

POPULATION CHANGES IN 9TH TO 12TH CENTURY ZALAVÁR, HUNGARY

by

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Population Changes in 9th to 12th century Zalavár, Hungary

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This paper will propose a project analyzing the biological distance of 9th to 12th century cemeteries at Zalavár, Hungary. The area became especially significant in the eighth century, when it stood as the eastern part of the Frankish Carolingian Empire. Only in 895, when the Magyar tribes from the East invaded the Carpathian Basin, did the Frankish people of Zalavár flee westward. In the year 1000 AD, the area was again Christianized upon the formation of Hungary. After this transition it is obvious that people returned to Zalavár, evidenced by the rebuilding of churches near the sites of older church ruins.

The question remains as to whether the area was repopulated by the descendants of those Franks who fled westward just 100 years earlier, the invading Magyar tribes, new populations of Slavic people, or some combination of these three possibilities.

Biological distance studies can help estimate the number of genetically interbreeding groups present during these two periods, namely the period before the Magyar conquest and the period after 1000 AD. This analysis will utilize dental morphology and dental metrics to draw estimations of genetic relatedness. A statistical comparison of the samples from these two time periods can help to determine whether the original populations later returned to the area. The study will be aided by comparing these samples to known Carolingian and Árpád period sites.

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PREFACE

The area of Zalavár, on the south-western point of Lake Balaton in Hungary, has been an important center since Roman times. The area became especially significant in the eighth century, when it stood as the eastern part of the Carolingian Empire. Only in 895, when the Magyar tribes from the East invaded the Carpathian Basin, did the Frankish people of Zalavár flee westward, abandoning this booming metropolis.

In the year 1000 AD one of the Chief Princes of the Magyars, Vajk, later christened István (Stephen), joined the Holy Roman Empire and widely established Christianity in Hungary. After this transition it is obvious that people returned to Zalavár, evidenced by the rebuilding of churches near the sites of older church ruins. The question remains as to whether the area was repopulated by the descendants of those Franks who fled westward just 100 years earlier, the invading Magyar tribes, new populations of Slavic people, or some combination of these three possibilities.

While there has been much archaeological and historical research focused on this area, bioarchaeological data and biological distance studies can provide further insight into these questions of resettlement. Biological distance studies can help estimate the number of genetically interbreeding groups present during these two periods, namely the period before the Magyar conquest (the Carolingian period) and the period after 1000 AD (the Árpád period). A statistical comparison of the samples from these two time periods can help to determine whether the original populations later returned to the area. The study will be aided by comparing these samples to known Carolingian and Árpád period sites. This paper will first provide a historical and theoretical background of biological distance studies, and continue with a more detailed

explanation of the historical background and project proposal.

CHAPTER 1

BIOLOGICAL DISTANCE STUDIES

Biological distance studies estimate the genetic similarities and differences between individuals and populations based on phenotype, the combination of observable genetic characteristics and environmental influence, “in order to reconstruct patterns of gene flow, population origins, or long-distance migration” (Stojanowski and Schillaci 2006: 49). The form (morphology) and size (metrics) of bones and teeth can inform how closely related two populations may be. Biological distance studies use the morphologies and/or metrics of the skeleton to determine genetic relatedness within, or between, populations and assumes that populations sharing these morphological variations are more closely related than those with differences (Larsen 1997). Those populations which exchange mates will become more phenotypically similar over time, and those that separate from the population will become less similar over time. These possible relationships between populations can be used to address questions concerning ethnic identity, gender differences, kinship practices, and more. Biological distance studies provide a means of answering these archaeological, cultural, and historical questions.

Biological distance studies began as physicians and the first biological anthropologists became interested in human variation and the differences between human populations. Here, I will explore the trajectory that biological distance studies took during the 19th and 20th centuries, ending with modern studies being conducted today. I will examine the theoretical background of these periods and also the change in methodologies that occurred during the various analyses.

The first biological distance studies began using cranial measurements and morphological traits to find genetic variability and similarity. Soon thereafter, biological distance saw the integration of dental metrics (measurements of the teeth) and dental morphology (shape and characteristics of the teeth) into their analyses, and even later DNA studies and other methodologies. As the dentition will be used in the present study, an outline of dental morphology and metrics is presented.

Biological distance studies are not without their problems. There is much argument over the effects of genetics versus the effects of the environment on the morphology and metrics of the skeleton and dentition. In order to properly analyze and understand the possible underlying genetic affiliations of individuals and populations, possible complications in data collection and environmental effects on the skeleton must be understood. These factors are discussed in the final sections.

Racial Typology and Biological Distance: The first studies

In 1775, German physician and anatomist Johann Friedrich Blumenbach (1865) published his doctoral dissertation entitled *De Generis Humani Varietate Nativa (On the Natural Varieties of Mankind)*. It was he, in 1795, who categorized humans into five color categories: Caucasian (light-skinned people), Ethiopian (dark skinned), American (populations of the New World), Mongolian (Asia), and Malayan (people of the Pacific and Australia). These categorizations were based on morphological variations in humans – grouping human populations together based on physical features. At the time, all human populations (or in this case, racial groups) were seen to be discrete, meaning that each group was perceived as separate and distinct. According to Stephen Jay Gould (1994), it was Blumenbach's idol, Linnaeus, who

is to be credited with developing the four-race classification model of humankind. Blumenbach's contribution was the addition of the Malay variety, which "changed the geometry of human order from a geographically based model without explicit ranking to a hierarchy of worth, oddly based upon perceived beauty, and fanning out in two directions from a Caucasian ideal" (Gould 1994, 66).

Although he classified humans, Blumenbach recognized that the divisions were arbitrary, and that each division blends with the others: "It is very clear they are all related, or only differ from each other in degree" (Blumenbach 1865, 246). However, even with this recognition that his categories were subjective, Blumenbach still placed his racial types on a scale, stating that "one is said to be better and preferable to another" (Blumenbach 1865, 246). This idea of placing types on a scale, or ranking, is further explored in this review.

While Blumenbach's studies were quite influential, they probably most notably impacted the works of the 19th century physician Samuel George Morton. After being inspired by Blumenbach's five-category scheme, Morton took it upon himself to create a typological collection of skulls. Although he was surprised that he could "neither buy nor borrow a cranium of each of these races" (Morton 1848, 218), Morton still managed to form a collection of skulls at the University Museum in Philadelphia before his death in 1851. In his *Crania Americana* (1839), Morton further categorized humans into 22 families, dividing Caucasian into seven families, Mongolian into five families, Ethiopian into six, and both the American and Malay into two each. It was also Morton who later renamed and refined Blumenbach's five "varieties" into four "races," the term that has since been used to classify human populations (Brace 2005). Shortly after this time, French physician Pierre Paul Broca standardized measurements and developed instruments to measure both living humans and skeletons. Inspired by Morton, these

measurements and instruments aided to further classify and establish race (Armelagos and Van Gerven 2003, Brace 2005).

Interest in skeletal morphology became increasingly prevalent in biological anthropology during the early 20th century. Earlier studies, such as Aleš Hrdlička's seminal 1920 paper, explored these questions of morphology in the skeleton and dentition as well. Hrdlička's paper, which described shovel-shaped incisors, is considered by many as the "foundation paper" in the study of human tooth crown morphology (Scott and Turner 2000). Hrdlička found that there was a close similarity between Asian groups and Native Americans, and that they differed significantly from Europeans and Africans in their degree and frequency of shoveling (Hrdlička 1920). A year later, Hrdlička (1921) published a paper providing a descriptive review of tooth morphology.

Also in the 1920s, W.K. Gregory (1922) published his seminal work describing the evolution of the human dentition. In this work, Gregory (1922) countered the typological views of race, suggesting that "apart from a few striking cases...racial characters in the teeth are at most not very conspicuous" (476), as due to "almost unlimited migration" (479) it is nearly impossible to recognize the component elements of race. Gregory suggested that those dental characteristics used to type races were not significant.

That being given, Gregory classified the various morphological characteristics of the dentition into "low" and "high" varieties, in order to better understand the relationships between the races. The low characteristics included shoveling in the incisors, a molar cusp formation of 4-4-4/5-5-5, a Carabelli's cusp on the first and second molars, and a retention of the *Dryopithecus pattern* (or 5Y) on the mandibular molars, which refers to the special groove pattern formed between the cusps of molars. The high characteristics included absent, or

lessened, shoveling of the incisors, an absence or scarcity of the Carabelli's cusp, rounded and three-cusped maxillary second molars, and mandibular molars with a "+" rather than a "Y" pattern. This was followed by an extensive discussion and division of the races and sub-races of humans.

Campbell's (1925) study of the *Dentition and Palate of the Australian Aboriginal* explored some morphological variables of the dentition, such as cusp number, root number, and Carabelli's trait. In his study, Campbell foreshadowed the popularity of dental studies in anthropology (Scott and Turner 2000). In 1927, Krogman provided an overview of the dentition "written not for the anthropologist, but for the student of anthropology" (Krogman 1927: 2). Krogman's extensive paper, which was given an entire issue of the *Journal of Dental Research*, covered everything from the growth of the dentition, dental morphology, and the dentition of evolutionary species. A few years later, in 1931, Shaw published *The Teeth, the Bony Palate and the Mandible in Bantu Races of South Africa*, in which he examined root number and shovel-shaped incisors (Scott and Turner 2000). Taken together, these studies show that metric and nonmetric traits, whether in the dentition, crania, or post-crania, were very much used to differentiate populations.

In the 1920s and 1930s, Harvard professor Earnest A. Hooton conducted many morphological and typological studies of human cranial remains. In 1925, he studied the crania of the protohistoric Canary Islanders. This study examined over 9,000 individuals based on hair and eye color, cephalic index (the ratio of the breadth to length of the skull), nasal index (ratio of the width to the height of the nose), and stature, and concluded that "pure" Nordics and Mediterraneans were significantly prevalent in the Canary Island population (Hooton 1925). In 1930, Hooton published *The Indians of Pecos Pueblo*. Hooton divided the varieties of Native

American groups, including Basket Maker, Pseudo-Negroid, and Pseudo-Australoid, among others, and created extensive morphological descriptions for each skull type. Using these morphological types, Hooton attempted to interpret the biological history of the Pecos Pueblo people. Hooton's methodologies significantly impacted biological anthropology in the early- to mid- 20th century. Although Hooton did classify humans into distinct racial types, he recognized that biology did not determine the social ranking into which people would fit: each "race," or human type, had within it people of all social classes.

Hooton had many students at Harvard, and while a few kept their focus on ideas of race, some seriously began to critique his works by the 1950s and 60s (Armstrong et al. 1982, Caspari 2003). One of Hooton's biggest critics was his former student Edward E. Hunt Jr., who in 1959 presented a work evaluating Hooton's typological analyses (Hunt 1959). Hunt criticized the use of morphological types "without genetic research" (81) to determine affinities between populations and, as is further discussed in following sections, emphasized the importance of environmental influence on body measurements.

This section reviewed early studies in race typology, and traced the pre-Darwinian concept that biological populations are discrete categories. Thinking at that time emphasized morphology and typology, and any morphological similarities and differences found between individuals were solely attributed to the admixture of primary racial types (Armstrong et al. 1982). Early researchers tended to ignore the environment and adaptive traits, as well as the concept of convergent evolution: similar traits can arise simultaneously in unrelated populations. The following sections examine several individuals who have been revolutionary in the shift away from typological anthropology and also explore how the earlier paradigm has shifted toward a "new" physical anthropology.

The New Physical Anthropology

Even with the publication of *On the Origin of Species* by Charles Darwin in 1857, and the works of Gregor Mendel in genetics, the concept of race in biological anthropology was not immediately re-evaluated from an evolutionary point of view. This re-evaluation required the application of genetics to evolutionary theories. In the 1930s, Sewall Wright began trying to determine how skeletal morphology was genetically controlled (Wright 1934). By studying guinea pigs and controlling their breeding, Wright indeed found that various skeletal and dental traits are genetically inherited. A similar analysis was conducted by Grüneberg, who instead studied the absence of the third molar in mice (Grüneberg 1952). He came to similar conclusions as Wright, but also considered the effects of the pre- and post-natal environment. A new concept of human phenotypic variation started to develop: attention now shifted away from the idea of predetermined human types, or “races,” toward the consideration of environmental, cultural, and genetic factors on development.

In the early 20th century, Franz Boas challenged the idea that all physical characteristics were merely due to heredity, and the idea that these characteristics determined a person’s culture and where each fits on a social ladder. Boas (1912) conducted a study of head shape and the cephalic index, examining over 17,000 individuals, and utilizing sophisticated statistical techniques. He concluded that head shape could change significantly after one generation, and that American-born children of immigrants were affected by different cultural and environmental factors, resulting in different anthropomorphic measurements.

Boas warned that researchers must avoid arbitrary classification, as classification is dependent on the viewpoint of the observer. He urged that, rather than only considering biology in the heredity of traits, researchers must “consider each measurement as a function of a number

of variable factors which represent the laws of heredity and environment” (Boas 1893: 574). As mentioned, biological distance studies assume that those populations sharing morphological variations are more closely related than those that do not. Boas also added the factor of the environment to this concept, stating that two variations or measurements would be “close when they depend largely upon the same factor, slight when they depend largely upon distinct factors” (Boas 1893: 574).

Boas influenced the study of biological anthropology in several ways. First, Boas argued against the idea of classification: that (in this case) humans could be classified based on an immeasurable number of variables, and classifications would vary greatly depending on which factors were used. Secondly, Boas argued against the idea of biological determinism, stating that biology does not determine culture. Culture and environment, on the other hand, can influence biology and evolution, a theory known as biocultural evolution. The idea here is that humans adapt to their environments, and biology will be altered through time (through the survival of more favorable genes) to suit new environments and environmental variables. This is important as human populations were now beginning to be seen as part of their environment, and not as mere biological entities. The questions of distance in biology now began to shift away from the hierarchical, or vertical, ranking of humans, toward the geographical, or horizontal ranking, and to the historical relatedness of human populations.

In the 1950s came another revolution in anthropology: that of the New Physical Anthropology, launched by Sherwood L. Washburn. Washburn emphasized that much of the methodology used in biological anthropology was created prior to the acceptance of the ideas of evolution, and all before the science of genetics (Washburn 1951). He urged biological anthropologists to support the synthesis of Darwin’s theory of evolution and Mendelian genetics.

Washburn's new physical anthropology incorporated several subjects from primatology to genetics (Caspari 2003), advocated the study of biological process over the study of form, and condemned typological thinking.

The "old physical anthropology," as Washburn calls it, was focused on technique. The new physical anthropology, however, should be more interested in understanding the processes of primate evolution and human variation. It is no longer about simply classifying humans anymore, but about understanding the evolution and genetics of the human animal. Biological anthropologists must consider adaptation to the environment: as all animals adapt, humans do as well. It is impossible to describe evolution in terms of non-adaptive traits, Washburn explains, as evolution is largely due to selection and adaptation (Washburn 1951). However, before being able to understand how humans adapt to their environment, "it is necessary to know how long a people has been in an area and under what conditions they have been living" (Washburn 1951: 299). According to Washburn (1962), when it comes to the evolution of human types, all of these factors are controlled by culture. However, Washburn (1962) emphasized the importance of both culture and biology together, rather than the over-emphasis on either alone.

Washburn's New Physical Anthropology caused a shift in the discipline, causing adaptation and evolution to now be the main focus of modern research (Armelagos and Van Gerven 2003). As is seen in later sections, the 1960s began to see an embracing of Washburn's New Physical Anthropology. Researchers began to apply theories of evolution and Mendelian genetics to their studies. New methodologies were developed in determining the genetic factors behind traits, while still considering environment as an important factor in physical characteristics. The main interest of biological anthropology was no longer the mere categorization and description of populations, but in the diffusion of traits, geographic

distribution of individuals, and environmental impacts on human populations. Biological distance studies could now consider the environment and adaptation as factors in morphological and metric differences, and researchers began to have a more accurate view of the genetics and evolution of human populations. No longer was the differentiation of populations and individuals as simple as looking for certain characteristics; researchers now had to consider many other factors.

Biological Distance in the Washburn Era

In the 1950s and 1960s, biological distance studies began to emerge in the *American Journal of Physical Anthropology* (Buikstra et al. 1990). At this time, along with previously mentioned studies by Hooton, several investigations of the morphology of human populations were presented, with an emphasis on the physical anthropology of the American Indian. One example is Neumann's 1952 study of American Indian "varieties." Neumann attempted to uncover the migration routes of Native Americans by determining a succession of morphological types. This was done through the examination of human remains from contemporaneous strata of archaeological sites in the United States, as Neumann believed this would provide the most genetically homogeneous groups. He then divided his findings into several groups: the Otamid, Iswanid, Ashiwid, Walcolid, Lenapid, Inuid, Deneid, and Lakotid (Neumann 1952). Hanna (1962) studied Native American groups of the Southwestern United States. The Native American people of the Southwest comprised several ethnic groups: the Yuma, Mohave, Maricopa, Pima, Papago, Yaqui, and White River Apache. Through measurements of the cranium, Hanna concluded that the Yaqui and Apache were significantly different from the other groups, and the Yuma were most similar to the Apache. Both of these studies are examples of

how, in the 1950s and 1960s, craniometry was still being used for mere classification and typology.

This period saw a shift of emphasis from North America to Eurasia, making use of cranial and dental measurements to differentiate populations. Sangvhi (1953) conducted a study in Bombay on 500 unrelated men. He compared genetic traits via blood groups, color blindness, and taste reactions for PTC to cranial morphology, and concluded that similar results could be attained by all methods. In the later 1950s, Hungarians Acsádi and Nemeskéri (1957) published a study recognizing skeletal morphology as a critical factor in reconstructing past populations in anthropology. This study is recognized as an early example of kinship analysis (Alt et al. 1998). In the early 1960s, Dahlberg (1961) studied the relationship between mesiodistal (length) measurements of the dentition and the number of cusps found on the molars on 200 Melanesian individuals. He found that there is indeed a relationship between cusp number and the size of the dentition, but only in the mesiodistal (length) dimension, and not buccolingually (width). Moss and Chase (1966) took several dental measurements on the casts of 21 Liberian Negro children, which were then compared to two American White and three Japanese populations. Some of the maxillary teeth and the mandibular molars of the Liberian children were found to be significantly larger than in the other samples. Through these studies, a shift toward the development of new methodologies becomes apparent.

These studies show that in the 1950s and 1960s, typological studies were continuing, and morphology and metrics were still used to differentiate populations. The 1960s saw a shift away from North America to studies focusing on Europe and Asia. As is seen in the following sections, biological distance studies continue to refine methodologies and to move away from typological studies.

Biological Distance in the Post-Washburn Era

In the 1970s, biological distance studies began to gain recognition (Stojanowski and Schillaci 2006). At this time, skeletal morphology and the heritability of traits was further investigated, with odontological studies beginning to gain importance. For example, Goose (1971) studied tooth size among British families and found a high rate of heritability. Also, Goose and Lee (1971) examined Carabelli's trait among British families, and concluded that the inheritance of this trait is multifactorial and more variable than previously indicated. Turner (1971) examined and compared frequencies of three-rooted mandibular first permanent molars (3RM1) in several Native American and Inuit groups. He found the Aleut and Eskimo groups to have much different frequencies than the Native American groups. This decade saw a questioning of the discrete nature of traits, and a consideration of other factors that affect characteristic and trait expression.

Methodologies began to focus on differing effects on trait expression, whether by the environment, age, sex, or development (Dahlberg 1971, Garn et al. 1964, Garn et al. 1979). Garn and colleagues (1964) found a small discrepancy in tooth size between 243 male and female children, but found the difference to be more pronounced in the dentition than in stature. Garn et al. (1979) found that prenatal factors affect crown size of both the deciduous and permanent dentition. This study is important as an example of how environmental factors were now being considered in the development of methodologies. No longer is crown size of sole importance, but also the environmental (in this case prenatal) factors that could influence and change that crown size are important factors for consideration. Hanihara (1978) showed that differing populations exhibit diverse levels of sexual dimorphism (differences in variation between the sexes) in the dentition, while Moss (1978) demonstrated that sexual dimorphism in

human canines could be caused by differing periods of enamel formation. Another focus in methodology was on the correlation of traits, as shown by Garn et al (1966). Here, Garn and colleagues found a relationship between the number of cusps and the relative molar size of the mandibular first and second molars.

In the 1980s, methodologies were still being further refined. Falk and Corruccini (1982) tested methods of traditional and non-traditional cranial and dental measurements, and found cranial measurements to be more reliable than dental measurements for their study. Lalouel (1980) attempted to refine statistics used in biological distance studies. Harris and Bailit (1980) analyzed the variability of occurrence and size of the metaconule trait in over 1000 living people. Susanne (1984) demonstrated a relationship between genetic factors and various cranial and postcranial metric traits. Clearly the focus has shifted from the simple differentiation of populations to a more complex consideration of genetics and environment, and the reassessment of methodologies.

During that decade, several papers were published that shaped the field of biological distance studies. Owsley and colleagues (1982) explored intrasite variation in cranial morphology among three areas at the Mobridge site in South Dakota. Through comparisons of metric data of the cranium, they found the skeletal data supported the archaeological data in showing that the three cemeteries of the site were likely from different time periods. Biological data was now being used along with cultural and archaeological data to answer cultural and historical questions. Sofer and colleagues (1986) compared Jewish and non-Jewish populations, both contemporary and skeletal. They found significant similarities in the Jewish groups, although the Jewish groups varied more widely in geographical area as compared to the non-Jewish groups. This study applied cultural questions in consideration of spatio-temporal distance.

Konigsberg (1988) re-evaluated migration models and conducted a study of cranial morphology on eight sites from west central Illinois. He found that females had a slightly higher variability than males in those sites, suggesting a patrilocal residence pattern, or one in which females had better mobility.

At this time, biological distance studies continued to gain popularity, and many studies were published exploring the ideas of dental morphology and metrics (Greene 1982, Greene 1984, Harris and Rathbun 1991, Lukacs and Hemphill 1991, Turner 1987), craniofacial and craniometric variation (Relethford 1994, Van Gerven 1982), and developing new methodologies and models (Konigsberg 1988, Konigsberg 1990, Relethford and Blangero 1990). It is clear that methodologies are continuing to be refined. More importantly, however, a major paradigm shift is now quite evident, away from the mere typology of human populations to the consideration of environmental variables and the cultural adaptation of populations.

The early paradigm for the classification of human types has been reviewed, and the new physical anthropology and its effects on biological anthropology through the 20th century have been discussed. The mid-20th century saw a major shift in biological anthropology toward an embracing of evolutionary theory and Mendelian genetics, and the consideration of environment and cultural adaptation on human populations. We will now explore recent trends and studies in biological distance.

Recent Biological Distance Studies

Now that a history of biological distance studies has been surveyed, along with the paradigm shifts and changes in theory, attention turns to several of the most recent studies. Biological distance studies have continued to refine methodologies. Several studies have

focused on examining the relationships between traits (Edgar and Lease 2007, Harris 2007, Kalichman and Kobylansky 2006) and developing new statistical methods (Bedrick et al. 2000, Krzanowski 2003, Petersen 2000, Stojanowski 2003). Others have centered attention on biological factors affecting skeletal morphology and metrics, such as the genetics of trait expression (Hughes et al. 2000), the heritability of traits (Veleminský and Dobisiková 2005), and developmental biology (Jernvall and Jung 2000). The use of dental anthropology in biological distance studies also continues to have a strong presence (Bernal et al. 2010, Guatelli-Steinberg et al. 2001, Hanihara and Ishida 2005, Hanihara 2008, Irish 1997, Irish 1998, Irish 2006, Ricaut et al. 2010, Stojanowski et al. 2007).

Population origins and migration patterns continue to be a focus of biological distance studies (Biró et al. 2009, Blom et al. 1998, Godde 2010, Guatelli-Steinberg et al. 2001). Hallgrímsson and colleagues (2004) explored the genetic makeup of archaeological Icelandic populations. These samples were compared with Norwegian and Irish series, since it is known from historical and archaeological records that these were likely to be the founding populations of Iceland. A sample from Greenland was also used as an outgroup. An outgroup refers to a series that is known to have little genetic relatedness to any of the groups being used in analysis, and is hence used as a control group. Hallgrímsson and colleagues also compared the degree of cranial morphological variation in the Settlement Period population with neighboring groups, as an increase in among-individual variation would seem likely, given a heterogeneous geographic origin. Lastly, they attempted to estimate the degree of admixture between the Norwegian and Irish components in the founding population. The researchers found that the Icelandic samples clustered with the Norwegian samples, with the Irish samples forming a separate cluster. They also found that the Settlement Period population was likely not of diverse geographic origin, and

that the founding population was likely 60-90% of Norwegian origin. The ethnohistory of Iceland was taken into account for this study, looking to all the areas from which people could have come. This study is an example of how biological distance studies are today being used to answer cultural, historical, and archaeological questions.

Recent studies have used DNA analysis to determine genetic relationships among populations (Biró et al. 2009, Černý et al. 2009, Coia et al. 2009, Gusmão et al. 2010, Kemp et al. 2009, Mendes-Junior and Simões 2009, Simms et al. 2010). For example, Ricaut and colleagues (2010) recently published a study comparing genetic and morphological data in the estimation of biological relationships from the Egyin Gol necropolis in Mongolia. Ricaut and colleagues found that the nonmetric and genetic data did correlate. However, they cautioned that nonmetric traits do not have the resolution necessary for detecting close genetic proximity in kinship analysis.

In the past few decades, biological distance studies have moved further away from mere typology and have attempted to begin answering questions of a social and cultural nature (Sutter and Verano 2007, Tatarek and Sciulli 2000). While much work is yet to be done on the understanding of genetic and environmental variables, biological distance studies have much application in answering cultural and archaeological questions. In order to better understand the proposed biological distance analysis for this project, the anatomy, morphology, and metrics of the dentition is now reviewed.

CHAPTER 2

THE DENTITION

Biological distance studies have utilized many different methodologies focusing on various parts of the skeleton, including the post-crania (Finnegan 1978, Velemínský and Dobisíková 2005), morphology of the cranium (Berry et al. 1967, Berry and Berry 1967, Hauser and De Stefano 1989), cranial metrics (Byrd and Jantz 1994, Cole and Cole 1994, Hanihara and Ishida 2009, Owsley et al. 1982, Van Gerven 1982, Van Gerven et al. 1977), and dentition (Greene 1982, Guatelli-Steinberg et al. 2001, Hanihara 2008, Hanihara and Ishida 2005, Soafer et al. 1986, Stojanowski et al. 2007, Turner et al. 1991). For some time, dentition has been recognized as a method for testing heritability and relatedness (Garn et al. 1964, Moss and Chase 1966).

Teeth provide a number of advantages for the study of biological distance. First, the teeth are the most durable part of the body (Alt and Türp 1998, Soafer et al. 1986, Buikstra and Ubelaker 1994), which allows for the acquisition of data from ancient or extensively decayed and fragmented remains. Secondly, the scoring techniques for dental morphology and dental metrics have been standardized, so subjectivity has been reduced (Soafer et al. 1986, Buikstra and Ubelaker 1994). Since speed of data collection is always an important consideration for researchers, biological distance studies offer yet another advantage: they allow for swift data collection since large numbers of individuals tend to be analyzed. Morphological traits are easily identified and the measurement of teeth can be quite rapidly completed, which also allows for quick data collection (Alt and Türp 1998, Alt and Vach 1998, Turner et al. 1991). Importantly,

the anatomical details of teeth remain stable through time, and the post-formation effects of the environment have less influence on the dentition than on bone (White and Folkens 2005). Additionally, the use of dentition is relatively non-invasive and allows reproduction of the analysis. Lastly, dental characteristics are widely believed to have a high genetic component to their formation and a higher heritability than the crania, especially more so than the skeleton, allowing for the collection of more compelling data.

Tooth Anatomy

A tooth is composed of two basic areas: the crown and the root. The crown of the tooth, or the area protruding above the gum, is covered by a very hard tissue called enamel. Enamel can vary in thickness, depending on species, tooth, and the area of the tooth. The root of the tooth is the part which sits in the bone sockets, known as alveoli, and is held in by periodontal ligaments. Roots are covered in a thin layer of cementum, which is softer than enamel. The area where the enamel meets the cementum, or where the crown meets the root, is known as the cement-enamel juncture, or CEJ. Adult dentition is made up of two upper (right and left) and two lower sets of two incisors, one canine, two premolars, and three molars. All surfaces of the teeth are assigned orientational terms.

In order to understand morphological variations of the dentition, the general anatomical features of the teeth should be reviewed. Molars generally exhibit three roots in the upper teeth and two roots in the lower, but this can vary between individuals (Hillson 1996, White and Folkens 2005). The upper molars commonly have four cusps, or projections, on the occlusal surface of the tooth (Hillson 1996, White and Folkens 2005). The mesiobuccal cusp is known as the paracone, the distobuccal cusp is called the metacone, and the mesiolingual cusp the

protocone. The distolingual cusp, the hypocone, is at times not present on the upper molars (Buikstra and Ubelaker 1994, Schwartz 2007, Turner et al. 1991). In the upper molars a fifth cusp, known as the metaconule, may occasionally also be present in the distal fovea of the upper molars between the metacone and the hypocone, and ranges in size from a tiny cuspule to a prominent cusp (Buikstra and Ubelaker 1994, Harris and Bailit 1980, Hillson 1996, Turner et al. 1991).

The lower molars have five main cusps, but can exhibit only four (Hillson 1996, White and Folkens 2005). The mesiolingual cusp is known as the metaconid, the protoconid lies mesiobuccally, the entoconid is distolingual, and the hypoconid is distobuccal. The fifth cusp, known as the hypoconulid, is generally present on the distal and occlusal aspect of the tooth, between the entoconid and hypoconid. A sixth cusp, often called tuberculum sextum or entoconulid, can occur lingual to the hypoconulid. A seventh cusp, known as the tuberculum intermedium or metaconulid, can even be present, lying in the lingual groove between the metaconid and entoconid. Along with several other morphological variations, the lower first molars can bear an *anterior fovea*, a groove found in front of the metaconid and protoconid (Hrdlička 1924, Schwartz 2007, Turner et al. 1991).

The dentition can be utilized in two main ways in biological distance studies: morphology and metrics. Dental morphology refers to the form of the teeth, while dental metrics refer to standardized measurements that are commonly taken of teeth. Studies in dental morphology and metrics, as well as the techniques used, are outlined in the following sections.

Dental Morphology

Dental morphological studies examine characteristics of the dentition: the number and arrangements of the molar cusps, root shape and number, and the shape and structure of the incisors, canines, and premolars. Several of these features are more closely examined in the next section. Morphological traits are often referred to as non-metric traits, as they are not quantitative. Dental morphological traits have been described and refined for nearly two centuries. In 1842, George von Carabelli described a variation on the surface of the paracone of the upper molars, varying from grooves to cusplets and other topographic features, and which now bears his name (Scott and Turner 2000, White and Folkens 2005). CS Tomes (1889) described human crown and root variants and put them in the perspective of comparative odontology (Scott and Turner 2000). Several decades later, Hrdlička published his seminal paper on shovel-shaped incisors (1920) and, in the following year, a comprehensive review of tooth morphology (1921). Also in the 1920s, W.K. Gregory (1922) classified morphological variations in the dentition and described various traits such as Carabelli's cusp, shovel-shaped incisors, mandibular molar 5Y and "+" patterns, and mandibular and maxillary molar cusp numbers. Three years after Gregory's work, Campbell (1925) published a study of Australian Aboriginals, in which he examined morphological variations such as cusp number, root number, and Carabelli's trait. In the early 1930s, J.C.M. Shaw (1931) published a study examining root number and shovel-shaped incisors in South Africans. These early studies in dental morphology focused on the description of certain dental variations, which are still used in studies today. Few studies in dental morphology were published in the very early 20th century, but more appeared in later decades.

In the 1940s and 1950s, dental morphology studies continued to gain popularity, but they

still focused largely on the description of morphological variation of one single population. In the 1940s, Albert A. Dahlberg worked on dentition in the American Southwest, particularly the Pima Indians of central Arizona. Over a thirty-five year period, he and his wife Thelma collected several thousand dental casts and associated genealogical records (Scott and Turner 2000). Several studies also focused on the dentition of Inuit groups: in 1949, P.O. Pedersen (1949) published a study of the East Greenland Eskimo, followed by C.F.A. Moorrees' study of the Aleut (1957).

The study of dental morphology gained more popularity in the 1960s. In the first half of the decade, Brothwell (1963a) published an edited volume covering dental variations such as incisor shoveling, two-rooted canines, and the absence or incomplete development of the third molar. In the early 1970s, Christy G. Turner II began to publish extensively on dental morphology. Turner (1971) examined and compared frequencies of three-rooted mandibular first permanent molars (3RM1) in several Native American and Inuit groups. He found the Aleut and Eskimo groups to have much different frequencies than the Native American groups. Morris and colleagues (1978) described a trait of the maxillary first premolar of the Uto-Aztecan speaking Native American groups. This trait was first described by Hrdlička (1921) under a different name, but Morris et al. (1978) explained that this trait is most frequently seen in areas of Arizona, is solely seen in Uto-Aztecan speaking groups, and is not seen outside of North America. Recently, Delgado-Burbano and colleagues (2010) revisited the question of the Uto-Aztecan premolar in a response to Morris and colleagues (1978), and found the trait to be present outside of the Uto-Aztecan language family. While there was a rise in the popularity of dental morphological studies during these decades, the studies were very trait- and population- specific.

The 1980s saw a similar trend to previous decades: publications focused on the variation

and analysis of one trait, or morphological variation, in one population. Scott (1980) added to the discussion on Carabelli's trait by examining nearly 2000 individuals, and he discovered that the total frequency of trait expression and the level of expression were highest among Europeans. Harris and Bailit (1980) examined the frequency and size variability of the metaconule in over 1,200 living Melanesians. They found the trait frequency to be highest on the maxillary first molar. They also found the trait to be more frequent in females, suggesting that males and females should be examined separately for this trait. Harris and Bailit (1980) suggested that variations of the tooth crown are not entirely genetically controlled, as mentioned in earlier literature, but are also influenced by environmental parameters.

Other studies during this decade continued to focus on the examination of single populations. Kieser and Preston (1981) examined the crown morphology of over 200 living Lengua Indians of Paraguay, and compared their results to other populations. Kieser and Preston found a high frequency of Carabelli's trait among the Lengua, and also found little sexual dimorphism, supporting the suggestion that this trait could be studied without correction for sex. The authors concluded that the Lengua present the expected frequencies of Mongoloid and Amerindian populations for tooth crown morphology. Kaul and Prakash (1981) studied the dental casts of both deciduous and permanent teeth in over 600 Jat individuals of India. The authors found marked sexual dimorphism in this population and note that the differences are more apparent in permanent dentition. After examining the frequency of several other traits, Kaul and Prakash (1981) compared their data to that of other Indian populations and discovered their data to be most closely related to the Punjab populations. Scott and colleagues (1983) examined the crown morphology of over 1500 Pima Indians of Arizona, after which they compared the frequencies of fourteen traits with those of other populations, based on language

categories. They found that the Pima and Hopi, who are classified in the same language category, were not biologically similar based on the fourteen morphological traits. Scott et al.'s (1983) findings show that one language category can comprise several biologically distinct populations. While still focusing on specific populations, researchers were now beginning to turn to linguistic and archaeological questions.

In the following decades, a number of publications focused on standardizing and describing dental morphology (Alt and Türp 1998, Buikstra and Ubelaker 1994, Mayhall 2000, Scott and Turner 1988, Scott and Turner 2000, Turner et al. 1991). In addition, Irish presented several studies of the morphological variation of Sub-Saharan African populations (Irish 1997, Irish 1998). Irish (1997) examined 32 sub-Saharan and North African samples, comprising nearly 1000 sub-Saharan-affiliated Africans, for 36 morphological traits, in order to assess these people's dental affinities to one another, and to identify those traits which best distinguish sub-Saharan populations from others. He made three determinations: populations of the two geographic regions of sub-Saharan and North Africa were not closely related to one another, the North African samples showed similarity to the European samples, and the sub-Saharan samples were distinct from all other samples. One year later, Irish (1998) published a study of sub-Saharan dental traits and their implications for modern human origins. In the same year, Sciulli (1998) examined 57 morphological features in the deciduous dentition of 370 individuals from the prehistoric Ohio Valley. Sciulli found that morphological variation among these populations over time was limited.

Recently, studies have begun to utilize both dental morphology and dental metrics (Harris 2007, Lukacs and Hemphill 1991). Dental morphology has continued to be used extensively to answer questions of biological distance (Guatelli-Steinberg 2001, Hallgrimson et al. 2004, Sutter

and Verano 2007). Guatelli-Steinberg and colleagues (2001) examined nearly 400 samples of Canary Islanders and compared them to several Northwest African samples, in order to answer questions of origin and inter-island biological variation. Guatelli-Steinberg and colleagues found a close affinity between the Canary Islanders and Northwest African samples, suggesting the Canary Islanders derived from the Maghreb people. The inter-island analysis suggested one founding population of Canary Islanders, but the authors suggest a more complete genetic analysis is needed. Hanihara (2008) compared several geographically diverse sample populations based on 15 nonmetric traits, in an attempt to reconstruct a worldwide demographic history. Supporting the work of Irish (1998), Hanihara (2008) concluded that his findings suggest a sub-Saharan African origin for anatomically modern humans.

While early studies focused on the description of morphological variation and anomalies of the dentition, later analyses began to focus on the heritability of traits and the potential environmental influences affecting morphological features. Studies also began to focus on the applications of dental morphology, while still concentrating on the description of features. Dental morphology studies also began to focus on archaeological questions, as exemplified by the Uto-Aztecan studies. These studies first described variations in one population, but eventually looked to comparisons between populations in order to support archaeological and linguistic hypotheses. As the use of dental morphology began to gain popularity in dental anthropology and biological distance studies, the standardization of traits and methodologies rapidly gained importance. The next section will look to some examples of morphological variation which have been mentioned throughout these studies.

Morphological Variations of the Dentition

One major focus of dental morphological studies has been to standardize the traits and methodologies used by researchers. As morphological studies tend to be more subjective than other forms of analysis, standardization is critical in order to aid in precision and replicability. In order to standardize these diverse morphological variations, researchers began developing casts. In 1956, Dahlberg released a series of reference plaques to help standardize observations on morphological variables of tooth crown (Mayhall 2000, Scott and Turner 2000, Buikstra and Ubelaker 1994, Turner et al. 1991). A set of casts was also developed for the deciduous dentition by Kazuro Hanihara in the early 1960s (Buikstra and Ubelaker 1994, Mayhall 2000, Turner et al. 1991). Later, Turner and colleagues created a set of casts of adult dentition and developed a descriptive system, known as the Arizona State University (ASU) Dental Anthropology System (Turner et al. 1991, Buikstra and Ubelaker 1994). The traits used for the ASU system were carefully selected: they were found to be the most readily observable and to have little, or no, sexual dimorphism (Turner et al. 1991). This means that traits will not be influenced by sex and will not require males and females to be separately analyzed in the population. The ASU Dental Anthropology System is now widely used in the analysis of dental morphology and has aided in the standardization of dental morphology.

Morphological traits are difficult to observe objectively as they can present themselves in many ways due to their complex mode of inheritance. Save for a few rare abnormalities, no dental traits have been shown to have a simple mode of inheritance (one gene, two alleles) (Scott and Turner 1988). Although morphological traits can have a wide range of expression, they are often recorded in biological distance studies as present or absent. This is an important differentiation, and Dahlberg (1971) differentiates between the penetrance, or appearance, of a

trait, and the degree of expression, both of which are important to morphological studies. Not only must we consider whether a trait is present or absent, but the *degree* to which that trait is present.

Traits are often scored on a continuum, varying from a mild form of the trait to more severe. Other times, they are frequently scored as simply as present or absent. However, traits do not obey Mendel's laws for dominant-recessive inheritance (or "simple" inheritance), and they are considered "complex" (Scott and Turner 2000). Wright (1968) called such traits *threshold dichotomies*, meaning that whether these traits are expressed is dependent on the complex interaction between genes and the environment. This term was coined to distinguish these traits from *point dichotomies*, which have simple modes of inheritance (Scott and Turner 2000). Grüneberg (1952) also illustrated a similar state in the skeletal traits of mice, one which he termed *quasicontinuous*. There is an apparent discontinuity in the expression of these kinds of traits, hence, these nonmetric traits are not simply characterized as present or absent, but are seen as a range of expression from slight to pronounced.

A common morphological variation of the upper molars is known as Carabelli's Trait. This trait occurs on the mesiolingual (tongue) surface of the maxillary molars, and it can vary from a small groove to a Y-shaped depression, a bump, or a large free cusp (Turner et al. 1991, Schwartz 2007). Previously it has been suggested (Kraus 1951) that this trait follows a simple mode of inheritance, but the range of variability seen in this trait would suggest that the inheritance may not be so simple. This range could be due to a differentiation in penetrance of the trait, but the possibility remains that the trait includes more than one morphological phenomenon.

Of further note is the morphological variability of the upper incisors. First described and

scaled by Hrdlička (1920), the upper incisors can exhibit what is known as shoveling. Shovel-shaped incisors are characterized by thick mesial and distal marginal ridges on the lingual surface of the tooth, and in cross-section can look like a small scoop, or shovel. This trait is the most cited example attributing ethnic origin to dental morphology, and it has been found to have the lowest frequency in Western Eurasia, Africa, and Sahul-Pacific groups, and the highest frequency of occurrence in Asian and Native American populations (Hrdlička 1920, Mayhall 2000, Schwartz 2007, Scott and Turner 2008). Similar to Carabelli's trait, the mode of inheritance of shovel shaping is unknown.

In this section, a review of studies in dental morphology has shown a change in trend from mere description of morphological traits and the examination of morphology in one population to the use of dental morphology in biological distance studies to answer archaeological and historical questions. Features most commonly used in studies of dental morphology have also been identified. The next section will review studies and techniques in dental metrics.

Dental Metrics

Dental metrics have been used for several decades in biological distance studies. Recently, many analyses have made use of this approach, including Bernal et al. 2010, Hanihara and Ishida 2005, Harris and Rathbun 1991, Lease and Sciulli 2005, Schnutenhaus and Rösing 1998, Stojanowski et al. 2007. Commonly, dental metrics are used in conjunction with dental morphology in bioarchaeological and biological distance studies. Several studies, however, have focused solely on dental metrics, some of which will be outlined here.

In the 1920s and 1930s, metric studies focused on the reduction of tooth size in the course

of hominin evolution (Brace 1967, Brace et al. 1987, Lukacs 1985), the gradual change in tooth size over time in one population (Ebeling et al. 1973, Kieser et al. 1987, Lunt 1969), comparisons in tooth size among populations, the relationships of tooth size to morphological traits, and the inheritance of tooth size. Moss and Chase (1966) provided a descriptive study, taking standard dental measurements of the deciduous teeth of 21 Liberian children. Dahlberg (1961) took cusp measurements of a sample of Melanesian individuals. Upon comparing these measurements to the number of cusps found on the molars, Dahlberg found a significant correlation between cusp number and the mesiodistal dimension of the molars. Goose (1971) examined members of 123 British families and concluded that the heritability of the size of the teeth was very high and indicated little environmental influence.

In the following decades, several overviews of dental metrics were presented (Brace et al. 1991, Hanihara and Ishida 2005, Kieser 1990, Schnutenhaus and Rösing 1998). Harris and Rathbun (1991) compared mesiodistal and buccolingual measurements across an extensive number of geographically-diverse samples, and they discovered there to be ethnic differences in the apportionment of tooth size. Stojanowski and colleagues (2007) used dental metric variation to conduct a biological distance study of a late 17th century church cemetery at Mission San Luis de Apalachee, Florida. Based on several dental measurements, they concluded that individuals buried in the same row were phenotypically similar to one another, while there was no similarity between rows. This indicates a kin-structured burial, as has been documented in other sites in La Florida.

This review of seminal works in dental metrics is followed by a review of methodologies associated with these analyses. The next section provides an overview of the specific measurements commonly used in biological distance studies.

Methodologies in Dental Metrics

According to Buikstra and Ubelaker's widely-accepted *Standards* (1994), three measurements are common in metric analysis. The first is the mesiodistal maximum diameter (or crown length), which involves measuring the maximum length of the tooth crown in the mesiodistal plane. Alternatively, the measurement can be taken between the interproximal contact points of the teeth (the points where the teeth meet), although this method is less reliable as these landmarks can be obscured by interstitial wear, or the wear that occurs at the points between the teeth (the teeth rub together over time, hence the true original length of the tooth is often never known). Second is the buccolingual (or faciolingual) maximum diameter (or crown width), which can be considered as the width of the tooth, measured in the buccolingual plane. Lastly, crown height is commonly measured. In the anterior teeth (incisors, canines, and premolars), this measurement is taken from the cement-enamel junction (CEJ) to the occlusal surface, or the chewing surface, of the tooth. In the molars, this is considered the distance between the CEJ and the top of the mesiobuccal cusp.

All of these measurements can be affected in some way by dental wear, which will be further discussed below. In order to avoid this problem, alternative measurements have been suggested. Hillson and colleagues (2005) recommend taking cervical diameters, or measurements at the base of the crown, in the mesiodistal and buccolingual planes. They tested these measurements in a study of relatively unworn teeth and found these alternative measurements to be correlated with the accepted crown diameter measurements. Hillson and colleagues (2005) found these measurements to be just as reliable as the three above-mentioned standard measurements and suggest the alternative measurements would be a preferable for use in archaeological remains. A few years later, Stojanowski (2007) tested the results of Hillson et

al. (2005) on an alternative skeletal population. He found that the buccolingual cervical measurements did indeed correlate with the crown diameters, but the mesiodistal cervical measurements did not correlate.

Dental metrics and dental morphology have been reviewed, and now some of the potential problems that can arise in data collection will be outlined. These factors can impact both the ease of data collection and the outcome of the data. The next section presents an overview of possible environmental factors that can influence dental metric and nonmetric traits.

CHAPTER 3

METHODOLOGICAL ISSUES

A number of factors influence data collection of metric and morphological data. Pathological conditions can seriously affect sample size resulting in a large number of teeth that are unable to be scored. Also, the expression of a trait can render a tooth more susceptible to certain types of deterioration (Mayhall 2000). For example, shovel-shaped incisors can be more prone to dental caries (cavities) as food can become entrapped in the pit between the mesial and distal ridges (Mayhall 2000).

Dental caries form on the enamel surface of the teeth and progress through the tooth layers with varying degrees of severity (Caselitz 1998). Caries appear in several stages, beginning as a discoloration of the enamel, but only those that have formed cavities can be recorded in an archaeological context (Freeth 2000). Destruction of the tooth due to carious lesions can be quite problematic for dental studies because they can remove dental morphologies and make gathering accurate measurements impossible.

Non-pathological conditions can also influence data collection. For instance, the presence of dental calculus, or tartar, can render teeth difficult to accurately measure and make it impossible to observe certain morphological characteristics. This calculus, which hardens on the crown of the tooth, is formed from a build-up of plaque (Brothwell 1963). Calcified plaque usually begins seriously forming in adolescence and worsens with age (Csiba 1987). Calculus can be removed, but the process compromises future studies utilizing this tartar.

Also, dental wear must be considered, as wear can seriously influence the detection of

dental morphologies and can render the measurement of the crown height especially impossible. Dental wear results from the loss of enamel from the occlusal surface of the tooth, followed by the rapid wearing of the underlying dentin (Rose and Ungar 1998). There are three basic types of dental wear: attrition, abrasion, and erosion. Attrition is dental wear caused by contact between the teeth, either during chewing or by grinding the teeth. Dental abrasion is caused by the contact between the tooth and a hard foreign object, such as dietary abrasives or by certain cultural activities, such as smoking a pipe or using the teeth as an anchor. Dental erosion is chemically influenced, and in clinical literature it is associated with eating disorders and alcoholism (Freeth 2000, Larsen 1997). Even the slightest bit of occlusal wear will reduce the height of the crown by a measurable amount, and interproximal wear will reduce the measurement of the mesiodistal width, thus affecting the accuracy of research (Hillson et al. 2005). These measurements must then be omitted, significantly reducing sample size (Buikstra and Ubelaker 1994).

While the measurement of teeth is relatively objective, there are several other problems associated with the study of dental morphology. First, while there are standards in place, the analysis of dental morphologies does stay relatively subjective since scoring (assigning a level of presence to a trait) can vary with each researcher. The modes of measurement can also vary, and hence they can make comparative analyses quite difficult, if not impossible (Kieser 1990).

Lastly, the heritability of morphological traits must be considered. Problems can arise in the way in which traits are inherited, especially given that humans grow two sets of dentition. A trait may be expressed in the deciduous dentition and not in the permanent dentition, or vice versa. This must always be taken into account when studying dental morphology: it is possible that an individual carries the genes to express a given trait, but the trait is not seen on their

permanent dentition (Scott and Turner 2000). Population differences can also be obscured by environmental variables (Soafer et al. 1986). As potential problems in data collection have just been discussed, the effects of environmental and biological variables are discussed in the following section.

Biological and Environmental Variables

Biological distance utilizing the dentition estimates population relationship based on polygenic traits, which refer to those traits controlled by more than two genes. Because these polygenic traits generally have both environmental and genetic components, biological distance can reflect both genetic and environmental differences. In order to properly utilize the dentition in biological distance studies, several important considerations must be kept in mind. Understanding how dental morphology and metrics can be affected is crucial. Another key factor is the fact that, despite scoring characteristics having a discrete nature, most morphological traits are polygenic and therefore continuous. The effects of environment on the dentition versus heredity must also be considered; several factors can affect trait expression and tooth size, including genetics, dental development, environment, sex, and age.

Much work has been done to determine the effects of environment and heritability on skeletal and dental metric and non-metric traits (Dahlberg 1971, Garn et al. 1964, Garn et al. 1979, Goose 1971, Goose and Lee 1971, Hughes et al. 2000) and, as a result, the complexity of this heritability is now known. Several studies have been conducted in an attempt to identify the heritability of dental traits and size. For example, in his study of 123 families in England, Goose (1971) measured the mesiodistal width of the incisors and canines. He found a high heritability in tooth size in families and no differences in the sexes besides the size of the canine. Hughes

and colleagues (2000) examined deciduous dental models of 221 pairs of twins and 160 singletons, and found a strong genetic component in deciduous crown size.

Tooth development and gestation can have much influence on the size and morphology of the dentition. Garn et al. (1979) published a study attempting to determine the influences of gestational factors upon crown dimensions. They found that certain disorders and large birthweights were associated with large dentition, while crown dimensions were small with low birthweight and maternal hypertension. Garn and colleagues also questioned whether those studies performed on twins might have been influenced by the inclusion of premature, and hence low weight, multiple births. They suggest that crown breadth and length measurements simply reflect systematic prenatal influences on developing teeth.

Sexual dimorphism is observed in all animals and primates of the same species. In humans, body size and tooth size vary worldwide and also between the sexes, thus presenting sexual dimorphism (Alt and Türp 1998, Hanihara 1978, Kieser 1990, Schnutenhaus and Rösing 1998). In particular, in the permanent dentition, sexual dimorphism affects both the maxillary and mandibular canines and first molars, as well as the maxillary central incisors (Alt and Türp 1998). According to Gingerich (1974), the teeth that develop later in ontogeny exhibit greater sexual dimorphism due to the differences in the production of sex hormone in males and females. In a recent study, Agnihotri and Sikri (2010) demonstrated that there exists a statistically significant difference in the size of the maxillary first molar between male and female Indian Jat Sikhs. Among morphological traits, the one which consistently shows sexual dimorphism is the distal accessory ridge of the canine (Scott and Turner 2000). The canine is also the most sexually dimorphic in terms of size (Goose 1971). Moss (1978) suggests that males and females can exhibit sexual dimorphism in the canines due to a longer period of enamel formation in

males.

Sexual dimorphism in dental morphology is not as well understood as sex differences in the size of the teeth. Those studies that have been done on the topic show conflicting results. For example, several studies have found no significant difference in the expression of Carabelli's Trait between the sexes (Garn et al. 1966, Harris 2007, Scott 1980). Other studies, however, did find difference in expression among the sexes (Goose and Lee 1971, Kaul and Prakash 1981, Kieser and Preston 1981, Scott et al. 1983). A similar debate can be seen for other morphological traits, for instance in the shoveling of the incisors. Some studies did find differences among the sexes (Harris and Bailit 1980, Kaul and Prakash 1981), while other studies did not (Kieser and Preston 1981). In order to address this issue in studies, especially with dental metrics, researchers could separate the males and females in the population to be analyzed.

When discussing complex traits, such as dental morphological and metric traits, the general assumption is that the phenotype is made up of a combination of both the genotype and the environment surrounding the organism. For quite some time, the environment has been understood to be a major factor in the morphology of the cranium and, to a somewhat lesser although still significant extent, the dentition. As early as 1912, Boas demonstrated that cranial morphology can be affected and altered in just a single generation, due to changing environmental factors. The effects of environment and heredity on nonmetric traits and the size of the dentition are not yet fully understood, and more research is necessary to understand this complex relationship.

As demonstrated in this section, there is now a large emphasis on the effects of the environment on physical characteristics. It is now difficult to imagine a time when these factors were not taken into consideration, as they have become such a concrete part of the understanding

of the limits of human biology and genetics.

One of the ways in which biological distance studies can be used is to reconstruct the population patterns of a given area, as in the example of Zalavár. The following sections will outline the project proposal for a biological distance study of this 9th to 12th century material.

CHAPTER 4

PROJECT PROPOSAL

Hungary lies in an area known as the Carpathian Basin, a drainage area of the middle Danube valley named after the mountains that border it from the north, east, and south. Present-day Hungary is divided into two main regions: the region to the west of the River Danube is known as Transdanubia, while the Great Hungarian Plain stretches without a single hill from Budapest, to Oradea in the east, and to Belgrade in the south (Engel 2005).

The area of Zalavár, on the south-western tip of Lake Balaton in Hungary, was an important center for the Carolingian Empire in the 9th century. The area was depopulated after the invasion of the Magyars in 895 AD, and repopulated in the 11th century. The proposed project will look at questions of the migration of the Frankish people and subsequent repopulation of Zalavár.

In order to fully grasp the questions of this proposed research, it is important to understand the historical background of the area. Once the history has been overviewed, the site will be introduced. We end with a discussion of specific methodologies that will be used for analysis.

History of the Area

This section outlines a history of Hungary and the Carpathian Basin, which has been densely inhabited since the Neolithic. We will begin with the Roman Empire and early invading populations, then turn to the Carolingian Period, followed by the Magyar invasions and the

establishment of Hungary during the Árpád Period. This history will be relatively brief given the rich history of the Carpathian Basin. The provided history is intended to show the tumultuous past of the area, and to situate the specific history of Zalavár.

Early History. The area of modern-day Hungary has been an important geographic area for thousands of years, due to its central point between Europe and Asia. In the 8th century BC, the Roman Emperor Tiberius established the area of Pannonia north of the River Sava and west of the River Danube (Makkai 1990a). By the first millennium, the Carpathian Basin was divided in two major regions: the Romans had Pannonia in Transdanubia, and the northern and eastern areas were occupied by mostly Germanic groups (Fodor 1996). The 3rd century saw the Goths attack and settle in the Pontic steppe, and the Germanic Gepid tribes came from the north and settle between the Tisza and Transylvanian border ranges (Makkai 1990a). Christianity became the state religion in the 4th century, until which time it was persecuted in the area.

In 375, the Gothic Empire was destroyed by the Huns. The most famous king of the Huns, Attila, took the title in 434 AD. As Attila was raised as a hostage in Rome, the Western Roman Empire considered the Huns as allies. Hence, the Romans yielded Pannonia to the Huns, in exchange for help against the Visigoths, in 434 (Makkai 1990a). Now, the entire area between the Carpathian Basin and the Ural mountain chains now belonged to the Hunnic Empire. After Attila's death in 453, many Hun princes retreated to the Pontic steppe.

By the year 565, the Avars approached from the East, driven to the area by the Turks and pushing all other peoples out of their path (Fodor 1996). It quickly became obvious that the Avars would rule the Carpathian Basin, and they did so for the following two and-a-half centuries. Early settlements were concentrated in the eastern and southern regions of the Carpathian Basin, as the Avars led campaigns against Byzantium nearly every year. From the late

6th century, the Avars began populating Transdanubia, marking its south-western border by the Zala Valley (Szőke 2007). Christianity quickly ceased under the Avars, and all institutional and organizational background of the religion disintegrated for centuries (Szőke 2005b).

The Avars ruled the area until their power began to diminish in the late eight century, and were subjugated by Charlemagne (r. 768-814) between 791-803 (Engel 2005, Makkai 1990a). How the defeat of the Avars occurred is still not well known, but it is thought to be due to a civil war amongst the Avars, and the rapid break-up of their confederacy (Collins 2010). Charlemagne then defeated the Avar tribes in a series of three campaigns and took over the Transdanubia.

The Carolingian Period (The Franks). After Charlemagne's defeat of the Avars, around 830 the southern area of the Great Hungarian Plain and the Marós valley to the east came under the authority of the Bulgars. The plain between these two areas became *deserta Avarorum*, “the wasteland of the Avars,” a no-man's land (Fodor 1996).

Charlemagne was the leader of the Carolingian Empire, a Germanic family that rose to power in the eighth century. Under the height of their power, the Carolingian Empire spread from the Atlantic coast to the River Danube, and from the North Sea to the Adriatic (Backman 2009). The greatest achievement of the Carolingians was the formation of a western cultural identity. Due to their emphatic promotion of Christianity, the people of the European continent began to identify themselves as members of the *Christendom* (Backman 2009). Although short-lived, the legacy of the Carolingian Empire survived long after its collapse in the tenth century.

In the early 9th century, a Slavic principality was established under Pribina. In the 830s, the Moravian Prince Moimir expelled Pribina from his principality, as it became incorporated

into the Moravian principality (Fodor 1996). Pribina fled to the Franks, who rewarded him with estates in Transdanubia for his services. He established his seat at Mosaburg, later known as Zalavár, with its center at Zalavár-Vársziget (castle Zala – castle island).

Just before the conquest of the Magyars in 895 AD, Carpathian Basin was under the influence of three major political powers: the Carolingians, the Moravian principality, and the Danubian Khaganate of the Bulgarians. (Engel 2005, Fodor 1996). The Moravians were the majority in the north, in the area of today's Slovakia. In Transdanubia, there were remnants of the Avar population, Frankish-Bavarian colonists, and an overwhelming majority of Slavic people. Christianity had also returned to the area due to the influence of the Carolingian Empire, and churches and cemeteries became increasingly more popular.

The Magyar Conquest Period. Around 550 AD, Turkish Bulgar tribes from the east pushed the Magyars to the Ural mountain chain, the area where Europe meets Asia. From where the Magyars originate is hotly debated, but the Magyars likely belonged to a Khazar Kaganate, which is evidenced by the Magyar language. For example, in Hungarian the word for God, “Isten,” derives from *Istemi*, a western Turk Kagan who lived in the 6th century (Makkai 1990b). According to István Fodor (1996), the unique language of the Magyars meant that they could not communicate with their neighbours, which “effectively ruled out ethnically mixed marriages and ensured the continuum of ancestral traditions and customs” (15).

In the 9th century, the Magyars slowly began their move to the Carpathian Basin, being mentioned for the first time as allies of the Bulgars around 830-840, and in Latin sources in 862 (Engel 2005, Fodor 1996). The Magyars began to be employed as mercenary tribes in 881 by the Moravian prince Svatopluk against the Franks, and in 892 by Arnulf, the governor of Frankish

provinces, against the Moravian prince (Fodor 1996). In 893, Leo the Wise, Emperor of Byzantium, allied with the Magyars against the Bulgarians. In return, the Bulgarian Tsar retaliated against the Magyars and made an alliance with the Petchenegs, another eastern tribe. They attacked the Magyars in 895 AD, driving them out of their homes in the Black Sea region to the Carpathian Basin.

In 895, Chief Prince Álmos led the Magyars through Transylvania. It was his son, Árpád (d. 907), who led them across the Verecke pass and into the Tisza valley – the area of present-day Hungary. The Magyar troops quickly pacified the region and massacred the Franks (Fodor 1996). The sources are relatively quiet from 895-899, but upon Arnulf's death at the end of the 9th century, the Magyars took over Transdanubia and the eastern part of Bavaria, completing their occupation by 900 (Engel 2005, Fodor 1996).

The Árpád Period. The mid-10th century began to see changes in the Magyar Empire, when Árpád's grandson, Taksony, became Chief Prince in 955. Taksony introduced an economic system based on the old Carolingian system, he established court-run sites and permanent settlements, and eventually ceased tribal unit alliances, centralizing power (Makkai 1990c). Prince Géza (d. 997), also grandson of Árpád, took over after Taksony's death. Géza monopolized power, forced his subjects to convert to Christianity, set up the organization of the Christian church, and using his authority, took the title of King (Engel 2005).

The transformation of the country began with Prince Géza, but ended with his son, Vajk, who bore the name István (Stephen) since his baptism. In the year 1000 AD, Stephen (997-1038) asked for, and received, a crown from Pope Sylvester II. This marked the formation of the country of Hungary, and its entrance into the Holy Roman Empire. By the 11th century, Stephen

had established a law preventing people from moving too far from a church, and also a law stating that burial grounds must be formed around churches, tying ancestor worship to Christian holy grounds (Makkai 1990c). He had created 40 counties, and constituted a new political system on which the power of the Árpád Dynasty lasted until the 13th century. Stephen occupied Transylvania in 1003, and by the end of his reign his authority extended over all territories inhabited by Hungarians. As Stephen's son, Emeric, died in 1031 in a hunting accident, the descent of the throne became quite turbulent until the end of the Árpád Dynasty in 1301.

Summary. As is clear, the Carpathian Basin has had a turbulent history since Roman times. The rise and fall of Christianity in the area is seen from this time forward. Christianity rose in Roman Pannonia, but fell upon the arrival of the Avars. Once the Avars were defeated by Charlemagne and the Carolingian Empire, Christianity was once again introduced to the region. The arrival of the Magyars in 895 AD, and the defeat of the Franks, yet again ended Christendom in the area. Finally, the formation of Hungary by King St. Stephen and the entrance into the Holy Roman Empire marked a period of Christendom which would last through the rest of history.

History of the Site

Now that the history of the Carpathian Basin has been reviewed, we will more specifically review the region under study. The sites lie in Zalavár, a village located in Western Hungary just south-west of Lake Balaton, in the marshes of the River Zala. The location of Zalavár is such that, from the Roman period onward, it was at the center of activity. Many islands in this formerly marshy area were suitable for settlement, and were also positioned such

that they were easily defensible. Many of the places around Zalavár are named *sziget* (island), such as the Vársziget (castle island), which will be the main focus of this study.

The medieval archaeological topography of Zalavár is strikingly complex, as there are many known sites in the area. The most important is the Vársziget, which is identified with Mosaburg, the capital of Frankish Pannonia. The next island over, Kövecses, has settlements and cemeteries from both the Carolingian and Árpád periods. The neighboring island to Kövecses is Rezes, a known Carolingian site which will also be used for this study. There are many other sites, but important to mention is the site of Kápolna (chapel), which has a known Árpád period cemetery that will also be used in this analysis, and that is found just a few hundred meters from the Vársziget site.

The early history of Zalavár. When Pannonia was established by the Roman Empire, the area of Salla, today's Zalavár, was incorporated into the region (Redő 2007). Due to this province's proximity to Italy, the Roman conquest of Pannonia began and lasted the longest here. By 118 AD, the town of Salla was granted the rank of municipium, owed to its stone buildings and sewer system, but by the 3rd century Salla became depopulated due to invasions. After these plunders and attacks, a state-funded project was put in place to rebuild Salla, which is evidenced by many 4th century archaeological finds (Redő 2007). In 377 AD, the Gothic and Hunic attacks pushed Salla's citizens to Italy, Savaria, or an inland fort at Fenékpusztá, still in Zala county (Redő 2007).

As mentioned earlier, the Avars began populating the Zala Valley, along with Slav groups, in the 6th century. There is no archaeological evidence that the Avars built their own fortifications, so it is likely that upon their arrival the Avars used late Roman forts and

settlements (Szőke 2007). The construction of basilicas and cemeteries begin to be seen around the 6th century at Fenékpusztá - evidence of a local Christian community. Avar cemeteries were abandoned in this region around 670-680 AD (Szőke 2002, Szőke 2007).

Zalavár during the Carolingian period (Mosaburg). The history of Zalavár as a regional center started in 840 AD, with the founding of Mosaburg. The history of the settlement is well described in the *Conversio Bagoriorum et Carantanorum* (On the Conversion of Bavarians and Carantans), written in 870 AD (Engel 2005, Mordovin 2005). In the ninth century, Prince Pribina had to flee from Nitra, the center of the Slavs in the Northern Carpathians. Around the year 840, the Emperor Louis the German gifted Pribina with some territories in Pannonia by the River Zala. By 847, the center of this area became the fortified settlement of Mosaburg (Mordovin 2005). On January 24, 850 AD, Liupram, Archbishop of Salzburg (836-859), consecrated a church dedicated to the Virgin Mary, from here-on referred to as the Church of St. Mary (Szőke 2007). Pribina then asked the bishopric for craftsmen, painters, and builders to establish another church, which held the reliquary of Hadrian the Martyr (Mordovin 2005). This church was later finished after the writing of the *Conversio*, and will henceforth be referred to as the Hadrianus Church. The *Conversio* also mentions a third church, built in honor of Saint John the Baptist, but not much is known about this church (Szőke 2007). Another 13 churches were erected outside the town in Pribina's lifetime, and another 12 were built outside Mosaburg under his son Kozel until the early 870s.

The end of the ninth century saw the Magyar conquest. The arrival of the Magyars brought an end to life at Mosaburg (Szőke 2005a). Due to the disintegration of the local organization and ecclesiastical structure, part of the servicing people departed along with the

secular and ecclesiastical dignitaries (Mordovin 2005, Szőke 2005a). The area became isolation from western connections, and once again became a marshland.

Zalavár during the Medieval period. Because of its strategic position, as soon as the new state arose in the Carpathian Basin the former Mosaburg was reformed, but with a new name: Zalavár (castle Zala). Exactly when and how this new town was organized is still under discussion, but it must have happened under King Stephen. In 1019, Stephen founded a monastery in Zalavár, dedicated to the same St. Hadrian as the former church, and likely built on the foundations of the former St. Mary's church (Mordovin 2005, Szőke 2007). This became one of the most prosperous Benedictine abbeys in Hungary, and had a very long-lived history until it was destroyed in 1702. A new (parish) church was built north of the monastery in the last third of the 11th century, known as Zalavár-Kápolna (chapel), and a cemetery was opened around the church (Ritoók 2007). This church was abandoned by the 13th century.

Summary. The area of Zalavár has been an important center since Roman times. In 840 AD, the Carolingian center of Mosaburg was founded. Here, several churches were established, including the Hadrianus Church and the Church of St. Mary. These churches were destroyed during the Magyar conquest, and in the 11th century a Benedictine monastery was built on the area surrounding the former Church of St. Mary. Here a new church was dedicated again to St. Hadrian. Cemeteries were in use surrounding all of these churches, and due to the proximity of the new Hadrianus Church to the old these cemeteries eventually, in some areas, became archaeologically indistinguishable.

Materials

There have been several earlier anthropological studies conducted on remains from the area of Zalavár. The analysis of the remains from the ninth century cemeteries of Garabon Ófalu I and II, and Zalasabár-Dezsősziget were completed by Éry (1992). Éry (1996) also completed the anthropological examinations of the cemetery at Alsórajk Határi tábla, found 12 kilometers from Zalavár.

The 9th to 10th century material from Zalasabár-Borjúállás was completed by Mende (2000). The similarly-dated material from Esztergályhorváti-Alsóbárándpuszta was studied from several angles: general anthropological examinations were completed by Éry and colleagues (2004), nonmetric traits were analyzed by Finnegan and Marcsik (2004), and pathology was studied by Marcsik and colleagues (2004). The analysis of this material from Esztergályhorváti-Alsóbárándpuszta, Alsórajk-Határi-tábla, and Zalasabár-Dezsősziget revealed that these populations were phenotypically similar, and differed more significantly from other 6th to 8th century cemetery populations in the Zala region than from populations buried in other Transdanubian and southern Slovakian cemeteries (Éry et al. 2004).

Several studies were completed on the Carolingian and Árpád period material from the Zalavár-Vár area. The material excavated between 1951 and 1953 of the Árpád period Zalavár-Községi and Zalavár-Kápolna cemeteries was analyzed by Acsádi and colleagues (1962). Of the same material, metric analysis was completed on the skulls by Howells (1974), and oral pathologies were observed by Frayer (1984). Wenger (1970) also completed a cranial metric analysis of the Zalavár-Kápolna remains. The analysis of the Zalavár-Kápolna material excavated between 2002 and 2003 was completed by Wolff (2009). The 10th to 11th century cemetery of Pusztaszentlászló was analyzed by Kiszely (1987). The Carolingian period

cemetery of Zalavár-Rezes was analyzed by Évinger and Bernert (2009), but the results remain unpublished.

Research Questions and Hypotheses to be tested. There are several questions that arise when looking at the anthropological material and history from Zalavár. Specifically, this research will utilize the skeletal material from the Hadrianus church. When the Church of St. Mary was rebuilt as the second Hadrianus Church, or Church of St. Hadrian, in the 11th century, the rapidly-growing cemetery surrounding the church quickly ran into the cemetery of the old Hadrianus Church. Because of this, it is difficult to tell which individuals belong to which period of history. It is presumed that the people of the Carolingian and Árpád periods are likely of different ethnicity, but it is not sure.

Mosaburg, or Zalavár, was a booming center of the Frankish Empire, but the Magyar conquest of 895 pushed the Franks Westward out of Zalavár. After the formation of the state in the year 1000 there is again evidence of life in this area. Archaeologists and historians are unsure as to whether the Frankish people returned to the area after this time, if the area was only settled by the invading populations, or if the medieval population was made up of Slavs and Franks who stayed behind. Biological distance analysis can help to shed light on these questions.

Hence, the research problem would be two-fold: to estimate how many genetically interbreeding populations are found in the cemetery, and once compared with cemeteries of known time-period, to determine whether the early inhabitants returned to the area in the 11th century.

It is likely that after the formation and re-Christianization of Hungary, the earlier populations who had fled to the west to escape the Magyars returned to their homes in Zalavár.

However, Slav and Magyar ethnic groups were also likely present in these later times.

Main sample: Zalavár – Vársziget Hadrianus Church. At the beginning of the 19th century, historians successfully identified Zalavár-Vársziget as the former Mosaburg, and the former center of Frankish Pannonia. Shortly thereafter, János Kollár, a Lutheran minister, discovered the archaeological site (Szőke 1976). The first excavations were conducted in 1841, at which time the ruins were still visible and identifiable. In 1881 the ruins were documented by Flóris Rómer. Despite efforts, destruction of the ruins continued, and today is simply an extraction pit for stone and sand.

Systematic excavations around Zalavár have been continuing since 1946, from prehistoric to 17th century sites. Géza Fehér headed the excavations since 1951, and was the first to realize the historical and archaeological importance of the site (Szőke 1976). After his death, Ágnes Sós took over excavations, and between 1981 and 1991 excavated a cemetery containing 600 graves. It is thought that this cemetery was actually the beginning the Vár site, which is the cemetery surrounding the Church of St. Mary (Béla Szőke, personal communication). After Ágnes Sós' death in 1993, Béla Szőke completed excavations of the cemeteries of the Hadrianus Church and Church of St. Mary between 1998 and 2004.

The excavation of the Zalavár-Vársziget Hadrianus Church cemetery occurred over several years. The remains are now housed at the Hungarian Natural History Museum, and are presently being analyzed, very near completion, by Sándor Évinger. At the museum there are approximately 2000 individuals from the cemetery. This is the first anthropological analysis being done on this material, and no dental analysis has yet been completed. Demographic data for the entire site is not yet available, but approximately 290 individuals will be suitable for

dental analysis.

There were not many grave goods found in the burials, but what has been uncovered has been compiled in a volume by the head archaeologist, Béla Szőke. Most individuals, about 90 percent, were simply wrapped in a cloth and buried in a wooden coffin (Béla Szőke, personal communication). Males often did not have any grave goods, perhaps just a simple dagger, and even these were limited to those males 20 years of age or under. Females also rarely had grave goods, but sometimes were buried with gold and silver jewelry. Most of these instances, about 90 percent, were only until they reached adulthood.

Comparative Samples. Two comparative samples and one outgroup will be used for analysis. The site of Zalavár-Rezes is known to be from the Carolingian period. Excavations at this site began in 1961, when archaeologists Károly Sági and Miklós Frech uncovered four graves. In the coming years, Ágnes Sós lead several excavation seasons at this site, in 1964, 1981-1982, and 1989, where they uncovered another 201 graves. The skeletal material is now kept at the Hungarian Natural History Museum, and demographic analysis was completed by Évinger and Bernert (2009). In total, there were 205 graves representing 207 individuals found. This analysis estimated that there are 52 infant I, 39 infant II, 7 juvenile, 66 adult, and 33 mature individuals in this series. Of all individuals, including those of unknown age-group, 47 are estimated to be male, and 60 female (see Table 1). Preliminary research found that of those individuals with all permanent teeth erupted, 54 are suitable for dental morphological and metric analysis.

Table 1: Age and sex distribution of Zalavár-Rezes (based on Évinger and Bernert 2009).

Age group	Male	Female	Unknown	Total
Infant I.	0	0	52	52
Infant II.	0	0	39	39
Juvenile	0	0	7	7
Adult	26	39	1	66
Mature	15	18	0	33
Senile	0	1	0	1
Unknown	6	2	1	9
Total	47	60	100	207

The cemetery at Zalavár-Kápolna is dated to the Árpád period, as it was built in the middle of the 11th century, and was used until the 13th century (Ritoók 2005). Excavations of this site began in 1948 under Sándor Soproni, and continued in 1951-1953 under the leadership of Ágnes Sós. After a several-decade hiatus, Béla Szőke and Ágnes Ritoók completed excavations in 1996 and 2002-2003 (Ritoók 2005). The skeletal material is now stored at the Hungarian Natural History Museum. There were 370 individuals uncovered in total, but this analysis will utilize the 128 people from the 2002-2003 field seasons. These include 21 infant I, 6 infant II, 7 juvenile, 61 adult, 29 mature, 1 senile, and 3 individuals of unknown age group (Wolff 2009). Of the adults, 52 were determined to be male and 39 female (see Table 2). Preliminary research found that of those individuals with all permanent teeth erupted, 78 are suitable for dental morphological and metric analysis.

Table 2: Age and sex distribution of Zalavár-Kápolna (based on Wolff 2009)

Age group	Male	Female	Unknown	Total
Infant I.	0	0	21	21
Infant II.	0	0	6	6
Juvenile	0	0	7	7
Adult	35	25	1	61
Mature	15	14	0	29
Senile	1	0	0	1
Unknown	1	0	2	3
Total	52	39	37	128

An outgroup is a sample population which is known to be not closely related to any of the populations being analyzed in the research, and is used as a control group. As an outgroup for the present research, the site of Fonyód - Bézsénypuszta will be used. Excavated in 2003-2004 by Zsolt Gallina and Krisztina Somogyi, 350 graves were found dating to the Ottoman period. A few gravegoods were uncovered, including two Islamic octagonal amber rings, one metal ring with a pentagonal plate, remains of two children's head-dresses, and one Miksa coin dating to 1578 (Gallina 2004). Bodies were either wrapped in shrouds or laid in plain coffins before burial, indicated by finds of wooden remains and, more commonly, coffin nails.

Summary. The site of Zalavár-Vársziget Hadrianus Church will be examined for two main problems: to estimate how many genetically interbreeding populations are found in the cemetery, to determine whether the early inhabitants of Mosaburg returned to the Zalavár in the 11th century. Data from this cemetery will be compared to data taken from the Carolingian period cemetery of Zalavár-Rezes and the Árpád period cemetery of Zalavár-Kápolna. An Ottoman period sample will be used as an outgroup.

Methods

This final section will outline the methods that will be used for the collection and analysis of data. The goal of this project is to examine the genetic variability of Carolingian and Árpád period cemeteries at Zalavár, Hungary. The following variables will be measured and/or recorded: age, sex, dental measurements, and nonmetric dental traits.

Standard osteological methods will be used to estimate both age and sex (Buikstra and

Ubelaker 1994, Bass 1995, White and Folkens 2005). The following general age groups will be used: infans I, infans II, juvenis, adultus, maturus, senilis. These age groups will be adjusted as the analysis proceeds, as they must be based upon the sample. As preservation is very good for all sites, sex estimation will be possible in a significant portion of the adult sample.

Data Collection. This research will make use of a database created in Open Office Base. This will facilitate data entry and analysis. This database makes use of a form which is created using a data entry key. These data keys account for age and sex estimation, dental data including oral pathologies, dental metrics, and dental morphology. Other dental data, including dental wear and oral pathologies such as abscesses, will be collected in order to a) have knowledge of specifically which teeth can be utilized for analysis, or which data must be discarded, and b) to facilitate future research in these areas.

The buccolingual and mesiodistal dimensions of each tooth will also be recorded using a Mitutoyo 573-721 caliper, as described earlier in the report. Only the left tooth measurement will be recorded, unless it is unavailable. Nonmetric traits will be recorded for the dentition, which was also described earlier. Those morphologies which will be recorded are summarized below in Table 3. During preliminary research, traits have begun to be added and eliminated, as this is necessary for the creation of the database. However, upon further examination of the sample as research proceeds, traits will likely continue to be added and eliminated.

Table 3: Dental nonmetric traits for biodistance analysis (Buikstra and Ubelaker 1994, Scott and Turner 1997)

Teeth	Nonmetric Traits
Maxillary	
Incisor	Winging, labial curvature, shovel, double-shovel, interruption groove, tuberculum dentale, peg-shaped incisor, radical number
Canine	Tuberculum dentale, distal accessory ridge, root number, radical number
Premolar	Root number, radical number
Molar	Metacone, hypocone, cusp 5, Carabelli's cusp, C2 parastyle, enamel extension, root number, radical number, reduced M3
Mandibular	
Incisor	Radical number
Canine	Distal accessory ridge, root number, radical number
Premolar	Premolar lingual cusp variation, Tomes root, root number, radical number
Molar	Groove pattern, cusp number, protostylid, cusp 5, cusp 6, cusp 7, enamel extension, root number, radical number

Data Analysis. Once data is collected, it must be sorted and refined. For example, if one nonmetric trait is observable in nearly all individuals, or along that same vein in no individuals, it must be removed to eliminate redundancy. Data will then be subject to various tests to identify any correlations between age, sex, and trait presence, as it is important to eliminate these variables (Pilloud and Larsen 2011).

The frequency of dental traits will be compared using chi-squared tests in order to determine whether these trait distributions occur by chance or whether they are significantly different. In order to compare traits, Mean Measure of Divergence (MMD) and a modified Mahalanobis Distance will be used (Irish and Konigsberg 2007, Konigsberg 1990, Harris and Sjøvold 2004). Making use of these statistics, relationship (R) matrices will be created to analyze the genetic affinity between populations. The dental measurements (mesiodistal and

buccolingual) will be analyzed using a one-way analysis of variance (ANOVA) test. ANOVA will help in comparison of the Zalavár-Vársziget Hadrianus Church site to the two other comparative samples, as the test determines whether the populations deviate from a shared mean. The genetic distances between the cemeteries can be demonstrated graphically by using cluster analysis and Principal Components Analysis. The squared Euclidian distance will also be calculated, which determines phenetic similarities between populations and individuals based on several variables (Pilloud and Larsen 2011).

The data can tell us several things. First of all, the sites of Zalavár-Rezes and Zalavár-Kápolna can be compared to ensure that the two biological groups of different time-periods do phenotypically differ. An intersite analysis of Zalavár-Vársziget Hadrianus Church will also be completed to determine how many genetically interbreeding groups are present in the cemetery. Lastly, these differing genetic groups will be statistically compared to the Zalavár-Rezes and Zalavár-Kápolna data to estimate their similarities.

Summary. Standard osteological methods will be used to estimate both age and sex. Morphological features will be scored based on the ASU Dental Anthropology System, and the buccolingual and mesiodistal measurements will be taken. Data will be analyzed using various statistical tests.

CONCLUSIONS

The history of physical anthropology has been heavily influenced by the attempt to explain human phenotypes and diversity. While there are no clearly defined biological boundaries between human populations, a similarity in morphological traits and metrics can be seen in interbreeding populations. While it is not always clear whether these traits are influenced by heredity or by environment, they can provide insight into migration patterns, kinship practices, and ethnic origins of human populations.

Morphological traits of the dentition, as well as measurements of the dentition, can provide a method for analyzing population distances. While the genetic influences on morphological traits are not fully understood, much work has been done on their standardization. Relatively recently, studies have begun using DNA to estimate biological distance. However, dentition has the advantage of providing a non-destructive method for the assessment of population distances. Also importantly, biological distance studies of skeletal and dental morphology and metrics allow for replication of data and methodologies as these studies are non-invasive and materials are often readily available. That said, biological distance studies must continue to test methodologies and to clearly articulate the nature of the cultural-historical questions for which they are theoretically and methodologically appropriate.

The proposed study will examine cultural and historical questions through biological distance studies using the paradigm of the post-Washburn era. Questions about the population changes at Zalavár can be aided through the use of dental morphology and metrics. Biological distance, along with archaeology and history, will provide a critical segment to this multi-disciplinary study.

In the future, studies could be conducted comparing the biological distance data obtained from this study to biological distance data from the crania, and also to the cultural and historical data obtained through archaeology and ethnohistory. In the case of Zalavár – Vársziget Hadrianus Church, it is difficult to derive ethnicity through archaeology, as most individuals were simply wrapped in cloth and/or buried in a wooden coffin, and grave goods are rare. Béla Szőke (personal communication) relied on stratigraphy and soil content to date the individuals from this cemetery. In the future it would be beneficial to consult written sources, such as the *Conversio Bagoariorum et Carantanorum*, which is made up of nine manuscripts from the 10th to 13th centuries. Sources such as this one, along with charters, can provide important ethnohistorical insight. All these elements would be components of a significant multidisciplinary study.

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