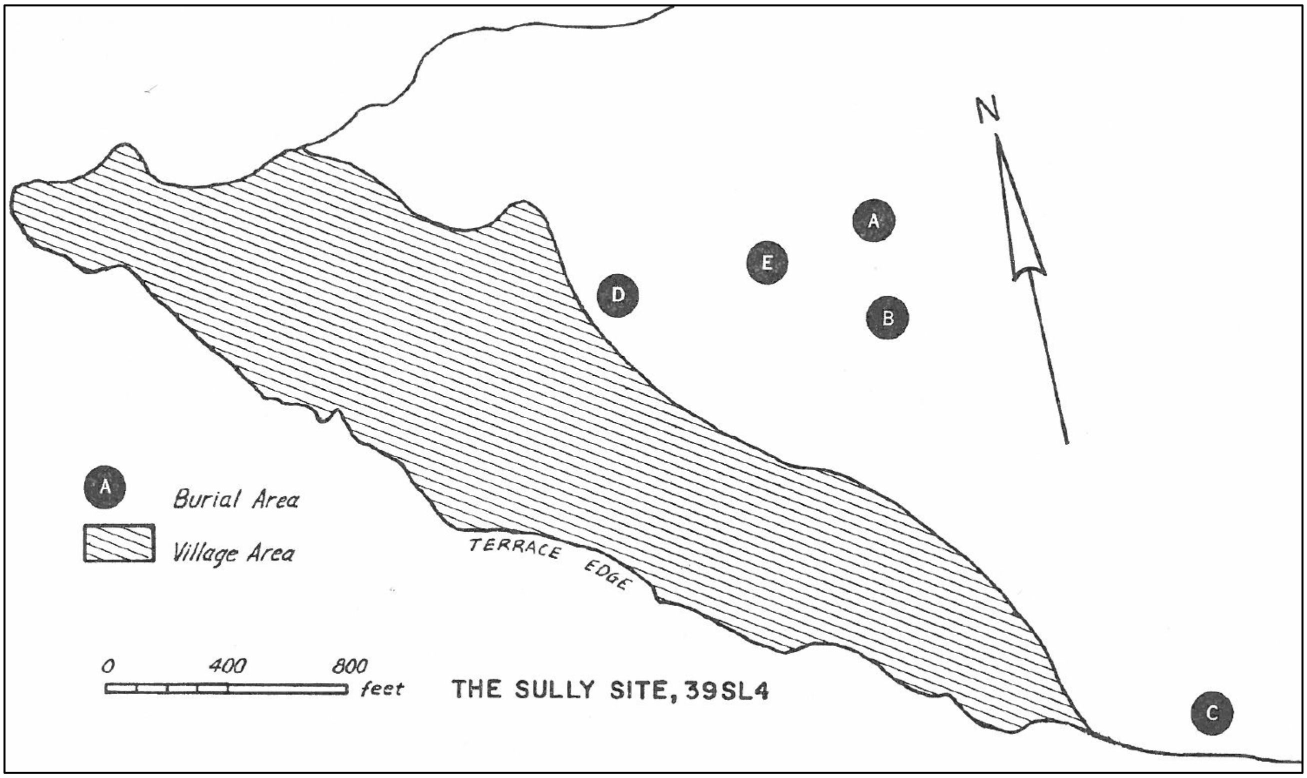

Figure 4-5. Sully Site (39SL4) Map (Bass et al. 1971:136)

Table 4-2. Sully Site (39SL4) cemetery areas, feature designations and recovered burials.

Cemetery Area	Feature Designations	Number of Burials Recovered
Area A	115, 116, 218, 416, 418	146
Area B	117, 417	13
Area C	219	14
Area D	220, 320, 420	118
Area E	421	253

Note: Adapted from Bass et al. 1971:135.

There appear to be two distinct components at the Sully Site, one belonging to the Extended Coalescent and one to the Post-Contact Coalescent. Johnson (2007) indicates the Sully site was first established within the Extended Coalescent, dating its occupation from about

AD 1550 to AD 1725 (Johnson 2007:148). The site would eventually become the largest within the Middle Missouri subarea, containing approximately 200 house depressions. Moreover, it appears three or four periods of superimposing lodge building took place at Sully which could ultimately increase the total number of lodges constructed to a much higher number (Johnson 2007:148). Given the dates Johnson (2007) provides, Sully would be the longest continually occupied site within South Dakota (Johnson 2007:185).

A formal site report has never been issued for the Sully site and information regarding the cemeteries and burials must be drawn from a handful of other sources that discuss the site and associated burials (e.g. Bass 1965; Bass et al. 1971; Owsley and Jantz 1978).

The temporal ordering of the cemetery areas has not yet been clearly determined. Bass (1965) believed, based on archaeological context and associated artifacts, Cemetery D was the earliest at the site, followed by E and then A, with B being the most recent (Owsley and Jantz 1978:140; Billeck et al. 2005:359). While certainly not baseless, the chronological ordering is tenuous and even Bass et al. (1971:143) acknowledged, “temporal differences between the areas within the Sully Cemetery are not positively demonstrable” on the basis of grave goods.

Owsley and Jantz (1978) utilized discriminant function analysis to compare crania from the Sully cemeteries (A, B, D and E) to three other Arikara sites (Leavenworth [39CO9], Buffalo Pasture [39ST216], and Rygh [39CA4]) and the earlier Murphy Site (25DK9) believed to be affiliated with the Central Plains St. Helena phase. Their results indicated the cemeteries at Sully did seem to align with the archaeological based chronology Bass (1965) had put forth. When examining Sully male crania, Owsley and Jantz (1978:145) found Cemeteries B and A were closer to the historic Leavenworth Site, Cemetery D was closest to early Rygh and Murphy sites, and Cemetery E was intermediate. The female crania displayed a similar pattern with Cemetery A being closest to the Leavenworth Site; however, Cemetery E aligned more with the earlier sites and Cemetery D assumed the intermediate position (Owsley and Jantz 1978:145). Overall, Cemeteries D and E appeared to represent burials of the earlier inhabitants at Sully, whereas Cemeteries A and B seemed to have been comprised of remains of the later occupations.

In a slight reordering, Key (1983:31) chose to associate Cemeteries A and D with the La Roche phase of the Extended Coalescent and Cemeteries B and E with the Le Beau phase of the Post-Contact Coalescent. This same chronological ordering of the Sully cemeteries was similarly taken by Jantz (1977) and Wescott and Cunningham (2006). In her geometric morphometric analysis of Arikara crania, McKeown (2000) begins by acknowledging these varying approaches to the chronological ordering of the Sully cemeteries, but her conclusions provide a slightly different interpretation. Specifically, she attests the placement of Cemetery E within the Le Beau phase of the Post-Contact Coalescent is not warranted on the basis of biological affinity (McKeown 2000:157). McKeown (2000) argues these individuals are closer to the La Roche phase individuals of the Extended Coalescent and some individuals within cemetery E may actually represent Initial Coalescent burial at the site.

Based on the information presented above and, for the purpose of this investigation, Sully D and Sully E are considered to belong to the Extended Coalescent, whereas Sully A and Sully B are considered to be part of the later Post-Contact Coalescent.

Figure 4-6. Aerial photograph of the Sully Site (39SL4). MRBS photograph 30SL4-11, courtesy W. Raymond Wood.

4.1.12 Swan Creek Site (39WW7)

Swan Creek is a multicomponent site, representing both Extended and Post-Contact Coalescent variants of the Coalescent tradition (Hurt 1957). The site is located in Walworth County, SD, near the mouth of Swan Creek on the east side of the Missouri River. Swan Creek was first recorded and excavated by William H. Over of the Museum of the University of South Dakota in 1920; subsequent excavations by Over took place in 1928 and 1932 (Billeck et al. 2005). In 1954, the South Dakota Archaeological Commission, the University of South Dakota Museum and the National Park Service entered into a cooperative agreement to excavate the

Swan Creek Site in anticipation of its planned inundation following construction of Oahe Dam (Hurst 1957). These excavations, which took place between 1954 and 1955, were supervised by Wesley R. Hurt. The occupation area was described as being 1230 feet in length and 1170 feet in width; a cemetery area was identified east of the occupation area (Hurt 1957:1).

Hurt (1957) identified four distinct occupation areas which he labeled A, B, C and D. Occupation Area A was the largest of all occupation areas although a large portion of it was covered by successive occupations. Occupation Area A, the earliest occupation, represents an unfortified village, which Hurt assigned to the Akaska focus of the Extended Coalescent. Occupation Area B was slightly reduced in size from Occupation Area A, although it overlapped approximately two-thirds of Occupation Area A (Hurt 1957). Additionally, the Occupation Area B village was surrounded by a moat and palisade. Hurt (1957) did not believe these two earliest occupation areas at Swan Creek represented continuous habitation, a position he took based not solely on the frequency, but also the presence and absence, of certain types of ceramics recovered from each area. Moreover, he also identified both primary and secondary burials within the cemetery area; the primary burials were believed to be associated with Occupation A, whereas the secondary burials were thought to be associated with Occupation B (Hurt 1957:24). The village of Occupation Area C was also surrounded by a moat and palisade but was only half the size of Occupation Area B, apparently having been rebuilt following the destruction of the village by fire (Hurt 1957:25). Finally, Occupation Area D is represented by three houses located just outside of the southern fortification wall of Occupation Area B. Hurt (1957) was not able to ascribe a specific time period to the area; however, recovered ceramics from excavations in these houses suggest they were contemporaneous with Occupations B and

C. Based on the similarity of ceramic types and frequencies, Hurt (1957) assigned Occupation Areas B, C and D to the Le Beau phase of the Post-Contact Coalescent.

Although skeletal remains were recovered from the cemetery during both Over's 1920s and Hurt's 1950s excavations, only the skeletal remains from Over's excavation are housed at the Smithsonian Institution and data collected from that assemblage are included in this analysis. In Over's early notes concerning his excavations at Swan Creek, he appears very confident "the occupants of the site were Arikara" (Sigstad and Sigstad 1973:307). However, later updates to these notes, following additional excavations in 1928 and 1932, indicated Over was less certain about the cultural affiliation of all of the inhabitants of the site. Specifically, he distinguishes between the earliest inhabitants, who buried their dead approximately six feet deep, and the later inhabitants, which he ascribed to the Arikara, whose burials were intrusive to the former (Sigstad and Sigstad 1973). Over felt these "two periods of habitation by people of different habits and customs" was proven at Swan Creek during the 1932 excavation in which the outline of a square lodge was uncovered underneath a more recent round lodge, the latter a house style more historically associated with Arikara (Sigstad and Sigstad 1973:305).

Interestingly, Hurt (1957) also believed the two burial complexes (i.e., primary burials and intrusive secondary burials) at Swan Creek were evidence of more than one culture at the site. However, contrary to Over's interpretation (Sigstad and Sigstad 1973), Hurt (1957:29) believed the earlier primary interments belonged to the Arikara and the intrusive secondary burials were likely to have been burials of skeletal elements derived from the scaffolding practices by ancestors of either the Mandan or Hidatsa.

Swan Creek is one of a handful of Le Beau phase sites in South Dakota where tribal affiliation of the site occupants has been questioned. Owsley et al. (1981) utilized craniometric comparisons to investigate interpopulation relations at the Post-Contact Coalescent sites of Four Bear (39DW2), Oahe Village (39HU2), Stony Point Village (39ST235) and Swan Creek (39WW7). Crania from these sites were analyzed against reference collections from known Arikara and Mandan. Additionally, because questions of tribal affiliation at Swan Creek developed on account of the presence of two burial complexes, Owsley et al. (1981) assessed the site for intrasite heterogeneity. In all analyses, Swan Creek classified as an Arikara site, although the authors could not rule out the possibility a small number of individuals present at Swan Creek may have been Mandan. Moreover, their assessment of the Swan Creek skeletal assemblage for possible intrasite heterogeneity concluded the two burial complexes at Swan Creek did not reflect burial customs arising from two distinct populations. Furthermore, based on the geographic location of Le Beau phase sites and the ceramic styles present at them, Lehmer (1971:203) felt it more reasonable to identify the Le Beau phase with the historic Arikara.

Given the above, the Swan Creek individuals excavated by Over in 1920 are ascribed an Arikara cultural affiliation and are assigned to the Akaska focus. The latter assignment is based on Over's field notes (Sigstad and Sigstad 1973) which give the impression most of these interments were primary burials. Hurt (1957:21) provided the following evidence that the primary burials at Swan Creek were the earliest, associated with Occupation Area A and, therefore, assigned to the Akaska focus:

1. [I]n several areas secondary burial pits were intrusive into primary burials;

2. When these secondary burial pits were constructed portions of the primary inhumations were removed;
3. Sherds found with the secondary burials belong on the whole to the Le Beau Focus of Occupation Areas B and C rather than to the earlier Akaska Focus of Occupation Area A;
4. Secondary burials were found in Refuse Mound E, which is correlated with Occupation B of the village site; and
5. No primary inhumations were found in Occupation Areas B and C, the two most recently inhabited areas of the village.

4.1.13 Leavenworth (Lewis and Clark) Site (39CO9)

The Leavenworth Site (39CO9) is located in modern day Corson County, SD on the right bank of the Missouri River (Bass et al. 1971). Because the river flows east to west at this locale, the Leavenworth Site is positioned north of the river. The site is situated in close proximity to several other sites along this stretch of the Missouri River. Anton Rygh (39CA4), Mobridge (39WW1), Larson (39WW2), and the protohistoric Nordvold sites (39CO31, 39CO32, 39CO33) are located directly south on the eastern bank of the Missouri. The Leavenworth Site is sometimes referred to as the Lewis and Clark Village, in reference to the visit paid to it by the Corp of Discovery explorers in October of 1804. Like many other archaeological sites along this stretch of the Missouri, the Leavenworth Site has since been inundated under the waters of the Oahe Reservoir following the completion of Oahe Dam in 1957 (Bass et al. 1971). A report on archaeological excavations conducted by William M. Bass and his field crews, under the supervision of Donald J. Lehmer, during the field seasons of 1965 and 1966 was published by the University of Kansas in 1971 and serves as a primary reference source for the skeletal materials recovered.

The Leavenworth Site is located at the point where Elk Creek (also known as Cottonwood Creek) empties into the Missouri River. On a map originally produced by John Thomas Evans during his 1795-1796 expedition and later used by Lewis and Clark on their voyage, Clark labeled this creek as Parnorni (Wood 1981). Portions of the site lay on both sides of the creek, one village to the east and one to the west. The eastern village is often referred to as the upper village, whereas the western village is referred to as the lower village. Both were surrounded by palisades. Historical accounts, as well as archaeological investigations, indicate each village held approximately 70 lodges (Billeck et al. 2005). Several burial areas were located north of the villages and have been denoted as Cemetery Areas A-E in the archaeological documentation. Cemetery Areas A, B, C, and D were located on the high terraces north of the villages on the east side of Elk Creek. Cemetery Area E was located to the west of Elk Creek north of the lower village. Bass et al. (1971) noted the graves in Cemetery Area E consisted of scattered graves, often containing non-articulated remains with few grave goods. These findings were in contrast to the areas of more concentrated burials on the high terraces, which contained mostly primary burials often accompanied by grave goods (Bass et al. 1971).

The Arikara are known to have inhabited the Leavenworth Site villages from circa 1800 to 1832. Wedel (1955) notes that by 1803, the Arikara had settled into three villages, one on Ashley Island and the other two at the location of the Leavenworth Site. The Lewis and Clark expedition visited these villages in October of 1804, first visiting the village located on Ashley

Island from October 8th to October 10th and subsequently the two villages at the location of the Leavenworth site on October 11th and 12th (Gass, 1958). Given the dates of occupation of the Leavenworth Site, it falls entirely within the Disorganized Coalescent variant.

4.2 Cranial Nonmetric Traits and Samples

Nonmetric traits of the human skeleton have been of interest to bioarchaeologists and skeletal biologists for some time now (Berry and Berry 1967; Ossenberg 1969; Corruccini 1974; Berry 1975; Finnegan 1978; Trinkaus 1978; Korey 1980; Ossenberg 1981; Saunders 1989). Historically, a great deal of attention has been paid to the potential for nonmetric traits to provide useful information on microevolutionary changes in human populations (Ossenberg 1981; Buikstra et al. 1990; Donlon 2000). However, relatively little research has investigated the relationship between FA nonmetric traits and developmental instability in hominoids (see Trinkaus 1978 as an exception).

The nonmetric portion of this study is based on two separate and previously collected data sets. The first was provided by the Repatriation Osteology Lab (ROL) of the Smithsonian Institution's National Museum of Natural History (NMNH) and the second was a cranial nonmetric dataset of the Crow Creek Site (39BF11) remains retrieved from the University of South Dakota.

4.2.1 Repatriation Osteology Lab (ROL) Dataset

A database comprised of bilateral scores for 25 separate cranial nonmetric traits collected from a total of 559 individuals was made available for use in this study. The nonmetric traits included in the database are derived from the Osteoware software program of the Repatriation Osteology Lab of the National Museum of Natural History, Smithsonian Institution. The selection of nonmetric traits included in the Osteoware program are derived from recommendations set forth in the Standards for Data Collection from Human Skeletal Remains (Buikstra and Ubelaker 1994). In the Osteoware program, nonmetric traits of the cranium are categorized according to the regions on the cranium where they are located. The four regions used for classifying trait location are: (1) facial, (2) lateral, (3) basilar, and (4) mandibular. The nonmetric traits included in these four regions are listed in Table 4-3. In addition, Appendix 8.2 provides description of the cranial nonmetric traits and Appendix 8.3 provides database abbreviations and associated ROL scoring codes used at the time of data collection. Figures 4-7 through 4-11 illustrate the location of these nonmetric traits on the cranium.

Table 4-3. Nonmetric traits of the ROL Dataset

Cranial Region	Nonmetric Trait	ROL Code
Facial	Supraorbital notch	SONOTCH
	Supraorbital foramen	SOFORAM
	Supratrochlear notch	STNOTCH
	Infraorbital suture	IOSUT
	Infraorbital foramen	IOFRAM
	Epipteric bone	EPIPTER
	Coronal ossicle	CORONL
	Zygomaticofacial foramen	ZYFFOR
Lateral	Parietal foramen	PFORAM
	Lambdoidal ossicle	LAMBOSS
	Asterionic bone	ASTRINB
	Ossicle in occipitomastoid suture	OMSUTS
	Parietal notch bone	PARNOTB
	Auditory exostosis	AUDEXOS
	Mastoid foramen location	MASTFRL
	Mastoid foramen number	MASTFRN
Basilar	Condylar canal	CONDCAN
	Divided hypoglossal canal	DIHYPOC
	Foramen spinosum incomplete	FRSPINI
	Foramen ovale incomplete	FOROVLI
	Pterygospinous bridge	PTSPBR
	Pterygoalar bridge	PTABRG
Mandibular	Mental foramina	MENTFOR
	Mylohyoid bridge location	MYLHBRL
	Mylohyoid bridge development	MYLHBRD

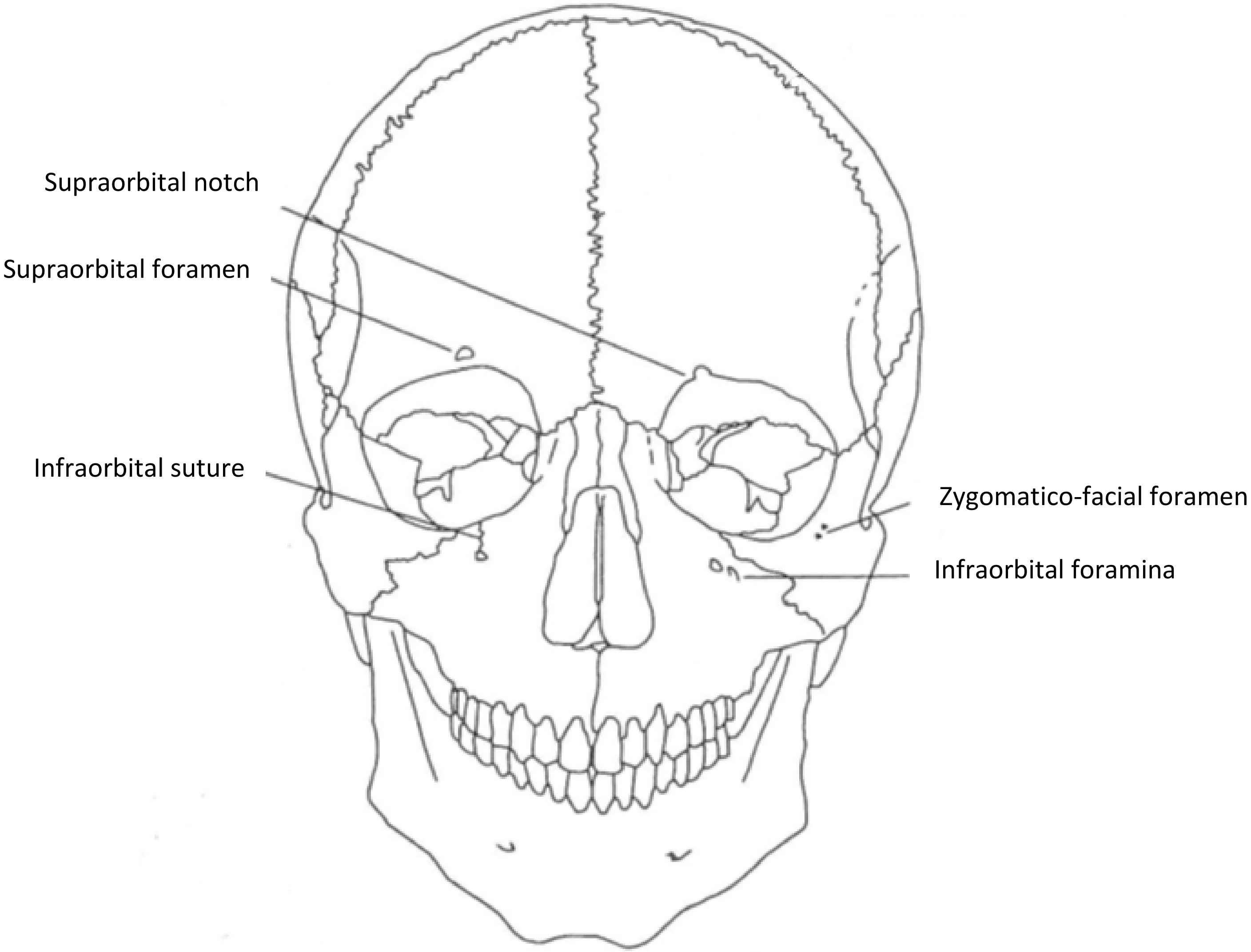

Figure 4-7. Anterior view of cranial nonmetric traits. (Adapted from Buikstra and Ubelaker 1994)

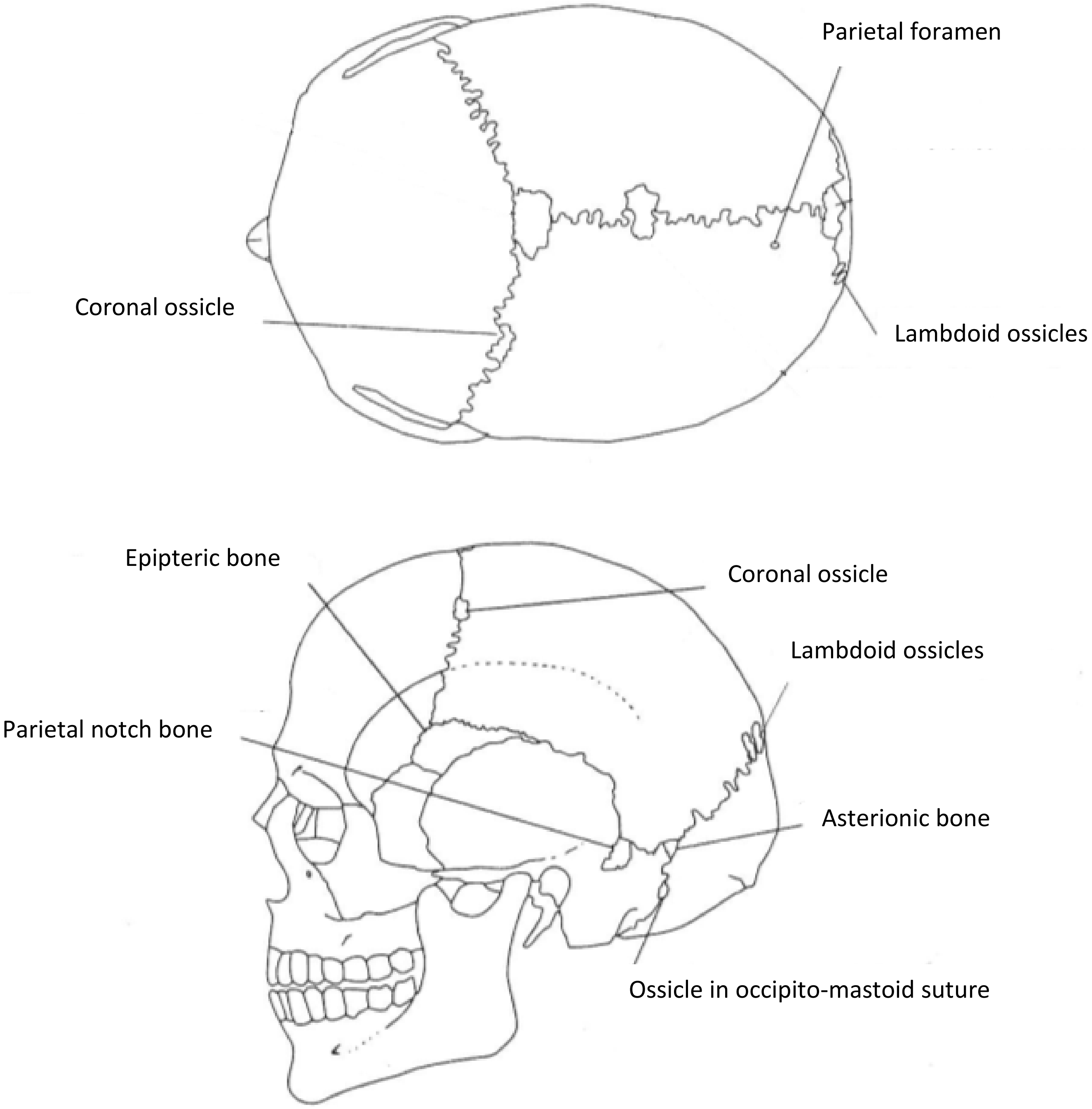

Figure 4-8. Superior and lateral views of cranial nonmetric traits. (Adapted from Buikstra and Ubelaker 1994)

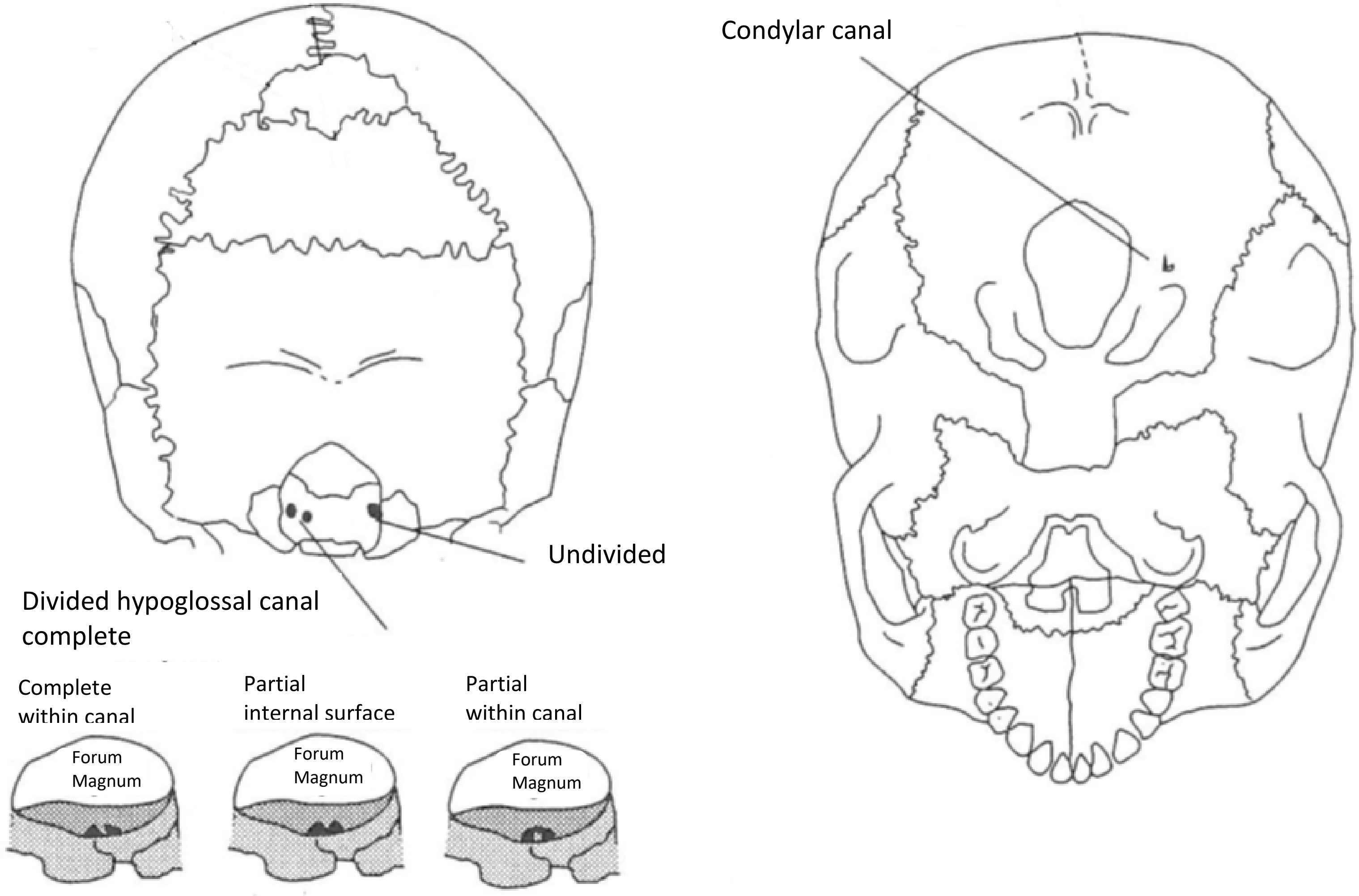

Figure 4-9. Posterior and basilar views of cranial nonmetric traits. (Adapted from Buikstra and Ubelaker 1994)

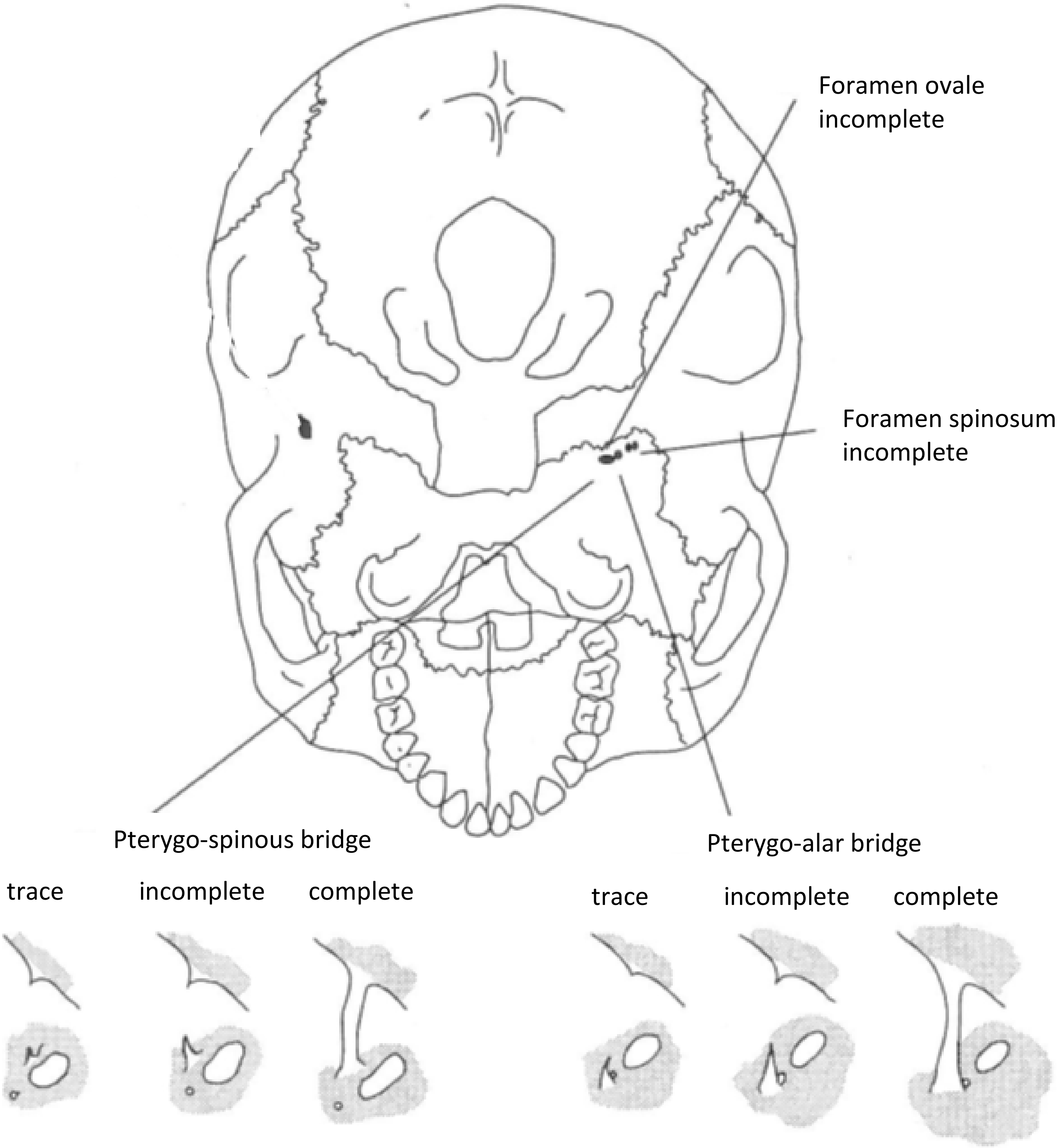

Figure 4-10. Basilar views of cranial nonmetric traits. (Adapted from Buikstra and Ubelaker 1994)

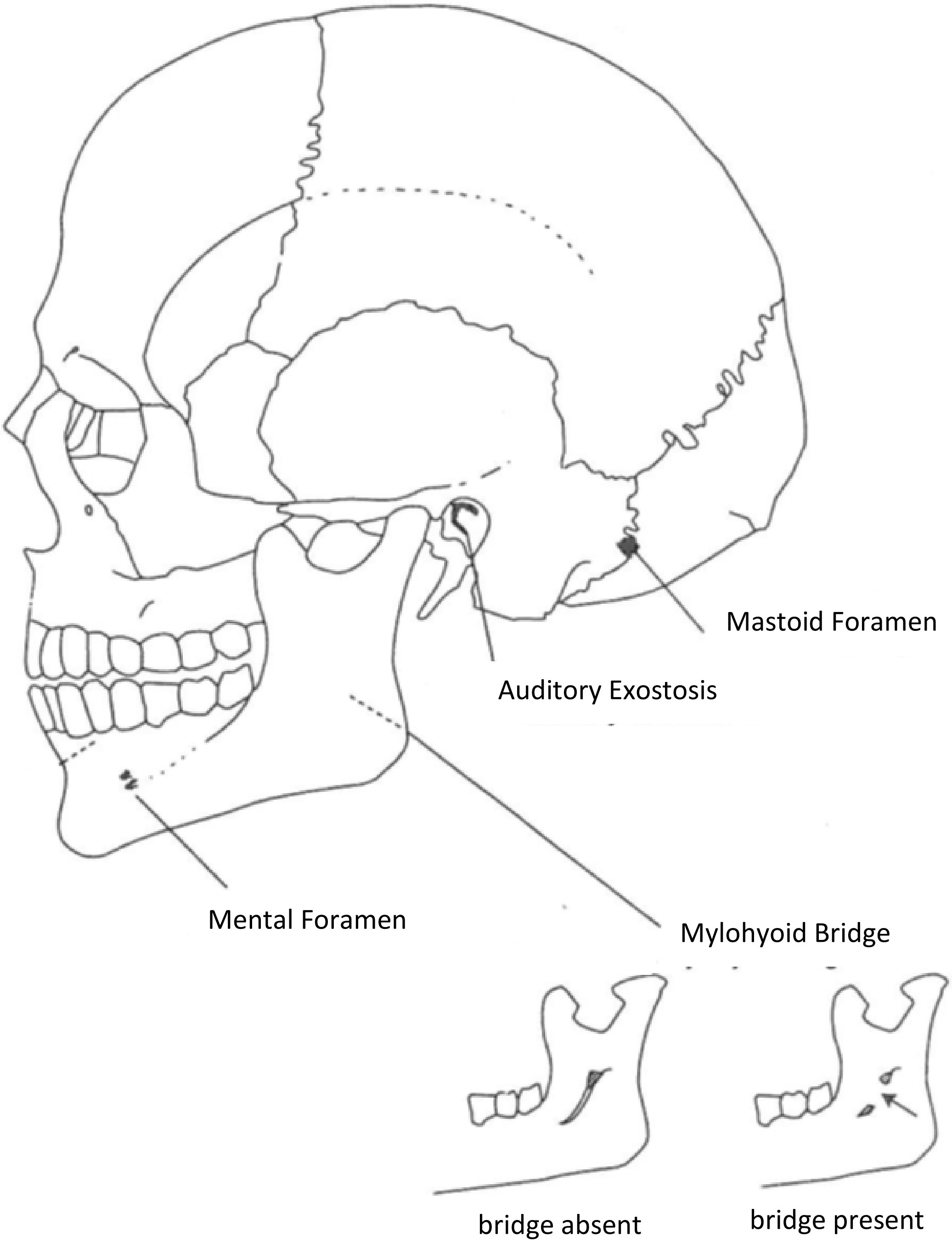

Figure 4-11. Lateral and mandibular views of cranial nonmetric traits. (Adapted from Buikstra and Ubelaker 1994)

Dr. Christopher Dudar, NMNH Repatriation Osteology Lab Manager, indicated the supplied nonmetric data had been collected by several individuals in the early 1990s, none of whom was known for conducting research into nonmetric data (Christopher Dudar, personal communication, May 2, 2012). Nevertheless, I assume data collection was standardized to some degree according to the use of publications such as *Standards* and the use of defined scoring codes provided in the Osteoware program and its software predecessors. Readers interested in additional information on the development of human skeletal remains documentation and the software created to facilitate the documentation process are referred to the *Osteoware Software Manual, Volume I* (Wilczak and Dudar 2011). Despite the aforementioned shortcomings of this database, its value lies in its overall sample size and scope. Several Arikara archaeological sites provide samples for three of the four Coalescent tradition variants (Table 4-4).

Table 4-4. Coalescent sites by variant and the number of individuals in samples for each cranial nonmetric trait region.

		Extended Coalescent		
Sites	*Facial*	*Lateral*	*Basilar*	*Mandibular*
Mobridge	23	25	26	22
Rygh	3	4	-	6
Sully Cemetery D	13	12	16	26
Swan Creek	10	10	1	8
Total	**49**	**51**	**43**	**62**
		Post-Contact Coalescent		
Sites	*Facial*	*Lateral*	*Basilar*	*Mandibular*
Buffalo Pasture	10	13	1	7
Cheyenne River	32	29	31	36
Indian Creek	1	2	-	3
Leavitt	7	6	1	9
Mobridge	44	54	55	74
Nordvold 1	3	3	4	4
Nordvold 2/3	32	33	28	31
Sully Cemetery A	22	25	16	43
Sully Cemetery B	2	2	1	3
Total	**153**	**167**	**137**	**210**
		Disorganized Coalescent		
Site	*Facial*	*Lateral*	*Basilar*	*Mandibular*
Leavenworth	11	16	19	22

4.2.2 Crow Creek Site Dataset

Data that comprise this dataset were originally recorded by Dr. P. Willey in 1979 during the few months when human skeletal remains from the Crow Creek Site (38BF11) were available for analysis. According to Dr. Willey (personal communication, December 23, 2008) documentation of cranial discrete traits followed the work of Berry and Berry (1967). Scoring of the traits in this database is very straightforward; traits are either present, absent, or unobservable.

On June 22, 2012, I traveled to Vermillion, SD where the original hardcopy records were being stored on the campus of the University of South Dakota. I made copies of the cranial nonmetric datasheets at that time, which I later transcribed into a digital spreadsheet. Accurate transcription of these data was verified by an independent reviewer. Some of the nonmetric traits recorded in the Crow Creek dataset are consistent with those documented in the Repatriation Osteology Lab (ROL) dataset, which provides for some amount of direct comparison between these data sets (Table 4-5). This particular dataset is, however, unique in that it provides data from the only archaeological assemble in this study representing the Initial Coalescent variant.

Table 4-5. Initial Coalescent site and the number of individuals for each cranial nonmetric trait region.

		Initial Coalescent		
Site	*Facial*	*Lateral*	*Basilar*	*Mandibular*
Crow Creek	46	33	-	42

4.2.3 Crow Creek to ROL Comparison

The Crow Creek dataset is comprised of 20 separate bilaterally paired nonmetric cranial traits. Most of these traits follow those described by Berry and Berry (1967) and their scoring is simply by presence or absence of the trait. Of these 20 traits, ten were deemed identical to the ROL traits; although, in some cases, some modifications were necessary to correct for differences in trait scoring. These traits and any scoring modifications are described below.

Supraorbital foramen

Berry and Berry (1967) refer to this trait as “supraorbital foramen complete,” which is how it was scored by Willey in the Crow Creek dataset. The ROL dataset refers to this trait as “supraorbital foramen” and the trait is scored as absent, present or multiple foramina. For comparison of these two datasets, the ROL dataset was modified so that “multiple foramina” are also subsumed within the “present” scores.

Coronal Ossicle

For both the Crow Creek and ROL datasets, this trait is scored as absent or present, thus scoring appears to be identical across the two.

Epipteric ossicle

For both the Crow Creek and ROL datasets, this trait is scored as absent or present, thus scoring appears to be identical across the two.

Parietal foramen

For both the Crow Creek and ROL datasets, this trait is scored as absent or present on the right and left, thus scoring appears to be identical. It should be noted, however, that the ROL database adds a “midline parietal foramen,” separate from the left and right sides, to allow for scoring of any foramen that happens to fall directly on the sagittal suture. Very few individuals were scored as having this variant and they were not included in this analysis.

Lambdoid ossicle

For both the Crow Creek and ROL datasets, this trait is scored as absent or present. However, in the Crow Creek dataset this trait was further subdivided into “medial lambdoid ossicle” and “lateral lambdoid ossicle” depending on where the ossicle fell along the length of the lambdoidal suture. For analytical comparison of these two datasets, the Crow Creek dataset was modified to combine the lateral and medial aspects into a single lambdoid ossicle score for either the left or right side.

Asterionic bone

For both the Crow Creek and ROL datasets, this trait is scored as absent or present, thus scoring appears to be identical.

Ossicle in occipitomastoid suture

For both the Crow Creek and ROL datasets, this trait is scored as absent or present, thus scoring appears to be identical. This trait is not among those listed in Berry and Berry (1967); however, Willey included it in the Crow Creek dataset.

Parietal notch bone

For both the Crow Creek and ROL datasets, this trait is scored as absent or present, thus scoring appears to be identical across the two. In the Crow Creek dataset this trait is simply referred to as “parietal notch,” which I infer to mean the presence or absence of an ossicle at this location. The parietal notch is a normal feature on human crania, whereas the presence of an ossicle at that location is a variable nonmetric trait. Berry and Berry (1967) also refer to this trait as “parietal notch bone.”

Mylohyoid bridge

The mylohyoid bridge is not a trait described in Berry and Berry (1967); however, it was included in the Crow Creek dataset. In the ROL dataset, the development of a mylohyoid bridge can be scored as either partial or complete, whereas the Crow Creek dataset only allows for the presence or absence of a bridge. Therefore, for comparison of these two datasets, the ROL dataset was modified to change all “partial” scores to “absence” of the trait.

4.3 Craniometric Data and Samples

Skeletal materials from two different institutions were utilized in this study. The first dataset was provided by the Repatriation Osteology Lab (ROL) of the Smithsonian Institution's National Museum of Natural History (NMNH) and included previously digitized cranial landmarks from skeletal materials housed at that institution. The second dataset was personally collected from skeletal materials housed at the University of Tennessee, Department of Anthropology. At the University of Tennessee, three-dimensional cranial coordinate data were collected using a MicroScribe® G2 digitizer. The digitizer was calibrated prior to each day's use to ensure the instrument was functioning properly and providing accurate measurements. Crania were placed on a platform that held the specimen in a particular orientation and kept it from moving while measurements were being collected. Cranial landmarks were measured in the same sequential order for every cranium. I approached each specimen from the same direction and orientation to avoid the possibility of introducing variability that might arise from changes in body posture.

Cranial landmarks chosen for inclusion in the analysis included five midline landmarks (opisthion, prosthion, nasion, bregma and lambda) and four bilaterally paired landmarks (frontomalare anterior, zygomaxillare, sphenion, and asterion). Descriptions of these cranial landmarks are provided in Appendix 8.4. Locations of these landmarks on the cranium are shown in Figures 4-12 through 4-16.

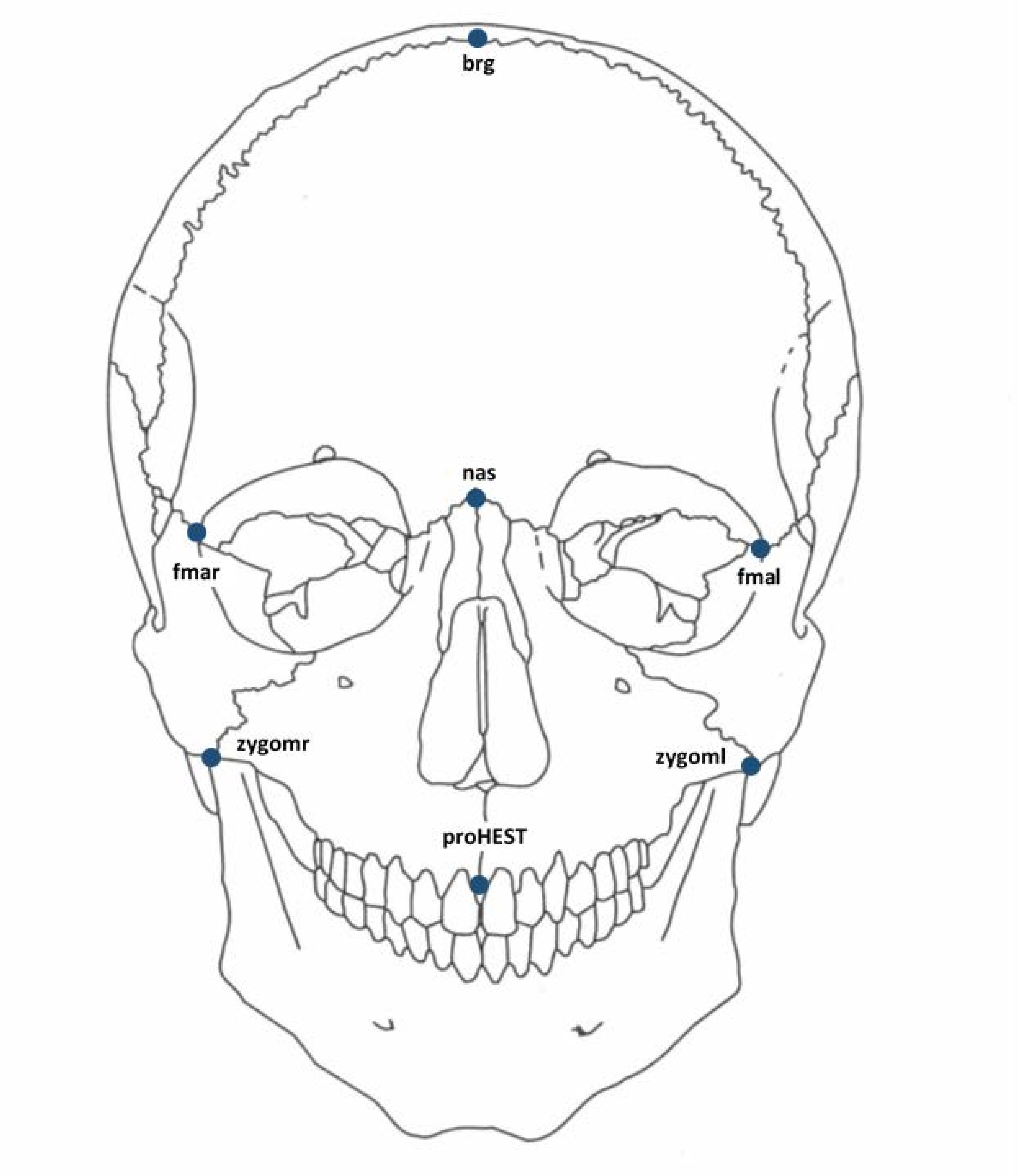

Figure 4-12. Cranial landmarks - anterior cranial view. (Adapted from Buikstra and Ubelaker 1994).

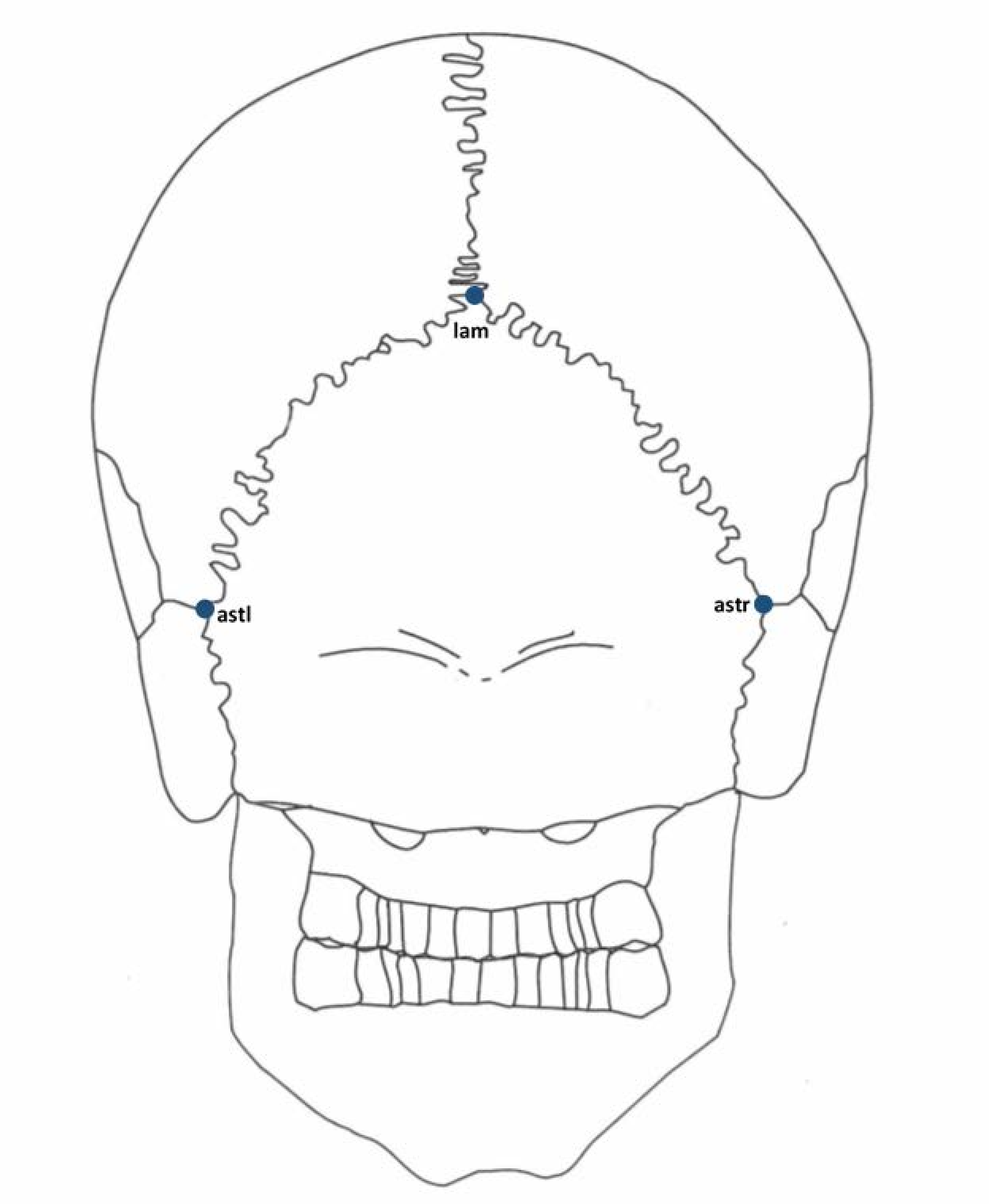

Figure 4-13. Cranial landmarks - posterior cranial view. (Adapted from Buikstra and Ubelaker 1994)

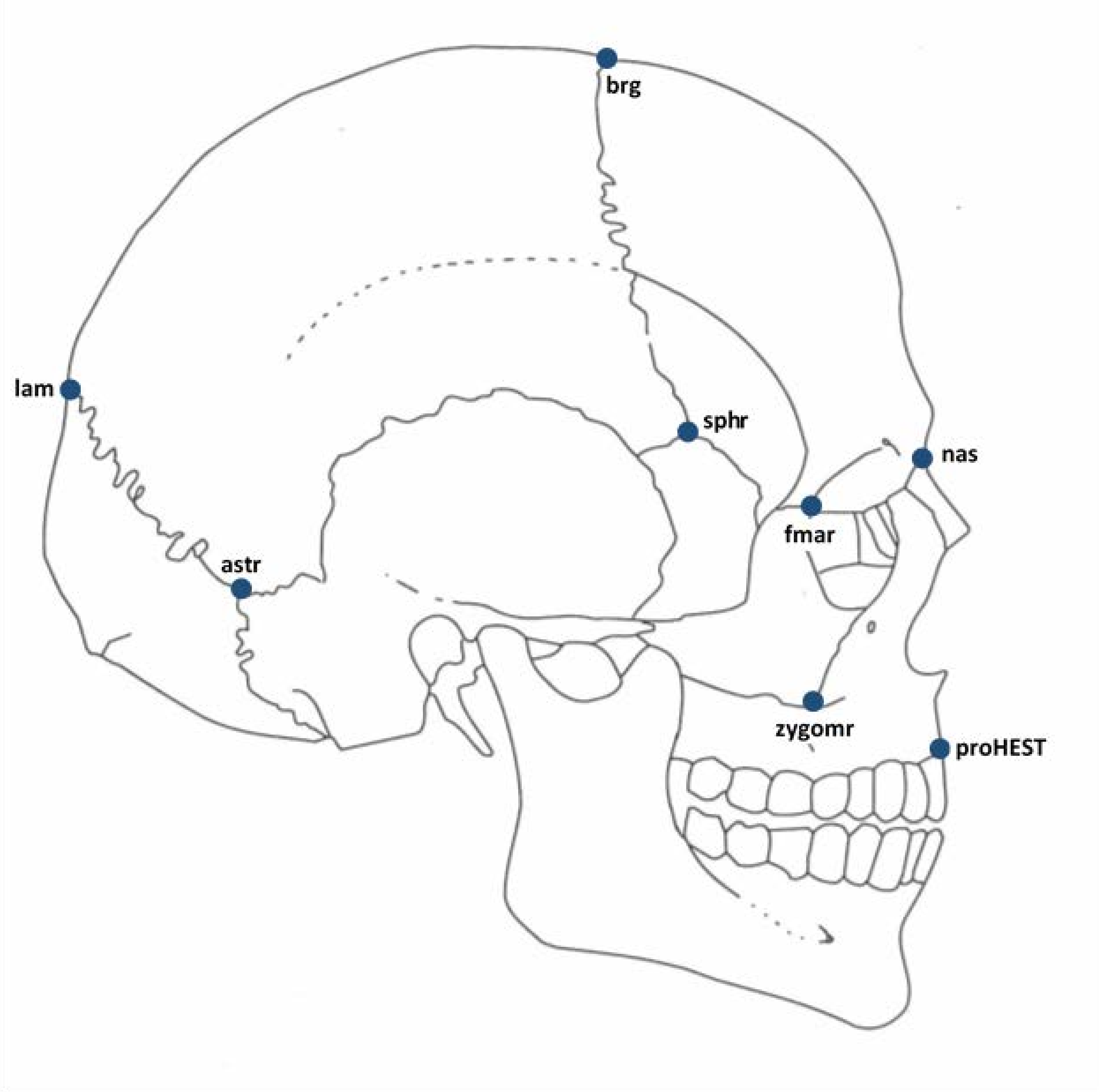

Figure 4-14. Cranial landmarks - lateral cranial view. (Adapted from Buikstra and Ubelaker 1994)

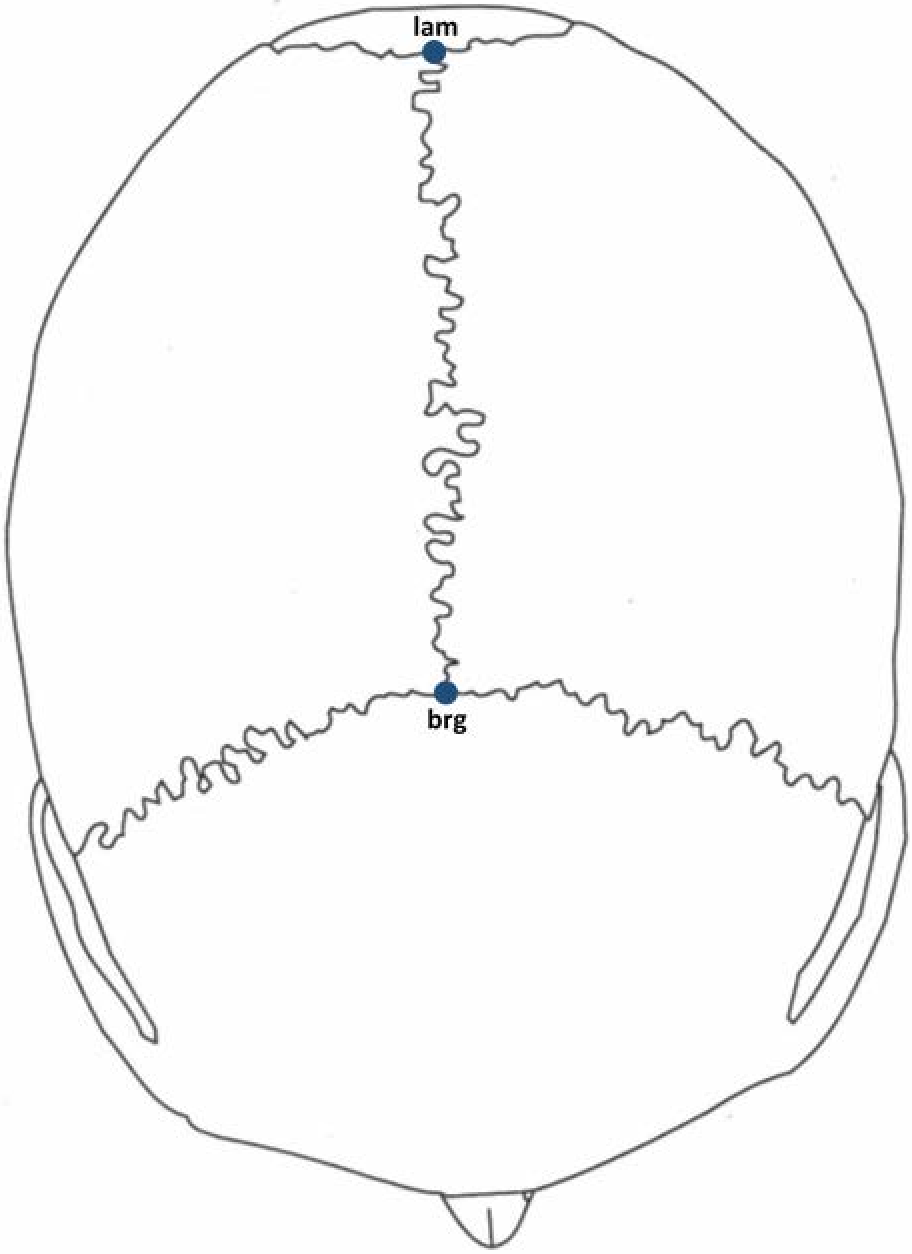

Figure 4-15. Cranial landmarks - superior cranial view. (Adapted from Buikstra and Ubelaker 1994)

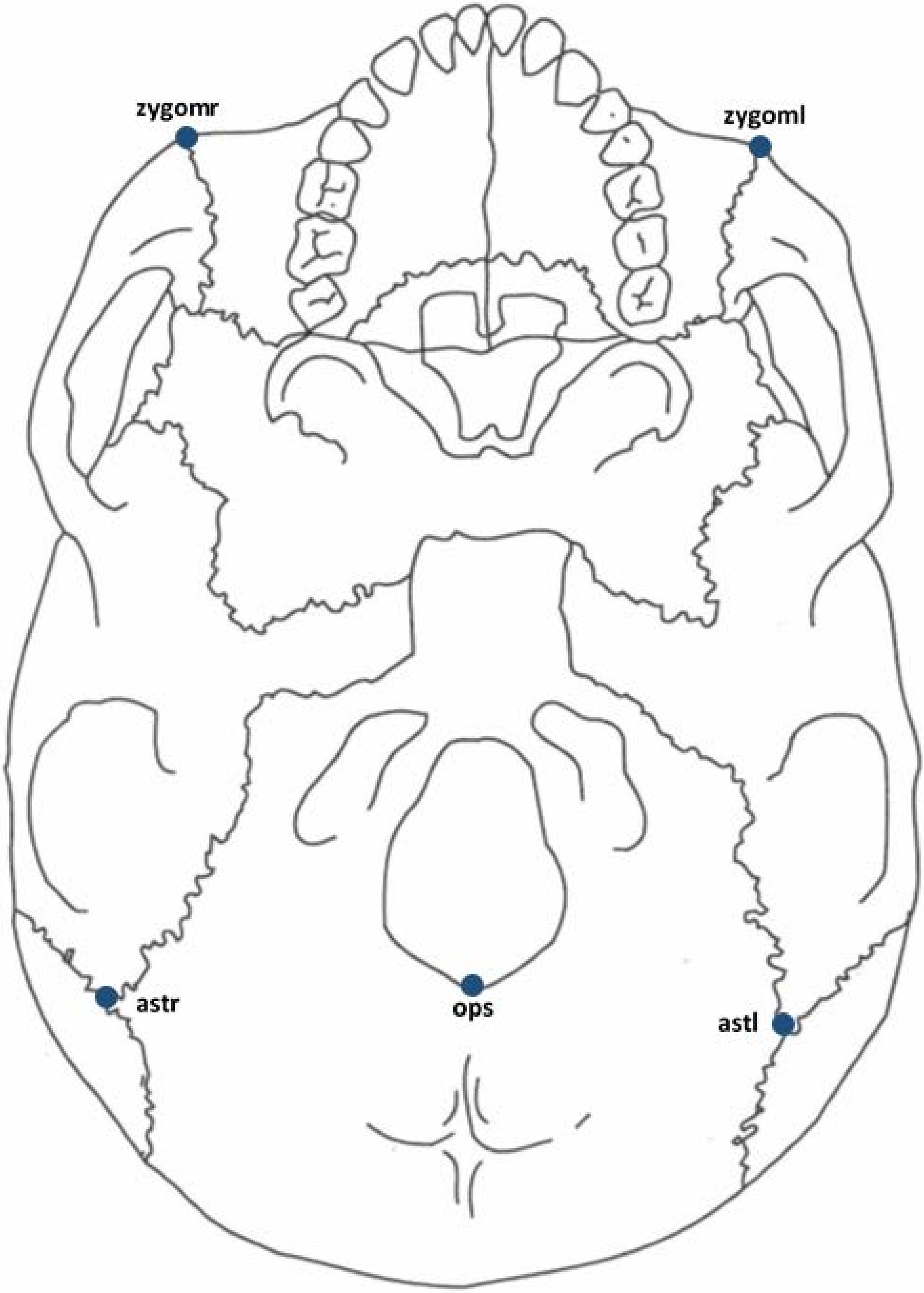

Figure 4-16. Cranial landmarks - inferior cranial view. (Adapted from Buikstra and Ubelaker 1994)

4.4 Post-cranial Measurements and Samples

Post-cranial metric data included measurements taken from the humerus, radius, femur and tibia. Measurements taken from each of these bones and the instruments used to collect them are provided in Table 4-6 for adults and Table 4-7 for juveniles.

Table 4-6. Adult post-cranial skeletal measurements.

Skeletal Element	Measurement	Instrument
Humerus	Maximum Length	Osteometric Board
	Maximum Midshaft Diameter	Sliding Calipers
	Minimum Midshaft Diameter	Sliding Calipers
	Epicondylar Breadth	Sliding Calipers
	Head Maximum Vertical Diameter	Sliding Calipers
Radius	Maximum Length	Osteometric Board
	Sagittal Midshaft Diameter	Sliding Calipers
	Transverse Midshaft Diameter	Sliding Calipers
	Radiocarpal Surface M-L (RCML)†	Sliding Calipers
Femur	Maximum (Morphological) Length	Osteometric Board
	Bicondylar (Physiological) Length	Osteometric Board
	Midshaft Anterio-posterior Diameter	Sliding Calipers
	Midshaft Transverse Diameter	Sliding Calipers
	Epicondylar Breadth	Osteometric Board
	Femoral Condyles M-L (FCML)†	Sliding Calipers
Tibia	Tibial Length	Osteometric Board
	Proximal Epiphyseal Breadth	Osteometric Board
	Distal Epiphyseal Breadth	Osteometric Board
	Tibiotalar Surface A-P (TTAP)†	Sliding Calipers

†Measurements taken from Ruff 2002. See Ruff (2002:334-337) for descriptions.

Table 4-7. Juvenile post-cranial skeletal measurements.

Skeletal Element	Measurement	Instrument
Humerus	Maximum Length	Osteometric Board†
	Maximum Midshaft Diameter	Sliding Calipers
	Minimum Midshaft Diameter	Sliding Calipers
	Distal Width	Sliding Calipers
Radius	Maximum Length	Osteometric Board†
	Sagittal Midshaft Diameter	Sliding Calipers
	Transverse Midshaft Diameter	Sliding Calipers
Femur	Maximum Length	Osteometric Board†
	Midshaft Anterio-posterior Diameter	Sliding Calipers
	Midshaft Transverse Diameter	Sliding Calipers
	Distal Width	Sliding Calipers
Tibia	Tibial Length	Osteometric Board†
	Proximal Width	Sliding Calipers
	Distal Width	Sliding Calipers

† An osteometric board was used when lengths exceeded the measurable range of the sliding calipers.

The osteometric board utilized in this study was manufactured by Paleo-Tech Concepts and was readable to increments of 0.5 mm. The sliding calipers were manufactured by Mitutoyo and were readable to increments of 0.01 mm.

Descriptions of these dimensions and instructions for their measurement can be found in Moore-Jansen et al. (1994). Illustrations of these dimensions for adults are shown in Figures 4-17 through 4-20. Illustrations are not provided for the dimensions on juvenile skeletons; however, the dimensions are effectively the same as in adults minus the proximal and distal epiphyses of these long bones.

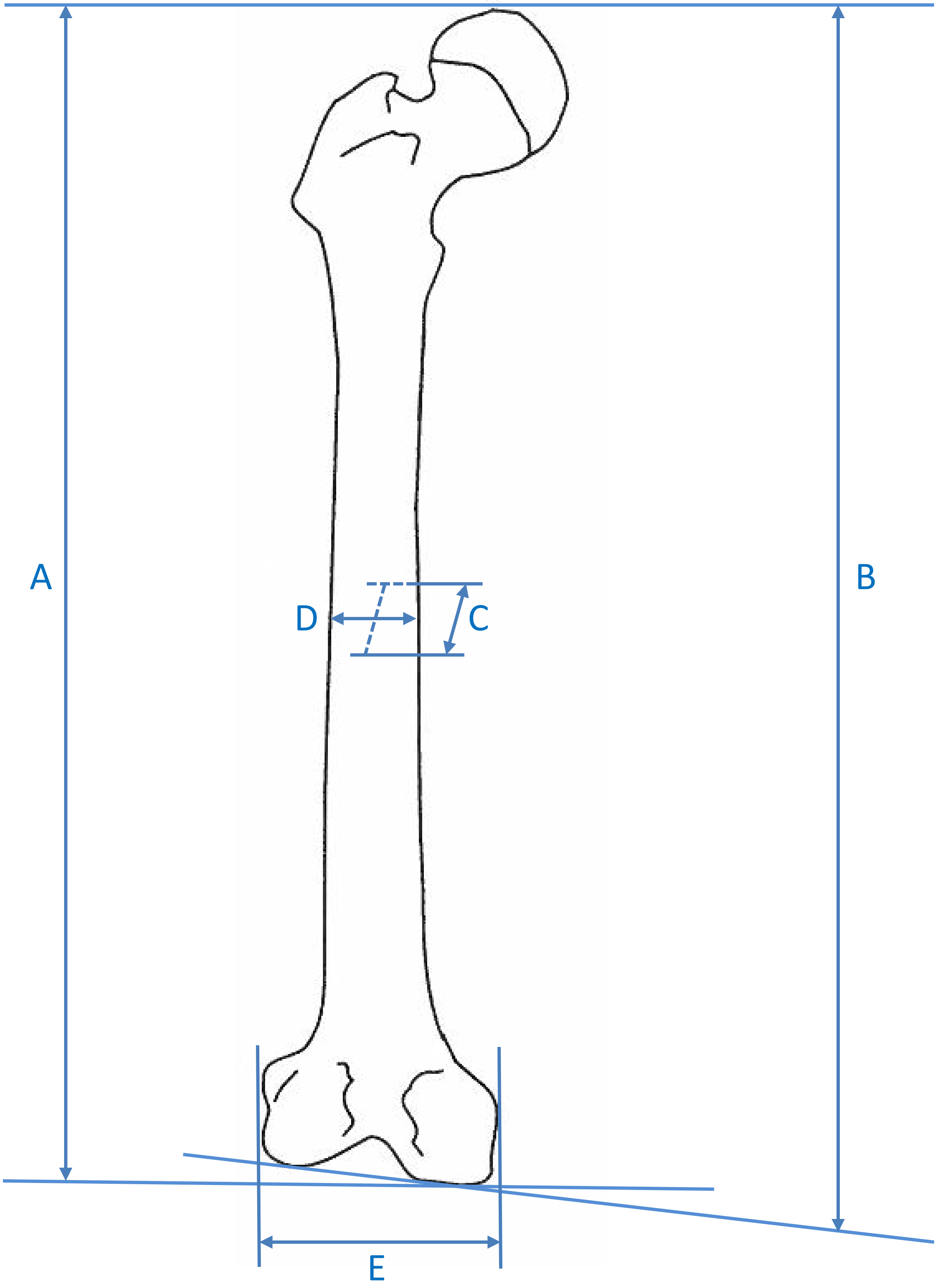

Figure 4-17. Femoral dimensions (left femur, posterior view). (Adapted from Buikstra and Ubelaker 1994). A = Maximum (Morphological) Length; B = Bicondylar (Physiological) Length; C = Midshaft Anterio-posterior Diameter; D = Midshaft Transverse Diameter; E = Epicondylar Breadth.

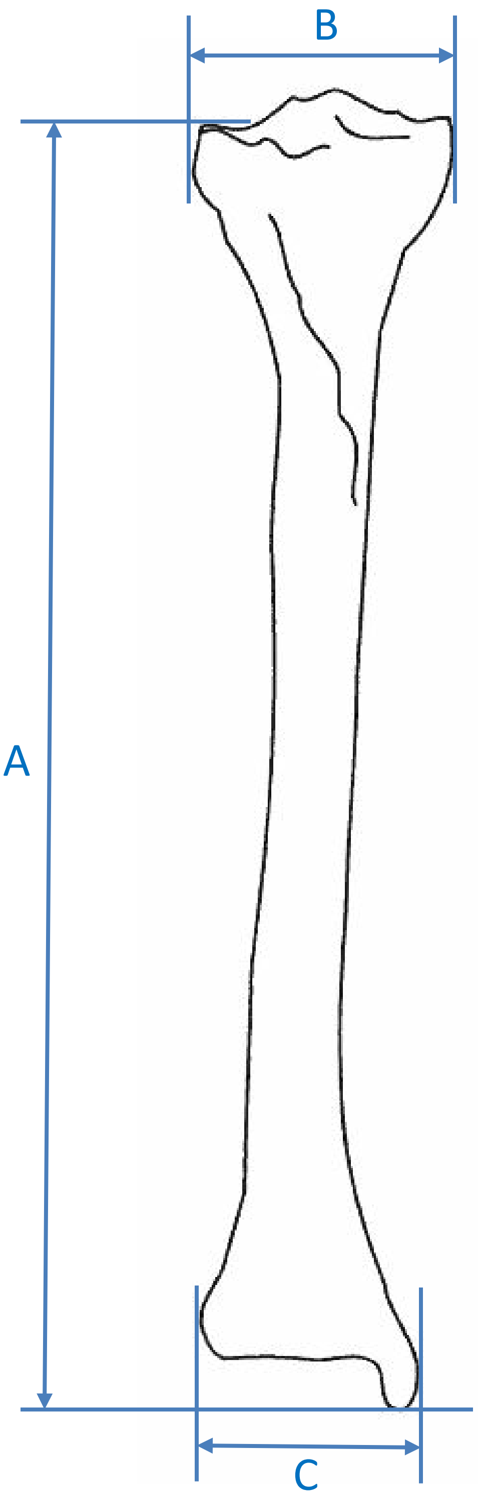

Figure 4-18. Tibial dimensions (left tibia, posterior view). (Adapted from Buikstra and Ubelaker 1994). A = Tibial Length; B = Proximal Epiphyseal Breadth; C = Distal Epiphyseal Breadth.

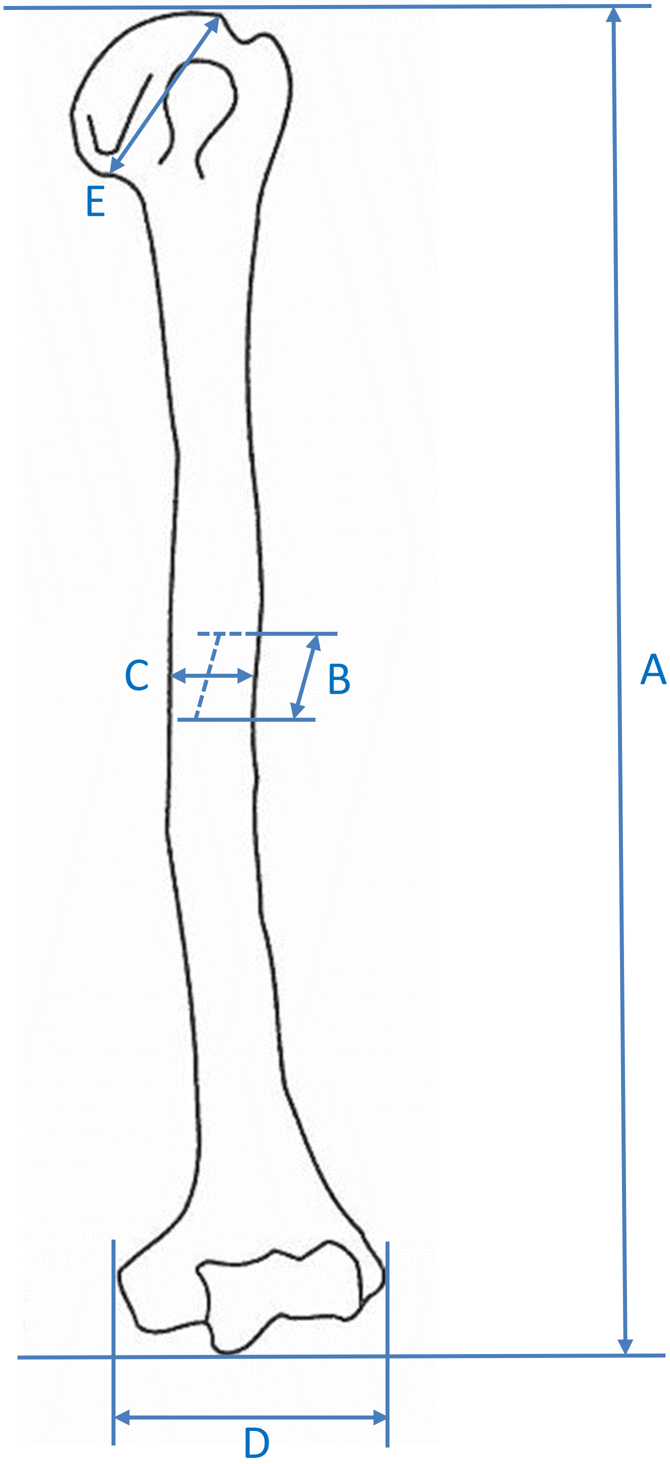

Figure 4-19. Humeral dimensions (left humerus, anterior view). (Adapted from Buikstra and Ubelaker 1994). A = Maximum Length; B = Maximum Midshaft Diameter; C = Minimum Midshaft Diameter; D = Epicondylar Breadth; E = Head Maximum Vertical Diameter.

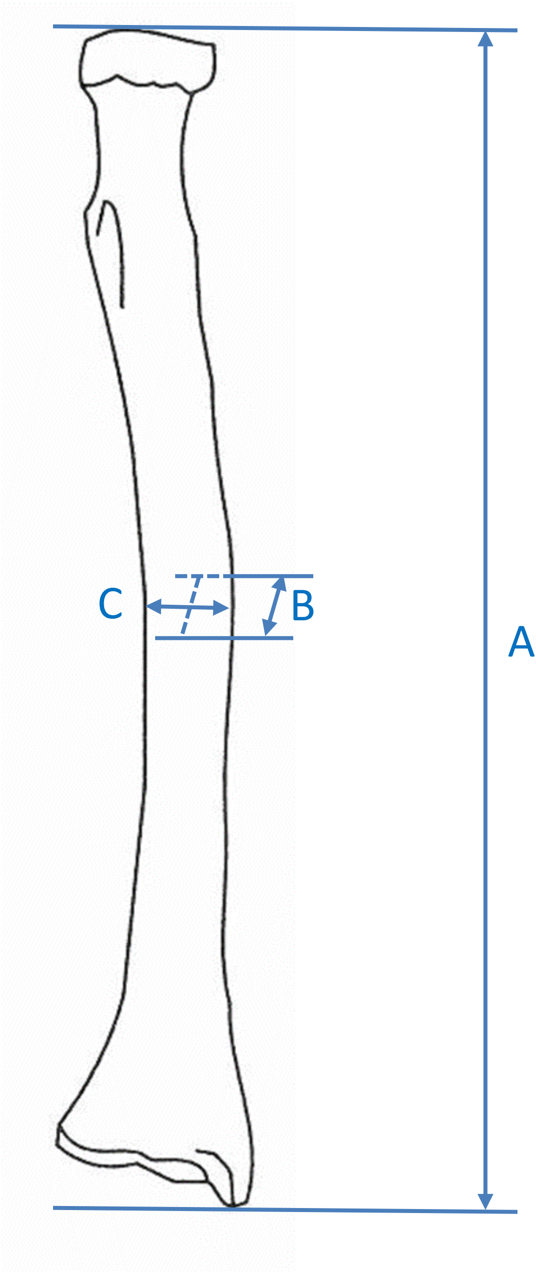

Figure 4-20. Radial dimensions (left radius, anterior view). (Adapted from Buikstra and Ubelaker 1994). A = Maximum Length; B = Sagittal Midshaft Diameter; C = Transverse Midshaft Diameter.

CHAPTER 5: ANALYTICAL METHODS

5.1 Measuring Asymmetry

One of the best guides to date on conducting analyses of fluctuating asymmetry has been produced by Palmer (1994). He covers important topics such as the choice of appropriate indices for describing the magnitude of FA in a sample, choice of traits, sample size, measurement error, and tests of significance for differences in FA. Each of these areas is briefly discussed below.

Several indices have been developed for use in analyzing the magnitude of FA among and between samples. The pros and cons of these indices, along with recommendations for their use, have been reviewed elsewhere (Palmer and Strobeck 1986; Palmer 1994). The most appropriate choice of an FA index depends on several factors including: (1) the size of the samples under study; (2) whether or not size dependence of |R-L| is present for a trait; (3) whether or not directional asymmetry and/or antisymmetry are present; and (4) whether single traits are being assessed or multiple traits are being combined to create an overall average asymmetry of individuals.

The most appropriate index for assessing FA in this study is FA4 (Palmer 1994), which is the variance of the signed asymmetry between the right and left sides and is denoted as:

var(R-L)

As Palmer (1994) notes, the benefits to using this index (FA4) are that it: (1) is easily computed; (2) lends itself to the most powerful test for differences between two samples (F test); (3) is more efficient than FA1 (unsigned asymmetry of |R-L|) for estimating between-sides variation; and (4) is not biased by directional asymmetry. This particular index is recommended where antisymmetry is absent and where |R-L| is not dependent on overall trait size (Palmer 1994).

Traits chosen for use in studies of FA are generally classified as either nonmetric (discrete, and sometimes meristic) or metric (continuous). Nonmetric traits are often used by biologists and generally are characterized by discrete attributes – the presence or absence of a trait (sometimes referred to as qualitative). These discrete traits may also be meristic in nature, such as the number of body segments. Metric traits are those in which variation is continuous. Palmer (1994) notes that multiple traits are preferred when testing for differences in developmental stability among samples. A combination of both nonmetric and metric traits is ideal, although these types of studies have shown differences in results originating in the different kinds of traits (see Hartl et al. (1995) for an example regarding the relationship between heterozygosity and FA). Examples of nonmetric traits in the human skeleton (e.g., presence/absence of parietal foramina) are variable in their expression and symmetry; however, whether this is related to levels of developmental instability has not been clearly demonstrated. Metric traits could include any of the various linear dimensions regularly measured as part of a skeletal analysis.

Sample size is a concern in any analysis that includes a statistical evaluation of data. As Palmer (1996:528) indicates, “measures of fluctuating asymmetry are measures of variability, and tests for differences in variability between samples are notoriously less powerful than tests for differences between sample means.” The F-test is the most powerful test to use in this situation; however, Palmer (1996) points out that even when utilizing the F-test, sample sizes must be at least 20 to detect a twofold difference in variance just 50% of the time, or 40 to detect those differences 75% of the time (Palmer 1996:528). Issues such as these can become problematic when dealing with small samples, like those often encountered in archaeological skeletal series.

Measurement error can also be particularly troublesome in studies of FA for the simple reason that we are measuring variance. As Palmer (1994) points out, in studies where one is concerned with obtaining the sample mean, increases in measurement error increase variation about the mean; however, when one is concerned with measuring the variance itself, increases in measurement error actually influence the accuracy of the variance calculations; therefore, "the greater the error, the greater the impact on the estimate of the between-sides variance" (Palmer 1994:15). Measurement error is not likely to be as significant an issue with regard to nonmetric traits, but it clearly can influence metric trait measurements. For this reason, estimates of measurement error should be made and reported where possible. Palmer (1994) suggests devising tests, involving at least 30 individuals, to determine the impact of measurement error for each of the traits under study. Assessments of measurement error in the current study will be discussed in more detail in Section 5.5.

5.2 Cranial Nonmetric Methods

As described in Section 4.3, multiple cranial nonmetric traits were used to assess asymmetry in this study. Although some traits were originally scored for several degrees of expression, only the presence or absence of symmetry was considered for this analysis. Following the approach of Zachos et al. (2007), the Wilcoxon signed rank test was used to differentiate between fluctuating and directional asymmetry. The null hypothesis for this test states there are no significant differences between the left and right side for the trait under study. The alternative hypothesis states there is a significant difference to either the left or right side.

The selected index of nonmetric fluctuating asymmetry (FA_{NM}) is the proportion of traits asymmetric in each individual (cf. Leary 1985; Suchentrunk 1993; Hartl et al. 1995; Zachos et al. 2007). Only individuals who could be scored for all traits of a particular cranial region were included in the analysis. Comparison of nonmetric traits between Coalescent variants were made for each of the four cranial regions identified (i.e. facial, lateral, basilar, and mandibular). Therefore, FA_{NM} scores were calculated for each of the four regions based on the traits of those regions (see Table 4.3).

5.3 Craniometric Methods

The use of a Euclidean Distance Matrix (EDMA) representation was suggested by Lele (1991) as an alternative to other models for comparing forms and shapes based on two-dimensional or three-dimensional landmark data. Nearly all traditional morphometric methods are based on superimposition to render form or shape differences. The use of superimposition techniques for studying asymmetry was originally conceived by Smith et al. (1990) and introduced by Bookstein (1991). This introduction was later expanded when the authors presented their research in which directional and fluctuating asymmetry were assessed by means of superimposition and analysis of the resulting Procrustes distances (Smith et al. 1997). This approach was followed by Auffray et al. (1996) who compared both traditional and Procrustes approaches in an analysis of fluctuating asymmetry in subspecific hybridization of *Mus musculus*. Klingenberg and McIntyre (1998) also employed Procrustes methods to assess patterns of FA in the wings of tsetse flies (*Glossina palpalis gambiensis*). The authors highlight the applications of geometric morphometrics as a means to move beyond traditional linear measurements to a more geometric concept of form and shape wherein FA of localized regions could be assessed by examining the covariance among landmarks (Klingenberg and McIntyre 1998).

However, as discussed by Lele (1991), these traditional methods of superimposition involve the use of loss functions, which serve to minimize the loss of information given that superimposition representations are not invariant under the subsequent steps of translation, rotation, scaling and reflection. Moreover, there are many choices of loss functions that can be selected and, as Lele (1991) demonstrated, different loss functions can yield different results. Thus, Lele's (1991) concern is with the differences in conclusions arising from shape and form analyses that can be attributed to the selection of specific loss functions in superimposition methodologies. Moreover, the lack of clear selection criteria that would dictate the choice of one specific loss function over others appears to make the process subjective and scientifically untenable. Lele (1991) sought to employ a method that would avoid superimposition and, therefore, the unguided selection of loss forms. Lele (1991) identifies the Euclidean Distance Matrix representation of the form of an object as one that remains invariant under translation, rotation and reflection.

Lele and Richtsmeier (1991) further discuss Euclidean Distance Matrix Analysis (EDMA) by demonstrating how the approach could be statistically extended to compare the average shapes from two samples. Lele (1993) demonstrated the strengths of EMDA over superimposition approaches, when estimating the mean and variance-covariance parameters of a sample. An example of the application of this type would be the estimation of missing landmarks on paleontological specimens arising from incomplete specimens. Not only are the estimators shown to be consistent and approach the true population as the sample size increases but, conversely, the superimposition methods are found to be asymptotically inefficient estimators (Lele 1993:574). Lele's (1993) more formal statistical demonstration reinforces the argument for the invariant approach of EDMA over traditional superimpositions methods.

There are a few reasons why the application of EDMA to analyses of FA is desirable. First, it readily allows for the analysis of three-dimensional landmark data. There are benefits of landmark data over traditional linear measurements, such as the retention of geometric relationships of all biological landmarks, which ultimately maintains the geometric integrity of the shape and form of the specimen under study (Lele 1991). In addition, landmark data can be more easily and quickly gathered with the use of a three-dimensional digitizer versus traditional linear measurements taken with spreading or sliding calipers. Second, it avoids the scientifically unsatisfactory problem of other geometric morphometric superimposition methods arising from the lack of clear criteria for selecting loss functions, which can have an impact on the analytical results (Lele 1991). Third, it avoids the statistically unsatisfactory problem of inefficient estimation of the form and shape as well as the poor estimation of the variance-covariance structure demonstrated (Lele 1993) to exist with superimposition methods. These problems arise from differences in available fitting criteria (criterion for superimposing two sides) used when matching reference objects to target objects in traditional superimposition methods, such as Procrustean approaches (Richtsmeier et al. 2005). Importantly, the choice of one fitting criteria over another, often dictated by the available software program, can lead to differences in the estimates of the variance-covariance structure rendered (Richtsmeier et al. 2005). Ultimately, a Euclidean Distance Matrix Analysis (EDMA) does not suffer from these problems of inaccurately estimating the variance-covariance structure and are, therefore, preferred when utilizing geometric morphometric methods to assess asymmetry.

5.4 Post-cranial Metric Methods

The post-cranial dimensions measured are listed and illustrated in Section 4.4. Evaluation of these measurements for inclusion in the analysis of FA between groups included an initial assessment for the presence of size dependence of FA within the samples. When assessing metric dimensions, it is important to determine if asymmetry varies with trait size. A good assessment of this relationship is visual inspection of the bivariate scatterplots of trait asymmetry versus a measure of trait size. This evaluation was performed by plotting the absolute value of the difference between right and left sides ($|R-L|$) against the average size of the two sides, $(R+L)/2$. In addition to the bivariate plots, regression analysis of these two variables was also performed to determine the strength of any relationship between the two.

Following the assessment of size dependence of FA within the samples, the magnitude of FA within samples was calculated as the variance of the signed asymmetry between right and left sides as denoted below:

$$\mathrm{var}(R-L)$$

As Palmer (1994:8) discusses, this FA index is commonly used because it is easily computed but, also, because it lends easily to the F-test, the most statistically powerful test for evaluating differences between two samples. Importantly, this index is also not biased by directional asymmetry, which is known to be present in the limb bones of modern humans (Auerbach and Ruff 2006). One potential downside to this particular index is that it can be sensitive to size dependence of the absolute FA (Palmer 1994) which underscores the importance of performing the size dependence assessments described above.

5.5 Measurement Error

5.5.1 Nonmetric Traits

Clearly, presence/absence data appear to lend themselves very easily to FA studies with little concern for measurement error. Because the nonmetric data analyzed in this study were collected by other observers, the actual measurement error is unknown. But, in the case of nonmetric traits, measurement error may not always present the same level of threat as it does in metric, or continuous, traits where measurement error is ubiquitous. Palmer (1994) discusses error in meristic traits, a term which is synonymous with non-continuous or, what physical anthropologists typically refer to as, nonmetric traits. For biologists, the counting of meristic traits can pose some problems if the traits being observed (e.g. bristles, scales) decrease in size to the point of requiring a subjective determination of their presence or absence, or whether they fall within some arbitrarily defined region on the organism under study (see Palmer 1994:16). For physical anthropologists assessing human skeletal remains, these measurement issues are not too worrisome for many traits. The presence or absence of many nonmetric skeletal traits (e.g. supraorbital foramen, parietal foramen, lambdoidal ossicle, mylohyoid bridge) is generally clear. That is not to say that physical anthropologists do not occasionally encounter subjective determinations of the presence or absence of some nonmetric traits. For example, when counting the number of mastoid foramina or the number of zygomaticofacial foramina, it may be difficult to determine if a small perforation in the bone surface actually counts as an additional foramen. Thus, for physical anthropologists, I suggest that when: (1) a measurement error test cannot be conducted and (2) the scoring of the presence or absence of particular skeletal nonmetric traits appears to involve subjective determinations, that trait be excluded from any FA analysis. Fortunately, many (especially cranial) nonmetric traits have been identified and scored by physical anthropologists, several of which can be expected to have low measurement errors. Additionally, in this study, errors arising from the types of subjective determinations described above have hopefully been minimized by rendering all traits as either present or absent.

5.5.2 Craniometrics

A common approach to dealing with measurement error when collecting three-dimensional cranial landmark data is to take replicate measurements and average the results (e.g. DeLeon 2007). That approach was not possible in the current study for two reasons. First, a portion of the data used was provided by the Smithsonian Repatriation Osteology Laboratory and not collected firsthand. The Smithsonian data did not include replicate measurement data for individuals. Second, time constraints when collecting firsthand data at the University of Tennessee did not allow for replicate measurements for each individual.

Despite the lack of replicate measurements for the three-dimensional cranial landmark data, some measures were taken to reduce the impact of measurement error. First, where cranial landmark coordinate data were collected firsthand, the G2X digitizer (Immersion Corporation, San Jose, CA) used to collect the data was calibrated daily prior to each data acquisition session. This calibration was performed by measuring the distance between two locations on a calibrated steel rule. The point coordinates from the two locations were entered into a spreadsheet formula that converted the landmark data to linear distance. If the calculated linear distances matched the distances between the two measured points on the calibrated rule, the digitizer was considered to be functioning properly. This calibration was performed at multiple distances on the rule, ranging from 5 mm to 150 mm, to ensure accuracy across a range of distances.

Second, cranial landmarks chosen for inclusion in this study were selected based on their measuring precision. Several studies investigate the measuring precision of three-dimensional cranial landmark data (Bookstein 1991; Corner et al. 1992; Slice et al. 2004; Slice 2005; Ross and Williams 2008; Sholts et al. 2011). Bookstein (1991) identified and others (Ross and Williams 2008; Sholts et al. 2011) have utilized three different types of landmark traditionally used in cranial morphometric analyses. Type I landmarks are defined geometrically as a point defined by a pattern of juxtaposition of tissue types or as a minute region of unusual histology (Bookstein 1991). An example of a Type I landmark would be the intersection of cranial sutures (e.g. bregma, lambda, nasion, asterion). Type II landmarks are defined geometrically, and not histologically (Bookstein 1991). An example of a Type II landmark would the midline point on the anterior or posterior margin of a feature (e.g. opisthion, prosthion). Finally, Type III landmarks are those regions that have at least one deficient coordinate (Bookstein 1991). Their location is typically defined as the location where a measurement minimum or maximum is reached (e.g. cranial breadth). Thus, Type III landmarks are not points, but rather instrumentally determined, localized regions (e.g. euryon, opisthocranion). Because Type III landmarks are not specific points, the repeatability of their measurement location is often prone to error (Ross and Williams 2008).

The landmarks selected for inclusion in this study were either Type I or Type II, which provide high repeatability and precision. Table 5-1 provides the name and type of landmarks utilized in this study.

Table 5-1. Landmark types utilized in this study.

Landmark	Midline or Paired	Type
nasion	midline	Type I
bregma	midline	Type I
lambda	midline	Type I
opisthion	midline	Type II
prosthion	midline	Type II
zygomaxillare	paired	Type II
frontomalare anterior	paired	Type II
sphenion	paired	Type I
asterion	paired	Type I

5.5.3 Post-cranial Metrics

As with the three-dimensional cranial landmark data, the ideal approach to dealing with measurement error in post-cranial metric measurements would be to take each measurement in replicate and average the results. Not only does this practice afford the researcher a small safeguard against recording a grossly erroneous data point, or “blunder” as described by Lyman and Van Pool (2009), it also allows the two points to be averaged and, therefore, removes some portion of the random variation (see Lyman and VanPool 2009) inherent in these types of measurements. However, as with the craniometric data, that approach was not possible given time constraints when collecting data at the Smithsonian Institution’s Repatriation Osteology Lab. Palmer (1994) concedes that replicate measurements may not always be feasible and suggests that in those cases a test for the impact of measurement error should be conducted for each trait on a subsample of individuals (1994:17). Because time was not available to conduct this test directly on the Smithsonian collections, a similar test was devised and carried out on skeletal elements from the Campbell Site (23PM5) collection housed at the University of Missouri’s Anthropology Museum Support Center.

The Campbell Site is located in southeastern Missouri and dates to the Late Mississippian Period Nodena Phase. Preservation of skeletal elements is variable according to burial but, overall, the general state of preservation is similar to that of the various Arikara burials utilized in this study. The use of a collection of similar age and preservation removes any potential biases that could potentially be present if, for example, a modern reference collection was used to perform a measurement error study for a research sample that was archaeological in nature. In both instances (Arikara sites skeletal remains and Campbell Site skeletal remains), measurements were only collected from skeletal elements where preservation was good enough to preserve the landmarks required to accurately record a specific measurement. Nevertheless, as is common in archaeological collections, a certain amount of judgment was required when deciding which traits could be accurately measured. As only one example, consider the measurement of human tibial length. This measurement is defined as the distance from the superior articular surfaces of the lateral condyle of the tibia to the tip of the medial malleolus (Moore-Jansen et al. 1994) and is typically recorded by means of an osteometric board with a hole cut into the endplate, which effectively removes the length and any measurement interference of the intercondylar eminence. The description of this measurement appears straightforward; however, in practice the analyst may have to make a judgment call on whether or not a small degree of cortical erosion on the outer medial condylar surface affects the measurement. Thus, one argument for using one archaeological assemblage to estimate measurement error for a study conducted on a separate archaeological assemblage is that the analyst is forced to make similar decisions based on various taphonomic effects or the degree of overall preservation.

The measurement error analysis utilized the skeletal remains of 33 individuals to collect data points on the measurements included in the post-cranial portion of this study. However, in no single case was any one individual set of skeletal remains preserved well enough to allow collection of the entire suite of 38 (measurements from 19 bilaterally paired traits) post-cranial measurements. Thus, the goal was to collect samples of 30 separate data points for each independent skeletal dimension measured. To facilitate attaining those sample sizes, the left and right side measurements of a single trait from a single individual were both added to the overall total for a given measurement. Therefore, the focus of the measurement error analysis was at the level of individual traits (i.e. maximum length of the humerus) and not specific to the point of left and right antimeres for each of those traits (i.e. maximum length of the right humerus, maximum length of the left humerus).

To avoid any bias, repeated measurements taken over the course of the measurement error study were collected blind, without reference to any prior measurement data collected.

Moreover, the two independent measurement sessions comprising the measurement error study were conducted two weeks apart to simulate time lapses between data collection sessions of the actual study. The significance of measurement error for each trait was assessed using the paired sample t-test for means. The paired sample t-test is often used in repeated-measures analyses to determine if one set of measures varies significantly from another. In this case, the null hypothesis states the true mean difference between the two sets of measurements is zero, whereas the alternative hypothesis states the true mean difference between the two is not zero. The p-value of 0.05 was established for a two-tailed test; below this threshold, the null hypothesis was rejected and the measurement was excluded from further analysis.

CHAPTER 6: RESULTS

6.1 Cranial Nonmetric Results

No cases of directional asymmetry were found to be present in any of the nonmetric traits examined in the Crow Creek sample. The percentages of asymmetry within each trait are provided in Table 6-1 along with the p-values of the corresponding Wilcoxon signed-rank test used to assess for directional asymmetry. Trait names and scoring methods corresponding to the Repatriation Osteology Laboratory (ROL) codes are provided in Appendix 8.3. For both epipteric bone (EPIPTER) and coronal ossicle (CORONL), the number of individuals displaying asymmetry for those traits was not sufficiently large to provide a meaningful assessment of directional asymmetry.

Table 6-1. Asymmetry of nonmetric traits measured in the Crow Creek (39BF11) sample.

ROL Code	*n*	*Symmetrical*	*Asymmetrical*	*P (Wilcoxon)*
SOFORAM	98	68 (69.4%)	30 (30.6%)	1.000
CORONL	89	88 (98.9%)	1 (1.1%)	-
EPIPTER	50	46 (92.0%)	4 (8.0%)	-
PFORAM	78	49 (62.8%)	29 (37.2%)	0.871
LAMBOSS	58	46 (79.3%)	12 (20.7%)	1.000
ASTRINB	58	48 (82.8%)	10 (17.2%)	0.575
OMSUTS	45	32 (71.1%)	13 (28.9%)	0.087
PARNOTB	68	59 (86.8%)	9 (13.2%)	0.767
MYLHBRD	42	30 (71.4%)	12 (28.6%)	0.610

n = sample size, *P (Wilcoxon)* = P-values of the Wilcoxon test for DA (Bonferroni-corrected significance level: 0.005)

Table 6-2 provides additional detail on the asymmetrical individuals for each nonmetric trait within the Crow Creek sample by providing percentages of presence of the traits' occurrence on the left and right sides.

Table 6-2. Sidedness of nonmetric asymmetries in the Crow Creek (39BF11) sample.

ROL Code	*n*	*Left Presence*	*Right Presence*	*P (Wilcoxon)*
SOFORAM	30	15 (50.0%)	15 (50.0%)	1.000
CORONL	1	1 (100.0%)	0 (0.0%)	-
EPIPTER	4	2 (50.0%)	2 (50.0%)	-
PFORAM	29	15 (51.7%)	14 (48.3%)	0.871
LAMBOSS	12	6 (50.0%)	6 (50.0%)	1.000
ASTRINB	10	6 (60.0%)	4 (40.0%)	0.575
OMSUTS	13	10 (76.9%)	3 (23.1%)	0.087
PARNOTB	9	5 (55.6%)	4 (44.4%)	0.767
MYLHBRD	12	7 (58.3%)	5 (41.7%)	0.610

n = sample size of individuals displaying bilateral trait asymmetry, P (Wilcoxon) = P-values of the Wilcoxon test for DA (Bonferroni-corrected significance level: 0.002)

All individuals from the ROL sample were combined as a single sample to assess for directional asymmetry. While a few instances of statistically significant directional asymmetry would be identified at the α = 0.05 level, a Bonferroni correction was applied to limit the overall experimentwise error rate. The Bonferroni method is used to lower the probability of committing a Type I error when the same dataset is used to test multiple hypotheses. Using the Bonferroni corrected level of significance, no cases of directional asymmetry were found in any of the nonmetric traits examined in the ROL sample.

The percentages of asymmetry within each trait are provided in Table 6-3 along with the p-values of the corresponding Wilcoxon signed-rank test used to assess for directional asymmetry. Trait names and scoring methods corresponding to the Repatriation Osteology Laboratory (ROL) codes are provided in Appendix 8.3.

Table 6-3. Asymmetry of nonmetric traits measured in the Repatriation Osteology Lab sample.

ROL Code	*n*	*Symmetrical*	*Asymmetrical*	*P (Wilcoxon)*
SONOTCH	415	288 (69.4%)	127 (30.6%)	0.939
SOFORAM	409	302 (73.8%)	107 (26.2%)	0.036
STNOTCH	400	348 (87.0%)	52 (13.0%)	0.334
IOSUT	326	275 (84.4%)	51 (15.6%)	0.113
IOFRAM	355	318 (89.6%)	37 (10.4%)	0.474
PFORAM	385	277 (71.9%)	108 (28.1%)	0.030
EPIPTER	272	239 (87.9%)	33 (12.1%)	0.448
CORONL	303	267 (88.1%)	36 (11.9%)	0.020
LAMBOSS	335	280 (83.6%)	55 (16.4%)	0.907
ASTRINB	309	277 (89.6%)	32 (10.4%)	0.537
OMSUTS	275	230 (83.6%)	45 (16.4%)	0.516
PARNOTB	321	293 (91.3%)	28 (8.7%)	1.000
CONDCAN	342	296 (86.5%)	46 (13.5%)	1.000
DIHYPOC	330	234 (70.9%)	96 (29.1%)	0.051
FRSPINI	306	246 (80.4%)	60 (19.6%)	0.822
FOROVLI	315	301 (95.6%)	14 (4.4%)	0.346
PTSPBR	309	269 (87.1%)	40 (12.9%)	0.408
PTABRG	310	249 (80.3%)	61 (19.7%)	0.738
AUDEXOS	408	396 (97.1%)	12 (2.9%)	0.041
MASTFRL	304	241 (79.3%)	63 (20.7%)	0.021
MASTFRN	305	241 (79.0%)	64 (21.0%)	0.017
ZYFFOR	335	294 (87.8%)	41 (12.2%)	0.683
MENTFOR	375	372 (99.2%)	3 (0.8%)	1.000
MYLHBRL	313	278 (88.8%)	35 (11.2%)	0.658
MYLHBRD	314	278 (88.5%)	36 (11.5%)	0.561

n = sample size, *P (Wilcoxon)* = P-values of the Wilcoxon test for DA (Bonferroni-corrected significance level: 0.002)

Table 6-4 provides additional detail on the asymmetrical individuals for each nonmetric trait within the ROL sample by providing percentages of presence of the traits' occurrence on the left and right sides.

Table 6-4. Sidedness of nonmetric asymmetries in the Repatriation Osteology Lab sample.

ROL Code	*n*	*Left Presence*	*Right Presence*	*P (Wilcoxon)*
SONOTCH	127	64 (50.4%)	63 (49.6%)	0.939
SOFORAM	107	41 (38.3%)	66 (61.7%)	0.036
STNOTCH	52	22 (42.3%)	30 (57.7%)	0.334
IOSUT	51	32 (62.7%)	19 (37.3%)	0.113
IOFRAM	37	21 (56.8%)	16 (43.2%)	0.474
PFORAM	108	41 (38.0%)	67 (62.0%)	0.030
EPIPTER	33	19 (57.6%)	14 (42.2%)	0.448
CORONL	36	10 (27.8%)	26 (72.2%)	0.020
LAMBOSS	55	27 (49.1%)	28 (50.9%)	0.907
ASTRINB	32	14 (43.8%)	18 (56.3%)	0.537
OMSUTS	45	20 (44.4%)	25 (55.6%)	0.516
PARNOTB	28	14 (50.0%)	14 (50.0%)	1.000
CONDCAN	46	23 (50.0%)	23 (50.0%)	1.000
DIHYPOC	96	59 (61.5%)	37 (38.5%)	0.051
FRSPINI	60	29 (48.3%)	31 (51.7%)	0.822
FOROVLI	14	5 (35.7%)	9 (64.3%)	0.346
PTSPBR	40	17 (42.5%)	23 (57.5%)	0.408
PTABRG	61	32 (52.5%)	29 (47.5%)	0.738
AUDEXOS	12	10 (83.3%)	2 (16.7%)	0.041
MASTFRL	63	21 (33.3%)	42 (66.7%)	0.021
MASTFRN	64	21 (32.8%)	43 (67.2%)	0.017
ZYFFOR	41	22 (53.7%)	19 (46.3%)	0.683
MENTFOR	3	2 (66.7%)	1 (33.3%)	1.000
MYLHBRL	35	16 (45.7%)	19 (54.3%)	0.658
MYLHBRD	36	16 (44.4%)	20 (55.6%)	0.561

n = sample size of individuals displaying bilateral trait asymmetry, P (Wilcoxon) = P-values of the Wilcoxon test for DA (Bonferroni-corrected significance level: 0.002)

A comparison of the FA_{NM} scores for the facial, lateral, basilar and mandibular regions of the skull are provided in Table 6-5. This table includes only information from the ROL database; therefore, there are no scores for the Initial Coalescent variant. Without the Initial Coalescent variant, the hypothesized relative ranking from greatest magnitude of FA (highest FA_{NM} score) to least magnitude of FA (lowest FA_{NM} score) would be Disorganized Coalescent, Extended Coalescent and Post-Contact Coalescent.

For the facial region, the Disorganized Coalescent does provide the highest magnitude of FA and the Extended Coalescent and the Post-Contact Coalescent produced nearly identical scores. The lateral region follows the predicted order with the Disorganized Coalescent displaying the highest magnitude, the Post-Contact Coalescent displaying the lowest FA magnitude and the Extended Coalescent being intermediate to the other two. For the basilar region, the ordering of the Extended Coalescent and the Disorganized Coalescent is reversed from what is expected; however, the Post-Contact Coalescent maintains the lowest score. Scores for the mandibular region appear to be the farthest from what would be expected. Although the Disorganized Coalescent does display the highest FA_{NM} score, the Post-Contact Coalescent score is intermediate and the Extended Coalescent score is considerably lower.

Table 6-5. Comparison of ROL FA_{NM} scores between Coalescent variants for major cranial regions.

	Facial*	Lateral†	Basilar‡	Mandibular§
Disorganized Coalescent	0.295	0.305	0.246	0.242
	(11)	*(16)*	*(19)*	*(22)*
Initial Coalescent	--	--	--	--
	--	--	--	--
Extended Coalescent	0.230	0.245	0.271	0.086
	(49)	*(51)*	*(43)*	*(62)*
Post-Contact Coalescent	0.228	0.223	0.236	0.157
	(154)	*(174)*	*(137)*	*(211)*

Note: Numbers in parentheses indicate the sample size of the calculated FA_{NM} scores above them.
* Facial traits include: supraorbital notch, supraorbital foramen, supratrochlear notch, infraorbital suture, infraorbital foramen, epipteric bone, coronal ossicle, zygomaticofacial foramen.
† Lateral traits include: parietal foramen, lambdoidal ossicle, asterionic bone, occipitomastoid suture ossicle, parietal notch, auditory exostoses, mastoid foramina, mastoid foramina number.
‡ Basilar trait include: condylar canal, divided hypoglossal canal, foramen ovale incomplete, pterygospinous bridge, pterygoalar bridge, palatine torus development.
§ Mandibular trait include: mental foramen, mylohyoid bridge, mylohyoid bridge development.

Table 6-6 provides similar information from both the Crow Creek and ROL databases and, therefore, is constructed from only those traits shared by both datasets (see Section 4.3). The table offers similar comparison of scores between these cranial regions with the exception of the basilar region for which no traits were common between the two datasets. With the inclusion of the Initial Coalescent (i.e. Crow Creek) data, the hypothesized relative ranking from greatest magnitude of FA (highest FA_{NM} score) to least magnitude of FA (lowest FA_{NM} score) is: Disorganized Coalescent, Initial Coalescent, Extended Coalescent and Post-Contact Coalescent.

This ranking is not demonstrated for the facial region because the Post-Contact Coalescent actually produces the highest FA_{NM} score and is close to that of the Disorganized Coalescent. The Initial Coalescent and the Extend Coalescent provide very similar scores for the facial region. In the case of the lateral region, the Initial Coalescent and the Disorganized Coalescent display the highest FA_{NM} scores as predicated, but their ordering is reversed. The Extended Coalescent and Post-Contact Coalescent variants actually produced the same FA_{NM} scores. As with Table 6-5, the scores for the mandibular region again appear to be the farthest from what is hypothesized. Beyond the reversal of the Disorganized Coalescent and the Initial Coalescent, there is also reversal between the Post-Contact Coalescent and the Extended Coalescent (which produced the lowest FA_{NM} score).

Table 6-6. Comparison of ROL and Crow Creek FA_{NM} scores between Coalescent variants for major cranial regions.

	Facial*	Lateral†	Basilar‡	Mandibular§
Disorganized Coalescent	0.202	0.250	--	0.273
	(19)	*(16)*	--	*(22)*
Initial Coalescent	0.152	0.279	--	0.286
	(46)	*(33)*	--	*(42)*
Extended Coalescent	0.150	0.165	--	0.129
	(49)	*(51)*	--	*(62)*
Post-Contact Coalescent	0.214	0.165	--	0.229
	(154)	*(174)*	--	*(211)*

Note: Numbers in parentheses indicate the sample size of the calculated FANM scores above them.
* Facial traits include: coronal ossicle, epipteric bone, and supraorbital foramen complete.
† Lateral traits include: lambdoidal ossicle, parietal foramen, parietal notch, asterion ossicle, and mastoid suture ossicle.
‡ No basilar traits were shared between datasets.
§ Mandibular trait includes the mylohyoid bridge.

Assuming the hypothesized ordering of Coalescent variants is correct, the data do not appear to strongly support the notion that FA of nonmetric traits can be used as a reliable indicator of developmental instability. It is possible that some traits and trait regions are better suited for use in FA analyses. For example, the lateral region appears to most closely follow the hypothesized rank order of Coalescent variants (i.e., greatest to least magnitude of FA as follows: DC, IC, EC, PCC), whereas the facial and mandibular traits do not match the ordering very well. It is interesting to note that in the ROL comparison (Table 6-5) the Disorganized Coalescent does display the highest magnitude of FA for all regions with the exception of the basilar region where it is second to the Extended Coalescent. In the ROL and Crow Creek dataset comparisons (Table 6-6), the highest magnitude of FA for both the lateral and mandibular traits is with the Initial

Coalescent, followed by the Disorganized Coalescent. This could suggest that the Initial Coalescent was very similar to the Disorganized Coalescent in terms of the social and environmental stresses felt by those populations.

6.2 Craniometric Analysis Results

Prior work by Jantz and Owsley (1984) investigated the health and nutritional status of the Arikara. In their analysis, climate conditions and increasing European contact were used to establish hypotheses for the relative levels of health and nutritional status across the Coalescent variants. Jantz and Owsley (1984) hypothesized the Extended Coalescent Arikara suffered from greater health and environmental stress owing to abbreviated growing seasons resulting from the cooler climatic conditions of the Neoboreal episode. In contrast, they felt the Post-Contact Coalescent should have been a time of improved health and nutritional status given amelioration of the Neoboreal and introduction of the horse, which allowed larger bison hunting ranges. Finally, the worst period of Arikara health and nutritional status would have occurred during the Disorganized Coalescent, a time period dominated by deadly disease outbreaks, population decline and social upheaval. On the basis of the findings of Jantz and Owsley (1984), the Disorganized Coalescent sample and the Post-Contact Coalescent sample are expected to have the greatest and least magnitude of FA, respectively, with the Extended Coalescent being intermediate between them.

The fluctuating asymmetry values were calculated using the EDMAware (Cole 2011) program where FA is estimated as the mean absolute asymmetry for each cranial distance after having been corrected for directional asymmetry, as illustrated in the following equation:

$$\text{Mean}|(L\text{-}R)\text{-}DA|$$

Statistical significance of each measure of FA was determined via confidence intervals established by means of the nonparametric bootstrap method where $\alpha = 0.10$ and the number of resamples was set to 1000.

The figures that follow provide graphic representation of group FA means for each of the bilateral landmarks examined in this analysis. In the craniometric analysis, data could not be collected on a sufficient number of Initial Coalescent individuals to allow adequate comparison to other Coalescent variants. Therefore, comparisons are only drawn between the Extended, Post-Contact and Disorganized variants.

Comparisons displayed in Figures 6-1 through 6-5 provide a total of twenty-six different bilateral comparisons between the Coalescent variant samples. Examination of the figures shows variability of the ordering of the magnitude of FA for each craniometric distance.

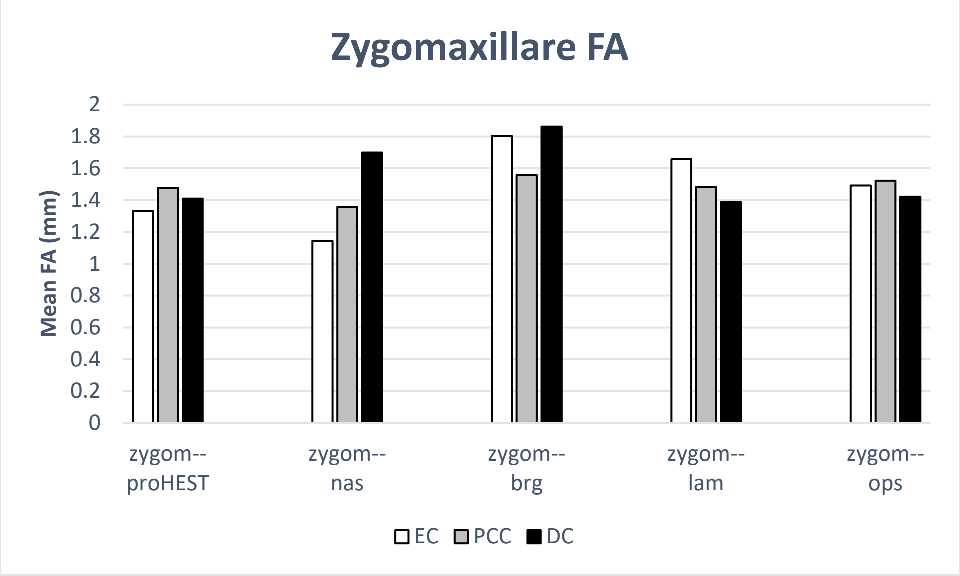

Figure 6-1. FA of zygomaxillare distances by Coalescent variants.

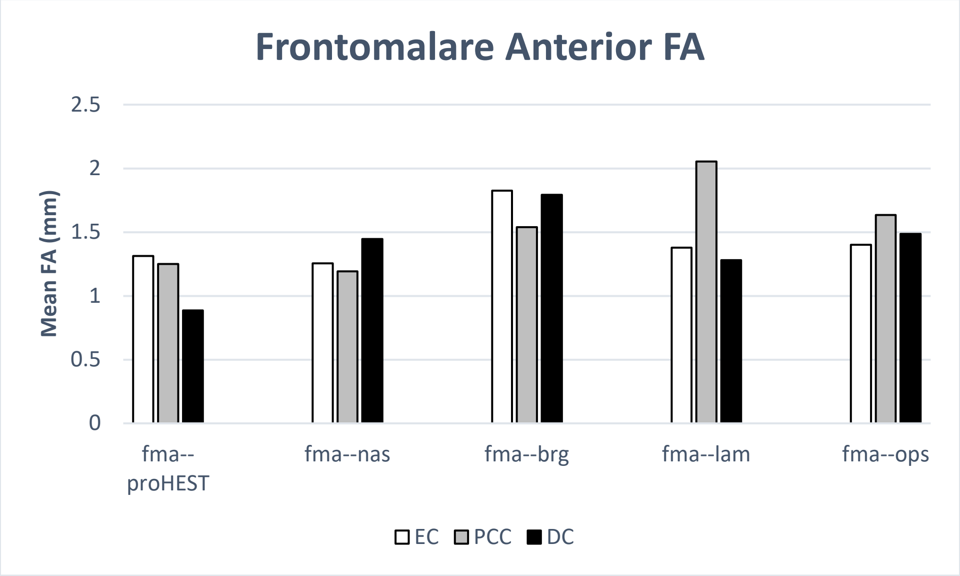

Figure 6-2. FA of frontomalare anterior distances by Coalescent variants.

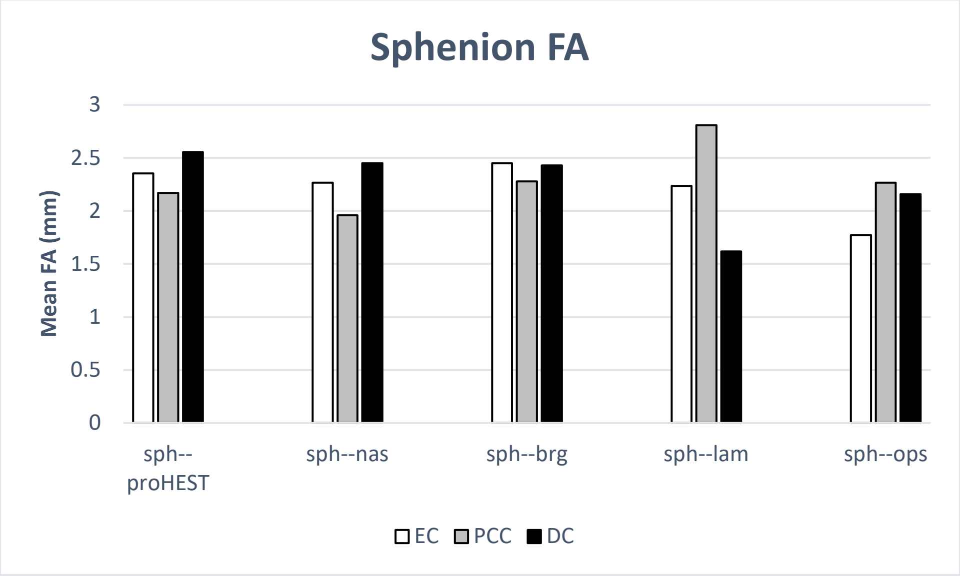

Figure 6-3. FA of sphenion distances by Coalescent variants.

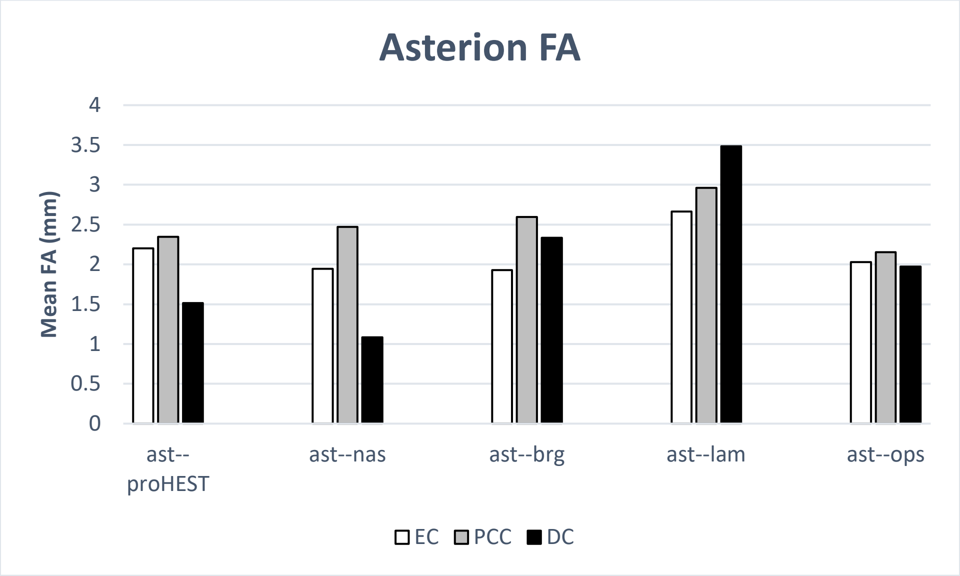

Figure 6-4. FA of asterion distances by Coalescent variants.

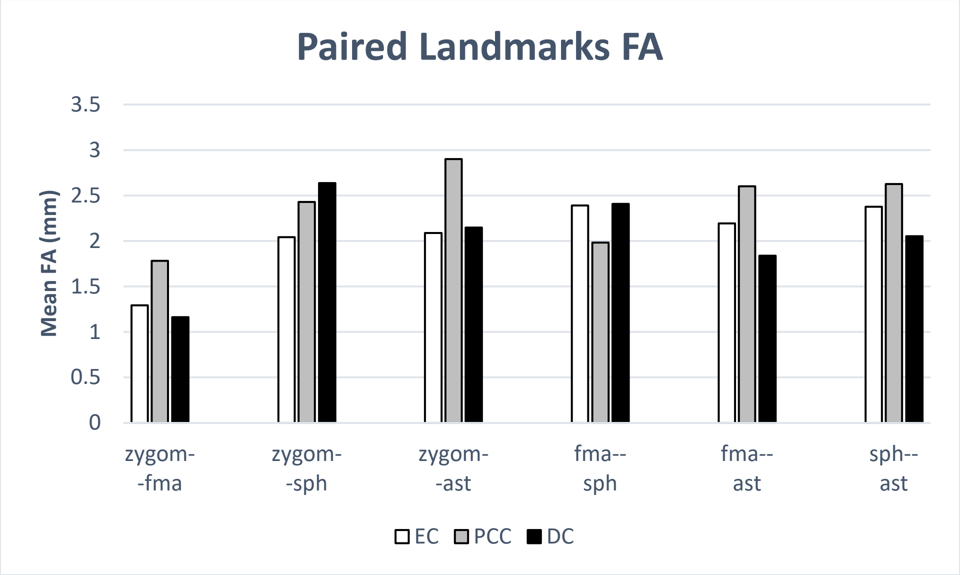

Figure 6-5. FA of different paired landmark distances by Coalescent variants.

Despite the variability present in the magnitude of FA for these bilateral measurements, a majority of the comparisons displays a greater magnitude of FA within the Post-Contact Coalescent than the other variants. Table 6-7 presents information on which Coalescent variant demonstrated the highest magnitude of FA for each bilateral assessment. The Post-Contact Coalescent accounted for 56% of the highest FA measurements, the Disorganized Coalescent and Extended Coalescent were second and third with 28% and 16%, respectively.

Table 6-7. Distribution of highest FA magnitude by Coalescent variants.

	Extended Coalescent	Post-Contact Coalescent	Disorganized Coalescent
zygom--proHEST		X	
zygom--nas			X
zygom--brg			X
zygom--lam	X		
zygom--ops		X	
fma--proHEST	X		
fma--nas			X
fma--brg	X		
fma--lam		X	
fma--ops		X	
sph--proHEST			X
sph--nas			X
sph--brg	X		
sph--lam		X	
sph--ops		X	
ast--proHEST		X	
ast--nas		X	
ast--brg		X	
ast--lam			X
ast--ops		X	
zygom--fma		X	
zygom--sph			X
zygom--ast		X	
fma--sph			X
fma--ast		X	
sph--ast		X	
Percentage	16%	56%	28%

Based on these findings, the assessment was refined to the site-specific level to determine which site or sites were most influencing the outcome. Only four sites, or site cemeteries, had sample sizes that were large enough to approximate a normal probability distribution of measurements. These included samples from Mobridge (39WW1) for both the Extended Coalescent (n = 31) and Post-Contact Coalescent (n = 39), the Post-Contact Coalescent sample (n = 65) from Larson (39WW2), and the

Disorganized Coalescent sample (n = 27) from Leavenworth (39CO9). Twenty-six bilateral comparisons between individuals from these four Coalescent sites resulted (Figures 6-6 through 6-10).

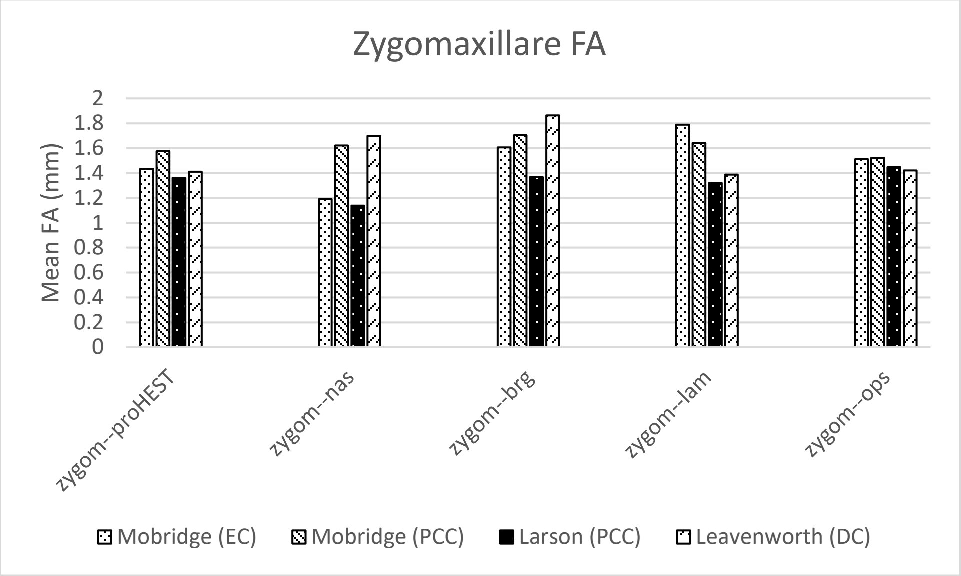

Figure 6-6. FA of zygomaxillare distances by site.

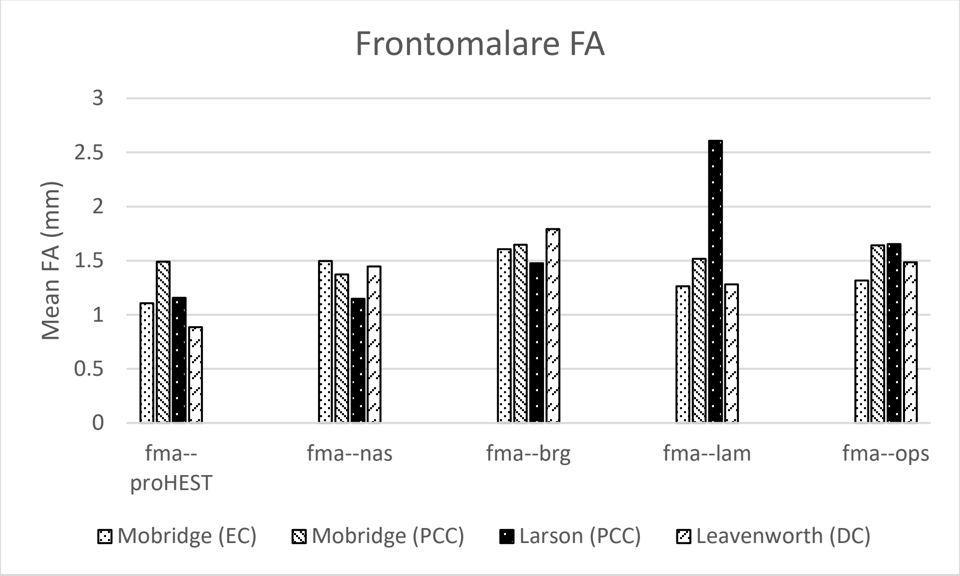

Figure 6-7. FA of frontomalare distances by site.

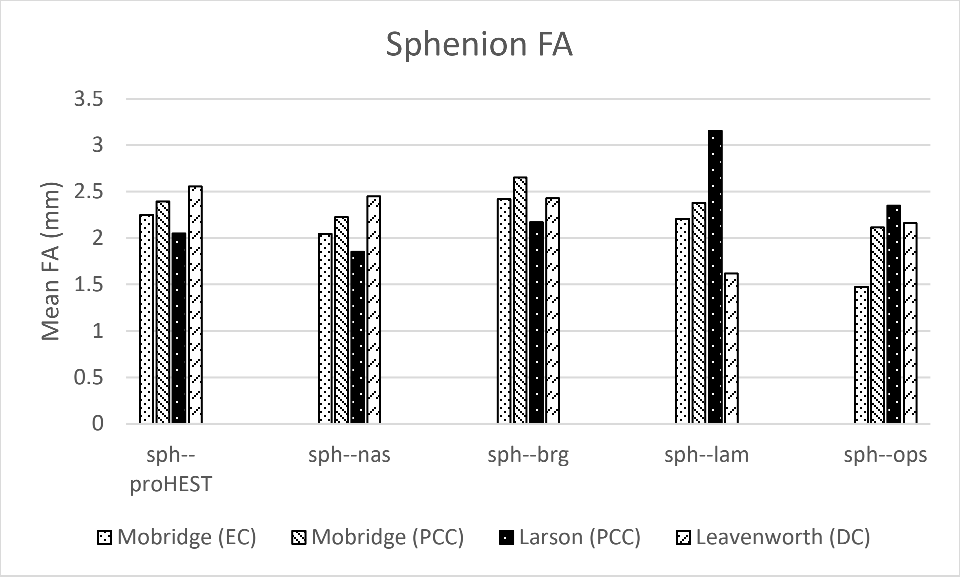

Figure 6-8. FA of sphenion distances by site.

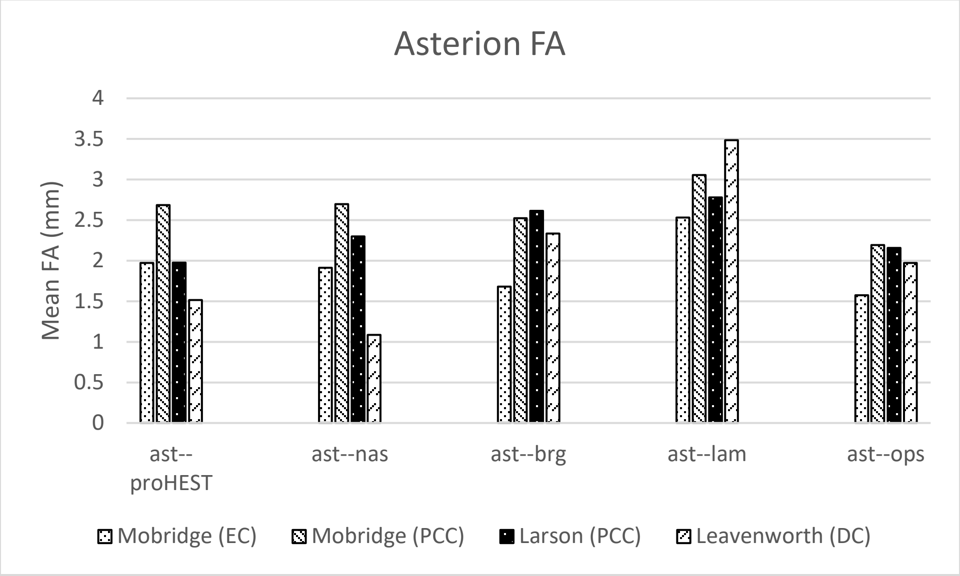

Figure 6-9. FA of asterion distances by site.

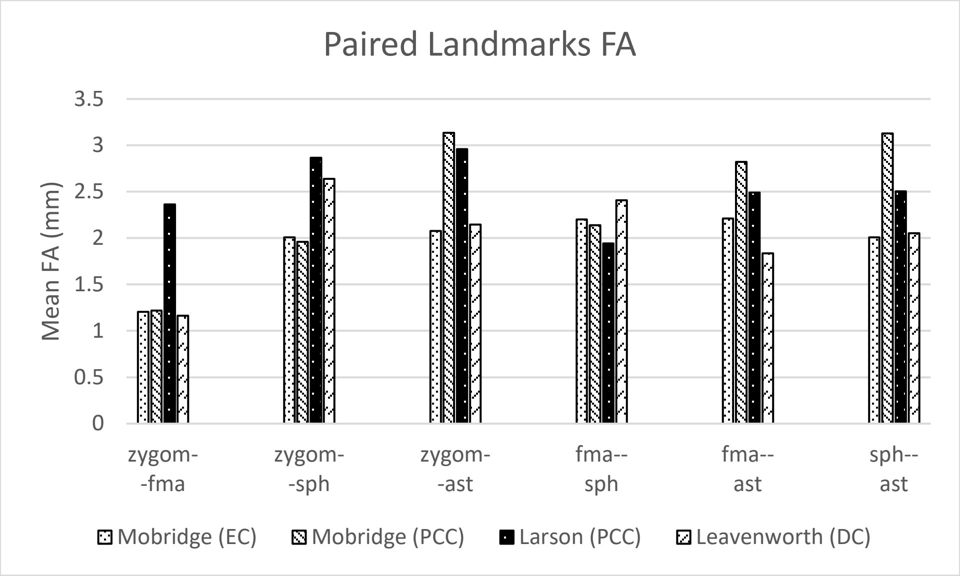

Figure 6-10. FA of different paired landmark distances by site.

Results of this site-specific comparison indicate most of the comparisons, which illustrate higher FA within the Post-Contact Coalescent variant, are derived from the Mobridge (39WW1) Post-Contact Coalescent sample. The Mobridge Post-Contact Coalescent sample accounted for 38.5% of the highest FA measurements, whereas the Larson (39WW2) Post-Contact Coalescent and the Leavenworth (39CO9) Disorganized Coalescent samples both account 26.9% of the highest FA measurements (Table 6-8). While simply removing the Mobridge Post-Contact Coalescent sample from the comparison does not create the pattern expected if the predicted arrangement of Coalescent variants is indeed accurate, it does suggest the possibility that the appropriate scale for comparison may not be at the level of the archaeological variant and, instead, for this population, may need to be at the level of the individual sites. The latter in turn suggests, as might be expected, different villages were subjected to different levels of stress and developmental instability.

Table 6-8. Distribution of highest FA magnitude by archaeological sites.

	Mobridge (EC)	Mobridge (PCC)	Larson (PCC)	Leavenworth (DC)
zygom--proHEST		X		
zygom--nas				X
zygom--brg				X
zygom--lam	X			
zygom--ops		X		
fma--proHEST		X		
fma--nas	X			
fma--brg				X
fma--lam			X	
fma--ops			X	
sph--proHEST				X
sph--nas				X
sph--brg		X		
sph--lam			X	
sph--ops			X	
ast--proHEST		X		
ast--nas		X		
ast--brg			X	
ast--lam				X
ast--ops		X		
zygom--fma			X	
zygom--sph			X	
zygom--ast		X		
fma--sph				X
fma--ast		X		
sph--ast		X		
Percentage	7.69%	38.46%	26.92%	26.92%

6.3 Post-cranial Metric Analysis Results

The significance of measurement error for each trait was assessed using paired sample t-tests for means (Appendix 8.9). Three dimensions had t-statistics that exceeded their respective critical values for the two-tailed test. These include the sagittal midshaft diameter of the radius, the maximum (morphological) length of the femur, and the tibial length. Because the null hypothesis that the mean difference between the two measurement sessions was zero was rejected, these dimensions were ultimately excluded from consideration in the final analysis of post-cranial metric FA.

Following evaluation for the significance of measurement error on post –cranial metric dimensions, an assessment was conducted to determine if asymmetry varies with trait size. This assessment took two forms. First, regression analyses of the difference between right and left sides (|R-L|) and the average size of the two sides, (R+L)/2, were performed to examine the relationship between the two.

Regression analyses performed separately for adults and subadults provided interesting results. Although the r-squared values for adults showed no size dependence of FA for these dimensions, the same was not true for many of these dimensions in the subadults (Table 6.9). In every instance where identical measurements were made between adults and subadults, the relationship between FA and size was more pronounced and stronger for subadults. Moreover, the maximum length dimension for each bone appeared to have the strongest size dependence of FA.

Table 6-9. Comparison of size dependence r-squared values for adults and subadults.

Element	Measurement	r^2 (Adults)	r^2 (Subadults)
Humerus	Maximum Length	0.009	0.491
	Maximum Midshaft Diameter	0.064	0.397
	Minimum Midshaft Diameter	0.252	0.368
	Epiphyseal Breadth	0.087	
	Head Maximum Vertical Diameter	0.072	
	Distal Width		0.170
Radius	Maximum Length	0.008	0.742
	Sagittal Midshaft Diameter	0.002	0.191
	Transverse Midshaft Diameter	0.055	0.198
	Radiocarpal Surface M-L (RCML)	0.0001	
Femur	Maximum (Morphological) Length	0.002	0.736
	Bicondylar (Physiological) Length	0.005	
	Midshaft Anterior-posterior Diameter	0.005	0.075
	Midshaft Transverse Diameter	0.00002	0.289
	Epicondylar Breadth	0.03	
	Femoral Condyles M-L (FCML)	0.024	
	Distal Width		0.353
Tibia	Tibial Length	0.009	
	Proximal Epiphyseal Breadth	0.004	
	Distal Epiphyseal Breadth	0.089	
	Tibiotalar Surface (TTAP)	0.005	
	Maximum Length		0.0002
	Proximal Width		0.0002
	Distal Width		0.72

Because there appears to be a dependence of FA on trait size in subadults, they were not included the final analysis to determine the nature of any relationship between FA and developmental instability.

In addition to the r-squared values in Table 6.9, bivariate plots of these two variables were also constructed for adults (Appendix 8.10) to allow visual assessment of the relationships between trait size and FA.

After taking into account the impacts of measurement error and size dependence, the magnitude of FA within samples was calculated as the variance of the signed asymmetry between right and left sides. Comparisons between Coalescent variants for each post-cranial dimension are provide in Table 6-10 for humeral dimensions, Table 6-11 for radial dimensions, Table 6-12 for femoral dimensions, and Table 6-13 for tibial dimensions.

Table 6-10. FA comparison between Coalescent variants for humeral dimensions.

	Extended Coalescent	Post-Contact Coalescent	Disorganized Coalescent
Maximum Length	14.9 (30)	15.8 (18)	28.8 (9)
Maximum Midshaft Diameter	0.74 (38)	0.49 (27)	0.50 (11)
Minimum Midshaft Diameter	1.33 (38)	1.13 (27)	0.6 (11)
Epicondylar Breadth	0.82 (20)	1.6 (17)	3.1 (7)
Head Maximum Vertical Diameter	0.95 (30)	0.97 (20)	1.2 (10)

Note: Numbers in parentheses indicate the sample size of the calculated FA magnitude above them.

Table 6-11. FA comparison between Coalescent variants for radial dimensions.

	Extended Coalescent	Post-Contact Coalescent	Disorganized Coalescent
Maximum Length	5.27 (19)	5.77 (20)	6.80 (5)
Transverse Midshaft Diameter	0.46 (34)	0.62 (25)	0.74 (7)
Radiocarpal Surface M-L (RCML)	0.44 (22)	0.25 (22)	0.31 (7)

Note: Numbers in parentheses indicate the sample size of the calculated FA magnitude above them.

Table 6-12. FA comparison between Coalescent variants for femoral dimensions.

	Extended Coalescent	Post-Contact Coalescent	Disorganized Coalescent
Bicondylar (Physiological) Length	33.8 (22)	10.2 (29)	5.72 (9)
Midshaft A-P Diameter	0.66 (35)	0.79 (33)	1.10 (11)
Midshaft Transverse Diameter	0.68 (35)	1.26 (33)	0.85 (11)
Epicondylar Breadth	0.66 (18)	0.52 (21)	0.63 (5)
Femoral Condyles M-L (FCML)	0.35 (13)	1.27 (10)	--

Note: Numbers in parentheses indicate the sample size of the calculated FA magnitude above them.

Table 6-13. FA comparisons between Coalescent variants for tibial dimensions.

	Extended Coalescent	Post-Contact Coalescent	Disorganized Coalescent
Proximal Epiphyseal Breadth	1.25	0.70	0.23
	(18)	(21)	(4)
Distal Epiphyseal Breadth	1.49	1.00	1.125
	(14)	(14)	(2)
Tibiotalar Surface A-P (TTAP)	0.84	0.76	0.47
	(20)	(24)	(6)

Note: Numbers in parentheses indicate the sample size of the calculated FA magnitude above them.

Data for the Disorganized Coalescent were limited to measurements collected from the Leavenworth Site (39CO9) individuals and, after removing subadults, sample sizes unfortunately became too small to provide reliable inferences. Therefore, the F-tests that were conducted to determine statistical significance for differences in variability between samples were limited to the Extended Coalescent and Post-Contact Coalescent samples. The F-test evaluates the null hypothesis that the variances between the Extended Coalescent samples and the Post-Contact Coalescent samples are equal. Outputs for the F-test comparisons between the Extended Coalescent and Post-Contact Coalescent for each skeletal dimension are provided in Appendix 8.11.

Of all the post-cranial dimensions measured and evaluated, only three produced statistically significant differences in variance between the Extended Coalescent and Post-Contact Coalescent: femoral bicondylar length, transverse diameter of the femur at midshaft, and the femoral condyles medial – lateral dimension (FCML). In the case of the femoral bicondylar length, the magnitude of FA was higher for the Extended Coalescent sample, which is consistent with the hypothesized ranking of the magnitude of FA.

However, for both the transverse diameter of the femur at midshaft and the femoral condyles medial – lateral dimension (FCML), the higher magnitude of FA was in the Post-Contact Coalescent sample.

CHAPTER 7: CONCLUSIONS AND DISCUSSIONS

7.1 Fluctuating Asymmetry Among the Arikara

Research presented in preceding chapters was conducted to determine whether specific measures of FA could provide meaningful insight into the developmental instability of Arikara populations across archaeological variants of the Coalescent tradition. Specifically, craniometric, cranial nonmetric, and post-cranial metric measurements were utilized to determine if statistically significant patterns in the magnitude of FA across these variants could be detected.

To assess if FA could be used as a measure of development instability among the Arikara, a hypothesis was developed from existing archaeological/ethnohistorical knowledge of the Arikara, the outcomes of prior studies (i.e. Jantz and Owsley 1984) examining the health of the Arikara, and the influences of changing climatic conditions across Coalescent variants. Based on this information, the hypothesized ordering of the magnitude of FA, from least to greatest, was expected to proceed as follows: Post-Contact Coalescent, Extended Coalescent, Initial Coalescent, and Disorganized Coalescent. Under this scheme, the populations of the Disorganized Coalescent would have incurred the most developmental instability, whereas the Post-Contact Coalescent would have incurred the least. Results of this study, however, do not appear to support this hypothesis.

FA analysis of nonmetric traits shows variability in the ordering of the magnitude of FA between the Coalescent variants. The Disorganized Coalescent does represent the highest and the Post-Contact Coalescent the lowest magnitude of FA in some regions of the cranium. However, there is enough variability in the ordering of the FA_{NM} scores to preclude a consistent pattern.

FA analysis of post-cranial metrics ultimately did not provide very many statistically significant results. In fact, only three dimensions of the femur (femoral bicondylar length, transverse diameter of the femur at midshaft, and the femoral condyles medial – lateral dimension) reveal statistically significant differences in variance between the Extended Coalescent and Post-Contact Coalescent samples. In these three cases, one dimension (femoral bicondylar length) demonstrated a higher magnitude of FA for the Extended Coalescent whereas two dimensions (transverse diameter of the femur at midshaft and the femoral condyles medial – lateral dimension) provided a higher magnitude of FA for the Post-Contact Coalescent. What is perhaps most compelling about these results is that post-cranial metrics may not be ideal measures for FA, although in this case, the femoral dimensions did provide statistically significant results whereas other skeletal elements examined did not. Beyond this, it is interesting to note there was a much stronger dependence of FA on trait size among juveniles. Reasons for this are unclear, but likely relate to mechanisms of bone growth and variation in growth rates during adolescence. This finding should be investigated further and researchers should be wary of incorporating juveniles in FA analysis samples until the nature of this dependence is made clear.

Finally, results of the craniometric analysis run counter to the hypothesized ordering of the Coalescent variants. Of all the bilateral cranial dimensions examined via

Euclidean Distance Matrix Analysis, the Post-Contact Coalescent demonstrated the greatest number of dimensions that provided the highest magnitude of FA. The Extended Coalescent demonstrated the least number of dimensions with the highest magnitude of FA and the Disorganized Coalescent was intermediate between the other two variants.

The cumulative result of these independent analyses is not entirely clear. This study alone will not resolve any previous questions regarding the relationship between fluctuating asymmetry and developmental instability. However, if it is assumed FA is a reliable indicator of developmental instability and these instabilities arise from social and environmental stressors, then it would appear we need to reevaluate the relative rank ordering of the Coalescent variants. Most important, the Post-Contact Coalescent does not appear to have been a time of prosperity and florescence as others (e.g. Jantz and Owsley 1994, Lehmer 1970) have described it. Alternatively, it may be that these archaeological variants (i.e. cultural horizons) are not the appropriate scale at which this analysis should be conducted. Other approaches may be more meaningful and provide greater resolution. As one example, Rogers (1990) constructed a chronological sequence of six periods based on Arikara interactions with Euro-American settlers. The first of these periods constituted the pre-contact period; the remaining five represented sequential periods during the post-contact era that were distinguished based on: the economics of the fur trade; changes in attitudes toward interactions; occurrence of epidemics; changes in the intensity of warfare; and the ability of the Arikara to continue to function within their culturally prescribed limits (Rogers 1990:79). Rogers dates his

Period II from 1681 to 1725 and describes it as the period of probable direct contact between Arikara and Europeans (Rogers 1990:80). Period III is given the age of 1726 to 1775, during which time contact with Europeans became much more frequent. As alluded to by Rogers (1990), Deetz (1965) described the period from 1720 – 1750 as being the most stressful period for Arikara (Deetz 1965:101). Deetz (1965), who had examined the relationship between Arikara social structure and their ceramics during the eighteenth century, posited that changes in ceramics design attributes during this period reflected changes in the residence rules of Arikara society. These changes were brought about by significant social upheaval and reorganization resulting from rapid depopulation arising from epidemic diseases and increasing participation in trade, predominately by men. The impact of these changes was a shift from matrilocal to patrilocal post-marital residence patterns. As women were the primary ceramic manufacturers, this change in residence rules resulted in extreme variations in ceramic stylistic attributes as the norms of matrilineal decent were weakened and replaced. If Deetz (1965) is correct, then there are major implications for how we should approach hypotheses about FA during this time. In this study, many of the Post-Contact Coalescent sites (e.g. Cheyenne River, Indian Creek, Leavitt, and Buffalo Pasture) would fall directly within the time period (1720 – 1750) that Deetz (1965) regards as being the most stressful.

Following through Rogers' later periods, the situation does not improve for the Arikara. Period IV runs from 1776 to 1805 and it is during this time that additional epidemics are recorded as having decimated Arikara populations, leaving them more susceptible to warfare with the Dakota (Rogers 1990:81).

Rogers' (1990) Period V and Period VI fall within the period of the Disorganized Coalescent, a time that all authors agree was an extremely difficult and tumultuous one for the Arikara. From the viewpoint of this analysis, the most important aspect of Rogers' (1990) approach is that it casts significant doubt on the notion that the Post-Contact Coalescent should be considered a time of flourishing and prosperity for the Arikara. This may have been true for the latter half of the seventh century; however, that situation could have taken a drastic turn for the worse during the early to mid-eighteenth century. Under the higher resolution chronological scheme put forth by Rodgers (1990), results of the FA analyses, especially the craniometric findings, presented here become much more compelling.

7.2 Beyond FA: Fluctuating Asymmetry and Biodistance Studies

For several decades, biodistance studies have enjoyed favor among bioarchaeologists. The underlying assumption holds that the traits used to calculate the distances are primarily controlled by genetic factors. Therefore, several authors (e.g. Stojanowski and Buikstra 2004; Sutter and Verano 2007) have utilized this approach to reconstruct microevolutionary changes in past populations. However, the underpinning assumption is not well founded and determining the heritability of skeletal traits is a difficult task to undertake in assemblages without clear familial relationships.

Nevertheless, biodistance studies persist because the microevolutionary information they are believed to provide is compelling.

Similarly, studies attempting to assess developmental instability through measurements of FA have become alluring to bioarchaeologists as a tool for monitoring both genetic and environmental stressors on past populations. Here, too, some assumptions are required. Paramount among them is the assumption that measured increases in FA in fact correlate with—and are caused by—increased stress; however, results have not been entirely complimentary (e.g., Freebairn et al. 1996; Bjorksten et al. 2000). Furthermore, the reliance of developmental instability studies on a variety of traits to measure FA is hampered by lack of knowledge concerning the canalization of the traits. Yet, as with biodistance, these studies endure because of the appeal of the information they are believed to offer.

Researchers focused on biodistance and those focused on developmental instability often seem to be talking past each other, despite the fact that they are essentially examining both sides of the same coin. Furthermore, it is necessary to stop relying on assumptions to support these lines of research. It is entirely possible that bioarchaeologists will make great gains in demonstrating how genetic and environmental interactions have shaped past and modern population, but the key to unlocking the potential of these approaches lies in synthesis of the two. Researchers focused on biodistance have clearly adopted an evolutionary perspective, yet they would be well served to adopt a multi-disciplinary approach to investigating the heritability of traits under investigation. Conversely, researchers focused on developmental instability have gained much by drawing on research in other fields, but stand to gain even more by examining how the stressors they propose have altered microevolutionary processes in the groups they study. With this in mind, it becomes clear that overcoming the problems inherent in both approaches must involve looking beyond one's own discipline. Yet, achieving a synthesis that combines the influence of both genetic and environmental factors on past populations also means looking inward to our colleagues for collaboration on these issues. The research presented here does not resolve the questions surrounding the utility of FA analysis to provide meaningful insight into the developmental instability of past peoples. However, it does add another piece to the puzzle that will someday show a clearer picture of how bioarchaeological analyses can not only demonstrate familial relationship and microevolutionary changes, but also the developmental instability of these peoples in response to the many intrinsic and extrinsic stressors they faced in their specific environments and during their time.

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APPENDICES

8.1 Coalescent Chronology Development

An important publication related to structuring the cultural chronology was published by Lehmer and Caldwell (1966) and produced a slightly modified version of Willey and Phillips' (1962) "archaeological unit concepts." Prior to Lehmer and Caldwell's (1966) system, the Midwestern Taxonomic Method had been applied. However, as Lehmer and Caldwell (1966) describe, in the Plains it eventually became modified into a "bastardized Midwestern system" (Lehmer and Caldwell 1966:511). This corruption occurred because, as Plains archaeologists sought to ascribe developmental relationships between archaeological units, they began assigning both temporal and spatial limits to Midwestern Taxonomic units, such as foci and aspect, although the original system did not take into account these chronologic or geographic distributions (McKern 1939; see also Lyman and O'Brien 2003).

Owing to the rapid accumulation of new archaeological information arising from the Missouri River Basin Surveys and the plethora of forthcoming foci, phases and aspects, Lehmer and Caldwell (1966) decided that the "archaeological unit concepts" of Willey and Philips (1962) provided the best classificatory tools to understand the archaeological development of the region. However, despite the improvements in constructing developmental relationships when applying the Willey and Philips (1962) method, Lehmer and Caldwell still faced some challenges when attempting to fit the extent of the geographic distribution and chronological duration into the Willey and Phillips (1962) framework.

As an example, related to geographic distribution, Lehmer and Caldwell (1966) distinguished a spatial unit intermediate between the Middle Missouri *region* and the various *localities* within this *region*. This intermediate spatial unit, referred to as a *district*, is defined as a "sub-division of a region which includes a number of localities" (Lehmer and Caldwell 1966:512). The creation of *districts* allowed Lehmer and Caldwell (1966) to describe distinctive cultural subdivisions, comprised of multiple localities, within the Middle Missouri region.

Similarly, Lehmer and Caldwell (1966) also struggled with the direct application of the Willey and Phillips (1962) large-scale, integrative unit of *horizon*. The *components* of the Coalescent *tradition* could readily be grouped into numerous *phases*; however, it became apparent "that some phases within each tradition resemble each other more closely than other units representing that tradition" (Lehmer and Caldwell 1966:514). Within the Willey and Phillips (1962) method, they felt the *horizon* was the most suitable unit for expressing similarity between contemporary phases. Despite this, Lehmer and Caldwell (1966) also felt the examples of horizons provided by Willey and Phillips (1962) were "extension[s] of particular cultural elements rather than extensions of whole cultural complexes" (Lehmer and Caldwell 1966:515). Faced with what they saw as the lack of the Willey and Phillips (1962) system's ability to provide a unit that encompasses "groups of phases that appear to be localized and contemporary expressions of the same cultural complex" (Lehmer and Caldwell 1966:515), Lehmer and Caldwell (1966) decided against creating a new category and, instead, choose to modify the concept of *horizon*. As defined by Lehmer and Caldwell (1966), a *horizon* is a "cultural stratum which includes two or more phases, or putative phases, which were approximately coeval and which are characterized by enough common traits, or variants of the same trait, to appear as manifestations of the same basic culture complex" (Lehmer and Caldwell 1966:515). Thus, given Lehmer and Caldwell's (1966) definition, *horizons* became "temporal divisions which crosscut traditions, with the implication that horizons were sequent cultural stages" (Lehmer 1971:32). One the basis of this definition, Lehmer and Caldwell (1966) identified three horizons within the Coalescent tradition; these included the Initial Coalescent horizon, the Extended Coalescent horizon, and the Post-Contact Coalescent horizon.

The newly formed scheme of Northern Plains horizons and traditions that Lehmer and Caldwell (1966) produced gained favor among other Plains archaeologists and was strengthened by subsequent excavations (Lehmer and Jones 1968). Donald Lehmer (1971) revisited this categorization of Plains village complexes and made additional nomenclatural changes in his 1971 report on Middle Missouri Archaeology. While the definition of *horizon* provided by Lehmer and Caldwell (1966) appeared to work well within the Middle Missouri subarea, horizons turned out to be less apparent in other subareas and, in some instances, appeared to be roughly contemporaneous, rather than sequent stages. Given this situation, Lehmer (1971) opted to substitute his and Caldwell's (1966) use of the term *horizon* with the new category of *variant*. Lehmer (1971:32) defined *variant* as "a unique and reasonably uniform expression of a cultural tradition which has a greater order of magnitude than a phase, and which is distinguished from other variants of the same tradition by its geographic distribution, age, and/or cultural content." Lehmer (1971:33) indicated that "cultural content" included such traits as settlement pattern, fortification systems, basic house type, certain pottery characteristics, and the presence or absence of some diagnostics artifact types.

8.2 Nonmetric Trait Definitions

Descriptions of the following cranial nonmetric traits are quoted directly from Berry and Berry (1967) and Buikstra and Ubelaker (1994) to provide the reader the exact description or scoring scheme used when the nonmetric trait scores were recorded.

Supraorbital notch

Notches may be present at the supraorbital margin of the frontal bone (Buikstra and Ubelaker 1994:87). The supraorbital foramen transmits the supraorbital vessels and nerve. They are frequently incomplete (or open); in this case, it is often described as a 'supraorbital notch' (Berry and Berry 1967:369).

Supraorbital foramen

The supraorbital foramen transmits the supraorbital vessels and nerve (Berry and Berry 1967:369). All foramina must present openings on both orbital and external surfaces to be scored present (Buikstra and Ubelaker 1994:87).

Supratrochlear notch

Foramina located at the confluence of the vertical (medial) and horizontal aspects of the orbit are considered supratrochlear (Buikstra and Ubelaker 1994:87).

Infraorbital suture

Located on the orbital and facial surfaces, though presence on the facial surface only will be scored. A complete suture extends from the orbital margin to the infraorbital foramen. Partial and complete sutures will be distinguished (Buikstra and Ubelaker 1994:87).

Infraorbital foramen

Foramina situated on the external surface of the maxilla below the infraorbital margin, above the canine fossa (Buikstra and Ubelaker 1994:87).

Epipteric bone

A sutural bone (the epipteric bone or pterion ossicle) may be inserted between the anterior inferior angle of the parietal bone and the greater wing of the sphenoid.

When large it may also articulate with the squamous part of the temporal bone (Berry and Berry 1967:367). Located at the junction of the frontal, parietal, temporal, and sphenoid bones (Buikstra and Ubelaker 1994:88).

Coronal ossicle

Ossicles are sometimes found in the coronal suture (Berry and Berry 1967:367).

Zygomaticofacial foramen

Foramina located on facial surface of zygomatic (malar) bone. Both size and number should be recorded (Buikstra and Ubelaker 1994: 87).

Parietal foramen

This pierces the parietal bone near the sagittal suture a few centimeters in front of the lambda. It transmits a small emissary vein, and sometimes a small branch of the occipital artery (Berry and Berry 1967:366). Located on the parietal cone, within or near the suture at obelion. Foramen should lead into canal extending to and perforating the internal table. Foramina existing only on the internal table should not be scored (Buikstra and Ubelaker 1994, 88).

Lambdoid ossicle

One or more ossicles may occur in the lambdoid suture. Up to about twelve distinct bones may be present on either side. (Berry and Berry 1967:366)

Ossicle at asterion

The junction of the posterior inferior angle of the parietal bone with the occipital bone and mastoid portion of the temporal bone is known as the asterion. A sutural bone may occur at this junction. (Berry and Berry 1967:368)

Ossicle in occipitomastoid suture

Located in the suture between temporal and occipital bones (Buikstra and Ubelaker 1994:88).

Parietal notch bone

The parietal notch is that part of the parietal bone that protrudes between the squamous and the mastoid portions of the temporal bone. It may form a separate ossicle which is known as the parietal notch bone (Berry and Berry 1967:368).

Auditory exostosis

Bony nodule developed within internal auditory meatus. Degree of canal occlusion should be estimated (Buikstra and Ubelaker 1994:91).

Mastoid foramen location

Foramen located posterior to the mastoid process, usually on the temporal bone, but occasionally on the occipital or within the occipito-mastoid suture (Buikstra and Ubelaker 1994:91).

Mastoid foramen number

Foramen located posterior to the mastoid process, usually on the temporal bone, but occasionally on the occipital or within the occipito-mastoid suture. Both location and number should be reported (Buikstra and Ubelaker 1994:91).

Condylar canal

Canal opening within the condylar fossa, posterior to the occipital condyles. An open or "patent" canal is directed anterio-medially, ending in a foramen located on the superior aspect of the pars lateralis, within the cranial cavity, or within the jugular notch (Buikstra and Ubelaker 1994:89).

Divided hypoglossal canal

They hypoglossal canal is located superior to the occipital condyle, normally at an angle perpendicular to the main axis of the condyle. The hypoglossal canal can be divided by spines located within the canal or on the internal aspect adjacent to foramen magnum. Both the location of the spines and the completeness of the bridge they form should be recorded (Buikstra and Ubelaker 1994:89).

Foramen spinosum incomplete

Foramen spinosum (sphenoid bone) open to foramen lacerum (Buikstra and Ubelaker 1994:90).

Pterygospinous bridge

Bony bridge due to fusion of lateral lamina between lateral pterygoid plate of sphenoid and spina angularis. Incomplete bridge (spur) should be distinguished from full ossification (Buikstra and Ubelaker 1994:90).

Pterygoalar bridge

Bony bridge due to fusion of lateral lamina between lateral pterygoid plate of sphenoid and inferior surface of the greater wing. Incomplete bridge (spur) should be distinguished from full ossification (Ubelaker 1994:90).

Mental foramina

Foramina located on the external aspect of the mandibular corpus inferior to P3. The most frequent variant is double foramina.

Mylohyoid bridge location

Bony bridge over mylohyoid canal of mandible, either in region of mandibular foramen of approximately in the center of the groove. Both location and degree of bridge formation should be recorded (Buikstra and Ubelaker 1994:91).

Mylohyoid bridge development

Bony bridge over mylohyoid canal of mandible, either in region of mandibular foramen of approximately in the center of the groove. Both location and degree of bridge formation should be recorded (Buikstra and Ubelaker 1994:91).

8.3 National Museum of Natural History Nonmetric Cranial Trait Descriptions and Criteria for Scoring

Non-metric traits of the facial region.

Trait Abbreviation	**Trait Name**	**Scoring**
SONOTCHL	Supraorbital notch, left	0. absent 1. present 2. multiple notches 9. unobservable
SONOTCHR	Supraorbital notch, right	
SOFORAML	Supraorbital foramen, left	0. absent 1. present 2. multiple foramina 9. unobservable
SOFORAMR	Supraorbital foramen, right	
STNOTCHL	Supratrochlear notch, left	0. absent 1. present 2. multiple notches 9. unobservable
STNOTCHR	Supratrochlear notch, right	
IOSUTL	Infraorbital suture, left	0. absent 1. partial 2. complete 9. unobservable
IOSUTR	Infraorbital suture, right	
IOFORAML	Infraorbital foramen, left	0. absent 1. partial internal division 2. complete internal division 3. 2 distinct foramina 4. > 2 distinct foramina 9. unobservable
IOFORAMR	Infraorbital foramen, right	
ZYFFORL	Zygomaticofacial foramen, left	0. absent 1. 1 large only 2. 1 large plus smaller foramina 3. 2 large foramina 4. 2 large plus smaller foramina 5. multiple smaller foramina 9. unobservable
ZYFFORR	Zygomaticofacial foramen, right	

Non-metric traits of the facial region.

Trait Abbreviation	Trait Name	Scoring
CORONLL	Coronal ossicle, left	0. absent 1. present 9. unobservable
CORONLR	Coronal ossicle, right	
EPIPTERL	Epipteric bone, left	0. absent 1. present 9. unobservable
EPIPTERR	Epipteric bone, right	

8.4 Cranial Landmark Definitions

Landmark	Abbreviation	Definition
opisthion	ops	The inferior edge of the posterior border of the foramen magnum in the midline (Howells 1973:169).
prosthion – Howells estimated	proHEST	The most anteriorly prominent point, in the midline, on the alveolar border, above the septum between the central incisors. Because of frequent damage, and of ante-mortem loss or avulsion of the incisors, location of prosthion for actual measurement may be difficult, resulting in the need for approximations or estimates of its original position (Howells 1973:169).
nasion	nas	The intersection of the fronto-nasal suture and the median plane (Howells 1973:169).
bregma	brg	The posterior border of the frontal bone in the median plane. Normally this is the meeting point of the coronal and sagittal sutures (Howells 1973:167).
lambda	lam	The apex of the occipital bone at its junction with the parietals, in the midline (Howells 1973:168).
left frontomalare anterior	fmal	The most anterior point on the fronto-malar suture on the left side of the skull (Howells 1973:168).
right frontomalare anterior	fmar	The most anterior point on the fronto-malar suture on the right side of the skull (Howells 1973:168).
left zygomaxillare	zygoml	The most inferior point of the left zygomatico-maxillary suture (Martin 1928).
right zygomaxillare	zygomr	The most inferior point of the right zygomatico-maxillary suture (Martin 1928).
left sphenion	sphl	The most anterior point of the left sphenoparietal suture. (Martin 1928).
right sphenion	sphr	The most anterior point of the right sphenoparietal suture. (Martin 1928).

left asterion	astl	The common meeting point of the temporal, parietal, and occipital bones on the left side of the skull (Howells 1973:166).
right asterion	astr	The common meeting point of the temporal, parietal, and occipital bones on the right side of the skull (Howells 1973:166).

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8.5 Crow Creek Site (39BF11) Nonmetric Cranial Traits and Criteria for Scoring

Trait Abbreviation	Trait Name	Scoring
RMELAMOS	Medial lambdoid ossicle present, right	0. unobservable 1. absent 2. present
LMELAMOS	Medial lambdoid ossicle present, left	
RLALAMOS	Lateral lambdoid ossicle present, right	0. unobservable 1. absent 2. present
LLALAMOS	Lateral lambdoid ossicle present, left	
RPARFOR	Parietal foramen, right	0. unobservable 1. absent 2. present
LPARFOR	Parietal foramen, left	
RMASFOR	Mastoid foramen, right	0. unobservable 1. absent 2. present
RMASFOR	Mastoid foramen, left	
RMASFOEX	Mastoid foramen exsutural, right	0. unobservable 1. absent 2. present
LMASFOEX	Mastoid foramen exsutural, left	
RCOROS	Coronal ossicle, right	0. unobservable 1. absent 2. present
LCOROS	Coronal ossicle, right	
REPITER	Epipteric ossicle, right	0. unobservable 1. absent

LEPITER	Epipteric ossicle, right	2. present
	Fronto-temporal articulation, right	0. unobservable 1. absent 2. present
	Fronto-temporal articulation, left	
	Parietal notch, right	0. unobservable 1. absent 2. present
	Parietal notch, left	
	Ossicle at asterion, right	0. unobservable 1. absent 2. present
	Ossicle at asterion, left	
	Ossicle in mastoid suture, right	0. unobservable 1. absent 2. present
	Ossicle in mastoid suture, right	
	Anterior condylar canal double, right	0. unobservable 1. absent 2. present
	Anterior condylar canal double, left	
	Accessory palatine foramen, right	0. unobservable 1. absent 2. present
	Accessory palatine foramen, left	
	Supraorbital foramen complete, right	0. unobservable 1. absent 2. present
	Supraorbital foramen complete, right	
	Frontal foramen, right	0. unobservable 1. absent 2. present

	Frontal foramen, left	
	Suture into infraorbital foramen, right	0. unobservable 1. absent 2. present
	Suture into infraorbital foramen, left	
	Accessory infraorbital foramen, right	0. unobservable 1. absent 2. present
	Accessory infraorbital foramen, left	
	Mylohyoid bridge, right	0. unobservable 1. absent 2. present
	Mylohyoid bridge, left	
	Accessory mental foramen, right	0. unobservable 1. absent 2. present
	Accessory mental foramen, left	

8.6 EDMAware Output (Extended Coalescent)

```
EDMAware version 0.011517 beta
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OUTPUT FOR ONE-SAMPLE ASYMMETRY PROCEDURE:

Number of paired landmarks:    4
Number of midline landmarks:    6
Number of dimensions:   3
Number of observations: 50

Asymmetry is defined as the difference between sides (L - R)

Confidence Intervals Parameters:
Alpha = 0.100
Nonparametric resampling
Number of resamples: 1000

Directional asymmetries (DA), unsorted:

                     Confidence interval
              Mean(L-R)    Upper      Lower
zygom--fma       -0.35257    0.00457   -0.72920

zygom--sph       -1.33546   -0.79849   -1.87990

zygom--ast      -0.36605    0.25665   -1.04705

fma--sph        -0.49928    0.16835   -1.16541

fma--ast        -0.14807    0.48873   -0.81678

sph--ast        -0.45482    0.33234   -1.27925

zygom--proHEST    0.36454    0.73295   -0.04096

zygom--proH       0.45263    0.84392    0.04653

zygom--nas       -0.48398   -0.17708   -0.82798

zygom--brg       -0.02938    0.50079   -0.57475

zygom--lam       -0.45538    0.02344   -0.91441
```

```
zygom--ops       0.04079    0.52301   -0.40882

fma--proHEST     0.06628    0.42415   -0.28256

fma--proH        0.12519    0.47540   -0.23749

fma--nas        -0.44684   -0.09393   -0.81740

fma--brg         0.55018    1.07348    0.01181

fma--lam         0.03925    0.42504   -0.33721

fma--ops         0.30481    0.69951   -0.09348

sph--proHEST    -0.51252    0.11155   -1.10775

sph--proH       -0.46034    0.17049   -1.06520

sph--nas        -0.34041    0.32674   -0.99335

sph--brg         1.66334    2.37191    0.93029

sph--lam         0.41269    1.07845   -0.25660

sph--ops         0.10557    0.65832   -0.44198

ast--proHEST    -0.01228    0.62213   -0.69501

ast--proH        0.02481    0.65407   -0.65378

ast--nas        -0.53318    0.04654   -1.18974

ast--brg        -0.22170    0.36575   -0.79590

ast--lam        -0.70676    0.14516   -1.55291

ast--ops         0.34879    0.97053   -0.38586


Directional asymmetries (DA), sorted:

                      Confidence interval
             Mean(L-R)    Upper      Lower
zygom--sph      -1.33546   -0.79849   -1.87990
```

```
ast--lam        -0.70676    0.14516   -1.55291
ast--nas        -0.53318    0.04654   -1.18974
sph--proHEST    -0.51252    0.11155   -1.10775
fma--sph        -0.49928    0.16835   -1.16541
zygom--nas      -0.48398   -0.17708   -0.82798
sph--proH       -0.46034    0.17049   -1.06520
zygom--lam      -0.45538    0.02344   -0.91441
sph--ast        -0.45482    0.33234   -1.27925
fma--nas        -0.44684   -0.09393   -0.81740
zygom--ast      -0.36605    0.25665   -1.04705
zygom--fma      -0.35257    0.00457   -0.72920
sph--nas        -0.34041    0.32674   -0.99335
ast--brg        -0.22170    0.36575   -0.79590
fma--ast        -0.14807    0.48873   -0.81678
zygom--brg      -0.02938    0.50079   -0.57475
ast--proHEST    -0.01228    0.62213   -0.69501
ast--proH        0.02481    0.65407   -0.65378
fma--lam         0.03925    0.42504   -0.33721
zygom--ops       0.04079    0.52301   -0.40882
fma--proHEST     0.06628    0.42415   -0.28256
sph--ops         0.10557    0.65832   -0.44198
fma--proH        0.12519    0.47540   -0.23749
```

```
fma--ops        0.30481    0.69951   -0.09348

ast--ops        0.34879    0.97053   -0.38586

zygom--proHEST    0.36454    0.73295   -0.04096

sph--lam        0.41269    1.07845   -0.25660

zygom--proH      0.45263    0.84392    0.04653

fma--brg        0.55018    1.07348    0.01181

sph--brg        1.66334    2.37191    0.93029


Fluctuating asymmetrics WITHOUT accounting for DA, unsorted:

                    Confidence interval
            Mean(L-R)    Upper      Lower
zygom--fma       1.32506    1.55616    1.10129

zygom--sph       2.19213    2.58850    1.79063

zygom--ast       2.10694    2.56603    1.68504

fma--sph        2.32737    2.77456    1.86976

fma--ast        2.20376    2.60687    1.82281

sph--ast        2.45810    3.10381    1.91489

zygom--proHEST    1.36848    1.57807    1.15758

zygom--proH      1.38017    1.60718    1.16076

zygom--nas       1.20658    1.42064    1.00816

zygom--brg       1.80234    2.16718    1.47376

zygom--lam       1.64862    1.94191    1.35809

zygom--ops       1.48823    1.78583    1.19306
```

```
fma--proHEST     1.32088    1.52619    1.11925

fma--proH        1.34298    1.54765    1.13768

fma--nas         1.36215    1.56100    1.15603

fma--brg         1.83707    2.19210    1.53250

fma--lam         1.37611    1.60379    1.16099

fma--ops         1.40846    1.65218    1.15217

sph--proHEST     2.37971    2.70475    2.00785

sph--proH        2.37938    2.69542    2.00785

sph--nas         2.26936    2.69630    1.83210

sph--brg         2.72811    3.31265    2.19362

sph--lam         2.25545    2.70518    1.81708

sph--ops         1.74585    2.16275    1.36055

ast--proHEST     2.19933    2.64635    1.79469

ast--proH        2.18539    2.62824    1.78002

ast--nas         2.04640    2.48484    1.66085

ast--brg         1.92016    2.28191    1.60806

ast--lam         2.79287    3.36927    2.21252

ast--ops         2.10719    2.57586    1.67827


Fluctuating asymmetrics WITHOUT accounting for DA, sorted:

                   Confidence interval
            Mean|L-R|    Upper     Lower
zygom--nas       1.20658    1.42064    1.00816

fma--proHEST     1.32088    1.52619    1.11925
```

zygom--fma	1.32506	1.55616	1.10129
fma--proH	1.34298	1.54765	1.13768
fma--nas	1.36215	1.56100	1.15603
zygom--proHEST	1.36848	1.57807	1.15758
fma--lam	1.37611	1.60379	1.16099
zygom--proH	1.38017	1.60718	1.16076
fma--ops	1.40846	1.65218	1.15217
zygom--ops	1.48823	1.78583	1.19306
zygom--lam	1.64862	1.94191	1.35809
sph--ops	1.74585	2.16275	1.36055
zygom--brg	1.80234	2.16718	1.47376
fma--brg	1.83707	2.19210	1.53250
ast--brg	1.92016	2.28191	1.60806
ast--nas	2.04640	2.48484	1.66085
zygom--ast	2.10694	2.56603	1.68504
ast--ops	2.10719	2.57586	1.67827
ast--proH	2.18539	2.62824	1.78002
zygom--sph	2.19213	2.58850	1.79063
ast--proHEST	2.19933	2.64635	1.79469
fma--ast	2.20376	2.60687	1.82281
sph--lam	2.25545	2.70518	1.81708
sph--nas	2.26936	2.69630	1.83210

```
fma--sph         2.32737    2.77456    1.86976

sph--proH        2.37938    2.69542    2.00785

sph--proHEST     2.37971    2.70475    2.00785

sph--ast         2.45810    3.10381    1.91489

sph--brg         2.72811    3.31265    2.19362

ast--lam         2.79287    3.36927    2.21252


Fluctuating asymmetrics ACCOUNTING for DA, unsorted:

                    Confidence interval
            Mean(L-R)    Upper      Lower
zygom--fma       1.29186    1.51553    1.06079

zygom--sph       2.04092    2.32252    1.65337

zygom--ast       2.08955    2.54058    1.63696

fma--sph         2.39069    2.82077    1.89176

fma--ast         2.19517    2.59483    1.79110

sph--ast         2.37629    3.07850    1.82152

zygom--proHEST    1.33353    1.52712    1.09740

zygom--proH      1.30640    1.51633    1.07191

zygom--nas       1.14495    1.32987    0.94177

zygom--brg       1.80352    2.14963    1.46593

zygom--lam       1.65662    1.91392    1.36051

zygom--ops       1.49273    1.78798    1.18001

fma--proHEST     1.31292    1.51287    1.09055
```

```
fma--proH       1.32444   1.52680   1.10198

fma--nas        1.25491   1.48387   1.00804

fma--brg        1.82619   2.13443   1.50317

fma--lam        1.37925   1.59107   1.14554

fma--ops        1.40010   1.61098   1.14285

sph--proHEST     2.35371   2.64028   1.96514

sph--proH       2.35337   2.64283   1.96999

sph--nas        2.26555   2.67008   1.81731

sph--brg        2.44963   2.97571   1.96027

sph--lam        2.23648   2.68061   1.78253

sph--ops        1.77150   2.25559   1.27627

ast--proHEST     2.20031   2.61280   1.77242

ast--proH       2.18423   2.59192   1.76301

ast--nas        1.94453   2.37022   1.55137

ast--brg        1.92903   2.27696   1.57798

ast--lam        2.66589   3.22407   2.06293

ast--ops        2.02821   2.52959   1.55191


Fluctuating asymmetrics ACCOUNTING for DA, sorted:

                  Confidence interval
          Mean|(L-R)-DA|   Upper     Lower
zygom--nas      1.14495   1.32987   0.94177

fma--nas        1.25491   1.48387   1.00804

zygom--fma      1.29186   1.51553   1.06079
```

zygom--proH	1.30640	1.51633	1.07191
fma--proHEST	1.31292	1.51287	1.09055
fma--proH	1.32444	1.52680	1.10198
zygom--proHEST	1.33353	1.52712	1.09740
fma--lam	1.37925	1.59107	1.14554
fma--ops	1.40010	1.61098	1.14285
zygom--ops	1.49273	1.78798	1.18001
zygom--lam	1.65662	1.91392	1.36051
sph--ops	1.77150	2.25559	1.27627
zygom--brg	1.80352	2.14963	1.46593
fma--brg	1.82619	2.13443	1.50317
ast--brg	1.92903	2.27696	1.57798
ast--nas	1.94453	2.37022	1.55137
ast--ops	2.02821	2.52959	1.55191
zygom--sph	2.04092	2.32252	1.65337
zygom--ast	2.08955	2.54058	1.63696
ast--proH	2.18423	2.59192	1.76301
fma--ast	2.19517	2.59483	1.79110
ast--proHEST	2.20031	2.61280	1.77242
sph--lam	2.23648	2.68061	1.78253
sph--nas	2.26555	2.67008	1.81731
sph--proH	2.35337	2.64283	1.96999

sph--proHEST	2.35371	2.64028	1.96514
sph--ast	2.37629	3.07850	1.82152
fma--sph	2.39069	2.82077	1.89176
sph--brg	2.44963	2.97571	1.96027
ast--lam	2.66589	3.22407	2.06293

8.7 EDMAware Output (Post-Contact Coalescent)

```
EDMAware version 0.011517 beta
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OUTPUT FOR ONE-SAMPLE ASYMMETRY PROCEDURE:

Number of paired landmarks:    4
Number of midline landmarks:    6
Number of dimensions:   3
Number of observations: 124

Asymmetry is defined as the difference between sides (L - R)

Confidence Intervals Parameters:
Alpha = 0.100
Nonparametric resampling
Number of resamples: 1000

Directional asymmetries (DA), unsorted:

                         Confidence interval
                  Mean(L-R)   Upper     Lower
zygom--fma      -0.48922    0.18575   -1.60492

zygom--sph      -2.00564   -1.32605   -2.94249

zygom--ast      -0.72823   -0.06346   -1.52857

fma--sph        -1.08989   -0.70807   -1.48045

fma--ast        -0.15506    0.36957   -0.65741

sph--ast        -0.20585    0.39329   -0.80833

zygom--proHEST    0.46029    0.72828    0.16339

zygom--proH      0.46432    0.73272    0.16509

zygom--nas      -0.70747   -0.46243   -0.96183

zygom--brg      -0.50722   -0.21682   -0.78760

zygom--lam      -0.40597   -0.13399   -0.67607
```

```
zygom--ops      -0.27763   -0.00138   -0.55927

fma--proHEST     0.36448    0.58466    0.11982

fma--proH        0.36760    0.58712    0.12022

fma--nas        -0.85321   -0.64741   -1.10348

fma--brg        -0.41212   -0.13005   -0.71252

fma--lam         0.46006    1.57150   -0.25644

fma--ops         0.15014    0.47283   -0.15809

sph--proHEST    -0.86319   -0.45160   -1.29667

sph--proH       -0.86021   -0.45809   -1.29154

sph--nas        -1.13293   -0.76468   -1.51337

sph--brg         0.72013    1.15109    0.29937

sph--lam         1.07786    2.13770    0.32638

sph--ops        -0.17440    0.25216   -0.62004

ast--proHEST     0.02882    0.45777   -0.43145

ast--proH        0.03057    0.46039   -0.42751

ast--nas        -0.59833   -0.11104   -1.12276

ast--brg        -0.74181   -0.26434   -1.28441

ast--lam        -0.06327    0.73623   -0.74373

ast--ops         0.13125    0.54625   -0.28117

Directional asymmetries (DA), sorted:

                      Confidence interval
                 Mean(L-R)    Upper      Lower
```

zygom--sph	-2.00564	-1.32605	-2.94249
sph--nas	-1.13293	-0.76468	-1.51337
fma--sph	-1.08989	-0.70807	-1.48045
sph--proHEST	-0.86319	-0.45160	-1.29667
sph--proH	-0.86021	-0.45809	-1.29154
fma--nas	-0.85321	-0.64741	-1.10348
ast--brg	-0.74181	-0.26434	-1.28441
zygom--ast	-0.72823	-0.06346	-1.52857
zygom--nas	-0.70747	-0.46243	-0.96183
ast--nas	-0.59833	-0.11104	-1.12276
zygom--brg	-0.50722	-0.21682	-0.78760
zygom--fma	-0.48922	0.18575	-1.60492
fma--brg	-0.41212	-0.13005	-0.71252
zygom--lam	-0.40597	-0.13399	-0.67607
zygom--ops	-0.27763	-0.00138	-0.55927
sph--ast	-0.20585	0.39329	-0.80833
sph--ops	-0.17440	0.25216	-0.62004
fma--ast	-0.15506	0.36957	-0.65741
ast--lam	-0.06327	0.73623	-0.74373
ast--proHEST	0.02882	0.45777	-0.43145
ast--proH	0.03057	0.46039	-0.42751
ast--ops	0.13125	0.54625	-0.28117

fma--ops	0.15014	0.47283	-0.15809
fma--proHEST	0.36448	0.58466	0.11982
fma--proH	0.36760	0.58712	0.12022
fma--lam	0.46006	1.57150	-0.25644
zygom--proHEST	0.46029	0.72828	0.16339
zygom--proH	0.46432	0.73272	0.16509
sph--brg	0.72013	1.15109	0.29937
sph--lam	1.07786	2.13770	0.32638

Fluctuating asymmetrics WITHOUT accounting for DA, unsorted:

		Confidence interval	
	Mean(L-R)	Upper	Lower
zygom--fma	1.71725	2.79700	1.11599
zygom--sph	2.78158	3.68964	2.15367
zygom--ast	2.86107	3.56264	2.33572
fma--sph	2.07775	2.39154	1.79540
fma--ast	2.59447	2.91827	2.27654
sph--ast	2.64288	3.05381	2.22614
zygom--proHEST	1.49175	1.68861	1.31188
zygom--proH	1.47591	1.66190	1.28961
zygom--nas	1.52908	1.68999	1.37953
zygom--brg	1.61839	1.79601	1.45061
zygom--lam	1.54625	1.69967	1.38930
zygom--ops	1.54080	1.71969	1.36845

```
fma--proHEST     1.25697    1.41625    1.10506

fma--proH        1.25752    1.41236    1.10433

fma--nas         1.37789    1.55474    1.21596

fma--brg         1.57379    1.73745    1.40623

fma--lam         1.99643    3.06335    1.34048

fma--ops         1.62443    1.82656    1.43192

sph--proHEST     2.26755    2.58481    1.95929

sph--proH        2.25103    2.56950    1.94283

sph--nas         2.09827    2.39875    1.83353

sph--brg         2.33862    2.61290    2.07356

sph--lam         2.80446    3.80487    2.15973

sph--ops         2.28293    2.52780    2.04122

ast--proHEST     2.35028    2.65352    2.08074

ast--proH        2.35028    2.66085    2.07645

ast--nas         2.52911    2.90161    2.21701

ast--brg         2.61999    2.95625    2.27221

ast--lam         2.96446    3.65533    2.46000

ast--ops         2.15981    2.41108    1.89095


Fluctuating asymmetrics WITHOUT accounting for DA, sorted:

                           Confidence interval
                Mean|L-R|    Upper      Lower
fma--proHEST     1.25697    1.41625    1.10506
```

fma--proH	1.25752	1.41236	1.10433
fma--nas	1.37789	1.55474	1.21596
zygom--proH	1.47591	1.66190	1.28961
zygom--proHEST	1.49175	1.68861	1.31188
zygom--nas	1.52908	1.68999	1.37953
zygom--ops	1.54080	1.71969	1.36845
zygom--lam	1.54625	1.69967	1.38930
fma--brg	1.57379	1.73745	1.40623
zygom--brg	1.61839	1.79601	1.45061
fma--ops	1.62443	1.82656	1.43192
zygom--fma	1.71725	2.79700	1.11599
fma--lam	1.99643	3.06335	1.34048
fma--sph	2.07775	2.39154	1.79540
sph--nas	2.09827	2.39875	1.83353
ast--ops	2.15981	2.41108	1.89095
sph--proH	2.25103	2.56950	1.94283
sph--proHEST	2.26755	2.58481	1.95929
sph--ops	2.28293	2.52780	2.04122
sph--brg	2.33862	2.61290	2.07356
ast--proH	2.35028	2.66085	2.07645
ast--proHEST	2.35028	2.65352	2.08074
ast--nas	2.52911	2.90161	2.21701

```
fma--ast        2.59447    2.91827    2.27654

ast--brg        2.61999    2.95625    2.27221

sph--ast        2.64288    3.05381    2.22614

zygom--sph       2.78158    3.68964    2.15367

sph--lam        2.80446    3.80487    2.15973

zygom--ast       2.86107    3.56264    2.33572

ast--lam        2.96446    3.65533    2.46000


Fluctuating asymmetrics ACCOUNTING for DA, unsorted:

                         Confidence interval
                 Mean(L-R)    Upper     Lower
zygom--fma       1.78295    3.36769    1.10593

zygom--sph       2.43072    3.64461    1.75741

zygom--ast       2.90114    3.67460    2.32846

fma--sph        1.98202    2.27367    1.70928

fma--ast        2.60003    2.92423    2.26375

sph--ast        2.62717    3.05684    2.21278

zygom--proHEST    1.47640    1.66169    1.29249

zygom--proH      1.46616    1.65016    1.28130

zygom--nas       1.35726    1.50173    1.19618

zygom--brg       1.55805    1.71596    1.39079

zygom--lam       1.48220    1.63128    1.32067

zygom--ops       1.52152    1.69295    1.34730

fma--proHEST     1.25132    1.40626    1.09679
```

```
fma--proH        1.24889    1.40532    1.09438

fma--nas        1.19182    1.34433    1.03351

fma--brg        1.54028    1.68752    1.36723

fma--lam         2.05468    3.54780    1.33945

fma--ops        1.63382    1.82671    1.43048

sph--proHEST     2.16848    2.47055    1.85141

sph--proH        2.16365    2.46445    1.85227

sph--nas        1.95944    2.22429    1.68294

sph--brg        2.27732    2.54264    2.00682

sph--lam         2.80880    4.03791    2.11718

sph--ops        2.26430    2.52259    1.99502

ast--proHEST     2.34795    2.65975    2.05517

ast--proH        2.34781    2.65721    2.05576

ast--nas        2.47149    2.82513    2.15170

ast--brg        2.59560    2.92574    2.24880

ast--lam         2.96038    3.67529    2.42998

ast--ops        2.15396    2.40181    1.88746


Fluctuating asymmetrics ACCOUNTING for DA, sorted:

                          Confidence interval
                 Mean|(L-R)-DA|    Upper     Lower
fma--nas        1.19182    1.34433    1.03351

fma--proH        1.24889    1.40532    1.09438
```

fma--proHEST	1.25132	1.40626	1.09679
zygom--nas	1.35726	1.50173	1.19618
zygom--proH	1.46616	1.65016	1.28130
zygom--proHEST	1.47640	1.66169	1.29249
zygom--lam	1.48220	1.63128	1.32067
zygom--ops	1.52152	1.69295	1.34730
fma--brg	1.54028	1.68752	1.36723
zygom--brg	1.55805	1.71596	1.39079
fma--ops	1.63382	1.82671	1.43048
zygom--fma	1.78295	3.36769	1.10593
sph--nas	1.95944	2.22429	1.68294
fma--sph	1.98202	2.27367	1.70928
fma--lam	2.05468	3.54780	1.33945
ast--ops	2.15396	2.40181	1.88746
sph--proH	2.16365	2.46445	1.85227
sph--proHEST	2.16848	2.47055	1.85141
sph--ops	2.26430	2.52259	1.99502
sph--brg	2.27732	2.54264	2.00682
ast--proH	2.34781	2.65721	2.05576
ast--proHEST	2.34795	2.65975	2.05517
zygom--sph	2.43072	3.64461	1.75741
ast--nas	2.47149	2.82513	2.15170

ast--brg	2.59560	2.92574	2.24880
fma--ast	2.60003	2.92423	2.26375
sph--ast	2.62717	3.05684	2.21278
sph--lam	2.80880	4.03791	2.11718
zygom--ast	2.90114	3.67460	2.32846
ast--lam	2.96038	3.67529	2.42998

8.8 EDMAware Output (Disorganized Coalescent)

```
EDMAware version 0.011517 beta
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OUTPUT FOR ONE-SAMPLE ASYMMETRY PROCEDURE:

Number of paired landmarks:    4
Number of midline landmarks:    6
Number of dimensions:   3
Number of observations: 27

Asymmetry is defined as the difference between sides (L - R)

Confidence Intervals Parameters:
Alpha = 0.100
Nonparametric resampling
Number of resamples: 1000

Directional asymmetries (DA), unsorted:

                              Confidence interval
                Mean(L-R)   Upper     Lower
zygom--fma       -0.75867   -0.29737   -1.23779

zygom--sph       -1.55855   -0.54845   -2.65728

zygom--ast       -0.28138    0.52913   -1.18836

fma--sph        -0.59726    0.38548   -1.61439

fma--ast         0.03366    0.76637   -0.69474

sph--ast         0.13044    0.90582   -0.66584

zygom--proHEST    0.44444    1.07919   -0.14252

zygom--proH       0.51208    1.13361   -0.06904

zygom--nas       -0.59558    0.10800   -1.27936

zygom--brg       -0.52233    0.22974   -1.33005

zygom--lam       -0.77704   -0.24092   -1.33383
```

zygom--ops	-0.87927	-0.33905	-1.47843
fma--proHEST	-0.20274	0.19160	-0.59418
fma--proH	-0.15480	0.25126	-0.55369
fma--nas	-0.56309	-0.02384	-1.12793
fma--brg	0.20850	0.92251	-0.53734
fma--lam	-0.24716	0.28149	-0.77046
fma--ops	-0.70140	-0.07615	-1.35529
sph--proHEST	-0.53835	0.47386	-1.64813
sph--proH	-0.49635	0.51645	-1.59745
sph--nas	-0.37611	0.56123	-1.36843
sph--brg	1.30864	2.31952	0.30450
sph--lam	0.48561	1.13574	-0.15376
sph--ops	-0.56219	0.24351	-1.47564
ast--proHEST	0.47857	1.08450	-0.11762
ast--proH	0.50347	1.11892	-0.09248
ast--nas	0.19077	0.66847	-0.28571
ast--brg	0.27329	1.28367	-0.72362
ast--lam	-0.21926	1.19287	-1.56393
ast--ops	-0.24540	0.58468	-1.10829

Directional asymmetries (DA), sorted:

		Confidence interval	
	Mean(L-R)	Upper	Lower

zygom--sph	-1.55855	-0.54845	-2.65728
zygom--ops	-0.87927	-0.33905	-1.47843
zygom--lam	-0.77704	-0.24092	-1.33383
zygom--fma	-0.75867	-0.29737	-1.23779
fma--ops	-0.70140	-0.07615	-1.35529
fma--sph	-0.59726	0.38548	-1.61439
zygom--nas	-0.59558	0.10800	-1.27936
fma--nas	-0.56309	-0.02384	-1.12793
sph--ops	-0.56219	0.24351	-1.47564
sph--proHEST	-0.53835	0.47386	-1.64813
zygom--brg	-0.52233	0.22974	-1.33005
sph--proH	-0.49635	0.51645	-1.59745
sph--nas	-0.37611	0.56123	-1.36843
zygom--ast	-0.28138	0.52913	-1.18836
fma--lam	-0.24716	0.28149	-0.77046
ast--ops	-0.24540	0.58468	-1.10829
ast--lam	-0.21926	1.19287	-1.56393
fma--proHEST	-0.20274	0.19160	-0.59418
fma--proH	-0.15480	0.25126	-0.55369
fma--ast	0.03366	0.76637	-0.69474
sph--ast	0.13044	0.90582	-0.66584
ast--nas	0.19077	0.66847	-0.28571

fma--brg	0.20850	0.92251	-0.53734
ast--brg	0.27329	1.28367	-0.72362
zygom--proHEST	0.44444	1.07919	-0.14252
ast--proHEST	0.47857	1.08450	-0.11762
sph--lam	0.48561	1.13574	-0.15376
ast--proH	0.50347	1.11892	-0.09248
zygom--proH	0.51208	1.13361	-0.06904
sph--brg	1.30864	2.31952	0.30450

Fluctuating asymmetrics WITHOUT accounting for DA, unsorted:

		Confidence interval	
	Mean(L-R)	Upper	Lower
zygom--fma	1.42312	1.70899	1.16009
zygom--sph	2.93246	3.71319	2.24173
zygom--ast	2.09485	2.60440	1.62376
fma--sph	2.40321	3.16905	1.74104
fma--ast	1.83568	2.25276	1.42301
sph--ast	2.05835	2.46677	1.68556
zygom--proHEST	1.45952	1.85468	1.08990
zygom--proH	1.50684	1.89969	1.14317
zygom--nas	1.72751	2.16695	1.31514
zygom--brg	1.88192	2.46715	1.31240
zygom--lam	1.48862	1.84945	1.15289
zygom--ops	1.48410	1.92538	1.08509

```
fma--proHEST     0.91263    1.15386    0.68858

fma--proH        0.93838    1.19512    0.70625

fma--nas         1.40177    1.82378    1.00943

fma--brg         1.84632    2.35416    1.37783

fma--lam         1.28008    1.60361    0.97336

fma--ops         1.51364    1.96702    1.10493

sph--proHEST     2.65358    3.36050    2.02414

sph--proH        2.64310    3.35000    2.01737

sph--nas         2.43041    3.04312    1.82925

sph--brg         2.73532    3.36021    2.16194

sph--lam         1.60310    2.00400    1.21167

sph--ops         2.21995    2.78409    1.72556

ast--proHEST     1.54681    1.98910    1.14090

ast--proH        1.56590    2.01257    1.15136

ast--nas         1.06863    1.37789    0.77802

ast--brg         2.32267    2.96097    1.71406

ast--lam         3.47659    4.35666    2.65179

ast--ops         1.96393    2.55049    1.45038


Fluctuating asymmetrics WITHOUT accounting for DA, sorted:

                          Confidence interval
                 Mean|L-R|    Upper      Lower
fma--proHEST     0.91263    1.15386    0.68858
```

fma--proH	0.93838	1.19512	0.70625
ast--nas	1.06863	1.37789	0.77802
fma--lam	1.28008	1.60361	0.97336
fma--nas	1.40177	1.82378	1.00943
zygom--fma	1.42312	1.70899	1.16009
zygom--proHEST	1.45952	1.85468	1.08990
zygom--ops	1.48410	1.92538	1.08509
zygom--lam	1.48862	1.84945	1.15289
zygom--proH	1.50684	1.89969	1.14317
fma--ops	1.51364	1.96702	1.10493
ast--proHEST	1.54681	1.98910	1.14090
ast--proH	1.56590	2.01257	1.15136
sph--lam	1.60310	2.00400	1.21167
zygom--nas	1.72751	2.16695	1.31514
fma--ast	1.83568	2.25276	1.42301
fma--brg	1.84632	2.35416	1.37783
zygom--brg	1.88192	2.46715	1.31240
ast--ops	1.96393	2.55049	1.45038
sph--ast	2.05835	2.46677	1.68556
zygom--ast	2.09485	2.60440	1.62376
sph--ops	2.21995	2.78409	1.72556
ast--brg	2.32267	2.96097	1.71406

fma--sph	2.40321	3.16905	1.74104
sph--nas	2.43041	3.04312	1.82925
sph--proH	2.64310	3.35000	2.01737
sph--proHEST	2.65358	3.36050	2.02414
sph--brg	2.73532	3.36021	2.16194
zygom--sph	2.93246	3.71319	2.24173
ast--lam	3.47659	4.35666	2.65179

Fluctuating asymmetrics ACCOUNTING for DA, unsorted:

		Confidence interval	
	Mean(L-R)	Upper	Lower
zygom--fma	1.16372	1.44108	0.84363
zygom--sph	2.63726	3.28140	1.92202
zygom--ast	2.14632	2.66377	1.58702
fma--sph	2.40725	3.05725	1.74109
fma--ast	1.83693	2.18887	1.39460
sph--ast	2.05426	2.39416	1.64057
zygom--proHEST	1.41062	1.79429	1.02781
zygom--proH	1.45544	1.80478	1.07211
zygom--nas	1.69942	2.05734	1.24706
zygom--brg	1.86247	2.39791	1.29332
zygom--lam	1.38780	1.65173	1.07994
zygom--ops	1.42235	1.73401	1.06137
fma--proHEST	0.88609	1.12223	0.65995

```
fma--proH       0.91029    1.17415    0.68034

fma--nas        1.44625    1.81339    0.99963

fma--brg        1.79226    2.29396    1.22974

fma--lam        1.27965    1.57021    0.96279

fma--ops        1.48508    1.83279    1.08464

sph--proHEST     2.55600    3.24677    1.89050

sph--proH       2.58302    3.26938    1.91428

sph--nas        2.44814    2.99658    1.82581

sph--brg        2.42990    3.01130    1.84243

sph--lam        1.61854    1.94512    1.19766

sph--ops        2.15857    2.63452    1.60001

ast--proHEST     1.51536    1.93064    1.12215

ast--proH       1.53023    1.95557    1.13426

ast--nas        1.08503    1.37060    0.77010

ast--brg        2.33287    2.95102    1.65062

ast--lam        3.48471    4.28047    2.58406

ast--ops        1.97301    2.52196    1.38022


Fluctuating asymmetrics ACCOUNTING for DA, sorted:

                       Confidence interval
               Mean|(L-R)-DA|    Upper      Lower
fma--proHEST     0.88609    1.12223    0.65995

fma--proH       0.91029    1.17415    0.68034
```

ast--nas	1.08503	1.37060	0.77010
zygom--fma	1.16372	1.44108	0.84363
fma--lam	1.27965	1.57021	0.96279
zygom--lam	1.38780	1.65173	1.07994
zygom--proHEST	1.41062	1.79429	1.02781
zygom--ops	1.42235	1.73401	1.06137
fma--nas	1.44625	1.81339	0.99963
zygom--proH	1.45544	1.80478	1.07211
fma--ops	1.48508	1.83279	1.08464
ast--proHEST	1.51536	1.93064	1.12215
ast--proH	1.53023	1.95557	1.13426
sph--lam	1.61854	1.94512	1.19766
zygom--nas	1.69942	2.05734	1.24706
fma--brg	1.79226	2.29396	1.22974
fma--ast	1.83693	2.18887	1.39460
zygom--brg	1.86247	2.39791	1.29332
ast--ops	1.97301	2.52196	1.38022
sph--ast	2.05426	2.39416	1.64057
zygom--ast	2.14632	2.66377	1.58702
sph--ops	2.15857	2.63452	1.60001
ast--brg	2.33287	2.95102	1.65062
fma--sph	2.40725	3.05725	1.74109

sph--brg	2.42990	3.01130	1.84243
sph--nas	2.44814	2.99658	1.82581
sph--proHEST	2.55600	3.24677	1.89050
sph--proH	2.58302	3.26938	1.91428
zygom--sph	2.63726	3.28140	1.92202
ast--lam	3.48471	4.28047	2.58406

8.9 Post-Cranial Metric T-Test (Paired Two Samples for Means) Output

Humerus, Maximum Length

	Max Length (L/R) Session 1	*Max Length (L/R) Session 2*
Mean	304.25	304.2
Variance	279.1	276.2
Observations	30	30
Pearson Correlation	0.999909784	
Hypothesized Mean Difference	0	
df	29	
t Stat	1.139520716	
P(T<=t) one-tail	0.131905561	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.263811122	
t Critical two-tail	2.045229642	

Humerus, Maximum Midshaft Diameter

	Max Mid Dia (L/R) Session 1	*Max Mid Dia (L/R) Session 2*
Mean	21.57	21.60
Variance	2.50	2.46
Observations	35	35
Pearson Correlation	0.993960534	
Hypothesized Mean Difference	0	
df	34	
t Stat	-0.983369963	
P(T<=t) one-tail	0.166185863	
t Critical one-tail	1.690924255	
P(T<=t) two-tail	0.332371725	
t Critical two-tail	2.032244509	

Humerus, Minimum Midshaft Diameter

	Min Mid Dia (L/R) Session 1	*Min Mid Dia (L/R) Session 2*
Mean	15.34885714	15.35028571
Variance	1.723316303	1.767926387
Observations	35	35
Pearson Correlation	0.998665983	
Hypothesized Mean Difference	0	
df	34	
t Stat	-0.120221979	
P(T<=t) one-tail	0.452507468	
t Critical one-tail	1.690924255	
P(T<=t) two-tail	0.905014936	
t Critical two-tail	2.032244509	

Humerus, Epicondylar Breadth

	Max Vert Dia (L/R) Session 1	*Max Vert Dia (L/R) Session 2*
Mean	41.84	41.83
Variance	16.74	16.71
Observations	31	31
Pearson Correlation	0.994888377	
Hypothesized Mean Difference	0	
df	30	
t Stat	0.095563697	
P(T<=t) one-tail	0.462251301	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	0.924502602	
t Critical two-tail	2.042272456	

Humerus, Head Maximum Vertical Diameter

	Epi Breadth (L/R) Session 1	*Epi Breadth (L/R) Session 2*
Mean	56.26	56.26
Variance	15.44	15.42
Observations	33	33
Pearson Correlation	0.999805093	
Hypothesized Mean Difference	0	
df	32	
t Stat	0.067267279	
P(T<=t) one-tail	0.473393735	
t Critical one-tail	1.693888748	
P(T<=t) two-tail	0.946787469	
t Critical two-tail	2.036933343	

Radius, Maximum Length

	Max Length (L/R) Session 1	*Max Length (L/R) 2nd Session*
Mean	234.2333333	234.1833333
Variance	112.9091954	110.8531609
Observations	30	30
Pearson Correlation	0.999013527	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.570826328	
P(T<=t) one-tail	0.286257282	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.572514564	
t Critical two-tail	2.045229642	

Radius, Sagittal Midshaft Diameter

	AP Mid Dia (L/R) Session 1	*AP Mid Dia (L/R) 2nd Session*
Mean	11.08382353	11.16705882
Variance	0.923400089	0.767281996
Observations	34	34
Pearson Correlation	0.975818703	
Hypothesized Mean Difference	0	
df	33	
t Stat	-2.216847574	
P(T<=t) one-tail	0.016818028	
t Critical one-tail	1.692360309	
P(T<=t) two-tail	0.033636056	
t Critical two-tail	2.034515297	

Radius, Transverse Midshaft Diameter

	ML Mid Dia (L/R) Session 1	*ML Mid Dia (L/R) 2nd Session*
Mean	14.80117647	14.83382353
Variance	1.718531907	1.748739483
Observations	34	34
Pearson Correlation	0.979701028	
Hypothesized Mean Difference	0	
df	33	
t Stat	-0.716894418	
P(T<=t) one-tail	0.239241446	
t Critical one-tail	1.692360309	
P(T<=t) two-tail	0.478482893	
t Critical two-tail	2.034515297	

Radius, Radiocarpal Surface Medial – Lateral

	RCML (L/R) Session 1	*RCML (L/R) 2nd Session*
Mean	25.535	25.57
Variance	2.253341935	2.251116129
Observations	32	32
Pearson Correlation	0.981455051	
Hypothesized Mean Difference	0	
df	31	
t Stat	-0.68502676	
P(T<=t) one-tail	0.249208765	
t Critical one-tail	1.695518783	
P(T<=t) two-tail	0.498417529	
t Critical two-tail	2.039513446	

Femur, Maximum (Morphological) Length

	Max Length (L/R) Session 1	*Max Length (L/R) 2nd Session*
Mean	433.9666667	433.8333333
Variance	420.2402299	421.6436782
Observations	30	30
Pearson Correlation	0.999879878	
Hypothesized Mean Difference	0	
df	29	
t Stat	2.283305312	
P(T<=t) one-tail	0.0149625	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.029924999	
t Critical two-tail	2.045229642	

Femur, Bicondylar (Physiological) Length

	Bicond Length (L/R) Session 1	*Bicond Length (L/R) 2nd Session*
Mean	429.4833333	429.4833333
Variance	443.8704023	444.2324713
Observations	30	30
Pearson Correlation	0.999883601	
Hypothesized Mean Difference	0	
df	29	
t Stat	0	
P(T<=t) one-tail	0.5	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	1	
t Critical two-tail	2.045229642	

Femur, Midshaft Anterio-posterior Diameter

	Mid AP Dia (L/R) Session 1	*Mid AP Dia (L/R) 2nd Session*
Mean	27.91290323	27.88387097
Variance	3.706974624	3.536611183
Observations	31	31
Pearson Correlation	0.993413224	
Hypothesized Mean Difference	0	
df	30	
t Stat	0.725058641	
P(T<=t) one-tail	0.237016989	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	0.474033979	
t Critical two-tail	2.042272456	

Femur, Midshaft Transverse Diameter

	Mid ML Dia (L/R) Session 1	*Mid ML Dia (L/R) 2nd Session*
Mean	26.02033333	26.01766667
Variance	3.447561954	3.475859885
Observations	30	30
Pearson Correlation	0.99483055	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.077143264	
P(T<=t) one-tail	0.469519682	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.939039363	
t Critical two-tail	2.045229642	

Femur, Epicondylar Breadth

	Epi Breadth (L/R) Session 1	*Epi Breadth (L/R) 2nd Session*
Mean	75.63461538	75.57692308
Variance	19.29115385	20.11384615
Observations	26	26
Pearson Correlation	0.999036727	
Hypothesized Mean Difference	0	
df	25	
t Stat	1.363636364	
P(T<=t) one-tail	0.092417998	
t Critical one-tail	1.708140761	
P(T<=t) two-tail	0.184835996	
t Critical two-tail	2.059538553	

Femur, Femoral Condyles Medial – Lateral

	FCML (L/R) Session 1	*FCML (L/R) 2nd Session*
Mean	70.07153846	70.58846154
Variance	26.7587641	23.16789744
Observations	13	13
Pearson Correlation	0.987884104	
Hypothesized Mean Difference	0	
df	12	
t Stat	-2.1774709	
P(T<=t) one-tail	0.025060137	
t Critical one-tail	1.782287556	
P(T<=t) two-tail	0.050120275	
t Critical two-tail	2.17881283	

Tibia, Tibial Length

	Lat Cond - Mal (L/R) Session 1	*Lat Cond - Mal (L/R) 2nd Session*
Mean	359.9714286	359.6285714
Variance	597.455042	597.6521008
Observations	35	35
Pearson Correlation	0.999645979	
Hypothesized Mean Difference	0	
df	34	
t Stat	3.11832206	
P(T<=t) one-tail	0.001845406	
t Critical one-tail	1.690924255	
P(T<=t) two-tail	0.003690812	
t Critical two-tail	2.032244509	

Tibia, Proximal Epiphyseal Breadth

	Prox Epi Breadth (L/R) Session 1	*Prox Epi Breadth (L/R) 2nd Session*
Mean	71.79032258	71.59677419
Variance	24.06290323	25.87365591
Observations	31	31
Pearson Correlation	0.983065064	
Hypothesized Mean Difference	0	
df	30	
t Stat	1.15009518	
P(T<=t) one-tail	0.12959521	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	0.25919042	
t Critical two-tail	2.042272456	

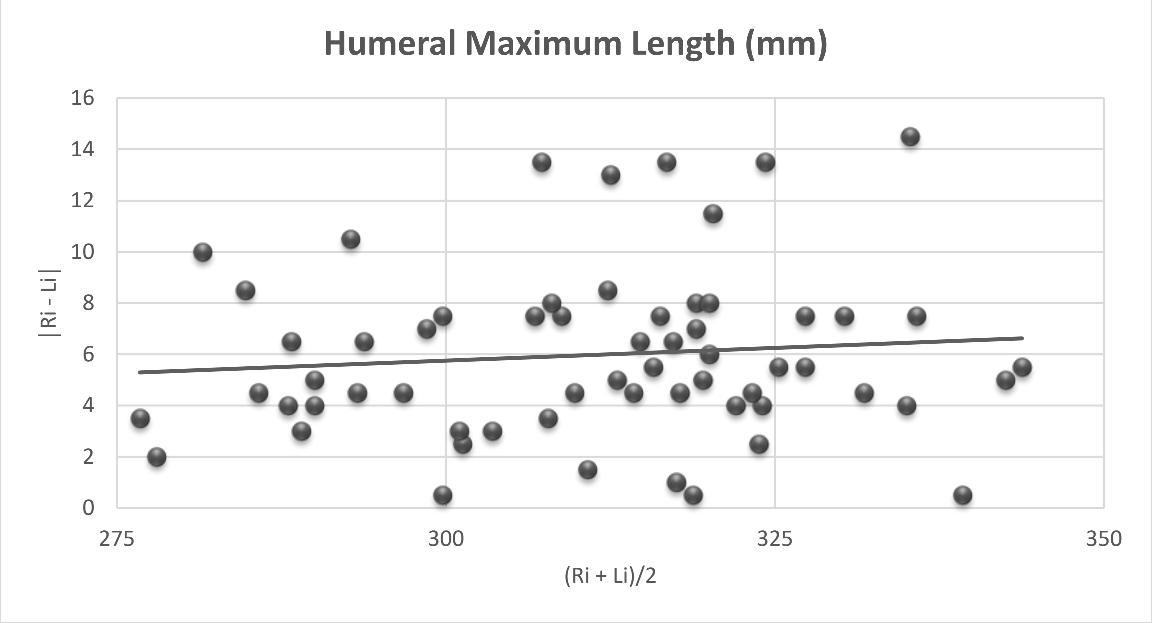
Tibia, Distal Epiphyseal Breadth

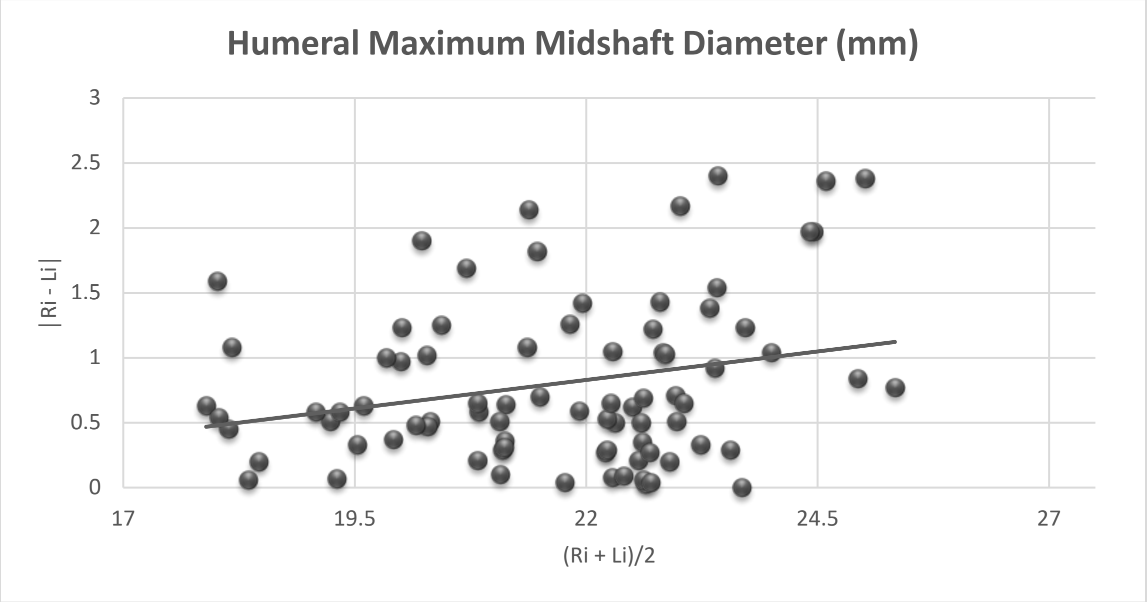
	Dis Epi Breadth (L/R) Session 1	*Dis Epi Breadth (L/R) 2nd Session*
Mean	45.26666667	45.31666667
Variance	12.71954023	13.12902299
Observations	30	30
Pearson Correlation	0.992553932	
Hypothesized Mean Difference	0	
df	29	
t Stat	-0.619079891	
P(T<=t) one-tail	0.270348487	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.540696974	
t Critical two-tail	2.045229642	

Tibia, Tibiotalar Surface Anterio-Posterior

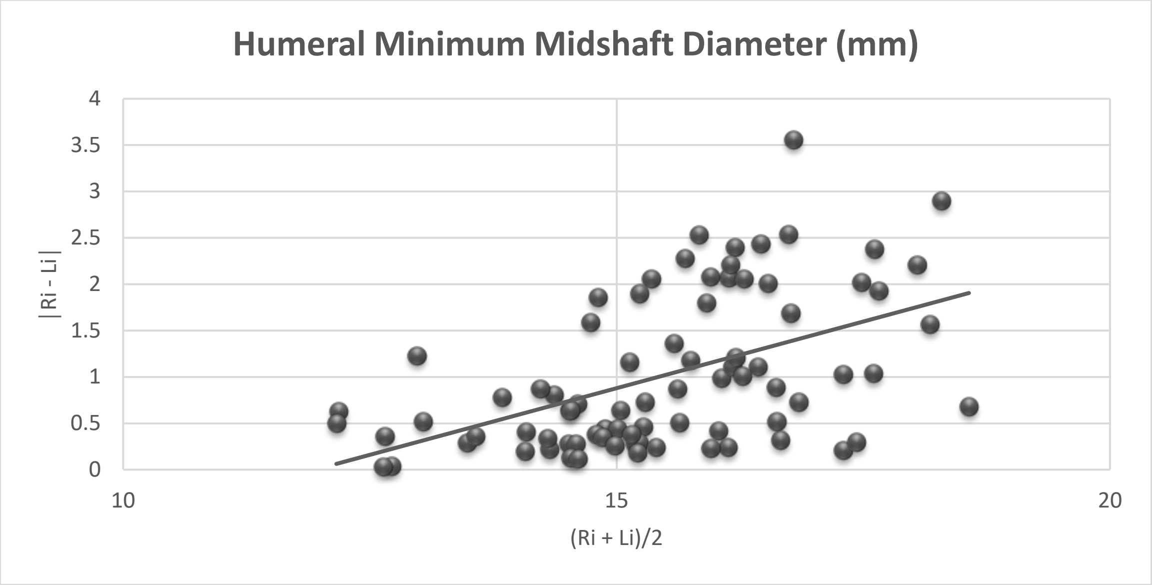
	TTAP (L/R) Session 1	*TTAP (L/R) 2nd Session*
Mean	25.50243243	25.45945946
Variance	7.63263003	7.301005255
Observations	37	37
Pearson Correlation	0.987697736	
Hypothesized Mean Difference	0	
df	36	
t Stat	0.603898352	
P(T<=t) one-tail	0.274849027	
t Critical one-tail	1.688297714	
P(T<=t) two-tail	0.549698054	
t Critical two-tail	2.028094001	

8.10 Bivariate Plots of (|Ri-Li|) and (Ri+Li)/2 for Post-cranial Metrics

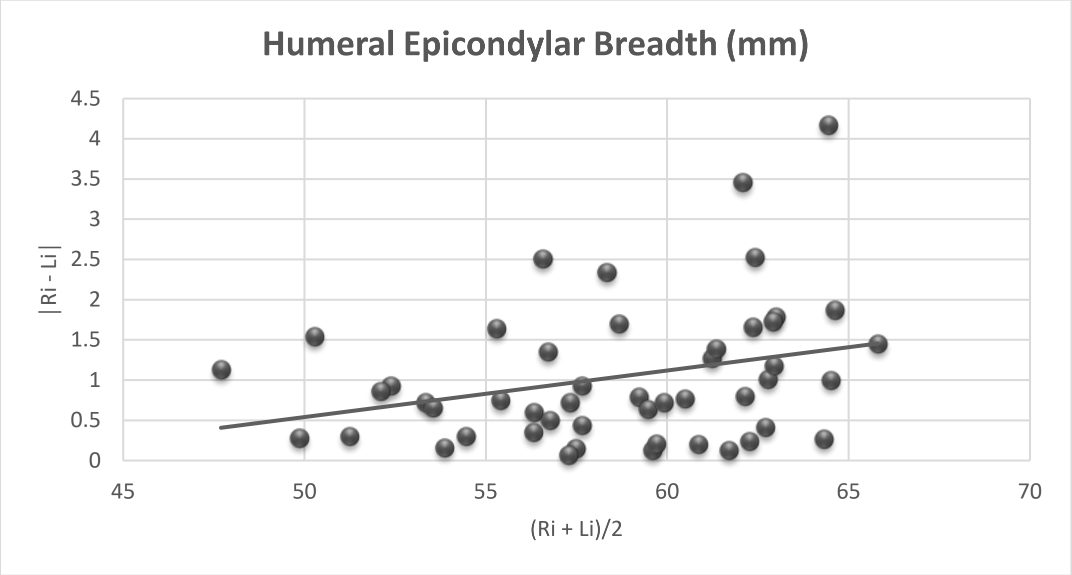




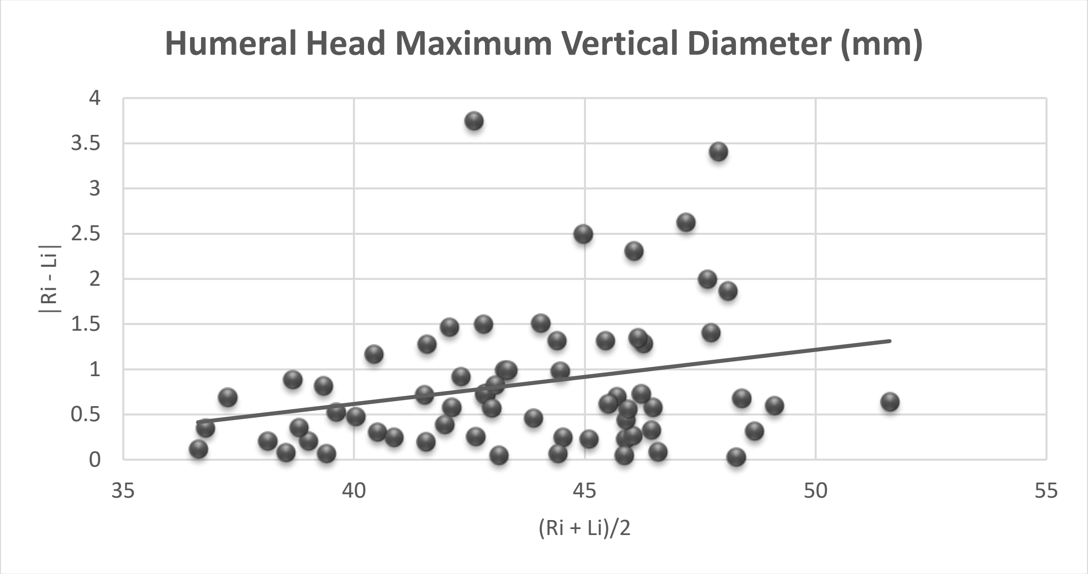
3

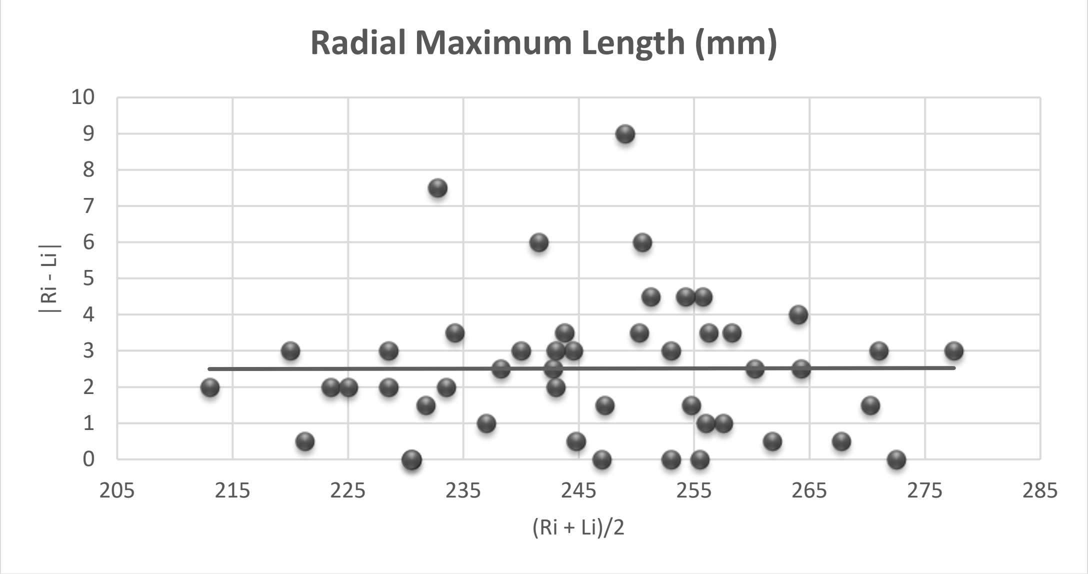


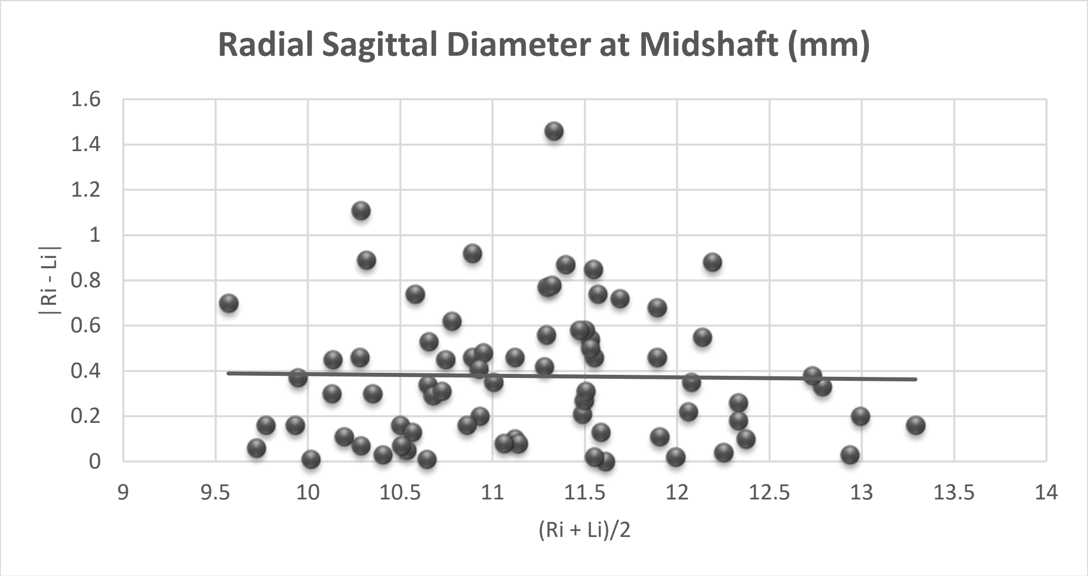
Humeral Minimum Midshaft Diameter (mm)
4
3.5
3
2.5
2
1.5
1
0.5
0
|Ri - Li|
10
15
20
(Ri + Li)/2

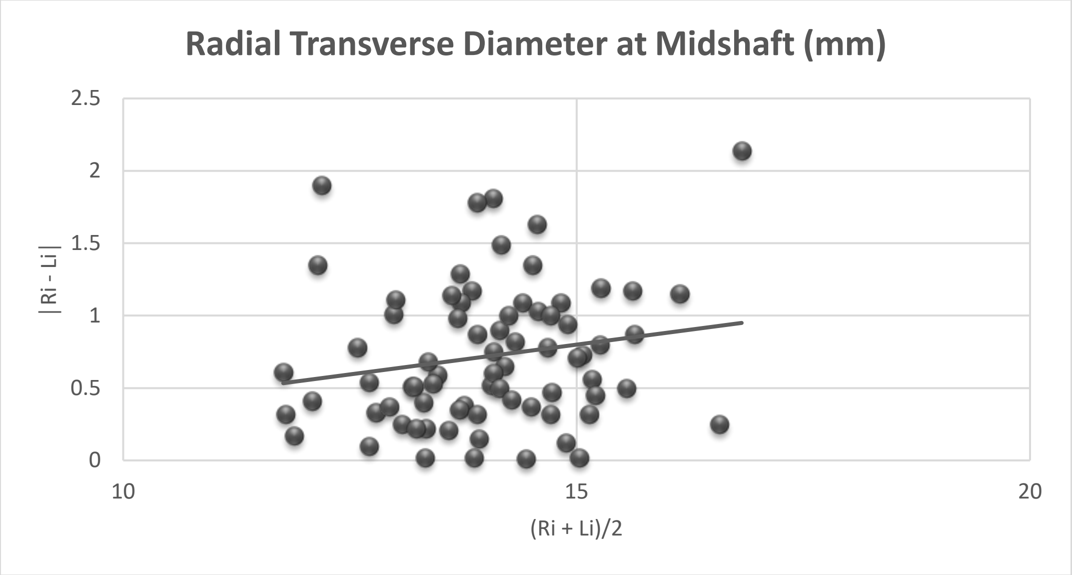


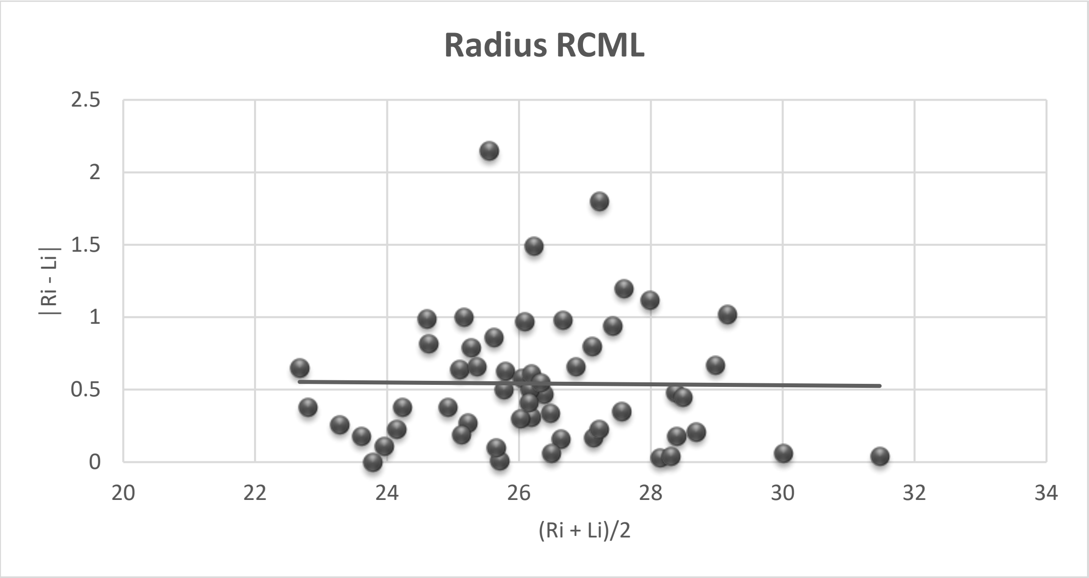
Humeral Epicondylar Breadth (mm)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
|Ri - Li|
45
50
55
60
65
70
(Ri + Li)/2

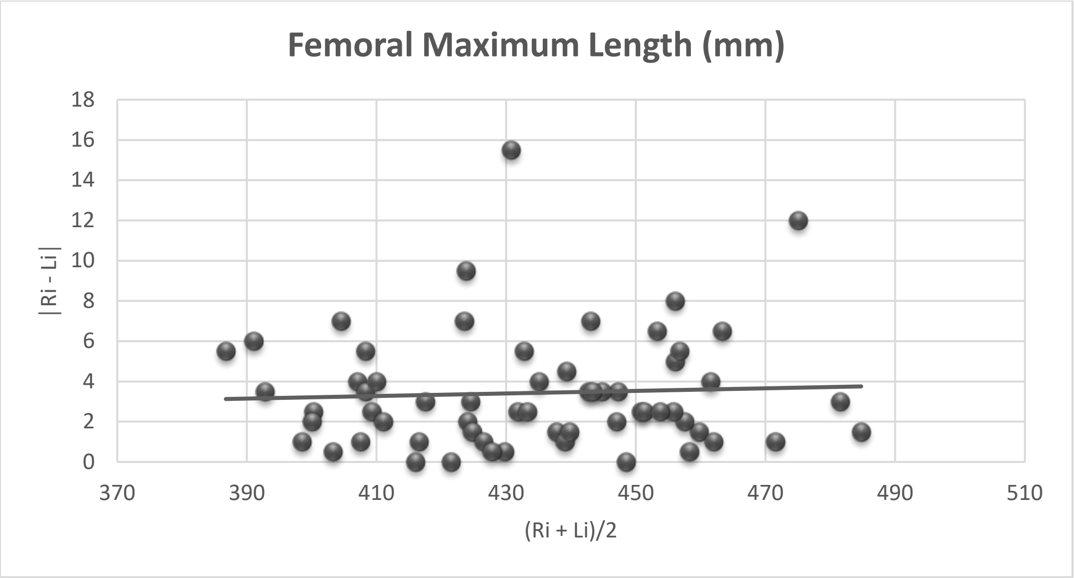

Humeral Head Maximum Vertical Diameter (mm)
|Ri - Li|
0
0.5
1
1.5
2
2.5
3
3.5
4
35
40
45
50
55
(Ri + Li)/2

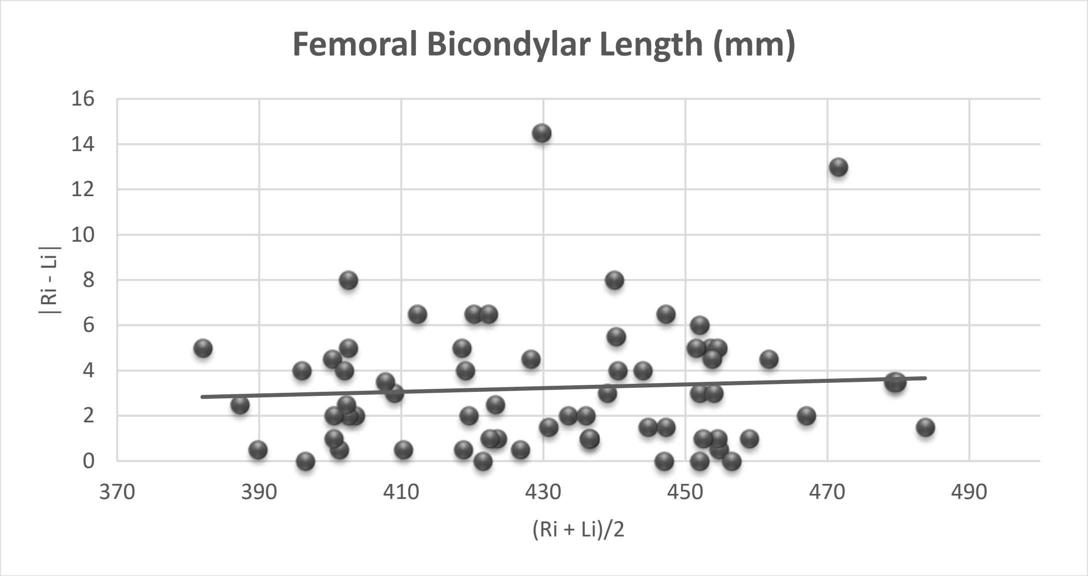

Radial Maximum Length (mm)
|Ri - Li|
0
1
2
3
4
5
6
7
8
9
10
205
215
225
235
245
255
265
275
285
(Ri + Li)/2

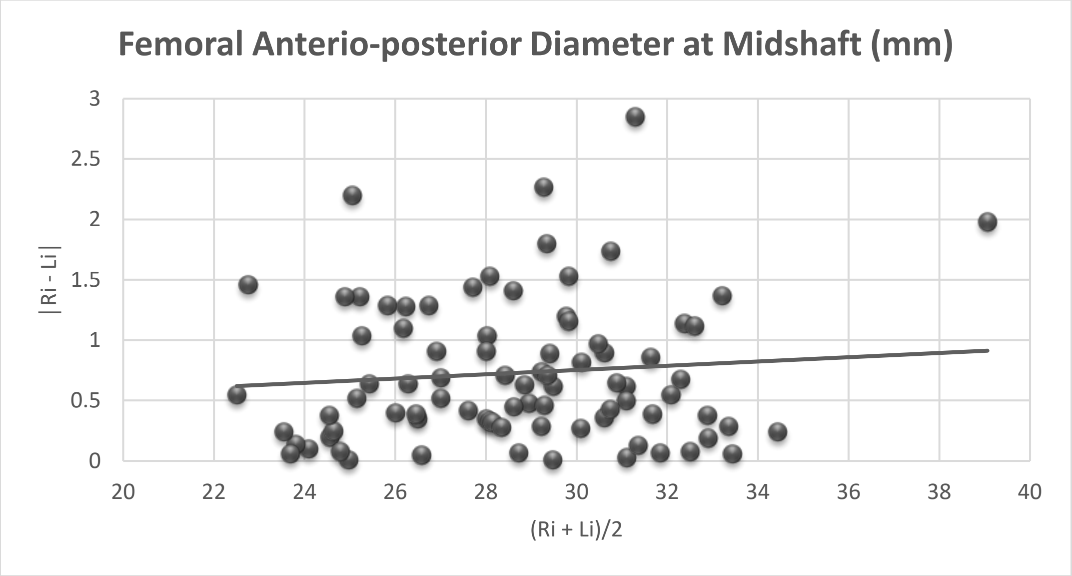

Radial Sagittal Diameter at Midshaft (mm)
|Ri - Li|
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
9
9.5
10
10.5
11
11.5
12
12.5
13
13.5
14
(Ri + Li)/2

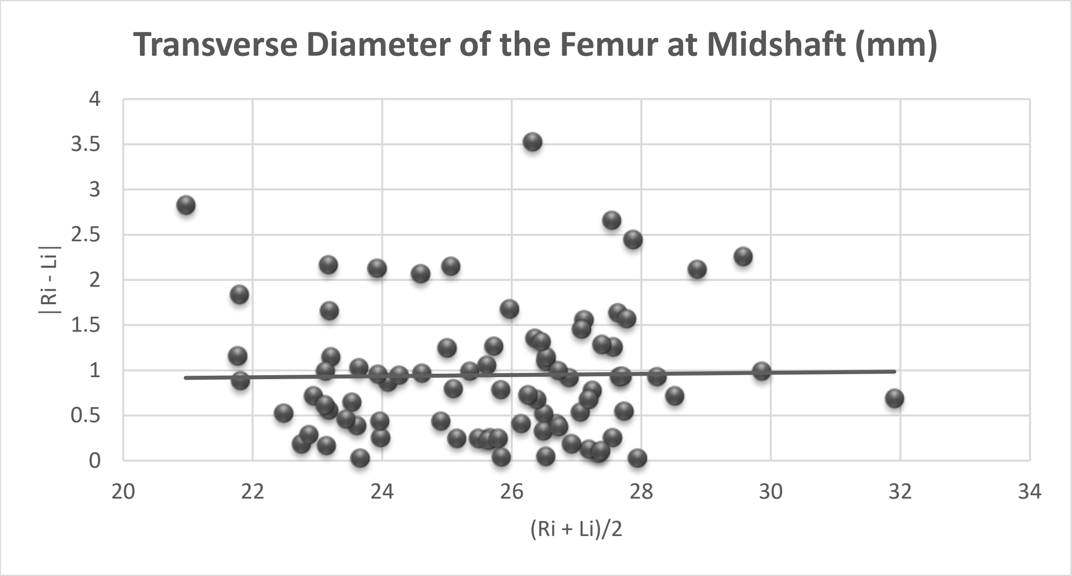

Radial Transverse Diameter at Midshaft (mm)
|Ri - Li|
2.5
2
1.5
1
0.5
0
10
15
20
(Ri + Li)/2

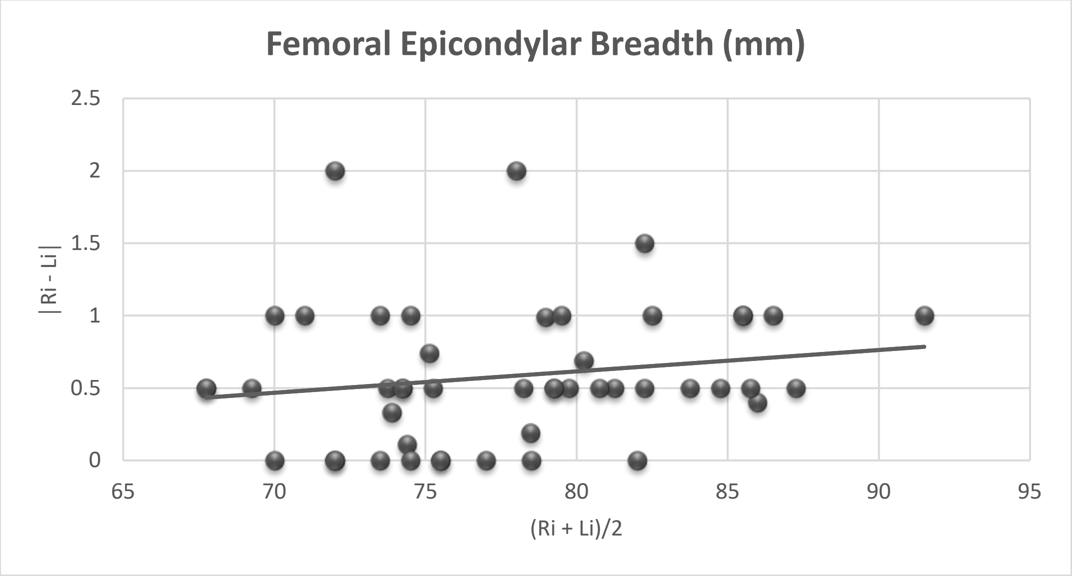

Radius RCML
2.5
2
1.5
1
0.5
0
|Ri - Li|
20
22
24
26
28
30
32
34
(Ri + Li)/2

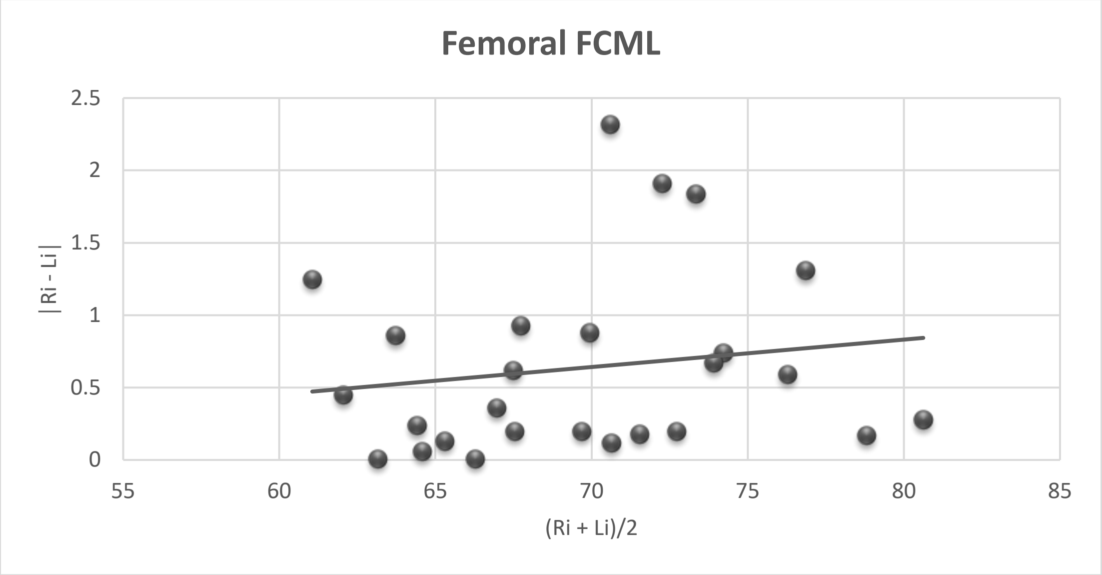

Femoral Maximum Length (mm)
18
16
14
12
10
8
6
4
2
0
|Ri - Li|
370
390
410
430
450
470
490
510
(Ri + Li)/2

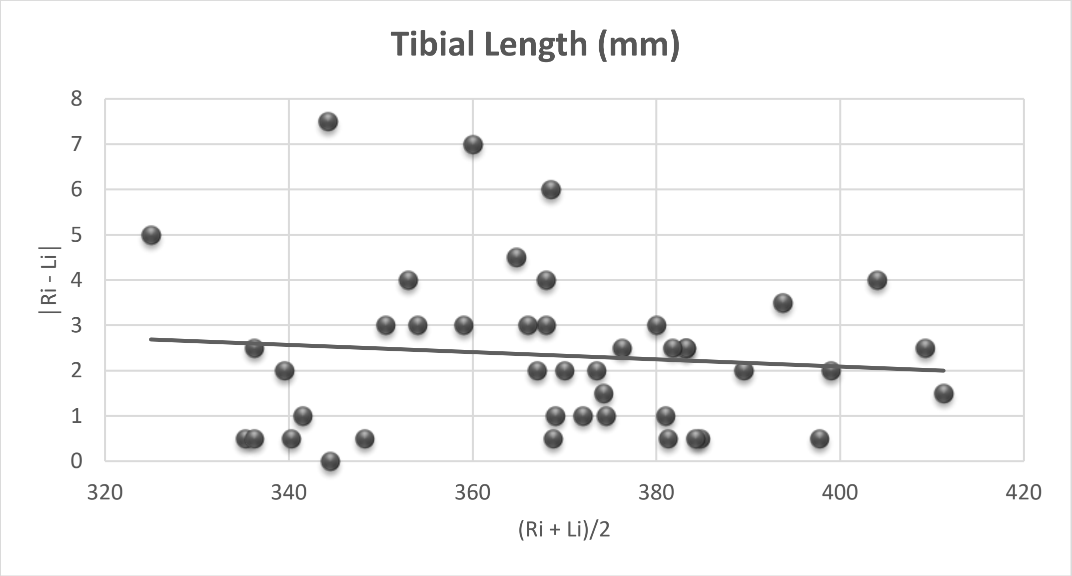

Femoral Bicondylar Length (mm)
16
14
12
10
8
6
4
2
0
|Ri - Li|
370
390
410
430
450
470
490
(Ri + Li)/2

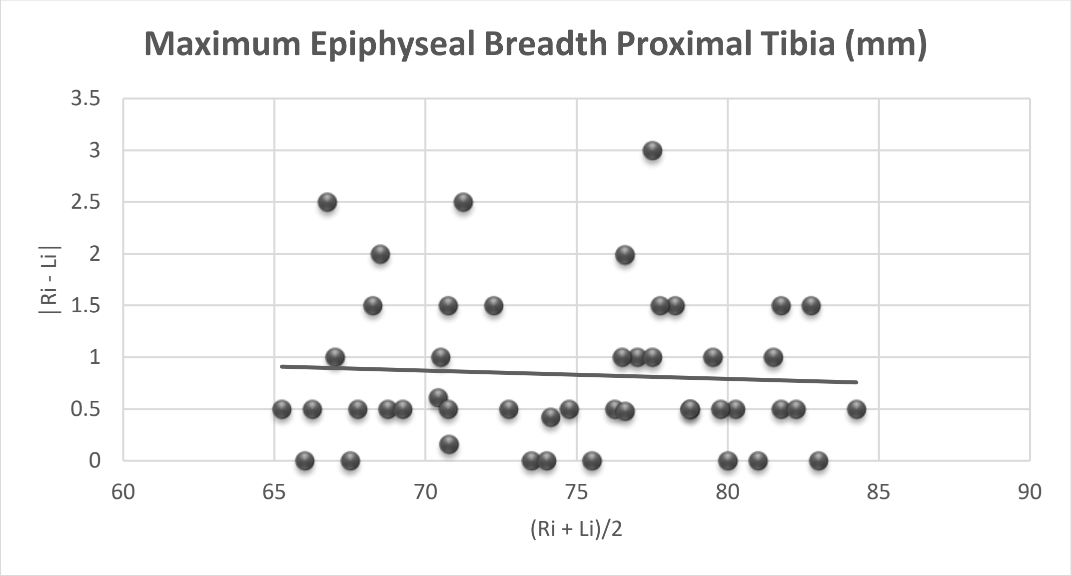

Femoral Anterio-posterior Diameter at Midshaft (mm)
3
2.5
2
1.5
1
0.5
0
|Ri - Li|
20
22
24
26
28
30
32
34
36
38
40
(Ri + Li)/2

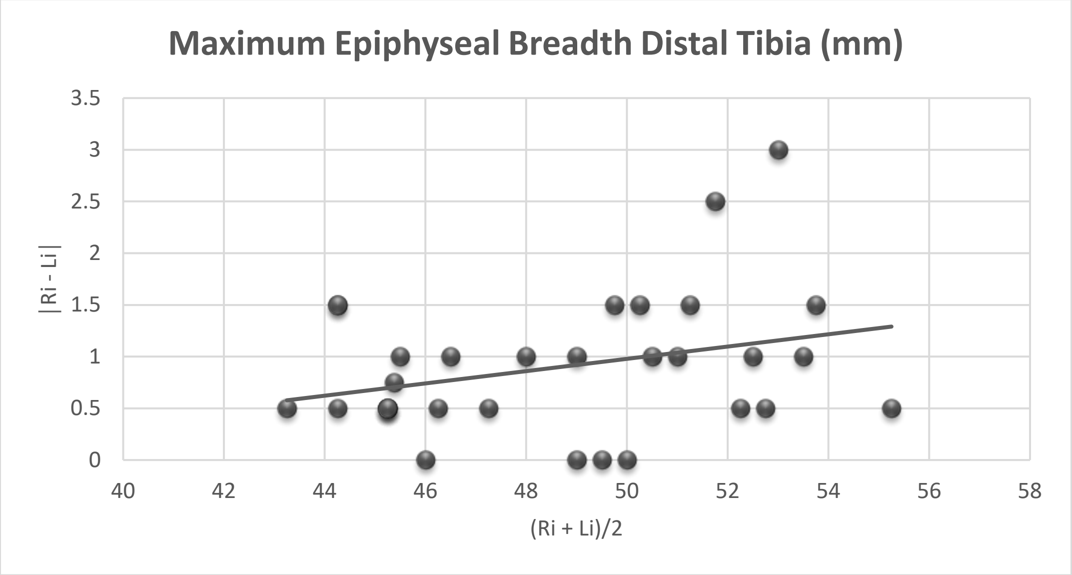

Transverse Diameter of the Femur at Midshaft (mm)
|Ri - Li|
4
3.5
3
2.5
2
1.5
1
0.5
0
20
22
24
26
28
30
32
34
(Ri + Li)/2

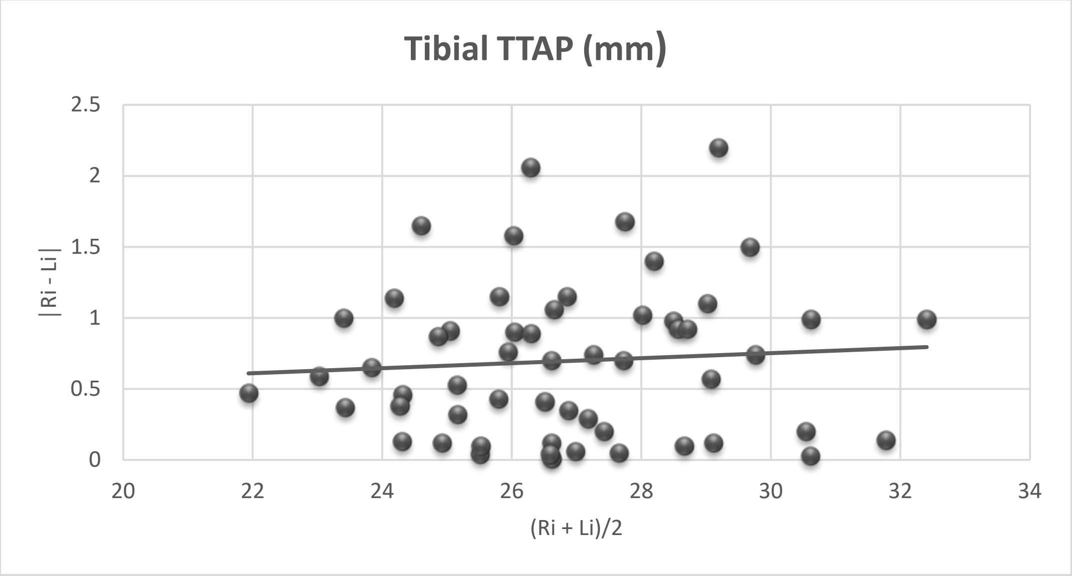

Femoral Epicondylar Breadth (mm)
|Ri - Li|
2.5
2
1.5
1
0.5
0
65
70
75
80
85
90
95
(Ri + Li)/2


Femoral FCML
2.5
2
1.5
1
0.5
0
|Ri - Li|
55
60
65
70
75
80
85
(Ri + Li)/2


Tibial Length (mm)
8
7
6
5
4
3
2
1
0
|Ri - Li|
320
340
360
380
400
420
(Ri + Li)/2


Maximum Epiphyseal Breadth Proximal Tibia (mm)
3.5
3
2.5
2
1.5
1
0.5
0
|Ri - Li|
60
65
70
75
80
85
90
(Ri + Li)/2


Maximum Epiphyseal Breadth Distal Tibia (mm)
3.5
3
2.5
2
1.5
1
0.5
0
|Ri - Li|
40
42
44
46
48
50
52
54
56
58
(Ri + Li)/2



Tibial TTAP (mm)
2.5
2
1.5
1
0.5
0
|Ri - Li|
20
22
24
26
28
30
32
34
(Ri + Li)/2

8.11 Post-Cranial Metric F-Tests (Two-Sample for Variances)

F-Test Output for Humeral Maximum Length

	PCC	*EC*
Mean	6.08333333	4.9
Variance	15.7721	14.8862
Observations	18	30
df	17	29
F	1.05950824	
P(F<=f) one-tail	0.43232868	
F Critical one-tail	1.98928434	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Humeral Maximum Midshaft Diameter

	EC	*PCC*
Mean	0.782894737	0.487407407
Variance	0.7422	0.4909
Observations	38	27
df	37	26
F	1.511916183	
P(F<=f) one-tail	0.136799351	
F Critical one-tail	1.865107448	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Humeral Minimum Midshaft Diameter

	EC	*PCC*
Mean	0.9387	0.6470
Variance	1.3278	1.1277
Observations	38	27
df	37	26
F	1.177380549	
P(F<=f) one-tail	0.335754478	
F Critical one-tail	1.865107448	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Humeral Epicondylar Breadth

	PCC	*EC*
Mean	0.60176471	0.495
Variance	1.6148	0.8238
Observations	17	20
df	16	19
F	1.96001469	
P(F<=f) one-tail	0.08125078	
F Critical one-tail	2.214895	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Humeral Head Maximum Diameter

	PCC	*EC*
Mean	0.6515	0.75
Variance	0.965719	0.950572
Observations	20	30
df	19	29
F	1.015934	
P(F<=f) one-tail	0.473428	
F Critical one-tail	1.958146	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Radial Maximum Length

	PCC	*EC*
Mean	1.175	2.394736842
Variance	5.770394737	5.266081871
Observations	20	19
df	19	18
F	1.095766241	
P(F<=f) one-tail	0.424798088	
F Critical one-tail	2.203297387	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Radial Transverse Diameter at Midshaft

	PCC	*EC*
Mean	0.5204	0.34
Variance	0.623804	0.4637394
Observations	25	34
df	24	33
F	1.3451607	
P(F<=f) one-tail	0.212035	
F Critical one-tail	1.8528139	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Radius RCML

	EC	*PCC*
Mean	0.551364	0.234091
Variance	0.440289	0.245254
Observations	22	22
df	21	21
F	1.795236	
P(F<=f) one-tail	0.094138	
F Critical one-tail	2.084189	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Femoral Bicondylar Length

	EC	*PCC*
Mean	-1.84091	-0.93103
Variance	33.7711	10.1915
Observations	22	29
df	21	28
F	3.313653	
P(F<=f) one-tail	0.001737	
F Critical one-tail	1.946222	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Anterior-posterior Diameter at Midshaft

	PCC	*EC*
Mean	-0.27303	-0.09486
Variance	0.785934	0.659414
Observations	33	35
df	32	34
F	1.191868	
P(F<=f) one-tail	0.307212	
F Critical one-tail	1.783043	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output Transverse Diameter of Femoral Midshaft

	PCC	*EC*
Mean	-0.64061	-0.37771
Variance	1.261837	0.684918
Observations	33	35
df	32	34
F	1.842318	
P(F<=f) one-tail	0.04123	
F Critical one-tail	1.783043	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Femoral Epicondylar Breadth

	EC	*PCC*
Mean	-0.22444	-0.05667
Variance	0.655779	0.520043
Observations	18	21
df	17	20
F	1.261009	
P(F<=f) one-tail	0.307092	
F Critical one-tail	2.166701	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for FCML

	PCC	*EC*
Mean	0.515	0.018462
Variance	1.274561	0.346197
Observations	10	13
df	9	12
F	3.681602	
P(F<=f) one-tail	0.01949	
F Critical one-tail	2.796375	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Maximum Epiphyseal Breadth Proximal Tibia

	EC	*PCC*
Mean	0.883889	0.279524
Variance	1.254343	0.698085
Observations	18	21
df	17	20
F	1.796835	
P(F<=f) one-tail	0.105102	
F Critical one-tail	2.166701	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Maximum Epiphyseal Breadth Distal Tibia

	EC	*PCC*
Mean	0.214286	0.446429
Variance	1.489011	1.001717
Observations	14	14
df	13	13
F	1.486459	
P(F<=f) one-tail	0.242343	
F Critical one-tail	2.576927	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Output for Tibial TTAP

	ECC	*PCC*
Mean	-0.2625	0.1675
Variance	0.840399	0.759445652
Observations	20	24
df	19	23
F	1.106595	
P(F<=f) one-tail	0.404154	
F Critical one-tail	2.060754	

Note: EC = Extended Coalescent, PCC = Post-Contact Coalescent

F-Test Two-Sample for Variances

	PCC	*EC*
Mean	0.5204	0.34
Variance	0.623804	0.4637394
Observations	25	34
df	24	33
F	1.3451607	
P(F<=f) one-tail	0.212035	
F Critical one-tail	1.8528139	

VITA

Mark Otto Beary was born on May 4, 1975 in Clarion, Pennsylvania. He received his Bachelors of Arts in Anthropology from Clarion University of Pennsylvania in 1998. In 1999, he was employed as a field archaeologist, conducting cultural resources management work on behalf of the Louis Berger Group, Inc. Over the course of the following three years, he surveyed and excavated at numerous archaeological sites throughout several New England, Mid-Atlantic and Mid-Western states. In the fall of 2002, he was accepted into the graduate program at Mercyhurst University and, in the summer of 2005, graduated with a Master's of Science in Forensic and Biological Anthropology. In the fall of that same year, Mark became a Ph.D. student at the University of Missouri, being admitted to candidacy in 2010.

During his time at the University of Missouri, Mark carried out research, taught numerous courses, and performed forensic consulting work for local law enforcement agencies. He coauthored publications and produced numerous forensic anthropology case reports. In the teaching realm, he served as an instructor for several classroom and online courses at the University of Missouri. In addition, he served as an adjunct faculty member at nearby Columbia College, teaching forensic anthropology for the Criminal Justice Department. In 2006, he began working with the Archaeometry Group at the University of Missouri Research Reactor (MURR). In 2010, he was promoted to Manager of the Analytical Chemistry Group and, in 2017, was further promoted to an Assistant Director position at the Research Reactor. Since 2010, Mark has also served as the consulting forensic anthropologist for the Boone County Medical Examiner's Office, located in Columbia, Missouri.