ABSTRACT

JONES, LAUREN BRITTANY. A Craniometric Analysis of English Skeletal Samples: Change and Continuity between the Iron Age and Post-Medieval time periods (400 BCE-1850 CE). (Under the direction of Dr. D. Troy Case and Dr. Ann H. Ross).

The degree of population variation in England is one usually discussed with reference to linguistic and historical sources. The influx of continental European influence between the Iron Age and the post-modern periods readily changed the culture of England, but the amount of biological change remains largely unknown. Utilizing a multivariate statistical approach, this study explores the biological variation between and among English groups from five time periods and twenty-two archaeological sites from between 400 BCE and 1850 CE.

At least thirty traditional inter-landmark distances (ILDs) were used to assess patterns of cranial morphological relatedness from a sample of approximately 1,268 individuals. Size and shape variables were calculated from these ILDs in order to study the latter without the confounding effects of size bias. These data were analyzed in SPSS, SAS, and the RMET R-matrix environment, from which Mahalanobis squared distances, canonical variates analyses (CVA), and *Fst* values were calculated for both time period and between site analyses.

Results from the D^2 matrices and CVAs illustrate that nearly all samples and time periods significantly differ from each other at the $p > .05$ level. Samples from the Iron Age and Anglo-Saxon time period are the most similar to each other, and most dissimilar to the medieval and post-medieval samples. The Romano-British sample is located between these paired groups, which suggests that periods of mass migrations are observable in the

bioarchaeological record. The medieval sample, which is comprised of individuals from sites dating to approximately 1050-1550 CE, is the most disparate. The eigenvalues also illustrate this variation with over 60% of the variation accounted for in the first two eigenvalues, which may indicate a morphologically or genetically distinct presence unobserved in the other time periods. If so, these results indicate that migrations into England did cause significant morphological cranial changes, especially during the Romano-British and medieval time periods.

A Craniometric Analysis of English Skeletal Samples: Change and Continuity between the Iron Age and Post-Medieval Time Periods (400 BCE- 1850 CE)

by
Lauren B. Jones

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Arts

Anthropology

Raleigh, North Carolina

2014

APPROVED BY:

Dr. Ann H. Ross Committee Co-Chair	Dr. D. Troy Case Committee Co-Chair

Dr. Chelsey Juarez

DEDICATION

For Mom and Dad, who didn’t think it was weird for me to want to dig up old stuff.

BIOGRAPHY

Lauren Jones is a Georgia native who has always considered ancient cultures her calling. After discovering archaeology in high school, Lauren went on to major in Anthropology and Classical Cultures at the University of Georgia, where she specialized in Roman and Celtic archaeology. Several trips abroad allowed her to study these cultures in situ, which ultimately led to her interest in bioarchaeology. Lauren is currently a candidate for the degree of Master of Arts in Anthropology at North Carolina State University.

ACKNOWLEDGMENTS

I cannot begin any acknowledgement section without first thanking the people who have supported me from the very beginning: my family. They are a constant source of encouragement, inspiration, and laughter, for which I am eternally grateful. I'd also like to thank my cohort, who has provided limitless entertainment and friendship these past two years.

I would like to extend my gratitude to Dr. C.K. Russell of Durham University for graciously allowing me to use the data from her dissertation. Also, to Dr. Rebecca Redfern and Jelena Bekvalac at the Museum of London's Centre for Human Bioarchaeology for allowing me access to the skeletal collections at the Museum, and for all of the wonderful advice.

Of course, I would not have been able to complete this thesis nor a graduate degree without the superb mentorship of my thesis committee: Dr. Troy Case, Dr. Ann Ross, and Dr. Chelsey Juarez at North Carolina State University. These three have given me opportunities I never dreamed of, and for that I will always be thankful. Specifically, I'd like to thank Dr. Troy Case for being a wonderful advisor and professor, and for taking the time to help me develop my professional career. Huge thanks go to Dr. Ann Ross, who first introduced me to the world of craniometrics and has been a constant source of inspiration and support throughout the past two years. Finally, I want to thank Dr. Chelsey Juarez for being incredibly supportive and never allowing me to accept less than the best for myself, and for giving me invaluable professional and personal advice.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The degree of population variation in England is one usually discussed with reference to archaeological, linguistic, and historical sources (Cunliffe 2005, de la Bedoyere 2010). The influx of Roman, Anglo-Saxon, and Norman influence during the last two centuries readily changed the culture of England, but the amount of biological change remains largely unknown. Utilizing a multivariate statistical approach, this thesis explores the biological variation among individuals from five different English time periods, ranging from the Iron Age (800 BCE-43 CE) to the post-medieval period (1550-1850 CE).

Craniometric measurements of human skeletal samples are integral to bioarchaeological analyses. Both genetic and environmental factors, such as geographic movement and climatic adaptation, can help explain craniometric variation in humans (Relethford 2004). Gene flow and natural selection are two of the largest influences on this variation, both of which are related to migration: geographic distance influences gene flow, whereby populations that are closer in terms of physical location are apt to be more genetically and phenotypically alike (Relethford 1994). Immigration to a new region can produce increased developmental plasticity in the juveniles of the founding population, caused by environmental change (Boas 1912, Roberts 1995). Over generations, population differences arise through natural selection, which create distinctly environmentally-adapted groups. Therefore, migration proves to be a major determinant of cranial morphology (Relethford 2004).

The British mainland has seen no less than five significant waves of migration since the end of the Iron Age (100 BCE-100 CE). Archaeologically, these are distinct time periods with evolving cultural norms that are incongruent. The peoples of the British Iron Age lived in farming communities in small settlements, building hillforts for visibility and protection (Cunliffe 2005). They were a self-sufficient population, which is not to say that they were isolated from the European mainland. Extensive trade patterns between England and the mainland are evidenced by the parallel development of material culture and settlement patterns of these two locations (Cunliffe 2005). With the arrival of the Romans in 43 CE, however, England experienced a significant shift in cultural norms and material culture.

Legions of Roman centurions introduced their own culture to England as they had in other locations such as Gaul and the Iberian Peninsula, in a process known as *romanitas*. In the first and second centuries, widespread trade routes were established as a result of the creation of an extensive road network in England. This network also brought money and Roman politics into the region (de la Bedoyere 2010). Architecture developed from simple to intricate. Brick and concrete buildings were erected anywhere with Roman influence, and many of these buildings were communal in nature. Dwellings were no longer arranged in small settlements; cities with large doma (Roman houses) became more numerous. Villas were erected in the countryside by Romans who did not live in the larger cities. Most importantly, however, the Romans introduced a new pool of genetic alleles to the British Isles (Ibeji 2011). Throughout the second, third, and fourth centuries CE, many native Britons adopted the Roman way of life. The beginning of the 5th century CE saw the end of payment for Roman legions in England, signifying the end of Roman rule on the island.

While Roman influence waned, influence from continental tribes, collectively known as the Anglo-Saxons, increased. European tribes settled largely in the area known today as England, and many more settled on the eastern coast than the western (Hills 2003). Roman architecture and infrastructure deteriorated quickly and were not repaired by the Anglo-Saxons. Trade, previously robust and pervasive, also deteriorated. In contrast to the Romans, cemeteries provided the most information about the population of this time period. By and large, the archaeological material of this time period originates from funerary sources and includes jewelry, clothing, ceramics, and weaponry (Higham 1994).

The Norman Invasion in 1066 ushered in the English medieval period, which was characterized first by motte-and-bailey castles, and later by large stone castles with buttressing and towers (Sawyer 1998). It was common for the Normans, peoples from the area of modern Normandy, to tear down earlier timber and stone buildings and reuse both the materials and the site, thus obliterating much of the structural evidence of the Anglo-Saxons. Having a direct connection to the European mainland meant that trade with the continent flourished once again. As the invaders replaced the long-standing aristocracy with their own nobility, Norman customs and institutions became the rule in England, rather than the exception (Sawyer 1998). Most notably, the use of the French language by the aristocracy at court influenced the development of the English language so greatly that its impact can still be observed in the modern version of the language.

It is obvious, then, that significant cultural differences occurred between time periods in England. Both archaeological and historical sources lend credence to this conclusion; however, there have been few studies examining the biological outcomes of these migration patterns. It is the aim of this study to assess skeletal and genetic data to determine if the aforementioned similarities and differences exist in the skeletal realm. This study seeks to ascertain the amount of cranial change and/or continuity between English populations of the Iron Age, Romano-British, Anglo-Saxon, medieval, and post-medieval time periods, and to determine the magnitude of these changes. A secondary aim of this study is to determine how much of the cranial variation in post-medieval English samples can be explained by the earlier populations of England.

Craniometric landmarks are utilized to assess the patterns of cranial morphological relatedness from a sample of approximately 1500 individuals, ranging in date from late Iron Age to post-medieval. Populations separated by time periods are analyzed using various multivariate statistics.

The following historical background will expound on the populations of England from the Iron Age to the post-medieval era. A comprehension of the settlement patterns of immigrant and invasive groups is paramount to a correct interpretation of any results of this study. Chapter 3 presents a thorough review of literature pertaining to craniometrics, biological affinity, and population histories. Research hypotheses and the materials and methods utilized in this analysis are presented in Chapter 4. The subsequent chapter provides results from the statistical tests mentioned above, of which Chapter 6 presents a comprehensive discussion.

II. HISTORICAL BACKGROUND

Migrations have played a major role in shaping the peoples and culture of England since the Neolithic (Cunliffe 2005). The British Empire of the 19th and 20th centuries, for example, covered almost one quarter of the earth's land and boasted 20% of the earth's population due to major im- and em-igration (Smith 1998). With the advent of rapid transportation and the expansion of trade routes, this type of cultural monopolization was possible. The resulting gene flow likely increased craniometric variation worldwide. The England of ancient times did not have steam ships or cross-Atlantic voyages, but did experience several waves of major migrations that may have resulted in craniometric changes.

The British Iron Age, roughly defined as the time period from the 8th century BCE to the early 1st century CE, saw surges of cultural diffusion and migration from north and central Europe (Cunliffe 2005). During this time, England was divided by tribes, many of which had cultural ties to the continent (Figure 1). The Iron Age was split into five sub-periods: Transitional Bronze/Iron Age (800-600 BCE), Early (600-400 BCE), Middle (400-100 BCE), Late (100-50 BCE), and Transitional Iron/Roman (50 BCE-100 CE). These time periods are delineated by the spread of continental Celtic cultural patterns into the British landscape. The transitional and early Iron Ages were characterized by regional pottery, dagger, and fibula (brooch) types that mirrored those of Hallstatt C, D, and La Tene I on the continent (Cunliffe 2005). The middle Iron Age was distinguished by the cultures of La Tene I, II, and III, including the establishment of inhumation as the primary burial type. The late

Iron Age also corresponded to La Tene III that was marked by increased fortifications, elaborate artifacts, and a transition to inhumation burials (Cunliffe 2005). Hillforts were used as defensive structures throughout Iron Age England, with their defenses increasing in complexity due to growing foreign threats.

Beginning in 43 CE, a remarkable cultural change occurred: the Roman Empire expanded into the British Isles (Figure 2). Julius Caesar came to England in 55 BCE to capture land for the Empire. However, his campaigns did little else than to establish a puppet king (Hadas 1942). No land was taken for Rome, nor did Roman culture flourish in the area; Caesar left without having made his mark. However, the Emperor Claudius decided to take England for his own in 43 CE, and set out to conquer England. Like his predecessor, Claudius saw little initial success. Over time, however, Roman influence grew through military campaigns and cultural diffusion. Roman influence in England peaked during the time of the emperor Trajan, in the early 2nd century CE (de la Bedoyere 2010). His successor Hadrian built the eponymous wall at the southern border of Scotland to keep Roman authority in - and Scottish "barbarians" out. During this time, cities flourished with the influx of Roman military might and wealth. Villas and bathhouses were erected; coins were fashioned to resemble those brought by the new aristocracy; legionnaires admixed with local women (de la Bedoyere 2010). Legionnaires in England, whether Roman or native, were granted full Roman citizenship and a parcel of land to retire on. Most chose land close to the camp they had served in; after 300 years of Roman occupation, however, these retirement parcels were liable to stretch into rural areas (Ibeji 2011). Very few women would have come with the legions; the men would have naturally turned to the local women for pleasure or marriage. One can only suppose that this admixture would have led to an increase in both gene flow and phenotypic variation in the English population. The extent of admixture outside of major cities or encampments is questionable, but is by no means of little consequence. In the past 3,000 years, the period of Romanization may have contributed the most significant amount of gene flow to England due to the diverse origins of its invaders.

The Roman English colonies asked their emperor for help in staving off a foreign invasion in 410 CE. The emperor refused, marking the end of Roman rule in England. Instead, the Britons asked their neighbors, the Saxons, for aid in defeating their Pictish enemies to the north (Sawyer 1998). The Saxons obliged, but would not tolerate English control and quickly turned against their allies. For the next one hundred years, Saxon tribes spilled onto the island from the European continent, with a reputation for violence and ferocity (Higham 1994). Other Danish tribes, such as the Angles, Jutes, and Mercians, also invaded southern and eastern England from the continent (Hills 2003). The violence tapered off as these tribes, known collectively as the Anglo-Saxons, settled in to their new lives in England (Figure 3). By 700, they were living in relative peace with the native Britons (Sawyer 1998). Clerics from mainland Europe introduced Christianity during this early Anglo-Saxon period, a factor that unified an otherwise diverse population (Higham 1994). The amount of admixture occurring between the Anglo-Saxons and Britons is unknown, as their kingdoms did not initially overlap. Viking raids began in Northumbria (the area of modern Edinburgh) and Ireland in the late 8th century, and by the mid-9th century a Viking stronghold had been established in modern York (Haywood 1995). A period of war between the English Anglo-Saxons and the Danish Vikings lasted from 867-884 CE, which resulted in the consolidation of the Danes into one kingdom, known as the Danelaw (Figure 4). With the Vikings contained, and their king made to accept Christianity, the English king was able to unify the numerous Anglo-Saxon kingdoms. A period of relative prosperity followed, in which the English king gained control of most of England and Scotland (Sawyer 1998). By the early 11th century, however, the Danes had once again wrested control from the English and driven the English king to Normandy. A son of the banished king, Edward the Confessor, was able to regain the throne in 1042, bringing with him the beginnings of the Anglo-Norman (medieval) culture. When he died in 1066, control of the kingdom fell to a noble Englishman, but a Norman challenger declared his rivalry for the throne (Neveux 2008). The medieval period began when William the Conqueror defeated the English king at the Battle of Hastings in 1066 (see Figure 5 for map).

William the Conqueror, formerly the Duke of Normandy, was a descendant of Vikings who had been welcomed to France in return for acting as protection against coastal raids (Crick and van Houts 2011). His ties to the English throne were secured through Edward the Confessor, whose father was English and mother was Norman. Only 8,000 Normans followed William to England; a small number compared to the vast amount of native English. The greatest impacts of the Norman invasion were on the upper classes, landholdings, and language of England (Harper-Bill and van Houts 2003). The English aristocracy was eradicated and replaced by Normans. Lands were taken away from the English and redistributed to Norman immigrants, leaving only 5% of English lands in English hands by 1086 (Thomas 2003). Anglo-Norman was adopted as the language of the ruling class, consequently introducing French words into English vocabulary (Neveux 2008).

Castles were the Norman mechanism for keeping revolts at bay; many were built by the Norman aristocracy to keep their power and influence out of English hands. With castles came feudalism, a fundamentally Anglo-Saxon idea with a Norman hierarchy of landholding (Thomas 2003). Slavery was abolished, but military quotas were demanded of lords, which in turn were demanded of the former slaves. Intermarriage between the English and Normans was not common immediately post-conquest, and took approximately one hundred years to become customary (Thomas 2007). The practice of Christianity by both the Normans and English was likely a driving force behind the admixture; had both groups not been of Christian faith, it would not have been possible as religion can act as a genetic barrier. The majority of this admixture likely took place among the upper classes in cities, and would have introduced French genetic material to the English gene pool (Crick and van Houts 2011).

Following the Norman invasion, the amount of immigration into England remained relatively stable; it was not until the early 17th century that another large-scale immigration event occurred (Figure 6). The Huguenots, a group of French Protestants, moved to England in droves following France's persecution of them for their religious beliefs. Some 50,000 immigrated to England, most of whom chose to settle in an area in the east end of London known as Spitalfields. Their influence was so great both culturally and genetically that an estimated quarter of London's current population claims Huguenot ancestry.

Understanding from whence a group of people came is important not only to defining a cultural identity, but also to recognize adaptations and differences that arise as a result of population changes. Historical documentation of migrations provides one level of evidence of biological origins; craniometric analyses provide an additional level of evidence that also illustrates specific skeletal traits of these groups. These analyses allow for the identification of traits that are results of both environmental and genetic factors. The following section will address craniometrics and how they have been used in the past, as well as specific instances of craniometric studies pertaining to England.

Figure 1. Iron Age England. After: http://www.emersonkent.com/map_archive/celtic_britain_1st_cent_bc.htm

Figure 2. Roman Britain. After: http://www.ancient.eu.com/uploads/images/575.png

Figure 3. Early Anglo-Saxon England. After: http://www.lib.utexas.edu/maps/historical/shepherd/britain_settlement_600_1923.jpg

Figure 4. Late Anglo-Saxon England. After: http://en.wikipedia.org/wiki/File:England_878.svg

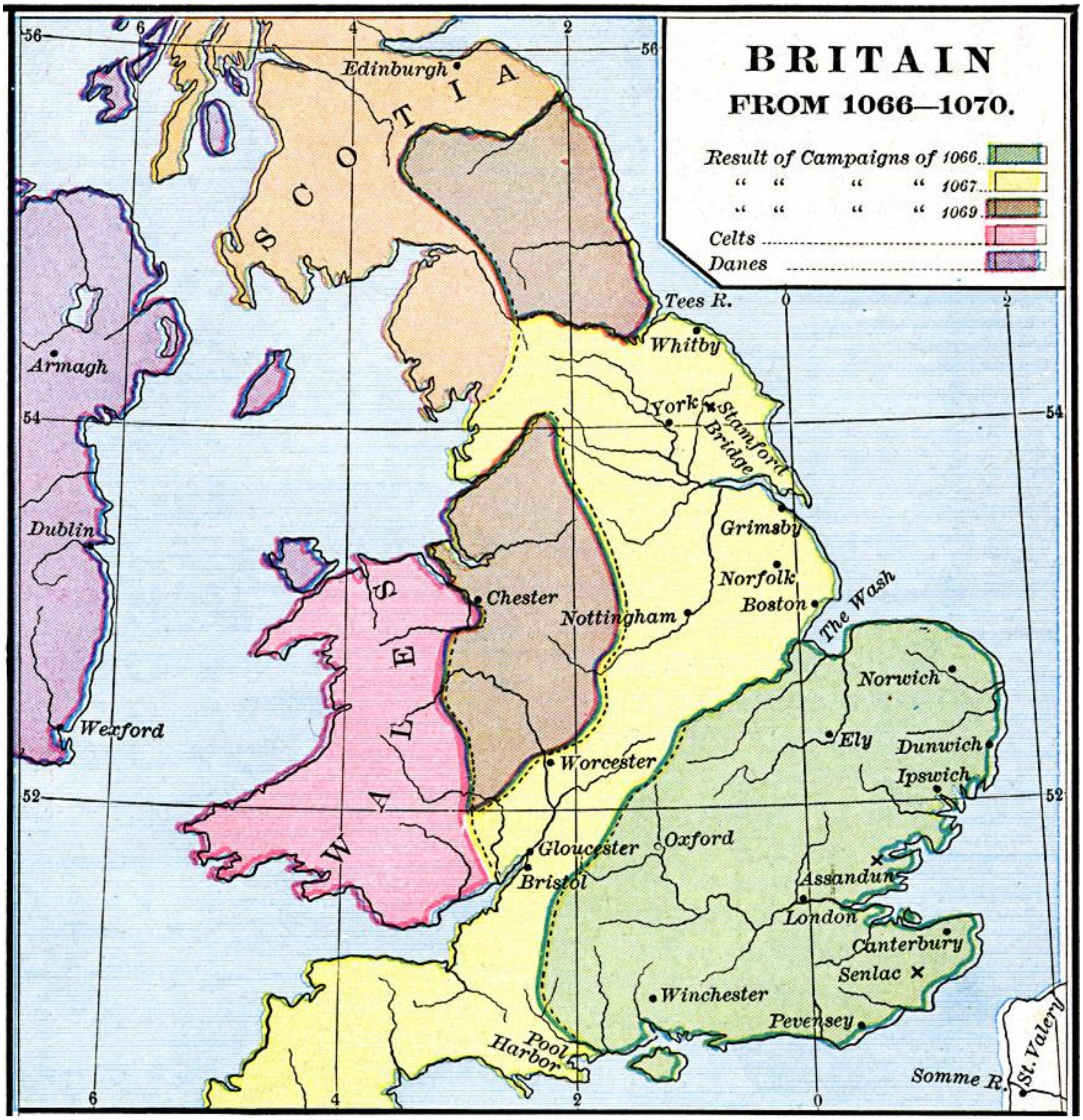

Figure 5. Early medieval England. After: http://etc.usf.edu/maps/pages/6800/6860/6860.htm

Figure 6. Modern England. After: http://people.bath.ac.uk/cf233/maps/ukmap.html

III. REVIEW OF THE LITERATURE

The cultural changes that occurred during the Iron Age, Romano-British, Anglo-Saxon, medieval, and post-medieval time periods are considered to be significant. Most aspects of life - material goods, religion, politics, and burial practices - varied widely and today help to distinguish one people from another. But what about physical remains? Specifically, can craniometrics help define the cultural affinity of English inhabitants? For hundreds of years, studies have dealt with this issue. The use of craniometrics to examine migration patterns and population affinity has been abused in the past; the 19th century saw many anthropologists, both American and British, making bigoted value judgments based on erroneous skeletal characterization. This gross abuse of science led to the suppression of population studies based on skeletal analyses throughout the 20th century (Hills 2003). Few studies have been undertaken recently to assess the change and continuity of English populations over time using craniometric data because of the earlier abuses using science as a justification. This chapter will explore these ideas as well as three major themes from related literature: the osteological paradox, craniometric studies, and English craniometric studies.

3.1 The Osteological Paradox

The osteological paradox is a major concern in any bioarchaeological study. Demographic non-stationarity and selective mortality are two components of this paradox that must be acknowledged before undertaking any study of past populations. Demographic stationarity is a feature of a society that is characterized by a lack of em- and im-migration;

constant fertility and mortality rates; zero growth rate; and an equilibrium age distribution (Wood et al. 1992). Non-stationarity, then, describes a society that departs from any of the above characteristics. Selective mortality refers to the fact that there will never be a complete sample of all of the individuals who were at risk of death at a certain age; we only have a sample of the individuals who actually died. These confounding effects make it difficult to draw conclusions about the population history of a past peoples, especially in demographic studies. Nonetheless, if these osteological paradoxes are taken into account, bioarchaeological studies are still an entirely viable means of understanding past populations. The samples in the current study are expected to illustrate demographic stationarity, but some areas may be characterized by non-stationarity between time periods; that is, a single population may live in a single location throughout differing time periods with minimal migratory influences.

3.2 Craniometric Literature

Widespread interest in human cranial morphology and variation began in the early 19th century, most notably with the work of Samuel Morton. A physician by occupation, Morton was an adherent to the principles of phrenology: that differences in skull morphology reflect different brain structures that then influence brain function. By collecting an extensive collection of skulls and examining them using cranial measurements, Morton formed a hierarchical system of races with Blacks at the bottom and Whites at the top (Jackson and Weidman 2006). Other 19th century anthropologists followed Morton's typological lead, and much of the research published during this time centered on racial hierarchies based on cranial morphology. In the early 20th century, Earnest Hooton and Aleš Hrdlička followed in Morton’s footsteps, utilizing cranial morphology to distinguish primary and secondary races (Katzenberg and Saunders 2008). Both of these men sat on the Committee on the Negro, a national council designed to study African-American anatomy. This council eventually suggested that African-Americans were closer to primitive man than White Americans. It was these types of arguments that led to the disregard of craniometrics during the mid-20th century.

In 1912, Franz Boas, father of American anthropology, undertook a craniometric study of immigrant children in the United States. The major outcome of this study was the finding that the cranial vault is highly plastic, that is, responds quickly to environmental stimuli. As such, the cranial vault would not have been an appropriate location to study for the determination of racial groups, as his anthropological contemporaries and forebears did. Boas championed the use of robust statistical analyses in the examination of craniometrics, although he did not have the computational power with which to undertake these analyses (Friedlaender 2007).

The use of craniometric landmarks and measurements to determine population affinity and history did not begin until the mid-20th century with WW Howells. Howells determined that there was no craniometric basis for the existence of races, and that humans illustrate more variability within groups than they do between them. He utilized size and shape characteristics, instead of morphological traits alone, to ascertain biological affinity (Friedlaender 2007).

Craniometric analyses are suitable to examine genetic relationships in part because inter-landmark distances (ILDs) are heritable (Pietrusewsky 2008). Different parts of the cranium are influenced by genetics and environment in different levels: the splanchnocranium, including the bones of the face, is largely environmental, while the neurocranium, including vault bones, is highly correlated with genetics (Harvati and Weaver 2006). Even though secular change can alter the morphology of the cranium, biological distance and genetic relatedness is still detectable. In 2002, Sparks and Jantz reexamined Boas' findings that suggested the plasticity of the skull as a response to environmental stimuli. By utilizing statistical techniques not available during Boas' lifetime, it was determined that the morphology of the skull is more heavily influenced by genetic components, rather than environmental.

Essentially, craniometric data is a reflection of population history and can be used to explore within and among-group variation, ancestral origins, and migration routes. Morphological craniometric traits are controlled both by genetics and environment, and provide insight into population relationships, biological distance, migration, and microevolution (Relethford 2004). In the same study, Relethford emphasizes that neither environment nor genetics will completely obscure the other. Studies that have examined craniofacial morphology in relation to population affinity are numerous and include studies of regional isolation, sexual dimorphism, and migration routes (Ross 2004, Humphries and Ross 2011, Hanihara and Ishida 2009). Ross (2004) found significant craniofacial variation between Bosnians and Croatians, who were previously believed to be relatively homogenous due to a common Slavic ancestry. Results from the study indicate that the disparity between populations was caused by a segregation of breeding groups produced by differing religious beliefs. In Humphries and Ross (2011), sexual dimorphism in craniofacial indices was calculated for two Iberian samples. The females from the Lisbon sample were found to be significantly different from the other samples, which may have been a result of previous immigration to the region. The study of the Jomon people of Japan by Hanihara and Ishida (2009) determined that the expansion of the Jomon culture began in the northern area of the Japanese archipelago and spread southward. By comparing craniometrics of the Jomon to populations from the Asian mainland, this study concluded that the two populations did share an ancestral gene pool. These studies are examples of research with outcomes regarding both internal and external variation. In addition, the results from these studies illustrate that humans can be accurately classified into geographical groups utilizing craniometrics.

3.3 British Craniometric Literature

During the 19th century, anthropologists noted the differences in cephalic index between the populations of England. For example, long-barrow people had long, narrow crania, a feature that did not reappear until medieval times (Brothwell and Krzanowski 1974). In 1885, John Beddoe published *Races of England*, which dealt with distinguishing the "races" of England based on skull shape and eye colour variation. He also used phenotypic expression as a means to separate races, arguing that "tall, fair southerners" came from Danish Viking stock and red-headed Scots from Frisians (Beddoe 1885). In addition, Beddoe defined classes of men phenotypically: learned men had larger skulls, while the artisan class was largely dark-haired (Hills 2003). These value judgments ultimately turned many European scholars away from the study of skeletal remains to examine population affinity and history. In the United States, craniometric study saw a resurgence beginning in the 1970s with the work of W.W. Howells (1973) and soon evolved into the work of R.M. Harding (1990) and J.H. Relethford (1994). These men provided valuable research for many different populations and sought only to determine differences and affinities between them; not to belittle them. However, this trend did not extend into England for some time; even today, it proves difficult to find contemporary craniometric studies.

There are a few exceptions to the rule, however. Brothwell and Krzanowski (1974) used eleven craniometric vault measurements to determine population dissimilarities between five early English cultures. These measurements were chosen simply because they had the least amount of missing data, as craniofacial bones were commonly incomplete. Some 2,000 skulls from time periods ranging from the Bronze Age to the medieval period were collected and measured for analysis. Using canonical variates analysis, they were able to discern the biological distances of each group from each other in terms of cranial likeness. Early Bronze Age and Neolithic English varied widely, while the Iron Age sample did not differ much from the Romano-British. Similarly, a wide berth divided the Saxons from the later Normans of the medieval age. These differences, although explained in some cases by small sample sizes, are likely statistically significant and suggest regional micro-evolution during the periods of greatest change (Brothwell and Krzanowski 1974). This groundbreaking study broke almost fifty years of craniometric silence from England, thus opening the door for future research. Soon after, Rösing and Schwidetzky used craniometrics to determine temporal trends of variation in European groups (1977, 1981). A similar study examined craniofacial variation and determined that there are significant associations with language affiliation, geography, and time period (Sokal et al 1987).

A more recent study examined English groups for craniofacial variation. Russell (2007) used skeletal samples from the Iron Age, Romano-British, and Anglo-Saxon periods in England to determine the population history and affinity of these groups. One thousand and four hundred individuals were analyzed utilizing univariate, multivariate, and matrix correlation methods to establish change or continuity in these populations. Several univariate and multivariate statistical analyses were used to test within- and among-group variation. Based on the hypothesis that phenotypic distances derived from craniometric measurements can be used as a measure of genetic distances, Russell was also able to calculate biological distances of groups based on R matrix analyses (Konigsberg 1990, Relethford et al 1997). These distances were mapped with principal component and cluster analyses and tested for correlation with geographical and temporal factors. The results from this study suggest that broad temporal trends in craniofacial shape exist, and are more easily recognizable in cranial, rather than facial, characteristics (Russell 2007). Unlike previous research, Russell discovered cranial discontinuity between Iron Age and Romano-British samples. In addition, the latter sample did not show any similarities to Danish samples, which were shown to be more closely related to both Iron Age and Saxon samples. An additional comparative matrix was designed by the author when geographic and temporal distances were found to have insignificant associations with the populations. This new cultural matrix tested the similarities of populations based on similarity of material cultural. While not an exact science, the cultural matrix did significantly correlate to biological distance in many of the samples studied. Relethford-Blangero analyses, although normally used only under the condition of panmixia (random mating within a breeding population), were conducted experimentally to test within-group and within-sex heterogeneity. The results suggested that temporal and regional variation existed in varying degrees, with some sites displaying more evidence of genetic influx than others (Russell 2007). Historically, this analysis makes sense: many groups migrated to or took over specific parts of England; naturally, their genetic material would be localized.

IV. MATERIALS AND METHODS

4.1 Introduction and Hypothesis

Results from previous studies indicate that there is a need for further study of English skeletal samples to determine population affinity and genetic heterogeneity. Disagreement regarding the genetic makeup of Romano-British samples begs further research, as does the discontinuity in cultural and physical remains found between the Saxon and Norman invasions. The extent of the impact of the Norman Conquest on English samples is yet unknown; although Brothwell and Krzanowski (1974) cite discord among researchers, the degree to which native populations were changed is largely unknown. In addition, no studies have directly examined the relationship between early and modern English populations, i.e., to what extent the Normans or Anglo-Saxons contributed genetic material to more modern samples.

The current study aims to clarify the relationships between several temporal groups. The following hypothesis will be tested, and two research questions addressed:

H_1: There are no significant craniometric differences between and among English samples of Iron Age, Romano-British, Anglo-Saxon, medieval, and post-medieval time periods.

RQ_1: Did the Norman Conquest bring widespread craniometric change to England?

RQ_2: Can any cranial variation in modern British samples be explained by influence from early English populations?

4.2 Materials

Archaeological populations suffer from the problem of poor preservation. The fragile bones of the face and the thin, flat bones of the cranial vault are especially susceptible to postmortem damage. Even if a population has a relatively good percent of preservation, these bones have a high likelihood of being fragmentary. As a result, bioarchaeological analyses are usually limited by smaller sample sizes.

The samples utilized in this study represent both a wide array of geographical locations and of temporal periods within England. Iron Age, Romano-British, and Anglo-Saxon data were provided for use in this study by Dr. C.K. Russell, Durham University. These data were collected by Dr. Russell from fourteen sites, either in person or using published and unpublished reports. Medieval and post-medieval data were either personally collected by the author or taken from the literature. Data from four medieval sites- Merton Priory, Bermondsey Abbey, Spital Square, and Guildhall Yard- were collected at the Museum of London's Centre for Human Bioarchaeology using a Microscribe G2 digitizer. An additional two medieval and two post-medieval samples were obtained from the Museum of London's Centre for Human Bioarchaeology (CHB)'s online database. A summary of these sites can be found in Table 1. Sex and age data were also provided to the extent possible. For further explanations of the Iron Age, Romano-British, and Anglo-Saxon sites, see Russell (2007).

4.2.a Iron Age Samples (450 BCE – 100 CE)

Wetwang and Garton Slack, East Yorkshire, England

This archaeological site in the northern reaches of England is the larger of the two Iron Age samples utilized in the present study. Usage of this site as a cemetery began in the 5th century BCE and ended in the 1st century CE, with the majority of burials occurring in the latter half of the period (Jay and Richards 2006). Three hundred and fifty-one adults were considered in the current analysis, although the final number of individuals is smaller due to statistical cleaning and data integrity. The determination of data integrity is outlined in section 4.3.c.

Maiden Castle, Dorset, England

Located in southwest England, the Maiden Castle site dates to the late Iron Age (roughly 100 BCE- 100 CE). Of the 100+ individuals who were excavated from the site, only 83 were complete enough to be considered for analysis (Russell 2007). Previous research indicates that there are no significant skeletal differences between this sample and Anglo-Saxon populations (Goodman and Morant 1940), which will be further explored in this treatise.

4.2.b Romano-British Samples (43 CE- ~500 CE)

Trentholme Drive, Yorkshire, England

The Romano-British cemetery located at Trentholme Drive, York, was actively in use from the mid-2nd century CE to the 4th century CE. The burials here numbered at least 340, with 179 having good or excellent skeletal preservation. The male-to-female ratio was high (4:1), but not unusual for the time period. In addition, as Russell (2007) points out, Trentholme Drive was an urban environment during the Romano-British period. As such, more variation is expected as the amount of admixture is likely higher than in rural areas.

Bath Gate, Cirencester, Gloucestershire, England

Cranial preservation was extremely poor at the site of Bath Gate, resulting in a sample of only 66 individuals. The cemetery was in use from 310 CE until the early 5th century CE, dated by coinage found with buried individuals. More males than females were buried in the Bath Gate cemetery, although previous research suggests that the age ranges of each individual indicate a common civilian population (McWhirr et al 1982). Unfortunately, the data for this thesis reflects this sex-based disparity.

4.2.c Anglo-Saxon Samples (~450 CE to 1100 CE)

Sewerby, East Yorkshire, England

The individuals from the Anglo-Saxon cemetery at Sewerby represent a small percentage of the total number of graves excavated (roughly 20%) due to variable skeletal preservation. The burials were dated mostly to the 6th and early 7th centuries CE, although a few could be attributed to the late 5th century (Hirst 1985). The total number of individuals from this cemetery is unknown, as only a portion of the site was excavated.

Castledyke South, Lincolnshire, England

The Anglian cemetery at Castledyke South was in use from the late 5th to 7th centuries CE. Over 200 individuals were found during the original excavation, with an estimated 200 still inhumed in unexcavated portions of the site. Previous research indicates that the population uncovered here was a healthy, prosperous one (Drinkall and Foreman 1998). However, skeletal preservation at this cemetery proved especially poor, thus only 7 individuals were able to be considered for analysis (Russell 2007).

Norton East Mill, Cleveland

In use from 550-610 CE, the cemetery at Norton East Mill likely represents a rural population of Anglo-Saxons. Most individuals were buried in similar orientations, and some were buried in groups- perhaps indicative of familial relationships (Russell 2007). Due to poor skeletal preservation, the number of individuals able to be utilized in the current analysis is low and therefore likely unaffected by the potential bias introduced by the familial element of the site.

Bidford-on-Avon, Warwickshire, England

The Anglo-Saxon cemetery at Bidford-on-Avon was discovered and excavated during the early 20th century. The excavators dated the site to the early 6th century CE, although the dating method is not reported; most likely, artifact typologies were used to determine this date. The cemetery is thought to represent an Anglo-Saxon community with all ages and sexes reported (Brash and Young 1935). Both cremations and inhumations were recovered from the site, with the number of adults applicable to the study being 49.

Morant London Museums, England

The individuals comprising the Morant London Museums sample come from a wide array of Anglo-Saxon sites across the south and east of England. Morant (1926) created this assemblage from individuals curated at various museums in London as a response to the lack of Anglo-Saxon samples in the early 20th century. The original reports divided the collection into geographically determined groups, which also corresponded to historical accounts by the Venerable Bede (Russell 2007). Although Morant (1926) dates the collection from the 5th to the 10th centuries CE, he stresses that most of the individuals in the sample were buried no later than the 6th century. Following Russell (2007), this pooled group is considered to be early Anglo-Saxon rather than late. Over 100 individuals had cranial preservation good enough to be considered for inclusion in the current study.

Burwell, Cambridgeshire, England

Individuals were excavated from the cemetery at Burwell during the early 20th century, like many other Anglo-Saxon sites. Archaeological typologies have dated the remains to the 7th century CE. These artifacts suggest that this cemetery represents a population in religious transition- from pagan to Christian (Brash and Young 1935). Cranial preservation was relatively good, with 69 individuals able to be analyzed.

Norton Bishopsmill School, Cleveland, England

This Anglo-Saxon cemetery immediately postdates that of the Norton East Mill site, but unlike its predecessor, represents a decidedly Christian population due to the alignment of burials and lack of grave goods (Russell 2007). Although the number of individuals recovered was relatively high, urban development and poor environmental factors (i.e., acidic soil) have made skeletal preservation poor. Very few individuals were complete enough to be included in the current data set.

Village Farm Spofforth, Yorkshire, England

This cemetery was excavated in 2001 and yielded roughly 180 individuals. Like other Anglo-Saxon sites, archaeological assemblages were utilized to date the remains to the early 8th century CE. Some artifacts suggest that the cemetery may have been in continuous use into the 12th century CE, but these are likely from intrusive burials. Burial orientations and archaeological material provide evidence of a Christianized population (Craig 2008). Preservation was moderate, with 48 individuals able to be included in the analysis.

Black Gate, The Castle, Newcastle, England

Russell (2007) reports that the Anglo-Saxon cemetery at Black Gate, which dates to the 8th century, was founded upon the area of Pons Aelius, a Roman fort from the 2nd century CE. Little is known about the sample or Anglo-Saxon site, but during the medieval period the location was used for the building of the New Castle upon Tyne. Reflected in the number of individuals from the site is the state of preservation, which was relatively good.

Hartlepool Church Walk, Teesside, England

Various ages and sexes were excavated at the cemetery at Hartlepool Church Walk, which would usually be indicative of a community-based population. The proximity to the Hartlepool monastery, though, may signify a less diverse population than would normally be seen. Radiocarbon analysis has dated this site to the 8th century (Russell 2007). Few individuals were cranially complete enough to include in the current analysis.

4.2.d Medieval Samples (~1050 CE – ~1550 CE)

St. Mary Graces, East Smithfield, London, England

The area of the former Royal Mint in East London boasts burials from two separate medieval periods. The cemetery found in conjunction with the Cistercian Abbey of St. Mary Graces, the later of these two periods, has been dated to 1350-1540. Individuals from this site were found both in the Abbey itself and in the cemetery, suggesting a range of socioeconomic statuses (Bekvalak 2007). Over 400 individuals were excavated from this cemetery, but the level of cranial completeness severely limited the number included in this study.

Bermondsey Abbey, Southwark, London, England

The site of the medieval Bermondsey Abbey and foundational St. Saviour monastic cemetery is located less than half a mile south of the River Thames in London. Interment took place here between 1066-1538 CE, with the exception of a few earlier inhumations (not included in the current analysis). St. Saviour was founded as a Christian Cluniac priory, and eventually attained the status of Bermondsey Abbey in the late 14th century (Bekvalac 2008). As such, the burials represent a Christian population. Of the 201 individuals examined, only 26 had complete cranial preservation.

Guildhall Yard, City of London, England

In use from 1050-1230 CE, the lay cemetery of St. Lawrence Jewry was a small communal burial ground in the City of London. Although there were two distinct burial phases (earlier and later), the site has been considered as a whole for the present work (Cowal 2007). In total, 68 individuals were excavated from the cemetery, with around 20% of those individuals able to be utilized for analysis.

East Smithfield Black Death, East Smithfield, London, England

The East Smithfield Black Death cemetery is the earlier of the two sites associated with the location of the former Royal Mint, in use from 1348-1350. It was the first Black Death cemetery established in London. Almost 1400 individuals have been exhumed to date, and 40-50% of the cemetery still lies unexcavated (Kausmally 2007b). Although preservation was relatively good, only 27 individuals from the site were recorded for the current study due to poor cranial quality.

Merton Priory, London, England

The site of St. Mary Merton Augustinian Priory (“Merton Priory”) lies 8 miles southwest of the City of London, with burials dating from 1117-1538 CE. The individuals uncovered at the site are typical of a religious community, and have been described as both lay people and religious officials. As with many monastic sites, most of the individuals at Merton Priory are male (Mikulski 2007). Skeletal preservation was good, allowing for 25 individuals to be utilized for analysis.

Spital Square, London, England

St. Mary Spital was one of the largest Augustinian religious complexes in England, featuring a priory, a large hospital, and a chapel. The burials from each of these locations were dated to consecutive time periods, with the priory burials beginning in 1197 and the chapel burials ending in 1320. Owing to the similar location and time periods, these individuals have been considered part of the same community for the purpose of this thesis (Bekvalac et al 2007). Skeletal preservation was excellent and 22 individuals were able to be used in this study.

4.2.e Post-Medieval Samples (1550 - 1850)

St. Bride's Lower, City of London, England

The Post-Medieval site of St. Bride's Lower was utilized as an overflow cemetery from St. Bride's church from 1770-1849. Individuals buried here were from low socioeconomic statuses, and likely worked in the nearby Bridewell workhouse or Fleet prison (Kausmally 2008). Over 600 individuals were excavated from this cemetery, and 139 were complete enough for inclusion in the current analysis.

Chelsea Old Church, Chelsea, London, England

Unlike the lower cemetery of St. Bride’s, the cemetery at Chelsea Old Church contained mostly upper-class individuals who were buried between 1712 and 1842. Both sexes were represented equally, and subadults made up roughly 25% of the population (not used for analysis). A majority of the burials were earthen, although a few were vaults. Even though the current address of the site is in London, during its period of use the cemetery would have been considered quasi-rural (Kausmally 2007). Of the 198 individuals with metric data available, 48 were cranially complete.

Table 1. Site Summary

Site	Time Period	Dates	Total n
Wetwang/Garton Slack	Iron Age	5th cBCE-1st cCE	351
Maiden Castle	Iron Age	1st cBCE-1st cCE	57
Trentholme	Romano-British	2nd-4th centuries	179
Cirencester	Romano-British	4th-5th centuries	66
Sewerby	Anglo-Saxon	6th-7th centuries	7
Castledyke South	Anglo-Saxon	5th-7th centuries	7
Norton East Mill	Anglo-Saxon	6th-7th centuries	16
Bidford-on-Avon	Anglo-Saxon	6th century	49
Morant’s Museum	Anglo-Saxon	5th-10th centuries	78
Burwell	Anglo-Saxon	7th century	69
Norton Bishopsmill School	Anglo-Saxon	7th-8th centuries	9
Village Farm	Anglo-Saxon	8th century	48
Black Gate	Anglo-Saxon	8th century	36
Hartlepool	Anglo-Saxon	8th century	12
St. Mary Graces	Medieval	14th-16th centuries	12
Bermondsey Abbey	Medieval	11th-16th centuries	26
Guildhall Yard	Medieval	11th-13th centuries	12
East Smithfield Black Death	Medieval	14th century	27
Merton Priory	Medieval	12th-16th centuries	25
Spital Square	Medieval	12th-14th centuries	22
St. Bride’s Lower	Post-medieval	18th-19th centuries	139
Chelsea Old Church	Post-medieval	18th-19th centuries	48

4.3 Methods

4.3.a Data collection

Iron Age, Romano-British, and Anglo-Saxon data were all provided for use in the current analysis by C.K. Russell. Data from two medieval and two post-Medieval sites were provided for use by the Museum of London Centre for Human Bioarchaeology. Data from the four remaining medieval sites- Guildhall Yard, Bermondsey Abbey, Spital Square, and Merton Priory- were collected by the author utilizing a MicroScribe G2 Digitizer and 3Skull, a computer program designed to aid in the capture of 3D cranial data (Ousley 2013). The process of taking craniometric measurements with a MicroScribe digitizer involves first placing the tip of the stylus onto the craniometric landmark at a perpendicular angle, and then depressing a button on the accompanying hand-held controller. This action results in the data being stored in the data acquisition program; in this case, 3Skull. In addition to recording the X, Y, Z coordinates of cranial landmarks (which will be discussed in the following section), 3Skull computes the measurement data for inter-landmark distances, which are used in the current study for analysis. These three-dimensional measurements are converted to traditional craniometric measurements in 3Skull, which allows for the direct comparison of data in the current analysis (Ousley and McKeown 1999). When appropriate, use of sliding or spreading calipers allowed for the correct identification of landmarks prior to digitizing.

4.3.b Craniometric measurements

Seventy-seven craniometric landmarks were digitized to the extent possible for each individual in the Guildhall Yard, Bermondsey Abbey, Spital Square, and Merton Priory samples. At least 30 inter-landmark distances (ILDs) were available for each of the remaining samples in each of the time periods. Due to the archaeological nature of these collections, though, cranial completeness is far less than what would be expected of more modern forensic samples. As a result, only a few ILDs are able to be used for statistical analysis. The complete list of landmarks and associated ILDs available for the current study is presented in Table 2.

Utilizing data from several sources required cleaning and processing due to a disparity in measurement definitions. The pre-medieval data were coded following Howells' as much as possible; any measurement without a concrete definition were assigned a new variable name, and in many cases were easily understood. The medieval and post-medieval data were originally coded using a biometric variable system instead of using standard craniometric variable names. These had to be associated with the standard craniometric names, and any that could not be associated were researched thoroughly and renamed. Most of the latter group were able to be associated based on the individual landmarks that composed the ILD. Through this procedure, the measurement methods and variables were standardized and accepted for statistical treatment.

Table 2. Inter-landmark Distances

ILD	From Landmark	To Landmark
ASB	Asterion	Asterion
BBH	Basion	Bregma
BNL	Basion	Nasion
BPL	Basion	Prosthion
DKB	Dacryon	Dacryon
EKB	Ectoconchion	Ectoconchion
FMB	Frontmalare temporale	Frontomolare temporale
FOB	FOB point L	FOB point R
FOL	Basion	Opisthion
FRA	Nasion	Bregma
FRC	Nasion	Bregma
GOL	Glabella	Opisthocranion
MAB	Ectomolare	Alveolon
NLB	Alare	Alare
NLH	Nasion	Subspinale
NPH	Nasion	Prosthion
OBB	Dacryon	Ectoconchion
OBH	Superior orbital border	Inferior orbital border
OCC	Lambda	Opisthion
PAC	Bregma	Lambda
TBA	Porion	Porion
WNB	Nasal suture pinch L	Nasal suture pinch R
XCB	Euryon	Euryon
ZMB	Zygomaxillare	Zygomaxillare
ZYB	Zygion	Zygion

4.3.c Data preparation

Data Cleaning

Data from each site were registered into an SPSS database once measurement collection was complete (IBM Corp. 2012). All subadults (< 18 years) were removed from the sample, as their cranial measurements would not be comparable to any adult samples. Although the skull continues to morphologically change throughout a person's lifetime, the total natural change after the age of twenty is usually only between 2-4% (Novotny 1993). Similarly, only adult individuals with a probable or likely sex were included for analysis following Russell (2007).

Each individual was then visually checked for inputting errors and other data entry mistakes. Once the integrity of the data was established, summary analyses were run in SPSS in order to identify outliers in the data set. Any individual with a measurement three or more standard deviations away from their sex and sample mean were double-checked with the original data file for accuracy. If no inputting error could be identified, the individual was left in the data set.

Estimating Missing Data

Archaeological skeletal material tends to be more fragmentary than contemporary material; as such, it was necessary to estimate some of the missing data from the original dataset. In order to maximize sample sizes for multivariate analysis, missing data were estimated for each site utilizing the SPSS Missing Values: Multiple Imputation tool. This tool is an "iterative Markov chain Monte Carlo (MCMC) method that can be used when the pattern of missing data is arbitrary" (IBM Corp. 2012). Multiple imputation is a statistical method that simulates random draws from nonstandard distributions; that is, missing data is imputed based on available data numerous times in order to account for natural variation in the data.

Variables with up to 50% missingness were considered suitable for multiple imputation analysis (Graham 2009). This high amount of missing data necessitated a high number of iterated data sets (n=40), which reduced the amount of introduced bias and improved the power falloff to <1% (Graham et al. 2007). Once the imputations were completed, the data from each site were combined into a single SPSS data set and re-checked for erroneous outliers or irregularities. A summary of the estimated variables for each time period can be found in the appendix. It is important to note, however, that not every imputed variable is utilized in the current study. Variables with more complete data were prioritized over ones with less, when possible.

4.4 Statistical Analysis

Statistical treatment of the data began with the assessment of size and shape from the original inter-landmark measurements, to analyze morphometric cranial trends. Size can confound the effects of shape variation, particularly across time periods, thus new variables for size and shape were calculated after Mosimann and James (1979) and Darroch and Mosimann (1985). Size, defined as the geometric mean of all variables

$$\text{geometric mean} = \left(\prod_{n=1}^{k} x_n \right)^{\frac{1}{k}}$$

where x_n represents variables and k the number of variables. In this treatment, eight variables (BBH, BNL, GOL, NLB, NLH, OBB, OBH, XCB) were utilized to calculate the size variable for all eighteen sites. Not all sites were included in this part of the analysis due to small sample sizes ($n<10$). The shape variables were calculated in Microsoft Excel by dividing the original raw measurement by the size variable, as follows:

$$\text{Shape} = \text{X} / \text{Size}$$

The resulting ratios are dimensionless, and therefore can be considered scale-free for the current analysis (Corrucini 1995, Jungers et al 1995). It is important to note that these size and shape variables are not necessarily related or unrelated; they are utilized to give a better approximation of geometric similarity than raw measurements alone (Ross 2004).

Next, a one-way analysis of variance (ANOVA) was calculated on the size variable in order to examine if the among-sample mean *size* (geometric mean) differed significantly between the 18 sites. In addition, a canonical variates analysis (CVA), a form of discriminant function based on linear combinations that provides the best discrimination between groups, was performed on the new shape variable in order to explore the craniofacial variation associated with the samples (IBM Corp 2012). A canonical variates analysis compares multiple variables in order to explore variation within or between populations. The resulting eigenvalues indicate the percentage of total variation that is provided by a particular canonical component. The lowest eigenvalue has the lowest within group correlation, while the highest is the most correlated. Two separate CVA's were executed: one with pooled time periods, and one to examine among-site variation. These tests were conducted in SPSS v21.

To further assess among- and between-group craniofacial variation, the raw measurements were explored in RMET, an R matrix environment that analyzes data with reference to a migration matrix against populations, the size of the population, and an estimate of external gene flow (Relethford et al 1997). RMET allows, in short, for one to compare craniometric data to genetic data. Heritability measures were set at 0.55 after Relethford (1994), with the option to correct for sampling bias. This request is necessary to account for any sampling effects that may influence the statistical treatment of the data, for example, correcting for non-random sampling. Statistical output of RMET includes *Fst*, within-group phenotypic variance, and a Mahalanobis D-square matrix. *Fst* compares the among-group variation relative to variation expected under complete panmixia, or random mating within a breeding population (Relethford 1994). It is expressed as the mean of the diagonals of the R matrix from each population analyzed, which measures genetic similarity. Because populations are equally weighted, these outcomes can be compared to genetic analyses (Relethford 1994). *Fst*, then, is a measurement of variation of a population, which is further discussed in section 6.3. Within-group phenotypic variance was calculated using the Relethford-Blangero Analysis, wherein any negative residual suggests genetic isolation and drift, and any positive residual suggests increasing gene flow. The Mahalanobis D^2 matrices were used to explore biological distances between groups, whereby smaller between-group distances suggest greater biological similarity. Statistical probabilities associated with the D^2 matrices were generated in SAS 9.4® Statistical Software.

V. RESULTS

5.1 Descriptive Statistics

The total number of individuals available for study are reported by time period in Table 3. These total numbers do not necessarily reflect the number of individuals utilized in the statistical analyses, but rather is an overall description of the available data. Table 4 presents the sample sizes of craniofacial landmarks in each of the five time periods. The subsequent five tables present the summary statistics (number of individuals, minimum, maximum, mean, and standard deviation) of each time period.

Table 3. Summary of Sample Sizes

	Frequency	**Percent**
Anglo-Saxon	318	25.0
Iron Age	394	31.0
Medieval*	126	9.9
Post-Medieval	187	14.7
Romano-British	245	19.3
Total	1270	100.0

*** Includes author-collected samples**

Table 4. Craniofacial Landmark Sample Sizes

	Iron Age	**Romano-British**	**Anglo-Saxon**	**Medieval**	**Post-Medieval**
ASB	392	0	110	114	187
BBH	392	245	318	126	187
BNL	392	245	309	126	187
BPL	336	245	172	98	187
DKB	0	0	240	126	187
EKB	0	0	67	126	187
FMB	0	0	67	126	187
FOB	336	0	311	126	187
FOL	336	0	299	126	187
FRA	392	66	297	126	187
FRC	392	0	229	126	187
GOL	392	245	318	126	187
MAB	0	0	74	126	187
NLB	392	245	311	126	187
NLH	392	245	311	126	187
NPH	392	245	208	126	187
OBB	392	245	311	126	187
OBH	392	245	311	126	187
OCC	392	0	229	126	187
PAC	392	0	229	126	187
TBA	336	0	53	126	187
WNB	392	0	238	126	187
XCB	392	245	318	126	187
ZMB	392	66	297	126	187
ZYB	392	245	318	126	187

Table 5. Iron Age Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
ASB	392	91.46	125.23	108.691	5.465
BBH	392	116.99	157.45	134.399	6.516
BNL	392	85.00	131.00	101.722	6.535
BPL	336	74.00	118.16	93.636	7.209
DKB	0	-	-	-	-
EKB	0	-	-	-	-
FMB	0	-	-	-	-
FOB	336	21.50	36.35	29.642	2.356
FOL	336	28.30	45.40	36.799	3.002
FRA	392	108.00	148.00	126.858	6.489
FRC	392	97.50	125.40	110.751	4.954
GOL	392	162.00	204.00	184.819	6.840
MAB	0	-	-	-	-
NLB	392	16.40	29.82	23.418	2.265
NLH	392	34.18	70.29	50.306	4.360
NPH	392	48.23	102.89	69.033	6.155
OBB	392	32.91	54.30	39.991	2.747
OBH	392	22.73	43.00	32.919	2.802
OCC	392	81.03	114.50	98.238	5.592
PAC	392	82.42	137.40	115.145	6.514
TBA	336	275.60	344.00	309.196	11.556
WNB	392	2.82	26.16	9.336	2.377
XCB	392	118.00	154.00	136.178	5.929
ZMB	392	56.22	106.05	90.182	6.202
ZYB	392	96.07	170.38	125.851	9.148

Table 6. Romano-British Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
ASB	0	-	-	-	-
BBH	245	115.70	155.80	132.211	6.323
BNL	245	83.99	118.25	100.855	5.328
BPL	245	73.50	115.99	94.760	6.359
DKB	0	-	-	-	-
EKB	0	-	-	-	-
FMB	0	-	-	-	-
FOB	0	-	-	-	-
FOL	0	-	-	-	-
FRA	66	106.13	146.30	128.747	7.691
FRC	0	-	-	-	-
GOL	245	170.00	205.70	186.125	6.906
MAB	0	-	-	-	-
NLB	245	17.13	34.00	24.051	2.407
NLH	245	42.91	61.06	52.333	3.487
NPH	245	50.49	89.95	72.330	5.333
OBB	245	33.50	49.16	40.110	2.400
OBH	245	23.84	40.39	33.961	2.448
OCC	0	-	-	-	-
PAC	0	-	-	-	-
TBA	0	-	-	-	-
WNB	0	-	-	-	-
XCB	245	122.00	160.00	141.773	6.354
ZMB	66	73.89	108.83	90.955	8.753
ZYB	245	98.35	151.39	129.528	8.862

Table 7. Anglo-Saxon Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
ASB	110	81.57	176.30	112.688	11.850
BBH	318	115.40	152.53	134.028	6.044
BNL	309	61.00	129.00	100.831	7.504
BPL	172	70.40	108.45	94.323	5.918
DKB	240	8.63	40.62	21.944	3.731
EKB	67	89.50	117.00	97.575	4.594
FMB	67	60.96	128.00	104.867	11.207
FOB	311	23.05	41.40	30.944	2.667
FOL	299	20.00	49.50	37.259	3.281
FRA	297	107.00	146.90	126.977	6.547
FRC	229	97.00	128.50	111.274	5.121
GOL	318	167.10	210.17	187.476	7.529
MAB	74	50.00	69.00	61.587	3.393
NLB	311	14.56	38.14	24.413	2.366
NLH	311	35.56	63.69	50.171	3.778
NPH	208	54.50	81.50	68.610	4.588
OBB	311	34.70	49.76	41.088	2.183
OBH	311	24.67	44.46	33.552	2.616
OCC	229	51.23	116.28	96.376	8.315
PAC	229	95.00	133.00	115.359	5.904
TBA	53	292.00	350.00	313.670	11.166
WNB	238	1.94	14.50	8.901	2.023
XCB	318	122.00	160.00	139.042	6.027
ZMB	297	76.52	111.71	92.158	6.507
ZYB	318	96.94	152.00	129.513	8.549

Table 8. Medieval Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
ASB	114	99.50	125.00	114.725	4.640
BBH	126	120.00	148.00	132.101	4.966
BNL	126	87.00	114.00	98.616	3.467
BPL	98	85.00	105.00	93.268	3.343
DKB	126	15.00	37.00	23.705	3.101
EKB	126	87.50	106.20	95.436	3.729
FMB	126	63.20	135.91	104.245	7.445
FOB	126	24.40	36.50	29.235	2.326
FOL	126	28.10	41.10	35.044	2.155
FRA	126	110.90	913.93	134.236	70.342
FRC	126	101.70	222.14	112.588	10.851
GOL	126	163.00	195.00	179.249	6.870
MAB	126	50.30	71.50	62.602	3.403
NLB	126	19.20	28.40	23.665	1.706
NLH	126	38.90	58.50	50.341	3.114
NPH	126	57.00	80.00	69.179	4.235
OBB	126	33.10	42.20	38.444	2.117
OBH	126	27.40	38.40	34.163	2.167
OCC	126	85.60	113.00	97.610	5.125
PAC	126	97.10	149.40	110.781	6.619
TBA	126	275.00	350.00	313.336	12.521
WNB	126	5.80	15.00	10.381	1.945
XCB	126	123.00	157.00	142.968	6.520
ZMB	126	79.70	106.30	93.993	5.263
ZYB	126	105.00	138.00	126.745	8.707

Table 9. Post-Medieval Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
ASB	187	97.50	129.32	110.391	5.705
BBH	187	114.63	149.00	129.153	6.544
BNL	187	84.00	110.00	97.276	4.969
BPL	187	68.16	111.07	91.268	7.212
DKB	187	14.01	29.86	20.848	2.908
EKB	187	85.09	109.30	94.321	4.462
FMB	187	90.60	118.46	101.878	4.692
FOB	187	25.00	34.70	29.993	2.114
FOL	187	29.40	43.30	35.377	2.272
FRA	187	115.00	145.00	128.683	6.784
FRC	187	99.40	127.00	111.992	5.485
GOL	187	165.95	200.00	182.907	7.128
MAB	187	46.12	68.89	57.084	4.872
NLB	187	19.10	40.32	23.652	2.489
NLH	187	41.00	70.40	51.230	5.545
NPH	187	56.00	113.43	70.997	9.835
OBB	187	0.00	46.80	31.040	15.078
OBH	187	0.00	40.00	28.178	14.422
OCC	187	81.50	111.49	96.009	5.497
PAC	187	93.40	129.00	113.072	7.066
TBA	187	270.00	350.00	301.301	13.808
WNB	187	3.40	14.10	8.309	1.890
XCB	187	123.00	159.35	138.270	6.630
ZMB	187	71.92	165.77	89.065	13.968
ZYB	187	80.47	349.18	130.766	33.278

5.2 ANOVA for Size Variable

The ANOVA for the *size* variable indicated no significant size differences between the five time periods (F=1.773; p= .194). The complete ANOVA table can be found in Table 10.

Table 10. ANOVA for Size Variables

	Sum of Squares	**df**	**Mean Square**	**F**	**P-value**
Between Groups	6.57	4	1.643	1.773	0.194
Within Groups	12.042	13	0.926		
Total	18.613	17			

5.3 Canonical Variates Analyses of Shape

Between Time Periods

For the between time period analysis, the four significant canonical variates are summarized in Table 11. Sixty-seven percent of the variation is accounted for on CAN1, 17% on CAN2, 10% on CAN3, and 6% on CAN4. The total canonical structure matrix, presented in Table 12, shows the correlation between the computed shape variables and the canonical variates. This matrix indicates that most of the variation on the first canonical axis is associated with XCB (maximum cranial breadth), while variation on CAN2 is associated with OBH (orbital height). Likewise, variation on the third and fourth canonical axes is associated with BBH (basion-bregma height) and NLH (nasal height), respectively.

Table 11. Canonical Variates for between-time period analysis

	Eigenval.	% of Variance	Total Variance	Canonical Correlation	Chi-square	df	Sig.
1	.511[a]	66.9	66.9	.582	762.990	32	.000
2	.129[a]	16.8	83.7	.338	281.568	21	.000
3	.078[a]	10.3	94.0	.270	140.351	12	.000
4	.046[a]	6.0	100	.209	52.255	5	.000

Table 12. Total canonical structure for between-time period analysis

	Function			
	1	**2**	**3**	**4**
XCB	**.487****	-.297	-.213	.199
OBB	-.418*	-.010	-.319	.359
OBH	.408	**.521****	.249	-.071
GOL	-.230	.383*	.004	-.281
BBH	-.226	-.243	**.697****	-.008
BNL	-.271	-.214	.333*	-.208
NLH	.089	-.170	-.203	**-.625****
NLB	-.026	-.019	-.264	.456*

Figures 7 and 8 graphically illustrate the relationship between the group means and canonical variates 1 and 2, and 3 and 4, respectively. Figure 7 represents the first and second canonical axes and represents 84% of the total among-group variation. The plot indicates that the Iron Age and Anglo-Saxon samples have the narrowest cranial breadth (XCB) of all of the time periods. The medieval population had the broadest cranial breadth as well as the smallest orbital height. The post-Medieval population, in contrast, is characterized by the greatest orbital height of any time period.

Figure 8 depicts the third and fourth canonical axes and represents 16% of the total among-group variation. This plot reveals that the Romano-British population had the smallest basion-bregma height, whilst the Iron Age, Medieval, and post-Medieval time periods had the largest. The Romano-British also illustrated the shortest nasal height, while the Anglo-Saxon and Medieval populations had the tallest.

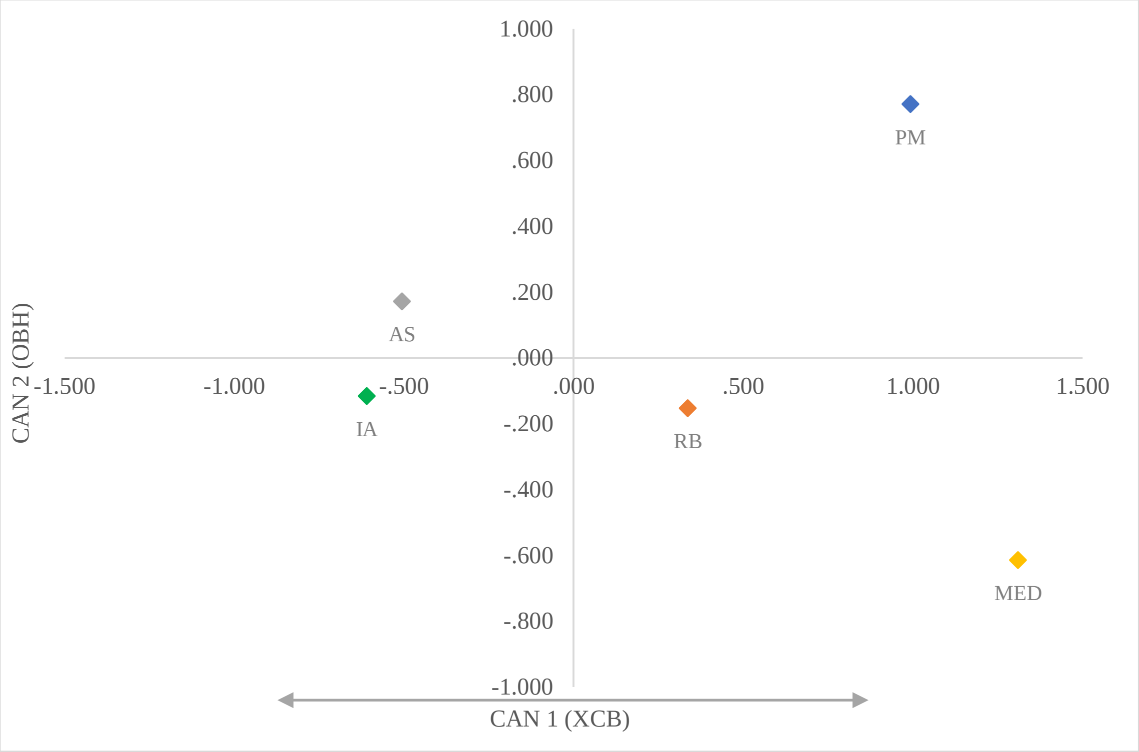

Figure 7. Canonical variates plot for CAN1 and CAN2, between time period analysis

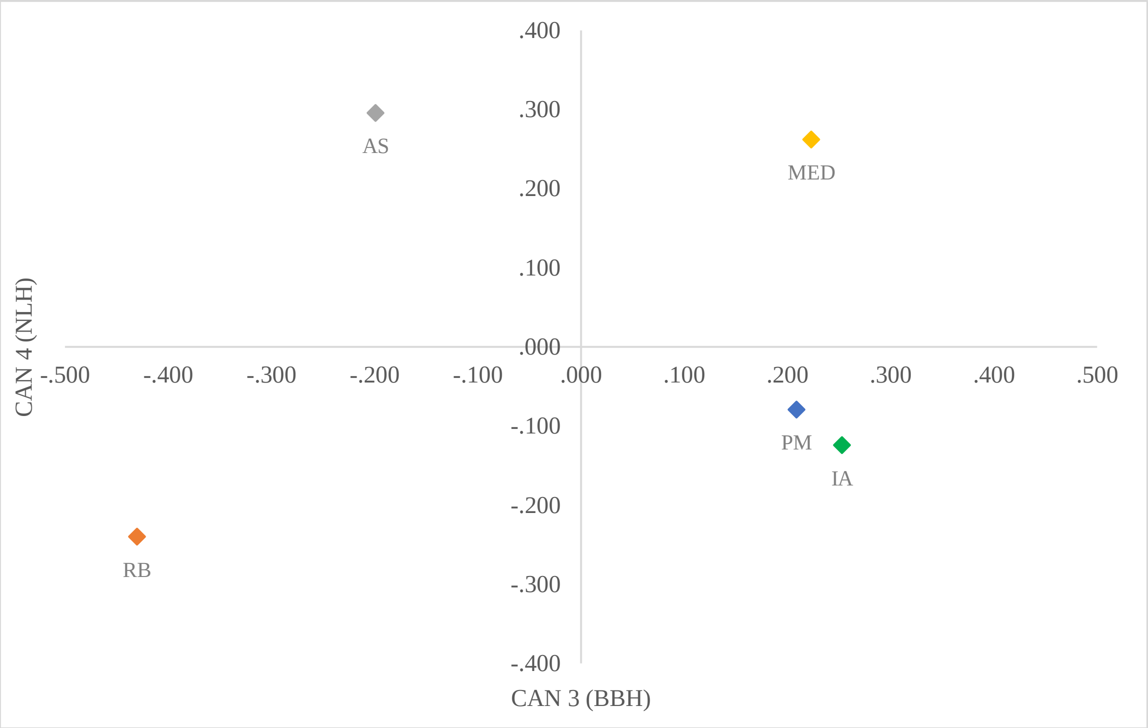

Figure 8. Canonical variates plot for CAN3 and CAN4, between time period analysis

Between Site Analysis

The four significant canonical variates of the between-site analysis are summarized in Table 13. Forty-nine percent of the variation is accounted for on CAN1, 16% on CAN2, 14% on CAN3, and 10% on CAN4. The remaining 11% variation is accounted for in the last four eigenvalues. The total canonical structure matrix, found in Table 14, illustrates the correlation between the computed shape variables and the canonical variates. This matrix indicates that variation on the first and second canonical axes is associated with OBB (orbital breadth). Variation on the third and fourth canonical axes is associated with GOL (glabello-occipital length) and OBH (orbital height), respectively.

Table 13. Canonical variates for between-site analysis

	Eigenval.	% of Variance	Total Variance	Canon. Correl.	Chi-square	df	P-value
1	.612[a]	48.7	48.7	.616	1253.147	136	.000
2	.201[a]	16.0	64.7	.409	699.274	112	.000
3	.174[a]	13.9	78.6	.385	486.361	90	.000
4	.121[a]	9.6	88.2	.328	299.789	70	.000
5	.087[a]	6.9	95.1	.283	167.752	52	.000

Table 14. Total canonical structure for between-site analysis

	Function				
	1	**2**	**3**	**4**	**5**
OBB	**-.499**	**.588****	.094	.190	-.041
OBH	.426	.008	-.295	**.633****	-.174
XCB	.424	.320	.196	-.543*	.325
NLB	-.044	.185	.084	.038	.359
BBH	-.200	-.501	.337	.002	.271
NLH	.087	.002	-.072	-.206	-.626
BNL	-.209	-.504	.200	-.125	-.102
GOL	-.193	-.288	**-.536**	-.338	.210

Figures 9 and 10 graphically illustrate the relationship between the group means and canonical variates 1 and 2, and 3 and 4, respectively. Figure 9 represents the first and second canonical axes and represents 64.7% of the total among-group variation. The first and second canonical axes are both influenced by orbital breadth (OBB). The plot shows that the first variate may be loosely related to time period, with the Iron Age and Anglo-Saxon samples having narrower orbital breadth and medieval and post-medieval samples having the broadest. Again, the Romano-British sample is characterized by a moderate orbital breadth. The second axis represents a positive increase in orbital breadth. The Anglo-Saxon and Iron Age populations are the most expressive of this attribute, while the Romano-British, medieval, and post-medieval samples are more moderate.

Figure 10 illustrates the third and fourth canonical axes and represents 23.5% of the total among-group variation. This plot reveals that individuals from the medieval sites exhibit the largest cranial length (GOL), whilst the Anglo-Saxon and post-Medieval sites had the smallest cranial length. The post-medieval sites are also characterized by the smallest orbital heights of any sites, while the Romano-British and medieval sites have the tallest.

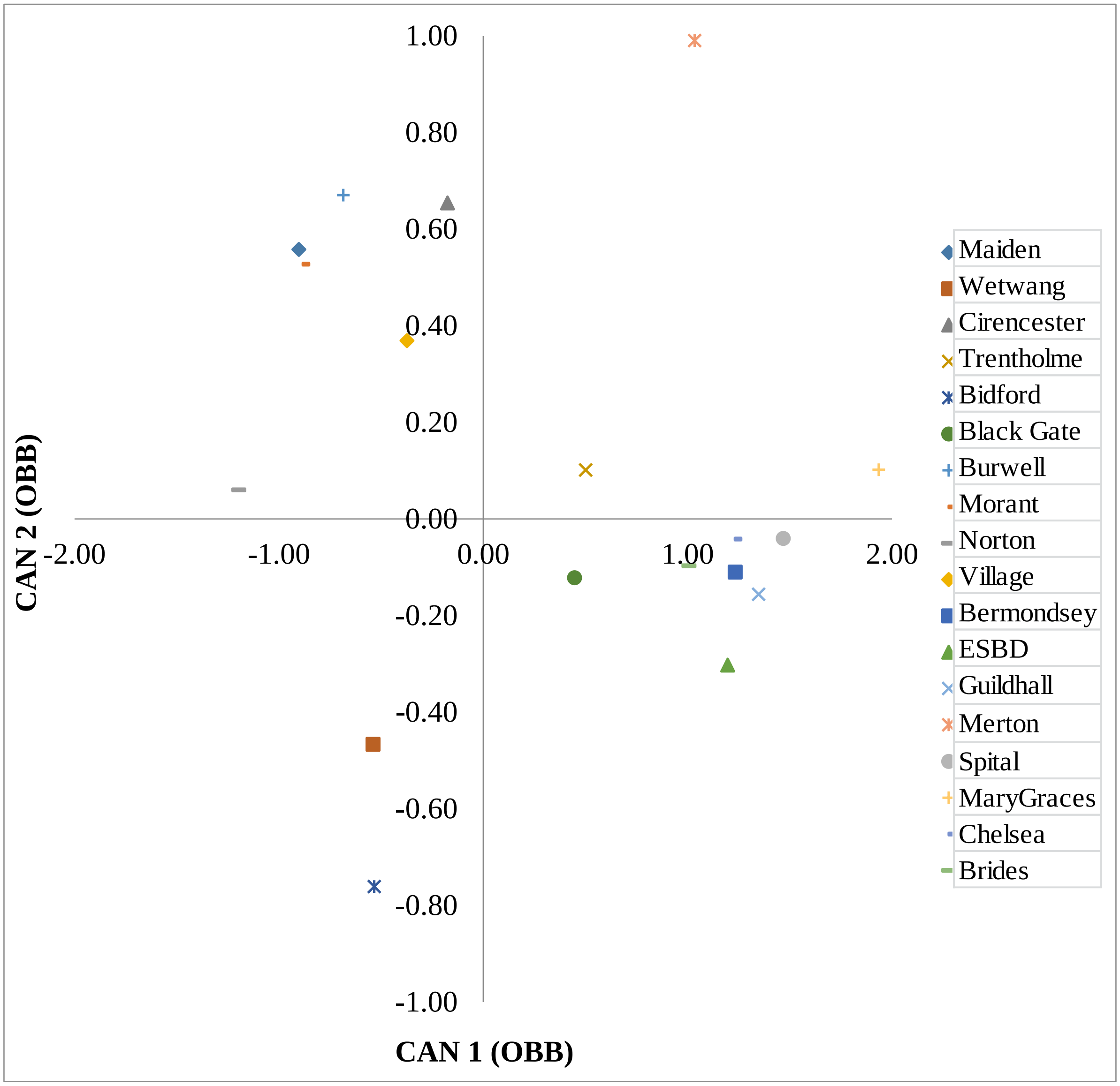

Figure 9. Plot of first two canonical axes, between site analysis

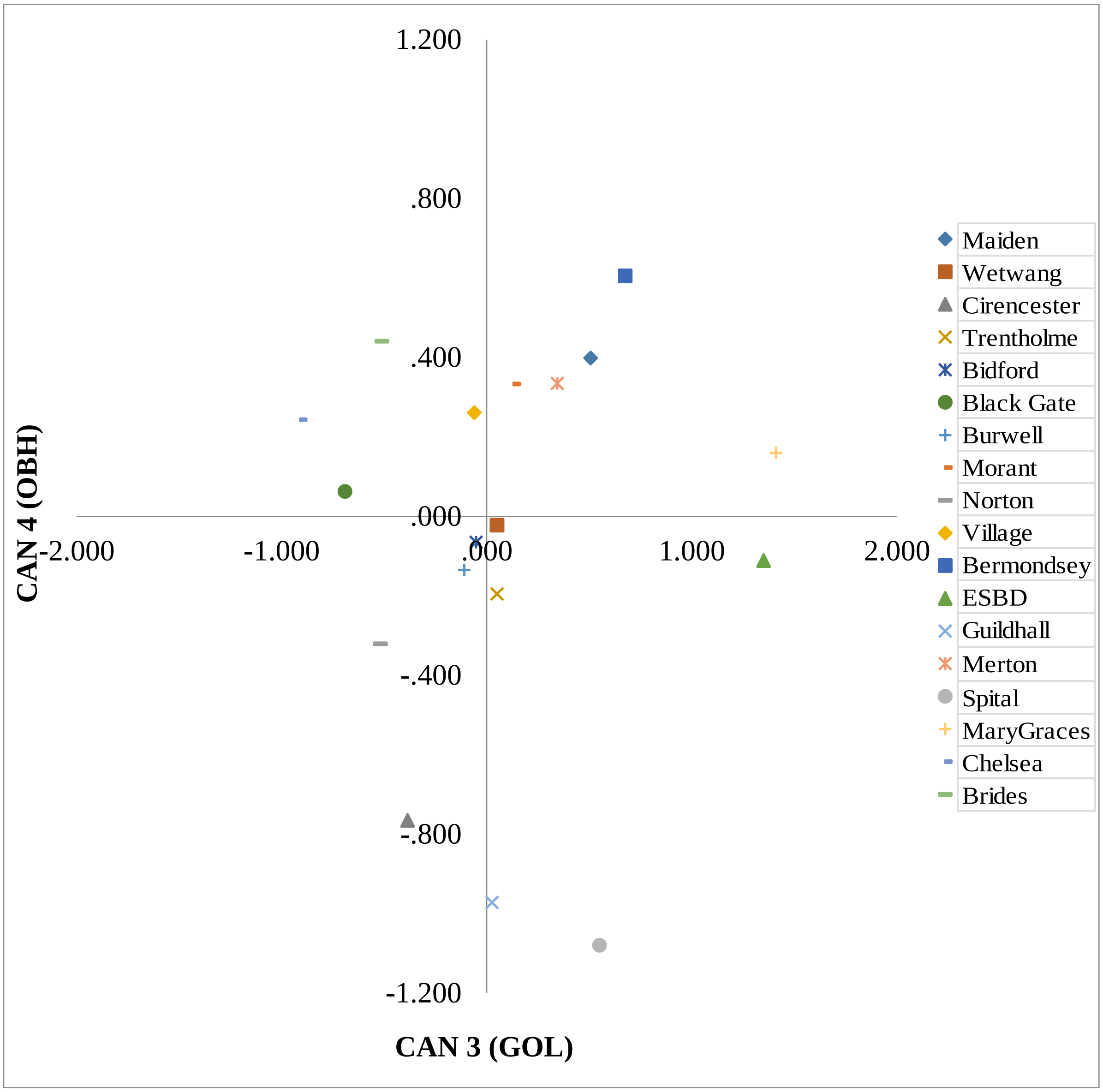

Figure 10. Plot of third and fourth canonical axes, between site analysis

5.4 Mahalanobis distances

Mahalanobis squared distances (D^2) are generated from genetic distance matrices based on craniofacial metric data and can be used as biological distance of different paired samples. This procedure also quantifies the significant differences that occur between the samples, if any. Mahalanobis squared distances were calculated between each site within the five time periods, as well as between time periods comprised of pooled site samples. Sites are considered more similar to each other as the distance between their group centroids decreases. The between site distances are reported in Table 15. The p-values associated with these distances illustrate the statistical significance of the biological distance and can also be found in Table 15. The least and most disparate site pairs are listed in Tables 16 and 17. The distances for the between-time period analysis is reported in Table 18, with accompanying p-values in Table 19. Table 20 lists the distances between time periods. Distances that are not significantly different are bolded. Any distance with a p-value of <.05 is considered significantly different.

The between site test of D^2 illustrates that nearly all of the samples tested are distinct from each other. Only twenty-three of the 210 site comparisons were not statistically significant with a p-value of >.05. All of the time periods are significantly different from each other.

Table 15. Mahalanobis Distances and P-values of between-site comparisons

		IA	AS	AS	AS	MED	MED	MED	MED	MED	PM
Time Period	**From site**	**Wetwang**	**Morant**	**Bidford**	**Burwell**	**Guildhall**	**Merton**	**Spital**	**ESBD**	**Mary Graces**	**Brides**
IA	**Wetwang**	0	**0.114**	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
AS	**Morant**	**0.121**	0	0	0	0.002	<.0001	<.0001	<.0001	<.0001	<.0001
AS	**Bidford**	0.638	0.842	0	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
AS	**Burwell**	1.124	0.579	1.285	0	0.012	<.0001	<.0001	<.0001	<.0001	<.0001
MED	**Guildhall**	2.696	1.799	4.114	1.378	0	**0.686**	**0.248**	0.004	0.006	**0.165**
MED	**Merton**	3.165	2.236	4.35	1.653	**0.289**	0	**0.571**	0.001	0.021	<.0001
MED	**Spital**	4.604	3.482	5.365	2.328	**0.74**	**0.238**	0	<.0001	0.021	<.0001
MED	**ESBD**	3.752	3.285	5.828	4.186	1.978	1.324	2.118	0	**0.295**	<.0001
MED	**Mary Graces**	6.25	5.395	8.007	5.432	2.545	1.379	1.495	**0.595**	0	<.0001
PM	**Brides**	1.141	0.6	2.559	0.768	**0.64**	1.395	2.471	3.008	4.722	0
PM	**Chelsea**	1.717	1.113	2.832	0.981	**0.972**	2.099	3.005	4.574	6.304	**0.26**
IA	**Maiden Castle**	0.283	**0.161**	1.033	0.795	1.728	1.769	2.914	2.27	4.058	0.913
MED	**Bermondsey**	1.9	1.467	3.621	2.149	**0.98**	0.745	1.681	**0.391**	1.446	1.301
AS	**Sewerby**	3.343	2.829	3.531	2.078	5.67	6.514	7.961	10.272	12.7	3.325
RB	**Trentholme**	1.201	0.672	1.663	**0.397**	0.589	0.774	1.279	2.557	3.517	0.591
RB	**Cirencester**	2.288	1.449	2.343	**0.252**	1.205	1.58	1.896	4.992	5.736	1.061
AS	**Village Farm**	0.638	**0.32**	0.818	**0.235**	1.405	1.874	2.638	3.912	5.48	0.653
AS	**Black Gate**	1.852	1.233	1.538	**0.208**	2.15	2.625	3.136	6.132	7.341	1.39
AS	**Hartlepool**	14.093	12.834	16.219	11.543	14.733	14.711	16.837	17.951	19.939	12.548
AS	**Castledyke**	**0.278**	**0.545**	**0.987**	1.947	2.888	3.392	4.764	3.357	5.863	1.57
AS	**Norton**	1.369	1.121	2.736	1.651	3.595	4.577	6.45	6.317	9.229	1.365

Table 15 continued.

		PM	IA	MED	AS	RB	RB	AS	AS	AS	AS	AS
Time Period	**From site**	**Chelsea**	**Maiden Castle**	**Bermondsey**	**Sewerby**	**Trentholme**	**Cirencester**	**Village Farm**	**Black Gate**	**Hartlepool**	**Castledyke**	**Norton**
IA	**Wetwang**	<.0001	0.009	<.0001	0	<.0001	<.0001	<.0001	<.0001	<.0001	**0.754**	0.001
AS	**Morant**	<.0001	**0.27**	<.0001	0.001	<.0001	<.0001	**0.064**	<.0001	<.0001	**0.481**	0.008
AS	**Bidford**	<.0001	<.0001	<.0001	0	<.0001	<.0001	0.001	<.0001	<.0001	**0.204**	<.0001
AS	**Burwell**	<.0001	<.0001	<.0001	0.011	0.001	**0.087**	**0.186**	**0.345**	<.0001	0.016	0.001
MED	**Guildhall**	**0.071**	0.003	**0.11**	<.0001	**0.194**	0.024	0.015	0.002	<.0001	0.015	0
MED	**Merton**	<.0001	<.0001	0.041	<.0001	0.001	<.0001	<.0001	<.0001	<.0001	0.001	<.0001
MED	**Spital**	<.0001	<.0001	0.001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
MED	**ESBD**	<.0001	<.0001	**0.272**	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.001	<.0001
MED	**Mary Graces**	<.0001	<.0001	0.019	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
PM	**Brides**	**0.059**	<.0001	<.0001	0	<.0001	<.0001	0	<.0001	<.0001	0.034	0.001
PM	**Chelsea**	0	<.0001	<.0001	0	<.0001	<.0001	0.002	0	<.0001	0.013	0
IA	**Maiden Castle**	1.747	0	0.004	0	<.0001	<.0001	0.006	<.0001	<.0001	**0.435**	0
MED	**Bermondsey**	2.479	0.89	0	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.037	<.0001
AS	**Sewerby**	3.471	3.708	6.804	0	<.0001	0.003	0.001	0.039	<.0001	0.001	**0.259**
RB	**Trentholme**	0.847	0.661	1.144	4.173	0	<.0001	**0.06**	<.0001	<.0001	0.049	<.0001
RB	**Cirencester**	0.943	1.778	2.884	2.605	0.587	0	0.003	**0.356**	<.0001	0.001	<.0001
AS	**Village Farm**	0.733	0.586	1.961	2.992	**0.258**	0.625	0	0.049	<.0001	**0.194**	0
AS	**Black Gate**	1.214	1.709	3.63	1.771	0.914	**0.206**	0.518	0	<.0001	0.003	0
AS	**Hartlepool**	14.353	13.137	14.898	6.215	14.899	12.36	14.41	12.064	0	<.0001	<.0001
AS	**Castledyke**	2.086	**0.612**	1.858	5.43	1.427	3.158	**1.008**	2.849	18.04	0	0.014
AS	**Norton**	1.878	1.762	3.674	**1.112**	2.741	2.589	1.905	2.108	7.94	2.649	0

Table 16. Sites with smallest Mahalanobis distances (not significant)

Site 1	Site 2	Mahal. D2	P-value
Wetwang (IA)	Morant (AS)	0.12094	0.114
Morant (AS)	Maiden Castle (IA)	0.16093	0.2704
Cirencester (RB)	Black Gate (AS)	0.20648	0.3558
Burwell (AS)	Black Gate (AS)	0.20848	0.345
Burwell (AS)	Village Farm (AS)	0.23516	0.185
Merton (MED)	Spital (MED)	0.23778	0.5711
Burwell (AS)	Cirencester (RB)	0.25181	0.086
Trentholme (RB)	Village Farm (AS)	0.25845	0.0601
Brides (PM)	Chelsea (PM)	0.26017	0.0589
Wetwang (IA)	Castledyke (AS)	0.2781	0.7538
Guildhall (MED)	Merton (MED)	0.28866	0.6855
Morant (AS)	Village Farm (AS)	0.32004	0.0644
ESBD (MED)	Bermondsey (MED)	0.39062	0.2718
Morant (AS)	Castledyke (AS)	0.54464	0.4809
Guildhall (MED)	Trentholme (RB)	0.58901	0.1939
ESBD (MED)	Mary Graces (MED)	0.59458	0.2954
Maiden (IA)	Castledyke (AS)	0.61171	0.4346
Guildhall (MED)	Brides (PM)	0.63992	0.1651
Guildhall (MED)	Spital (MED)	0.73998	0.2481
Guildhall (MED)	Chelsea (MED)	0.97162	0.0714
Guildhall (MED)	Bermondsey (MED)	0.97958	0.1101
Bidford (AS)	Castledyke (AS)	0.98725	0.2038
Village Farm (AS)	Castledyke (AS)	1.00825	0.1944

Table 17. Most disparate sites

Site 1	Site 2	Mahal. D2	P-value
Mary Graces (MED)	Hartlepool (AS)	19.93932	<.0001
Castledyke (AS)	Hartlepool (AS)	18.03955	<.0001
ESBD (MED)	Hartlepool (AS)	17.95107	<.0001
Spital (MED)	Hartlepool (AS)	16.83713	<.0001
Bidford (AS)	Hartlepool (AS)	16.21916	<.0001
Trentholme (RB)	Hartlepool (AS)	14.89932	<.0001
Bermondsey (MED)	Hartlepool (AS)	14.89798	<.0001
Guildhall (MED)	Hartlepool (AS)	14.73322	<.0001
Merton (MED)	Hartlepool (AS)	14.71074	<.0001
Village Farm (AS)	Hartlepool (AS)	14.4096	<.0001
Chelsea (PM)	Hartlepool (AS)	14.35319	<.0001
Wetwang (IA)	Hartlepool (AS)	14.09256	<.0001
Maiden Castle (IA)	Hartlepool (AS)	13.13674	<.0001
Morant (AS)	Hartlepool (AS)	12.83437	<.0001
Mary Graces (MED)	Sewerby (AS)	12.70019	<.0001
Brides (PM)	Hartlepool (AS)	12.54833	<.0001
Cirencester (RB)	Hartlepool (AS)	12.36028	<.0001
Black Gate (AS)	Hartlepool (AS)	12.06391	<.0001
Burwell (AS)	Hartlepool (AS)	11.54322	<.0001
ESBD (MED)	Sewerby (AS)	10.27163	<.0001
Mary Graces (MED)	Norton (AS)	9.22867	<.0001
Bidford (AS)	Mary Graces (MED)	8.00738	<.0001
Spital (MED)	Sewerby (AS)	7.96082	<.0001
Hartlepool (AS)	Norton (AS)	7.94044	<.0001
Mary Graces (MED)	Black Gate (AS)	7.3405	<.0001
Bermondsey (MED)	Sewerby (AS)	6.8038	<.0001
Merton (MED)	Sewerby (AS)	6.51375	<.0001
Spital (MED)	Norton (AS)	6.45032	<.0001
ESBD (MED)	Norton (AS)	6.31731	<.0001
Mary Graces (MED)	Chelsea (PM)	6.30405	<.0001

Table 18. Mahalanobis distances of between-time period analysis

Time Period	Iron Age	Romano-British	Anglo-Saxon	Medieval	Post-Medieval
Iron Age	0				
Romano-British	1.20264	0			
Anglo-Saxon	0.4239	0.5223	0		
Medieval	2.7716	1.33221	2.64868	0	
Post-Medieval	1.13806	0.57579	0.77185	1.85674	0

Table 19. P-values of Mahalanobis distances of between-time period analysis

Time Period	Iron Age	Romano-British	Anglo-Saxon	Medieval	Post-Medieval
Iron Age	1				
Romano-British	<.0001	1			
Anglo-Saxon	<.0001	<.0001	1		
Medieval	<.0001	<.0001	<.0001	1	
Post-Medieval	<.0001	<.0001	<.0001	<.0001	1

Table 20. Mahalanobis D^2 by time period

Time Period 1	**Time Period 2**	**Mahalanobis Distance**
Iron Age	Medieval	2.7716
Anglo-Saxon	Medieval	2.64868
Post-medieval	Medieval	1.85674
Romano-British	Medieval	1.33221
Romano-British	Iron Age	1.20264
Iron Age	Post-medieval	1.13806
Anglo-Saxon	Post-medieval	0.77185
Romano-British	Post-medieval	0.57579
Romano-British	Anglo-Saxon	0.5223
Iron Age	Anglo-Saxon	0.4239

5.5. *Fst*

Fst compares the among-group variation relative to variation expected under complete panmixia (Relethford 1994). According to the literature, global levels of variation should be 13% among regions, 6% among local populations within a region, and 81% within a local population (Relethford 1994, Relethford 2002). The unbiased *Fst* value for the between site analysis is .257 (SE=.013) when heritability is estimated at the human average of .55, which indicates a high level of population differentiation. The unbiased *Fst* value for the between time period analysis is .106 (SE=.007) when heritability is average. This is indicative of a population with higher than average amount of variation.

VI. DISCUSSION

There has been a dearth of biodistance research of archaeological English populations. The aim of this study is to shed light on the population affinity of the groups who inhabited England by examining 22 sites from five historical time periods for patterns of cranial change and continuity. This study illustrates a considerable amount of cranial variation among different English groups, but also illustrates skeletal discontinuity between samples of contiguous time periods.

6.1 Between time period outcomes

The canonical variates plots reveal many craniometric relationships between the time periods. The Iron Age and Anglo-Saxon samples were similar with narrow cranial vaults and short orbital heights, but varied in that the Iron Age sample was characterized by shorter orbits than the Anglo-Saxons. The medieval and post-medieval samples had broad cranial vaults, but differed in terms of orbital height: post-medieval samples were characterized by very tall eye orbits, while short orbits were characteristic of medieval samples. The Romano-British sample falls in the middle of the other four time periods; these individuals were characterized by slightly shorter orbital heights and broader cranial vaults on average. Basion-bregma height (BBH) and nasal height (NLH) had less influence on overall variation. The post-medieval, medieval, and Iron Age samples were similar in that all three demonstrated tall cranial vaults, but were different in that the post-medieval and Iron Age samples had short nasal heights when compared to the medieval sample. The Romano-

British time period had the shortest cranial vaults and nasal heights of any of the groups; the Anglo-Saxons had the tallest nasal height of any period.

These results are indicative of both genetic and climatic (environmental) differences between the time periods. There have been numerous studies that have attempted to discern cranial variation in relation to environmental and genetic influences in order to examine population variation. In a comparison between American-born and European-born children of American immigrants, Boas (1912) illustrated the plasticity of the cranial vault in response to environmental factors. In a response to Boas' study, Jantz and Meadows-Jantz (2000) found that the vault is more heavily influenced by secular change than the facial region due to the early development of the vault in childhood development. They also postulated that short term morphometric changes, over generations rather than centuries, occurred primarily as a result of environmental factors. Long-term changes were more indicative of genetic and environmental factors on the cranium. A follow-up study by Jantz (2001) found that the cranial base also illustrates plasticity as a result of both environmental and genetic factors. Following some debate about the accuracy of Boas' methods (see Sparks and Jantz 2002, Gravlee et al 2003), Relethford (2004) determined that Boas was correct in that environmental plasticity does play a role in cranial morphology, but only a small one that does not obliterate the underlying genetic influences. A study by Betti et al (2010) substantiated the idea of limited environmental influence on cranial growth and development. They noted that natural selection is the process by which the environment influences cranial morphology; natural selection, and therefore environmental influence, is usually only significantly correlated to the human skull in studies that do not treat size and shape as separate factors. Neutral genetic processes such as genetic flow and drift, on the other hand, are highly correlated to geographic distances and are frequently the primary cause of variation in studies that examine size and shape as separate variables. The same study determined that cranial characteristics are good neutral genetic markers in most circumstances (Betti et al 2010).

Morphometric traits of the facial region are usually genetically driven, with the exception of individuals from very cold geographic locations (Betti et al 2010). Craniometrically, cold climates affect cranial and facial breadths as well as the nasal and orbital apertures: changes in the nasal aperture are specifically a response to selective pressures of thermoregulatory breathing techniques (Betti et al 2010). It follows, then, that the elongated nasal heights of the Anglo-Saxon and medieval groups is suggestive of a colder, drier climate, while the shorter nasal heights of the post-medieval, Iron Age, and Romano-British time periods are reflective of a moderately warmer climate (Noback et al 2011). These findings are supported by climate data from these time periods: Europe experienced a cooling trend during the Anglo-Saxon and medieval periods and a warming trend during the 18th and 19th centuries (Jones and Mann 2004). If the association between colder climates and taller nasal aperture height is considered an indicator of environmental influence, the results from the current study suggest that the medieval and Anglo-Saxon samples had similar environmental influences. The Iron Age, Romano-British, and post-medieval samples were similar to each other in terms of nasal height, which indicates that these groups experienced similar environments. Another component of the difference in nasal heights is genetic: increased genetic flow during the Anglo-Saxon and medieval time periods could have been a cause of this trend as environmental factors account for less than 10% of total variation (Buretic-Tomljanovic et al 2007). Environmental influences, then, would have added to but not obliterated the genetic influences on the facial region.

The less environmentally-driven measure of orbital height is taller than the centroid mean in the post-medieval sample, while in the medieval sample orbital height is shorter than the mean. Because the measurement for orbital height is taken on the frontal and maxillary bones, which are respectively controlled by genetics and environment, this particular aspect of craniofacial variation is likely a good indicator of overall influences (Harvati and Weaver 2006).

When comparing maximum cranial breadth, the Iron Age and Anglo-Saxon populations are the most similar, both having narrow crania. The medieval and post-medieval samples exhibit the opposite trend: both groups have wide crania. This suggests a great amount of biological distance between the two groups of samples. The Romano-British population falls in the middle of the five groups, revealing that medieval and post-medieval populations are more biologically related to the Romano-British than they are to the Iron Age or Anglo-Saxon groups.

Tests of biological distance also indicate that each time period is significantly different from the others. As expected from the results of the discriminant function analyses, the Iron Age and Anglo-Saxon populations have the smallest Mahalanobis distance, and are therefore the most similar. The most dissimilar groups are the Iron Age and medieval populations, which is also consistent with the results from the discriminant function analyses. One major difference that is not evident from previous testing is the amount of disparity between the medieval population and the other four time periods. Of the ten time period comparisons, the medieval period had the four largest biological distances (Table 20). Medieval samples were the most different from Iron Age and Anglo-Saxon samples, which is surprising due to the temporal continuity between the Anglo-Saxon and medieval time periods. The Romano-British group was the most similar to the medieval, which suggests that there may have been similar Mediterranean or continental influences in both periods. This evidence rejects the hypothesis presented in the current study and supports the alternative that the Norman invasion in the early medieval period did, in fact, bring significant craniofacial change to England.

The Iron Age and Romano-British populations were the most dissimilar groups after the medieval period, suggesting that the influx of Romans into England was also highly influential on craniofacial dimensions. The post-medieval population is most different from the medieval population, and least different from the Romano-British. This implies that there is a significant amount of non-western European influence in both the post-medieval and Romano-British periods. It also suggests that there may have been a similar geographical component of the groups that immigrated into the area, since the medieval and post-medieval populations are the most craniometrically similar to the Romano-British population.

The four ILDs utilized in the between time period analysis, BBH, BNL, GOL, and XCB, are all variables that are controlled mostly by genetics, and environment to a lesser extent (Harvati and Weaver 2006). Therefore, the tests of Mahalanobis D^2 should be indicative of genetic relationships with environmental influences, rather than indicative of environmental factors with genetic influences.

6.2 Between site outcomes

The results from the between site analysis of canonical variates were much less clear than those from the pooled between-time period analysis. Orbital breadth is the greatest contributor of variation to the first and second canonical axes, which indicates that there are two confounding facets of orbital breadth between populations. It also suggests that variation between sites is a result of both genetic influences and environmental stimuli. Sites are arranged along the first axis in a roughly chronological order, with the Iron Age and Anglo-Saxon sites having the narrowest orbital breadth. The post-medieval and medieval sites are clustered on the higher end of the axis, meaning that the individuals from these groups have wider orbital breadths than earlier periods. The Romano-British sites were clustered between the Anglo-Saxon and medieval groups. On the second canonical axis, the sites are more spread out, with the only discernible trend being the medieval and post-medieval sites having similar moderate heights of the orbital aperture.

The measurement of orbital breadth is influenced most by genetics, but also has an environmental aspect as cold climate has a significant but small impact on orbital shape (Betti et al 2010). This is strongly substantiated by the grouping of sites by time period on the first canonical axis. The seemingly indiscriminate placing of sites along the second axis is likely due to a combination of environmental and genetic influences. It may also be biased by the number of individuals in each site, as some sites have a significantly larger sample size than others. In relation to both axes, the Iron Age and Anglo-Saxon sites were closely related to each other, as were the medieval and post-medieval sites. The former group had a great amount of variability with respect to the second axis, while homogeneity characterized the latter group.

The third and fourth canonical axes represent 23.5% of the variation seen across all of the sites. Maximum cranial length (GOL) is responsible for variation along the third axis where the sites tend to cluster by time period. Interestingly, the post-medieval sites exhibit the shortest vault length, while medieval sites exhibit the longest. This is a deviation from the trend identified in the other canonical variates analyses and may be due to a lessening in biomechanical loading during the post-medieval era. Anglo-Saxon sites have smaller cranial lengths than the Romano-British populations, while the Iron Age sites have longer crania than either from these two time periods. Variation along the fourth axis illustrates that the medieval sites have the largest range of orbital heights, which incorporates both the largest and the smallest site means for the measurement. The Romano-British sites have short orbital heights on average, while the Anglo-Saxon and Iron Age sites have moderately taller orbits. The post-medieval sites are characterized by tall orbits.

Tests of Mahalanobis D^2 (biological distance) indicate that nearly all sites are significantly different from each other, with exception of 23 pairs. Non-significant bivariate site correlations can be found in Table 16. When analogous, the site pairs tend to be from the same time period. Many of the Iron Age and Anglo-Saxon sites were not significantly different from each other, supporting the findings from the previous analyses that suggest that the samples from the two time periods were relatively homologous. Additionally, some temporally contiguous sites from the Romano-British and Anglo-Saxon time periods do not significantly differ, which suggests a moderate amount of genetic continuity between the populations.

The most dissimilar site pairs are listed in Table 17. The Anglo-Saxon site of Hartlepool is the most disparate. On average, the biological distance from Hartlepool to any of the other sites is over twice the distance seen between other sites. This could be a result of any number of factors, including genetics and data collection errors. Hartlepool is located in the northeast of England, on the coast of the North Sea: it would have been a prime location for Anglo-Saxon tribes or Danish raiders to settle due to its proximity to waterways and the major town of Monkchester (modern Newcastle-upon-Tyne). As such, Hartlepool would be expected to have additional genetic material unseen in the other sites of the study (Mackenzie 2013). This explanation seems unlikely, though, because contemporary Anglo-Saxon sites located close to Hartlepool were included in the current analyses. Should new populations have moved into the Hartlepool area, it would have been expected to see those genetic markers in nearby sites, such as Black Gate and Norton East Mill. It is also possible that the data was collected erroneously; e.g., taking ILD measurements from the wrong landmarks. A third possibility is that the individuals associated with Hartlepool were part of a monastic community (Russell 2007). The monastic way of life, if practiced for long enough in the same area, could produce distinct skeletal markers as a result of biomechanics and occupational stress. Intriguingly, the medieval sites are among the most different from Hartlepool, suggesting a stark discontinuity between the two time periods. This finding is also supported by the results from the between time period analysis of biological distance as well as the results from both discriminant function analyses.

Eleven of the top thirty most dissimilar site comparisons, not counting the Hartlepool sample, involve comparisons between Anglo-Saxon and medieval sites. Factors that may have influenced this discontinuity are social class, socioeconomic status, and political affiliations: during the medieval time period, the upper classes were comprised of mostly Norman aristocracy, who would have lived in the more urban sites such as London. Again, the hypothesis that no significant craniometric differences exist between individuals of the varying time periods is rejected.

6.3 Fst

Fst is a statistic that illustrates among-group variation relative to variation expected under complete panmixia (Relethford 1994). On average, *Fst* values indicate that craniometric variation is accounted for in the following ways: about six percent among local populations within a region; eighty-one percent within a local population; and thirteen percent among regions (Relethford 2004). The unbiased *Fst* value between time periods is .106 (10.6%) when heritability is average. The variation seen among British time periods, then, is higher than what would be expected. The amount of variation observed is between the among site and among region percentages, suggesting that the variation may be due in part to the temporal distance between samples.

The unbiased *Fst* value for the between site analysis is .257 (25.7%) when heritability is average, which indicates a very high level of population differentiation. A plausible explanation is that this number accounts for temporal, genetic, and environmental factors.

Unlike the pooled time period *Fst* value, the between site value may include variation due to both among population and between regions (regions, here, indicative of time periods).

VII. CONCLUSIONS AND FUTURE DIRECTIONS

7.1 Conclusions

The results from this study reject the hypothesis that there are no significant craniometric differences between and among English samples of Iron Age, Romano-British, Anglo-Saxon, medieval, and post-medieval time periods. Instead, data from this study indicate that all five time periods are characterized by significantly different craniometric patterns. The most similar samples are the Iron Age and Anglo-Saxon, which illustrate a relatively high degree of cranial continuity despite a lack of temporal continuity. The medieval period is the most disparate, which signifies a significant shift in genetic and environmental influences on the sample. The influx of the French and other continental groups beginning with the Norman invasion in the 11th century is likely the origin of this variation. Centuries of extreme cold and subsequent illnesses would have also affected the populations of medieval England, which are mirrored in craniofacial traits. The sample from the post-medieval period is the most similar to the Romano-British and medieval groups, signifying a great amount of heterogeneity in the populace. The outcomes of this study are able to answer the research questions posed at the beginning of analysis. The Norman Conquest did bring widespread craniometric change to England, and much of the variation in modern English populations is related to the Romano-British and medieval populations.

Specifically, this analysis has revealed several patterns of craniofacial traits of English populations. First, taller eye orbits are a recent phenomenon that are influenced both by genetics and the environment. Since the post-medieval period is the warmest on record, it may be that orbital height increases as the minimum climatic temperature increases (Jones and Mann 2004). Maximum cranial breadth appears to increase as the amount of variation within a population increases, as both the medieval and post-medieval groups have large cranial breadths. Additionally, nasal height appears to be significantly correlated with minimum climatic temperature. Both the Anglo-Saxon and medieval samples have tall nasal apertures, despite the fact that they are genetically dissimilar.

7.2 Limitations

The major problems of this study concern sample sizes, urbanization, and environmental influences on craniofacial variation. First, sample sizes for early England are small, and likely would not be large enough to determine significance if many of the individuals were unable to be measured. Second, many of the skeletal samples used for study are from urban areas, which introduces an important source of bias in the analysis. Invaders, specifically, tend to raid and occupy cities where wealth and prestige is greatest. Immigrants, on the other hand, are more likely to seek work in rural areas where competition is lower and land more plentiful (Haywood 1995). Thus, during a period of invasion such as the Norman Conquest, one would expect gene flow to be initially restricted to cities. As with the Normans, intermarriage with locals would likely not have occurred for some years post-conquest. Therefore, cities are expected to have the largest amount of gene flow, and a large biological distance from contemporary rural sites. These urban samples may also be over-representative of the biological distance of a population. Another major dilemma stemming from studying skeletal changes over time is the question of how the environment shapes genetic determinism. Some changes arise from adaptation to a new environmental factor, while others occur naturally over a period of time. According to Relethford (2004), "...both gene flow (via geographic distance) and natural selection (via climatic adaptation) have shaped global craniometric variation." For that reason, it is impossible to assume genetic or environmental influence alone accounts for craniometric variation.

7.3 Future Directions

This study illustrates that scholars can use craniometrics to examine population affinity, biological distance, and to discern the effects of both genetics and environment on a population. This data could be utilized to assign unknown individuals from English archaeological sites to more specific populations than previously possible. Moreover, this craniometric data can be utilized to help differentiate migration and settlement patterns in England. The addition of populations from France, Denmark, and Germany could aid in the identification of specific migratory periods or cross-Channel gene flow. This study therefore provides the framework from which one could study microevolutionary craniofacial trends in England.

FIN.

REFERENCES

Beddoe J. 1885. The races of Britain. Arrowsmith.

Bekvalac J. 2007. St. Mary Graces. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Medieval+cemeteries/StMaryGraces.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Bekvalac J. 2008. Saint Saviour monastic cemetery, Bermondsey Abbey. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Medieval+cemeteries/bermondseyabbey.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Bekvalac J, Cowal L, Kausmally T, Mikulski R. 2007. Spital Square. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Medieval+cemeteries/spitalsquare.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Betti L, Balloux F, Hanihara T, Manica A. 2010. The relative role of drift and selection in shaping the human skull. Am J Phys Anthropol 141(1):76-82.

Boas F. 1912. Changes in the bodily form of descendants of immigrants. American Anthropologist 14(3):530-562.

Brash JC, Young M. 1935. The Anglo-Saxon skulls from Bidford-on-Avon, Warwickshire and Burwell, Cambridgeshire, with a comparison of their principal characters and those of the Anglo-Saxon skulls in London museums: Part I. the Bidford-on-Avon skulls. Biometrika 27(3-4):373-387.

Brothwell D, Krzanowski W. 1974. Evidence of biological differences between early british populations from neolithic to medieval times, as revealed by eleven commonly available cranial vault measurements. Journal of Archaeological Science 1(3):249-260.

Buretic-Tomljanovic A, Giacometti J, Ostojic S, Kapovic M. 2007. Sex-specific differences of craniofacial traits in Croatia: the impact of environment in a small geographic area, Ann. Hum. Biol. 34: 296–314.

Corruccini RS. 1995. Of ratios and rationality. Am J Phys Anthropol 96(2):189-191.

Cowal L. 2007. Guildhall Yard. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Medieval+cemeteries/GuildhallYard.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Craig E. 2008. Village Farm, Spofforth osteological report. Unpublished report for Northern Archaeological Associates: Barnard Castle, North Yorkshire.

Crick J, van Houts E, editors. A social history of England, 900-1200. 1st ed. Cambridge: Cambridge University Press.

Cunliffe B. 2005. Iron Age communities in Britain: An account of England, Scotland and Wales from the seventh century BC until the Roman conquest. 4th ed. London: Routledge.

Darroch JN, Mosimann JE. 1985. Canonical and principal components of shape. Biometrika 72(2):241-252.

de la Bedoyere G. 2010. Roman Britain: A new history. London: Thames and Hudson.

Drinkall G, Foreman M. 1998. The Anglo-Saxon cemetery at Castledyke South, Barton-on-Humber. Sheffield: Sheffield Academic Press Ltd.

Friedlaender J. 2007. William White Howells. http://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/howells-william.pdf ed. Washington D.C.: National Academy of Sciences.

Goodman CN, Morant GM. 1940. The human remains of the Iron Age and other periods from Maiden Castle, Dorset. Biometrika 31(3-4):295.

Graham JW. 2009. Missing data analysis: Making it work in the real world. Annu Rev Psychol 60(1):549-576.

Graham J, Olchowski A, Gilreath T. 2007. How many imputations are really needed? Some practical clarifications of multiple imputation theory. Prevention Science 8(3):206-213.

Gravlee CC, Bernard HR, and Leonard WR. 2003. Boas's Changes in Bodily Form: The Immigrant Study, Cranial Plasticity, and Boas's Physical Anthropology. American Anthropologist, 105: 326–332.

Hadas M, editor. 1942. The complete works of Tacitus. New York: Random House.

Hanihara T, Ishida H. 2009. Regional differences in craniofacial diversity and the population history of Jomon Japan. Am J Phys Anthropol 139(3):311-322.

Harding RM. 1990. Modern European cranial variables and blood polymorphism show comparable spatial patterns. Hum Biol 62:733.

Harper-Bill C, van Houts C, editors. 2003. A companion to the Anglo-Norman world. Woodbridge: The Boydell Press.

Harvati K, Weaver TD. 2006. Human cranial anatomy and the differential preservation of population history and climate signatures. The Anatomical Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology 288A(12):1225-1233.

Haywood J. 1995. The Penguin Historical Atlas of the Vikings. London: Penguin Books.

Higham M. 1994. The English Conquest. Manchester: Manchester University Press.

Hills C. 2003. Origins of the English. London: Duckworth.

Hirst SM. 1985. An Anglo-Saxon inhumation cemetery at Sewerby, East Yorkshire. York: Dept. of Archaeology, University of York.

Howells WW. 1973. Cranial variation in man: A Study by multivariate analysis of patterns of differences among recent human populations. Papers of the Peabody Museum of Archeology and Ethnology 67:259.

Humphries AL, Ross AH. 2011. Craniofacial sexual dimorphism in two Portuguese skeletal samples. Anthropologie (Brno) 49(1):13-20.

Ibeji M. 2011. An overview of Roman Britain. http://www.bbc.co.uk/history/ancient/romans/questions_01.shtml ed. Britain.

IBM Corp. 2012. SPSS v21. Armonk, N.Y.: IBM.

Jackson J, Weidman N. 2006. Race, racism, and science: Social impact and interaction. Rutgers University Press.

Jantz RL. 2001. Cranial change in Americans: 1850–1975. J Forensic Sci 46(4):784–787.

Jantz RL and Meadows Jantz L. 2000. Secular Change in Craniofacial Morphology. Am J Hum Biol 12:327-338.

Jay M, Richards MP. 2006. Diet in the Iron Age cemetery population at Wetwang Slack, east Yorkshire, UK: Carbon and nitrogen stable isotope evidence. Journal of Archaeological Science 33(5):653-662.

Jones PD, Mann ME. 2004. Climate over past millennia. Rev Geophys 42(2):- RG2002.

Jungers WL, Falsetti AB, Wall CE. 1995. Shape, relative size, and size-adjustments in morphometrics. Am J Phys Anthropol 38(S21):137-161.

Katzenberg MA, Saunders S, editors. 2005. Biological Anthropology of the Human Skeleton. 2nd ed. Hoboken: John Wiley & Sons.

Kausmally T. 2007. Chelsea Old Church. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Post-medieval+cemeteries/Chelsea.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Kausmally T. 2007b. East Smithfield Black Death cemetery. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Medieval+cemeteries/ESmithfieldBlackDeath.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Kausmally T. 2008. Farringdon: St Brides lower churchyard. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Post-medieval+cemeteries/St+Brides+lower.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Konigsberg LW. 1990. Analysis of prehistoric biological variation under a model of isolation by geographic and temporal distance. Hum Biol 62:64.

Mackenzie E. 2013. Historical events: To 1584, Historical account of Newcastle-upon-Tyne: Including the borough of Gateshead. http://www.british-history.ac.uk/report.aspx?compid=43318 ed. University of London & History of Parliament Trust.

McWhirr AD, Viner L, Wells C. 1982. Romano-British cemeteries at Cirencester. Cirencester Excavation Cttee.

Mikulski R. 2007. Merton Priory. http://archive.museumoflondon.org.uk/Centre-for-Human-Bioarchaeology/Database/Medieval+cemeteries/MertonPriory.htm ed. London: Museum of London Centre for Human Bioarchaeology.

Morant GM. 1936. A first study of the craniology of England and Scotland from Neolithic to early historic times, with special reference to the Anglo-Saxon skulls in London museums. Biometrika 18:56.

Mosimann JE, James FC. 1979. New statistical methods for allometry with application to Florida red-winged blackbirds. Evolution 33(1, Part 2):444-459.

Neveux F. 2008. A brief history of the Normans: The conquests that changed the face of Europe. Philadelphia, PA.: Running Press.

Noback ML, Harvati K, Spoor F. 2011. Climate-related variation of the human nasal cavity. Am J Phys Anthropol 145(4):599-614.

Novotný V, Iscan MY, Loth SR. 1993. Morphologic and osteometric assessment of age, sex and race from the skull. In: Iscan MY, Helmer RP, editors. Forensic Analysis of the Skull. New York: Wiley-Liss, Inc. p 71.

Ousley SD. 2013. Threeskull 1.71.

Ousley SD, McKeown A. 1999. Three dimensional digitizing of human skulls as an archival procedure. In: Williams E, editor. Human Remains: Conservation, retrieval and analysis. London: Archaeopress. p 173.

Pietrusewsky M. 2008; 2007. Metric analysis of skeletal remains: Methods and applications. In: Biological Anthropology of the Human Skeleton. John Wiley & Sons, Inc. p 485-532.

Relethford JH. 1994. Craniometric variation among modern human populations. Am J Phys Anthropol 95(1):53-62.

Relethford JH, Crawford MH, Blangero J. 1997. Genetic drift and gene flow in post-famine Ireland. Hum Biol 69:443.

Relethford JH. 2002. Apportionment of global human genetic diversity based on craniometrics and skin color. Am J Phys Anthropol 118(4):393-398.

Relethford JH. 2004. Boas and beyond: Migration and craniometric variation. Am J Hum Biol 16(4):379-386.

Roberts DF. 1995. Human variability and plasticity. Cambridge: Cambridge University Press.

Rösing FW, Schwidetzky I. 1977. Vergleichend-statistische untersuchungen zur anthropologie des frühen mittelalters (500–1000 n.d.Z.). Homo 28:65.

Rösing FW, Schwidetzky I. 1981. Vergleichend-statistische untersuchungen zur anthropologie des hochmittelalters (1000–1500 n.d.Z.). Homo 32:211.

Ross AH. 2004. Regional isolation in the Balkan region: An analysis of craniofacial variation. Am J Phys Anthropol 124(1):73-80.

Russell CK. 2007. Whence came the English?: Exploring relationships between the Iron Age, Romano-British and Anglo-Saxon periods in Britain and Denmark : A craniometric biodistance analysis. PhD ed. Durham: Durham University.

Sawyer PH. 1998. From Roman Britain to Norman England. 2nd ed. London ; New York: Routledge.

Smith S. 1998. British imperialism 1750–1970. Cambridge: Cambridge University Press.

Sokal RR, Uytterschaut H, Rösing FW, Schwidetzky I. 1987. A classification of European skulls from three time periods. Am J Phys Anthropol 74(1):1-20.

Sparks CS, Jantz RL. 2002. A reassessment of human cranial plasticity: Boas revisited. Proceedings of the National Academy of Sciences 99(23):14636-14639.

Thomas H. 2003. The English and the Normans. Oxford: Oxford University Press.

Thomas H. 2007. *The Norman Conquest: England after William the Conqueror*. Critical issues in history. Lanham: Rowman & Littlefield Publishers, Inc.

Wood JW, Milner GR, Harpending HC, Weiss KM, Cohen MN, Eisenberg LE, Hutchinson DL, Jankauskas R, Cesnys G, Česnys G, Katzenberg MA, Lukacs JR, McGrath JW, Roth EA, Ubelaker DH, Wilkinson RG. 1992. The osteological paradox: Problems of inferring prehistoric health from skeletal samples [and comments and reply]. Curr Anthropol 33(4):343-370.

APPENDIX

Variable Summary for Iron Age data, pre-imputation

	Missing		Valid N	Mean	Std. Deviation
	N	Percent			
MAB	430	100.0%	0	.	.000
FMB	430	100.0%	0	.	.000
EKB	430	100.0%	0	.	.000
DKB	420	97.7%	10	20.00	2.749
BPL	253	58.8%	177	93.448	6.3656
FOB	240	55.8%	190	29.681	2.3379
ZYB	239	55.6%	191	126.050	6.9213
ZMB	236	54.9%	194	91.349	5.1867
NLB	225	52.3%	205	23.536	1.8867
WNB	215	50.0%	215	9.422	1.9407
NLH	211	49.1%	219	50.429	3.5671
OBH	209	48.6%	221	32.950	2.2949
OBB	205	47.7%	225	40.180	2.3062
FOL	201	46.7%	229	37.044	2.8743
NPH	199	46.3%	231	69.271	4.9528
TBA	159	37.0%	271	309.26	11.337
BNL	137	31.9%	293	101.197	5.8724
BBH	120	27.9%	310	134.373	6.0343
OCC	119	27.7%	311	98.448	5.4338
ASB	95	22.1%	335	108.896	5.0927
FRC	79	18.4%	351	110.774	4.9180
PAC	75	17.4%	355	115.244	6.1112
FRA	61	14.2%	369	126.756	6.4048
XCB	55	12.8%	375	136.208	5.9875
GOL	52	12.1%	378	184.735	6.8546

Variable Summary for Romano-British data, pre-imputation

	Missing		Valid N	Mean	Std. Deviation
	N	Percent			
WNB	294	100.0%	0	.	.000
TBA	294	100.0%	0	.	.000
FOL	294	100.0%	0	.	.000
FOB	294	100.0%	0	.	.000
FRA	250	85.0%	44	130.618	6.4957
PAC	245	83.3%	49	117.602	5.8336
OCC	245	83.3%	49	93.122	4.4588
MAB	245	83.3%	49	61.041	4.3049
FRC	245	83.3%	49	110.653	4.9056
FMB	245	83.3%	49	98.061	5.3780
EKB	245	83.3%	49	96.996	5.0070
DKB	245	83.3%	49	21.935	2.1459
ASB	245	83.3%	49	109.843	6.1615
ZMB	222	75.5%	72	92.472	5.3123
BPL	204	69.4%	90	94.123	5.6108
ZYB	201	68.4%	93	131.111	7.3549
NPH	194	66.0%	100	71.798	4.3040
NLB	146	49.7%	148	24.631	2.1409
NLH	143	48.6%	151	51.495	3.2057
OBH	134	45.6%	160	33.820	2.1484
OBB	130	44.2%	164	40.438	2.1311
BNL	75	25.5%	219	100.016	5.6286
BBH	58	19.7%	236	132.038	6.4250
XCB	6	2.0%	288	141.993	6.2259
GOL	6	2.0%	288	185.893	6.8506

Variable Summary for Anglo-Saxon data, pre-imputation

	Missing		Valid N	Mean	Std. Deviation
	N	Percent			
TBA	311	96.9%	10	314.80	16.632
EKB	294	91.6%	27	98.796	6.2965
MAB	282	87.9%	39	61.2172	4.14054
FMB	274	85.4%	47	107.117	7.9280
BPL	272	84.7%	49	94.0604	5.61415
ASB	257	80.1%	64	111.2750	4.71207
ZYB	226	70.4%	95	130.536	7.5934
NPH	223	69.5%	98	68.9170	5.24779
DKB	220	68.5%	101	21.8966	2.57817
WNB	211	65.7%	110	8.9793	1.83495
FOB	188	58.6%	133	30.5361	2.58810
FOL	177	55.1%	144	36.9827	3.53908
ZMB	174	54.2%	147	92.3363	6.10324
OCC	164	51.1%	157	97.6534	5.87990
BNL	163	50.8%	158	100.837	7.6179
BBH	157	48.9%	164	134.050	6.4338
NLB	156	48.6%	165	24.2932	1.84020
NLH	150	46.7%	171	50.0095	3.78108
OBH	148	46.1%	173	33.5429	2.28324
OBB	147	45.8%	174	41.1261	1.98332
PAC	132	41.1%	189	115.5004	5.73926
FRC	117	36.4%	204	111.3821	5.14630
XCB	77	24.0%	244	139.435	6.3882
FRA	68	21.2%	253	127.032	6.2840
GOL	60	18.7%	261	187.4366	7.38509

Variable Summary for medieval data, pre-imputation

	Missing		Valid N	Mean	Std. Deviation
	N	Percent			
ZYB	98	76.0%	31	124.216	8.985
BPL	94	72.9%	35	93.060	5.092
ZMB	83	64.3%	46	92.591	6.727
NPH	80	62.0%	49	67.771	5.137
NLH	79	61.2%	50	49.516	3.804
OBH	74	57.4%	55	33.541	2.143
OBB	73	56.6%	56	37.755	2.268
DKB	71	55.0%	58	24.132	3.734
MAB	69	53.5%	60	62.003	4.438
NLB	67	51.9%	62	23.891	1.942
BNL	67	51.9%	62	98.545	4.674
ASB	65	50.4%	64	113.979	5.696
WNB	63	48.8%	66	10.589	2.230
FOB	55	42.6%	74	29.183	2.495
TBA	53	41.1%	76	313.552	15.566
FOL	50	38.8%	79	35.055	2.480
BBH	49	38.0%	80	131.756	6.172
EKB	37	28.7%	92	95.404	4.220
XCB	31	24.0%	98	142.760	7.110
GOL	26	20.2%	103	179.315	7.551
OCC	23	17.8%	106	97.655	5.607
FMB	22	17.1%	107	104.896	4.714
FRC	17	13.2%	112	111.546	4.815
FRA	17	13.2%	112	127.793	7.110
PAC	14	10.9%	115	110.080	5.437

Variable Summary for post-medieval data, pre-imputation

	Missing		Valid N	Mean	Std. Deviation
	N	Percent			
ZYB	74	38.7%	117	123.485	7.4142
MAB	72	37.7%	119	57.773	4.3363
ZMB	66	34.6%	125	87.827	4.7627
BPL	64	33.5%	127	89.650	5.3706
NPH	61	31.9%	130	67.762	5.1402
WNB	42	22.0%	149	8.546	1.8053
NLB	41	21.5%	150	23.153	1.8545
NLH	38	19.9%	153	49.954	3.6117
DKB	37	19.4%	154	21.005	2.5251
EKB	30	15.7%	161	94.019	4.2506
FMB	26	13.6%	165	101.536	4.4285
TBA	22	11.5%	169	301.107	13.8847
BBH	20	10.5%	171	129.193	6.5308
OCC	19	9.9%	172	96.119	5.5069
BNL	19	9.9%	172	97.098	4.9636
XCB	15	7.9%	176	138.125	6.2350
FRA	14	7.3%	177	128.689	6.8730
ASB	14	7.3%	177	110.427	5.6154
FRC	13	6.8%	178	111.902	5.5593
PAC	12	6.3%	179	113.128	6.8564
FOB	12	6.3%	179	30.012	2.1122
GOL	11	5.8%	180	182.961	7.1585
FOL	11	5.8%	180	35.348	2.2755
OBH	0	0.0%	191	27.949	14.5721
OBB	0	0.0%	191	30.823	15.2908