ABSTRACT

SCHWALENBERG, MEGAN BETH. Frailty in the Lower Illinois River Valley: An Analysis of Periosteal New Bone Formation during the Transition to Agriculture. (Under the direction of Dr. D. Troy Case).

This study investigates the health of the people of the lower Illinois River valley during the transition to agriculture by analyzing interactions between age-at-death and the activity and severity of periosteal new bone formation. Periosteal new bone formation, also called periosteal lesions, is one of many skeletal non-specific indicators of stress used by bioarchaeologists to assess health patterns. While often utilized in paleopathological studies, little work has been done on differentiation between the activity of periosteal new bone formation - active, healed, or both - and any association with selective mortality and frailty. Previous studies on Black Death individuals have suggested that active lesions are associated with individuals with high frailty while healed lesions are associated with individuals of lower frailty. A total of 263 adult individuals from three Middle Woodland period (50 BCE – 400 CE) sites and three Late Woodland period (400 – 900 CE) sites were analyzed. Age-at-death was estimated using transition analysis and the presence, activity, and severity of periosteal new bone formation on the tibiae was noted. These data were analyzed using Kaplan-Meier survival analysis and chi square tests. The results suggest prehistoric Native American populations with both active and healed periosteal lesions on their tibiae had higher survivorship, and therefore were less frail than individuals that did not have any lesions on their tibiae. Additionally, while individuals from the Middle Woodland period had proportionally more lesions than individuals from the Late Woodland period, they had higher survivorship than the Late Woodland group. Assessing the association of skeletal lesions and

age-at-death data provides a more nuanced understanding of the transition to agriculture within the lower Illinois River valley.

Frailty in the Lower Illinois River Valley: An Analysis of Periosteal New Bone Formation during the Transition to Agriculture

by
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BIOGRAPHY

Megan Schwalenberg grew up in Plymouth, Wisconsin. Her love of history and science led to the University of Wisconsin – La Crosse, where she double-majored in Archaeological Studies and Biology. She attended Arizona State University's Bioarchaeology and Human Osteology Field School at the Center for American Archeology in Kampsville, Illinois which solidified her love of archaeology and the human skeleton. Megan was fortunate to work as first a teaching assistant and then lab director for four additional summers at the field school in Kampsville. After completing her course work in biological anthropology at North Carolina State University, she worked as an assistant laboratory manager at the Veterans Curation Program in Augusta, Georgia. For the past 2.5 years, Megan was an ORISE intern with the Mandatory Center of Expertise for the Curation and Management of Archaeological collections at the U.S. Army Corps of Engineers, St. Louis District. She was recently hired as an archaeologist in the same office and works on NAGPRA compliance.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Interpreting the health of past populations is a substantial challenge that the bioarchaeological community must constantly confront. An individual's health can be affected by the food they consume, the environment they inhabit, and the customs to which they adhere. Biological anthropologists have used many different skeletal indicators such as dental pathologies, skeletal lesions, and long bone lengths, to try to interpret the health and lifeways of past populations (e.g. Cohen and Crane-Kramer, 2007; Goodman et al., 1984; Larsen, 2015). Periosteal new bone formation, additional bone that is laid down on top of existing bone, has been the focus of many studies around the world (e.g., Buzon and Judd, 2008; DeWitte, 2014b; Klaus and Tam, 2009; Shuler, 2011). While periosteal new bone formation does not have a specific etiology, its presence, severity, and stage of activity, allows bioarchaeologists to assess variation in the general health of a population.

Bioarchaeologists and paleopathologists have long assumed that skeletal indicators of stress and disease meant that the individuals were not healthy (Cohen and Armelagos, 1984; Lallo and Rose, 1979). The seminal paper "The Osteological Paradox" (Wood et al., 1992) raised several critiques concerning the accuracy of this type of interpretation in an archaeological context. Wood et al. (1992) argued that it cannot be assumed that individuals without any signs of skeletal stress or pathologies were the healthiest people in a population, and those with multiple pathologies had the worst health. For example, illnesses such as influenza, pneumonia, and other viral diseases can affect the soft tissue or lead to death but leave no skeletal signature. Additionally, an individual with a better immune system could survive a condition that left lesions on their skeleton while another individual could quickly die from the same condition and not develop any lesions. These possibilities make interpreting skeletal lesions a challenging endeavor in an archaeological context.

Current researchers have been working to interpret, as well as to minimize, the major points of concern raised by Wood et al. (1992). The concepts discussed in the "Osteological Paradox" call into question conclusions reached by Cohen and Armelagos (1984) in their seminal book on the health outcomes of the transition to agriculture around the world. They concluded that the increase in skeletal stress markers from hunting and gathering groups to sedentary agriculturalists were clear signs that health declined due to this transition (Cohen and Armelagos, 1984; Gage and DeWitte, 2009). Gage and DeWitte (2009) discuss the use of skeletal lesions as a main indicator of increased stress and decreased health. They recommend not to completely disregard previous assumptions about the transition to agriculture, but to frame the questions and analyses of future research around the concepts of selective mortality and hidden frailty (Gage and DeWitte, 2009). Though her research is not focused on the transition to agriculture, DeWitte (2014b) found that following the Black Death, there was an increase in periosteal lesions, periosteal new bone formation, as well as an increase in frequency of these indicators among older adults in her sample of 597 individuals from pre-and –post Black Death cemeteries in London, England. Though this previously might have been viewed as a decline in health, a new way to interpret this finding is that individuals with lower frailty survived the Black Death and lived long enough to accumulate more skeletal lesions (DeWitte, 2014b).

In tandem with the changing trends in paleopathology, paleodemography saw similar adjustments to their methods over the past 50 years. "Farewell to Paleodemography" (Bocquet-Appel and Masset, 1982), sparked a reevaluation of paleodemographic methods as well as the use of certain age-at-death estimation methods. Bocquet-Appel and Masset's (1982:332) main critique of paleodemographic studies was that researchers were over-stating the conclusions that could be made from the data and methods utilized at the time. Over the next 20 years, research surrounding the bias inherent in skeletal age indicators as well as the issue of sample representation flourished, culminating in a summit of sorts in Rostock, Germany (Hoppa and Vaupel, 2002). In Hoppa and Vaupel (2002), the issues still facing the field of paleodemography are examined in addition to the introduction of multiple new methods and models that can be used and further tested for more accurate results. One such method for improving age-at-death estimation, transition analysis, has been utilized in several recent studies pertaining to the intersection between paleopathology and paleodemography (DeWitte, 2010, 2014a; Wilson, 2010, 2014). Transition analysis was the primary age-at-death method utilized in the present study.

As mentioned above, there are various ways in which researchers have used non-specific skeletal indicators of stress to test and research the factors of frailty and selective mortality (DeWitte, 2014a; DeWitte and Wood, 2008; Wilson, 2010). One such indicator, periosteal new bone formation, has been widely used in different paleopathological and bioarchaeological studies (Cook, 2007; DeWitte, 2014b; DeWitte and Wood, 2008; Hurst, 2013; Marx, 2011; Redfern and DeWitte, 2011; Yaussy et al., 2016). Periosteal lesions are assumed to be associated with infectious agents and their presence and severity can be important to the understanding of past populations' susceptibility and interaction with infections. Though it can be located throughout the body, periosteal new bone formation is most commonly found on the tibia (Klaus, 2014; Larsen, 2015; Weston, 2008). Weston (2012), points out that there is no set standard around the world for recording and assessing periosteal new bone formation, therefore, it is extremely difficult to compare the conclusions reached by different researchers.

DeWitte's (2010, 2014a, 2014b) research has centered on the effects of the Black Death with regard to frailty and selective mortality on the English population and has used several skeletal indicators to assess health, including periosteal lesions. DeWitte and Wood (2008) found an increased risk of mortality among individuals with periosteal lesions compared to individuals with no lesions among an English Black Death sample and a Danish pre-Black Death sample. This led DeWitte (2014a) to test if there is a difference in mortality risk among individuals with active, healed, or no periosteal lesions. From her data, DeWitte was able to conclude that individuals with active lesions were more likely to die at a younger age than individuals with healed lesions present. Broadly, her findings suggest that active periosteal lesions are associated with high frailty and low survivorship while healed periosteal lesions are associated with low frailty and high survivorship. This new analytical approach of associating the state of the periosteal bone reaction with age-at-death could provide further insight into frailty and health patterns seen in other areas of the world.

The lower Illinois River valley, located in west-central Illinois, is an excellent region to utilize and test this analytical approach of studying periosteal bone reaction and its association with frailty. Archaeological work in the lower Illinois valley has uncovered and excavated large cemeteries from the Archaic to the Mississippian time periods about which much research has been published (Buikstra, 1976; Charles et al., 1988; Conner, 1984; Goldstein, 1980; Perino, 1968, 2006). The current project builds upon past studies of health within the valley and is one of the first to assess mortality patterns of the Lower Illinois Valley skeletal populations using transition analysis. The transition to agriculture in the valley occurred throughout the Middle and Late Woodland periods, with the introduction of maize during the Late Woodland to supplement starchy and oily seeds and small grains that had been intensively cultivated during the Middle Woodland (Asch et al., 1979; Charles and Buikstra, 1999; Smith, 2011; Smith et al., 1992). In addition to the dietary shift, there was an increase in population density in the valley during the Late Woodland, which is hypothesized to have caused more stress on resources as well as the people (Charles and Buikstra, 1999).

The purpose of this study is to investigate the health of the people of the lower Illinois Valley during the transition to agriculture by studying frailty and selective mortality through the interaction between age-at-death and periosteal lesions. This was accomplished by estimating the age-at-death of several hundred adult individuals from the Middle and Late Woodland Periods. Skeletal remains from six different sites throughout the Lower Illinois Valley, three Middle Woodland mortuary sites and three Late Woodland mortuary sites, were assessed for this analysis. The tibiae of the individuals were observed for evidence of periosteal bone reaction, including the stage (healed or active) of any lesions present as well as its location on the diaphysis. It is hypothesized that individuals with active lesions or no lesions will have lower survivorship, or frailty, compared to those with healed lesions, and individuals that have diffuse periosteal lesions that could be associated with a chronic condition will have lower survivorship, or frailty, than individuals with localized or no periosteal lesions. It is also hypothesized that individuals in the Late Woodland Period with periosteal lesions were at a greater risk of death than their Middle Woodland counterparts due to the increased stress of high population density and changes in subsistence. Further, this study will compare the pattern noted in DeWitte (2014a), that individuals with active periosteal lesions have a lower age-at-death than individuals with healed periosteal lesions, to the pattern found in these prehistoric Native American populations, and see if it is consistent or if it varies across time periods and/or subsistence strategies.

Since paleodemography is a constantly evolving field with new methods and models continually being created, it is necessary to utilize these methodologies and models to observe how they enhance our understanding of past population structures. The methods utilized in this study could provide a clearer understanding of mortality patterns during the transition to agriculture within the Lower Illinois Valley, and how the population demographics shifted with changes to both subsistence and settlement patterns. The association between the type of periosteal bone reaction and age-at-death used in this study moves beyond the lesion-frequency-only approach to health that has been used for decades within paleopathological studies. Assessing skeletal lesions in this manner begins to address concerns put forth in the osteological paradox and offers a more in-depth and nuanced analysis of factors that can affect frailty and mortality. This thesis will demonstrate how DeWitte’s analytical approach to frailty and periosteal bone reaction can be used by bioarchaeologists and paleopathologists to provide a clearer understanding of past populations’ health patterns in prehistoric North America and around the world.

CHAPTER 2: ARCHAEOLOGICAL AND SITE BACKGROUND

This research focuses on population health during the transition to agriculture which occurred during Middle and Late Woodland Periods in West-Central Illinois. During these time periods, the groups living in this region employed a horticulturalist subsistence strategy and increasingly came to rely on maize agriculture. Though this study does not focus on the Mississippian Period, where maize agriculture was the predominant subsistence strategy, exploration of the implications of these transitionary periods may help explain health outcomes seen during the subsequent time periods. The following chapter will provide an overview of the archaeology of the lower Illinois Valley, a general description of the Middle and Late Woodland Periods, as well as background information on the sites and skeletal samples utilized in this study.

Archaeology in the Lower Illinois Valley

The lower Illinois River valley commonly consists of the southernmost 112 kilometers of the Illinois River and the surrounding valley and uplands from the Mississippi River to the west, to approximately 32 kilometers to the east (Buikstra, 1976). This region has a rich archaeological history, spanning from the Archaic period until European contact. Intensive archaeological excavations have occurred in this region; especially during the 1950s-80s. During this period, Stuart Struever, Gregory Perino, Northwestern University, and the Center for American Archeology excavated many mortuary, habitation, and ceremonial sites (Buikstra, 1971, 1976; Charles et al., 1988; Connor, 1984; Farnsworth, 1973; Farnsworth and Koski, 1985; Flotow, 1983; Goldstein, 1980; Perino, 1968, 2006; Stafford and Sant, 1985; Struever, 1968; Wiant and McGimsey, 1986). Stuart Struever started excavating in the region in 1958 at the Kamp Mound group located on the floodplain north of the current village of Kampsville (Carr and Case, 2006). Close to 10 years later, Struever started a non-profit archaeological foundation, currently known as the Center for American Archeology, which has been active in lower Illinois valley archaeology for 50 years. All the sites in this study are located within the lower Illinois valley.

The archaeological record shows evidence of occupation throughout the valley during most of the Archaic period (8000 – 500 BCE). Not only were people living in the valley, they were also burying their dead in both floodplain and bluff crest locations (Buikstra, 1976; Buikstra and Charles, 1999; Buikstra and Seddon, ND; Charles et al., 1988; Perino, 2006). These Archaic cemeteries appear to have later been utilized by Middle and Late Woodland groups. Excavations of many Woodland period mound sites in the region have revealed underlying Archaic components (Buikstra and Charles, 1999; Charles et al., 1988; Perino, 1968, 2006).

The Early Woodland period (500 – 50 BCE) in the lower Illinois valley was quite different from the Archaic. Few habitation and mortuary sites have been found in the valley from this time. The population density of the valley was extremely low, and the area is thought to have been somewhat abandoned during the period (Buikstra and Charles, 1999; Farnsworth and Asch, 1986; King et al., 2011). Resettlement of the valley is believed to have occurred from the north at the beginning of the 1st century BCE, as groups slowly made their way south (Buikstra and Charles, 1999; Charles, 1992). There is also evidence that groups came to settle the southern portion of the valley early in the Middle Woodland period from the east via the Macoupin Valley (Farnsworth and Koski, 1985; King et al., 2011). The mortuary structures that these migrant groups and their descendants created have been the focal point of most archaeological investigations in the valley. The appearance of mounded superstructures on or near burial locations and important ceremonial centers ushered in the Middle Woodland period.

Middle Woodland Period

The Middle Woodland period in the lower Illinois Valley spanned from 50 BCE – 400 CE (King et al., 2011). This time period is associated with the Hopewell culture that was centered in present-day Ohio along the Scioto River. The heartland of the Hopewell culture was the Scioto River valley in Ohio and was characterized by massive, geometric earthworks and large quantities of exotic goods found within mounds (Carr and Case, 2006). The Hopewell culture seems to have expanded outward and influenced many groups hundreds of miles away in all directions; from Wisconsin and Michigan in the north, Tennessee and Georgia to the south, North Carolina to the east, and Illinois and Kansas to the west (Brose and Gerber, 1979; Struever and Houart, 1972; Wright, 2014). While archaeological evidence from these regions suggests that there was communication, or at least trade with the Ohio Hopewell, each region had their own interpretation or style of Hopewell culture (Struever and Houart, 1972).

While the Illinois Hopewell did not construct large earthworks, with the possible exception of the Golden Eagle site, they did build hundreds of mounds, both on the bluff crest and on the floodplain of the Illinois valley (Buikstra, 1976; Buikstra and Charles, 1999; Charles, 1992; Hermann et al., 2014; King et al., 2011; Perino, 2006; Struever and Houart, 1972). Bluff crest mound sites usually consisted of conical or oval mounds that contained burials. Bluff crest mounds are usually found associated with a floodplain settlement site and are considered to be the community cemetery for that particular habitation site. The majority of the mounds had a central log-lined tomb with earthen ramps that encircled the grave. Based on the excavation of these central tombs, it appears that individuals would be placed in the grave for a time and then removed to be interred in another location, usually in bundle or pit burials around the ramp (Perino 2006). Other primary burials were placed around the central tomb with or without limestone roofs. The typical burial posture used by the Middle Woodland people was extended burial, while bundle burials were also present due to the gathering of bones from the processed individuals in the central crypts. The floodplain mound groups typically had fewer mounds than the bluff crest groups and were centered around open areas, or plazas, that were originally hypothesized to be centers of trade (Struever and Houart, 1972), but further research has suggested these mound groups were used for ceremonial purposes (Buikstra and Charles, 1999; Mueller, 2013). Floodplain mound groups were places of ceremonial gathering, where multiple communities in the immediate area would have traveled to and assembled (Charles and Buikstra, 2002; Mueller, 2013). Fewer burials were located in floodplain mound groups with the vast majority of the burials being male. It is believed that burials in floodplain mound groups were for leaders or those who held some importance within the community.

Middle Woodland settlement sites are primarily found at the base of the bluffs on the valley floor, near the convergence of one of the many tributaries of the Illinois River (Asch et al., 1979; Struever, 1968). Movement across the landscape would be necessary to procure food since semi-domesticated cultigens would not have been a reliable resource until the end of the Middle Woodland period. The groups living in the valley did interact with one another but movement of people between groups, especially over long distances, seems to have been somewhat restricted. Evidence of low group interaction is based on moderate levels of variation in lower Illinois valley groups seen in skeletal non-metric traits (Buikstra, 1976; King, 2016). This partially restricted group interaction could have been caused by these new groups focusing on acclimating to the new environment and only interacting with groups closest to them (Buikstra and Charles, 1999; King, 2016).

Overall, Middle Woodland groups exploited a wide variety of both floral and faunal resources (Asch et al., 1979; Holt, 2000; Mueller, 2013; Parmalee et al., 1972; Smith, 2011). The location of settlement sites that have been excavated on the floodplain would have provided an excellent place to live due to their proximity to the Illinois River and its tributaries, with its aquatic resources, as well as the forested upland with larger fauna, such as deer (Asch et al., 1979; Mueller, 2013; Parmalee et al., 1972). One important resource that had been exploited throughout the Archaic, and well into the Middle Woodland were nuts, such as hazelnuts, hickory nuts, and walnuts (Buikstra, 1984; Mueller, 2013). As discussed by Buikstra (1984), these nuts provided excellent nutritional value to the diet of the Middle Woodland people; however, a large population of people could not use nuts as a primary source of nutrients. Faunal remains from different Middle Woodland sites have shown a wide variety of both large and small creatures that were utilized throughout this time period (Flotow, 1983; Parmalee et al., 1972). Many mammals were exploited by the Middle Woodland people, including deer, raccoon, and beaver. Deer was the primary mammal resource in the area because they provided large quantities of meat (Buikstra, 1984; Parmalee et al., 1972). The meat of these mammals was used for subsistence, and their bones were also utilized for tools, such as awls. Aquatic resources such as fish and mussels were also exploited since the Illinois River and its tributaries were within walking distance of most of the settlement sites (Asch et al., 1979). Fish, like bowfins and catfish, were the most abundant aquatic subsistence resource, while mussels and other aquatic birds were part of their diet but in smaller quantities (Parmalee et al., 1972).

One major difference seen in Middle Woodland subsistence patterns in comparison to Archaic and Early Woodland subsistence strategies was an intensification of cultivation, as well as some evidence for domestication of several starchy and oily seeds and small grains (Asch et al., 1979; Mueller, 2013; Scarry and Yarnell, 2011; Smith et al., 1992). Sumpweed and sunflower, both oily seeds, were believed to be domesticated by this time period since an increase in seed size was observed in comparison to their wild seed counterparts (Harter et al., 2004; Scarry and Yarnell, 2011). Other starchy grains such as knotweed, maygrass, and goosefoot were also utilized but were only cultivated, not domesticated (Buikstra, 1984; Scarry and Yarnell, 2011). Oily seeds provided an excellent source of protein and fat and a small proportion of carbohydrates (Buikstra, 1984; Smith et al., 1992:208). In comparison, the starchy grains contain slightly less protein and fat, but more carbohydrates and fiber than their oily seed counterparts (Buikstra, 1984; Smith et al., 1992:208). The combination of these types of seeds provided Middle Woodland individuals with a balanced, nutritious diet.

Sample Middle Woodland Sites

The Gibson site (11C5), located in Calhoun County, Illinois (Figure 2.1), was excavated by Gregory Perino in 1969 (Buikstra, 1976; Perino, 2006). The mound group consisted of seven mounds located on a bluff ridge south of Kampsville Creek, and southwest of the current village of Kampsville, Illinois (Perino, 2006). The burials at the site ranged from the Archaic period (6000 - 1000 BCE) to the Late Woodland period (450 – 700

CE), with the majority representing the Middle Woodland period (Asch et al., 1979; Perino, 2006). All the mounds were conical in shape with Mound 5 being the largest, having a width of 53 feet, and a length of 65 feet (Perino, 2006:437). The site had been partially excavated in the 1890s, as well as the 1940s, and therefore some of the central areas of the mounds were pitted (Perino, 2006). The Buried Gardens of Kampsville site (11C373) is believed to be the settlement of the people who were buried at the Gibson site. The Buried Gardens of Kampsville (TBGOK) site is located underneath the present village of Kampsville, Illinois, and was recognized by a significant number of artifacts being discovered throughout the village during construction of buildings and the Illinois State Road 100 (Buikstra, 1976; Perino, 1968). The Pete Klunk mound group (11C4), located on the bluffs north of Kampsville Creek, is also thought to have been used by the inhabitants of TBGOK (Buikstra, 1976; Perino, 1968).

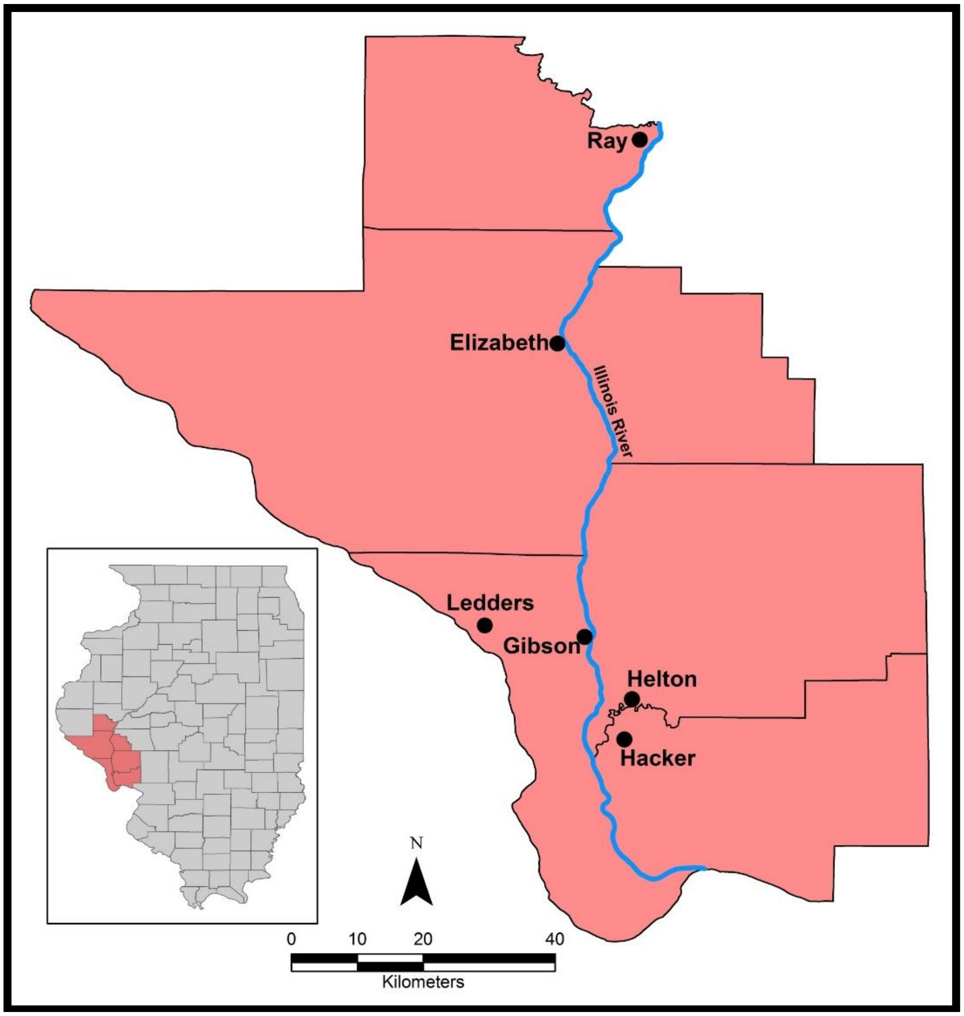

Figure 2.1. Middle and Late Woodland sites in lower Illinois River valley.

Over 150 Middle Woodland individuals were excavated from four of the seven mounds (Buikstra, 1976; Perino, 2006). The preservation of the skeletal remains was adequate, but the acidity of the soil varied by mound and was a factor in how well the bones preserved (Buikstra, 1976). Based on the demographic analyses conducted by Buikstra (1976), it is suggested that the mortality pattern of the Gibson population follows the typical pattern of high infant mortality, followed by low childhood mortality, and a steady increase of mortality into adulthood. Buikstra (1976) utilized a life table approach to create a mortality profile, which was then compared to a model mortality profile based on data from the United Nations. Further explanation of life tables and their use in paleodemographic research can be found in the next chapter. Based on the demographic analysis, it appeared that this was a representative mortuary population.

The Gibson mound group was the first completely excavated Middle Woodland mortuary site in the lower Illinois valley where a biological anthropologist was present during the excavations to assist with documentation of the burials. All the mounds from the Gibson site had a tomb or processing pit that was lined with either logs or limestone, consistent with Hopewell mortuary practices. Mound 5 showed evidence of the prehistoric clearing of skeletal remains from the central log tomb as major skeletal components were found along or on the ramps leading to the tomb (Perino, 2006). The burials processed in the central tombs were buried around the tomb or in the earthen ramps that surrounded the tomb (Buikstra, 1976; Buikstra and Charles, 1999; Perino, 2006). There were also burials excavated into the original ground surface around pits thought to have acted as charnel structures. While most burials did not contain any grave goods, there were some that contained exotic Hopewell artifacts like copper earspools and beads, smoking pipes, and marine shells. The central burial in Mound 3, which had an adult male and child, also contained a skeleton of a roseate spoonbill, a water bird not native to Illinois but whose likeness is present on pottery from this period, including pots at the Elizabeth site as well as from several mound sites in Ohio (Charles et al., 1988; Perino, 2006; Seeman and Soday, 1980).

The Elizabeth site (11PK512), located in Pike County, Illinois, was excavated between 1979 and 1985 by the Center for American Archeology Contract Program in conjunction with the Northwestern University Archeological Field Schools (Figure 2.1). The Elizabeth site is situated on the western bluff of the Illinois River in the northern portion of the valley. The site consisted of 14 mounds; five with Middle Woodland burials, seven with Late Woodland burials and one with Archaic period burials (Charles et al., 1988). One mound could not be associated with any temporal period since no burial features or diagnostic artifacts were found. Located below the mound group on the floodplain is the Napoleon Hollow site, which received its name from the neighboring valley. Napoleon Hollow (11PK500) is a large habitation site with both Archaic and Middle Woodland components (Charles and Buikstra, 1988; Wiant and McGimsey, 1986). Its location and extensive Middle Woodland occupation suggests that the Elizabeth site was used by the inhabitants of Napoleon Hollow, possibly as a ritual camp (Wiant and McGimsey, 1986).

There were a total of 50 Middle Woodland burials with 83 individuals among the 5 mounds at the Elizabeth site (Leigh et al., 1988). The demographic analysis published in the site report suggested that the skeletal sample recovered was relatively representative of normal mortality profiles (Frankenberg et al., 1988). A general pathological assessment was also completed and found that among adults from all time periods, osteoarthritis and generalized periostitis was common (Frankenberg et al., 1988). However, only frequencies of pathologies were assessed. Due to small sample sizes, no definite conclusions were made.

The excavation of the Elizabeth site allowed for an emphasis to be placed on the temporal sequence of the construction of the mound complex that had not been done before (Charles and Buikstra, 1988). From the radiocarbon dates as well as interpretations of mound construction, the Elizabeth site was utilized early in the Middle Woodland period. Mounds with Middle Woodland burials did not contain all the features that a Middle

Woodland mound would usually have, such as large, log-lined central tombs surrounded by ramps, peripheral burials with and without roofs, and bundled or pit burials around the ramp from individuals that had been processed in the central tomb (Leigh et al., 1988). Another outlier to the typical Middle Woodland tradition is the lack of burials of individuals who had been laid out in the central tomb to decompose. These individuals would typically be missing smaller, distal bones or would be bundled and buried near the central tomb (Leigh et al., 1988). None of the burials at the Elizabeth site showed evidence of missing small distal bones or being bundled (Leigh et al., 1988). Since it is believed the site was used early in the Middle Woodland period, these features or traditions were not fully utilized or incorporated into every mound (King et al., 2011; Leigh et al., 1988).

The Ray site (11BR104), in Brown County, Illinois, is located along a narrow ridge overlooking the confluence of the La Moine and Illinois Rivers on the west side of the valley (Figure 2.1). It is the northernmost site and lies on the border between the lower and central Illinois valley. The Ray site was excavated by Glen and Mary Hanning, avocational archaeologists, as well as a team of both amateur and professional archaeologists, between 1975 and 1980 (Flotow, 1983, 2006). The site was originally dated to the Middle Woodland period based on the presence of Hopewell artifacts, such as smoking pipes and Havana pottery (Flotow, 1983, 2006). Several calibrated radiocarbon dates from the site have suggested a late Middle Woodland occupation for the Ray site (Bullion and King, 2015). There has not been an associated habitation site found where the people buried at the Ray site may have lived. Though there are no data from any habitation site, some information on the diet of these people can be gleaned from their dentition. A caries rate of 16.7%, calculated using the tooth-count method from a sample of 48 individuals, suggests a more carbohydrate rich diet than most pre-agricultural societies (Schwalenberg, 2014). A high dental attrition rate early in life, compared to other contemporaneous sites, could be indicative of different food preparation or an elevated amount of grit present in diet (Flotow, 2006; Schwalenberg, 2013, 2014).

A total of 112 individuals were excavated from the Ray site (Flotow, 2006). The skeletons were in fairly good condition despite the ridge being historically used as a pasture for cattle. However, some of the burials that were close to the surface were damaged due to constant trampling (Flotow, 2006:25). The ratio of males to females was roughly equal to 1:1 with slightly more males being buried at the site. The mortality profile of the population varied from the expected pattern since there were significantly fewer individuals present between the ages of 20 – 30 years (Flotow, 2006). Flotow (2006) believes that this is most likely due to cultural practices rather than a preservation bias. There was a significant amount of pathologies present on the skeletal remains such as osteoarthritis, osteomyelitis, periostosis, and cribra orbitalia (Flotow, 2006). Evidence of fluorosis, from naturally occurring high levels of fluoride in the water, in the Ray skeletal remains has also been suggested (Nelson et al., 2016).

The Ray site is not a typical Middle Woodland mortuary site because it is missing the superstructures that are typical for this time period. The burials at the Ray site were laid out in a linear pattern with the majority being extended parallel to the ridge with the head facing down the slope (Flotow, 1983, 2006). Individuals were buried in one of three ways: placed on the original ground surface and then covered with dirt, placed in a shallow cut into the ridge and then covered, or in a pit burial (Flotow, 2006). Unlike other Middle Woodland mortuary sites, there were no burials that contained large numbers of grave goods. Of the

43% of individuals who had grave goods associated with them, most only had a few (Flotow, 2006). Since there are no other sites like it that date to the Middle Woodland period, the Ray site provides a means to investigate whether the individuals buried there were more similar to the Middle Woodland period, as the material culture suggests or to the Late Woodland period, as suggested by the lack of mounds.

Late Woodland Period

The Late Woodland period in the lower Illinois valley is generally dated to between 400 – 1000 CE. It is split into two phases: the White Hall phase, which occurs at the beginning of the period, and the Jersey Bluff phase, which occurs at the end of the period. Archaeologists usually designate the Late Woodland period by its lack of exotic materials, its plain ceramics, and its less elaborate mortuary rituals compared to the Hopewell culture that dominated the Middle Woodland period. The Late Woodland period saw the introduction of the bow and arrow and the first appearance of maize. It was also during this time that Cahokia, located approximately 96 kilometers southeast of the lower Illinois Valley, in the American Bottom, was beginning to grow in influence. The influence of Cahokia can be seen clearly in many terminal Late Woodland habitation and mortuary sites, with the presence of Mississippian artifacts in the assemblages (Buikstra and Charles, 1999; Farnsworth et al., 1991; Goldstein, 1980).

The Late Woodland subsistence pattern would best be described as transitional, with sites from the earlier part of this period having similar diets to Middle Woodland groups, while the intensification of maize agriculture is evident at later sites (Asch et al., 1979; Buikstra, 1984). During this time, hunting of fauna in the upland as well as a reliance on starchy seeds remained constant but there was an even further decline in the amounts of nuts incorporated in the diet (Asch et al., 1979). The reliability of cultivated seeds and grains most likely led to the decline of nuts in the diet. While deer remained an important dietary component, there appears to be an increased reliance on fish and a slight decrease in deer and other terrestrial mammals (Holt, 2000; Styles, 1981, 2011). The riverine environment of the valley, including the presence of backwater lakes, provided ample amounts of fish for the Late Woodland people to exploit (Styles, 2011). The consumption of starchy seeds slowly declined while an increase in maize is seen around the early Late Woodland period in both the Illinois and adjacent Mississippi valleys (Asch et al., 1979; Buikstra, 1984; Rose, 2003). The increase of maize in the diet was not a homogenous process throughout the valley; various levels of the proportion of maize in the diet are evident across time and space based on carbon isotope analysis (Buikstra et al., 1987; Conner, 1984; Rose, 2003).

A general population increase is evidenced by mortuary site data, suggesting that the lower Illinois Valley became progressively more densely populated (Asch et al., 1979; Buikstra and Charles, 1999). Due to this increase in population, a change in settlement pattern occurred near the end of the period. While there were still habitation sites located on the floodplain near the rich resources provided by the riverine environment, some groups moved into the uplands and at times, settled near mortuary sites, as seen at the Ledders site (Pickering, ND). Asch et al. (1979) suggest three reasons why a portion of the Late Woodland population moved their settlements to the uplands. First, the rapid spread of maize through the valley allowed for groups to be less reliant on riverine and seed resources. Second, the increase in population density in the valley could have stretched resources so some Late Woodland groups may have decided to venture away to locate more stable resources. The third was the introduction of the bow and arrow, which made hunting more reliable.

The Late Woodland mortuary program, again, varied from its Middle Woodland predecessor. Instead of conical mounds with central log tombs, the Late Woodland people buried their dead at ground surface, sometimes near a charnel structure. However, prior to mortuary activity, the original A horizon, the top layer of soil, was removed from most sites (Conner, 1984). Then, after a certain amount of time, all of the burials and the processing structures were covered with dirt, creating an elongated mound (Conner, 1984; Perino, 2006; Pickering, ND). Some charnel structures show signs of burning, which suggests that prior to the capping of the cemetery, the structures were burned. The internal structure of the Late Woodland mounds had more variation between mound groups than Middle Woodland mounds (Buikstra and Charles, 1999; Kerber, 1986). Late Woodland groups did not utilize flood-plain mound groups as their predecessors did for ceremonial as well as mortuary purposes (Charles and Buikstra, 2002). The predominant burial posture was flexed or semi-flexed but there were still individuals buried in an extended position. The amount and type of grave goods associated with burials also decreased from the Middle Woodland, including the disappearance of the exotic types of artifacts associated with the elaborate Hopewell burials (Buikstra and Charles, 1999).

Sample Late Woodland Sites

The Ledders site, located in western Calhoun County, Illinois (Figure 2.1), was excavated in 1971 by Jane Buikstra with the Northwestern Archaeological Program (Pickering, ND). The Ledders site consisted of two bluff crest mounds, which slightly overlapped, overlooking the Mississippi River (Conner, 1984). It originally consisted of three mounds, but one was destroyed by modern construction (Pickering, ND). The two remaining mounds were oval-shaped, with Mound 1 being 60 feet long, 40 feet wide and 8 feet high and Mound 2 being 55 feet long, 35 feet wide, and 3.5 feet high. Mound 2 shows evidence of pitting from looters. Each mound went through two separate building episodes where burials were placed on the original ground surface or in pits, and occasionally on existing mound fill, and covered with dirt (Pickering, ND). A site survey completed by Lois Braverman, located a habitation site on the bluff near the mounds that has a similar Jersey Bluff component (Pickering, ND).

A total of 218 individuals were excavated from the Ledders site, with 151 burials present in Mound 1 and 36 burials in Mound 2 (Conner, 1984; Pickering, ND). Preservation of the skeletal remains varied by mound, with Mound 2 having fair to poor preservation due to highly acidic soils, while Mound 1 had good preservation (Conner, 1984; Pickering, ND). There were 18 group burials, some of which included both adults and juveniles. The demographics of the Ledders site indicate that Mound 1 has a higher percentage of young adults compared to Mound 2. When the two mounds are combined, the sex ratio is approximately 1:1 and the age distribution matches closely to the normal mortality curve (Pickering, ND).

The mortuary program at the Ledders site is consistent with the general Late Woodland program. The majority of individuals were buried on their sides, in a flexed position; though a small number (n=9) were buried in an extended position (Pickering, ND). At least 41 individuals show evidence of processing, where the individual was left to decay in a pit but then the skeleton was transported to another location for final interment

(Pickering, ND). Few artifacts were found associated with burials at the Ledders site. All diagnostic Late Woodland ceramics were found in the mound fill, while seven Late Woodland projectile points were found associated with burials. The most abundant artifacts found at the site were Anculosa shell beads, including a cap covered in shell beads found on an infant skull (Pickering, ND).

The Hacker mound group, located in Jersey County, Illinois (Figure 2.1), consisted of six bluff crest mounds on the east side of the Illinois valley (Conner, 1984; Perino, 2006). The mound group is made up of two separate sites, Hacker North (11JY416) and Hacker South (11JY569). Hacker North consisted of four mounds, one that may have been Middle Woodland and three that may have been Late Woodland, that were previously excavated (Perino, 2006). The Hacker South mounds consisted of six mounds and four knolls, with five of the mounds associated with the Jersey Bluff phase. The Hacker South mounds were excavated by Greg Perino in 1974 with the assistance of archaeological field crews from the Center for American Archeology (Perino, 2006). A habitation site is present on the floodplain below the bluff where the mounds are located (Perino, 2006).

A total of 197 burials were excavated from the four Late Woodland mounds, with the majority of the burials being located in Mounds 1 and 2 (Perino, 2006). While the preservation of the skeletons varied by mound, the acidity of the soil from Mound 1 caused some skeletons to have less than ideal preservation. Perino (2006) noted that Mound 1 had a higher proportion of juveniles than the other mounds from the site. Currently, there is no formalized research that examines either the demographics or the paleopathology of the Hacker South individuals.

Charnel structures, areas where mortuary rituals would take place, were found in several of the mounds. Located within the boundary of these charnel structures are disarticulated burned and unburned human bones, shell beads, and burned soil. These findings suggest that individuals could have been disarticulated there or laid out to decompose and some elements were left behind when the individual was moved for final interment. It also suggests that at least partial burning of the remains or other associated materials was used as part of the mortuary process. Few artifacts, including Late Woodland projectile points and faunal bones, were associated with the burials, which is consistent with Late Woodland mortuary practices. The most abundant grave good found in the Hacker South mound group was Anculosa shell beads (Conner, 1984; Perino, 2006).

The Helton site, located in Greene County, Illinois (Figure 2.1) consisted of five bluff crest mounds on the east side of the Illinois valley, overlooking the Macoupin Creek entrance into the valley (Conner, 1984). No formal site report for the Helton site exists, therefore information on the site and the skeletal remains is derived from various published and unpublished manuscripts and doctoral dissertations. The site was excavated between 1973 and 1978 by Jane Buikstra and the Northwestern University Field School. While natural knolls were originally counted as mounds, the five confirmed mounds were 20, 21, 22, 46, and 47 (Cheverud, ND; Conner, 1984). The Helton site has several habitation areas associated with it, including several on the floodplain at the base of the bluff and the Koster site, which is located on the floodplain north of the bluff (Conner, 1984).

Over 300 individuals were excavated from the five Helton mounds (Cheverud, ND; Conner, 1984; Hinkes, 1977). The acidity of the soil from the Helton mounds was low which led to good skeletal preservation for most of the individuals (Cheverud, ND). Currently, there is no formalized research that examines either the demographics or the paleopathology of all Helton individuals. Paleodemographic analyses were completed on Mounds 20 and 21 respectively (Cheverud, ND; Hinkes, 1977). Mound 20's 83 individuals were used to create a mortality profile, which was compared to a series of model mortality profiles assembled by the United Nations (Cheverud, ND). Based on his analyses, Cheverud (ND) states that Mound 20's mortality profile is consistent with a normal human mortality profile with a high infant mortality rate. Hinkes (1977) compared the age-at-death distribution of the 14 individuals from Mound 21 to other Late Woodland groups in the valley that had larger populations. According to her comparisons, Hinkes (1977) suggests that the age distribution of individuals in Mound 21 was similar to that of other Late Woodland groups in the region.

Most of the cemetery was dated to the end of the Late Woodland period. Carbon isotope results from Mound 47 individuals suggest a wide variability of maize consumption, which is consistent with other Late Woodland groups in the area (Buikstra et al., 1987). Few artifacts were present at the Helton site, with the most abundant being Anculosa shell beads (Conner, 1984). The pottery sherds from the mounds as well as a few projectile points, were consistent with the Late Bluff period, the end of the Late Woodland period (Cheverud, ND; Conner, 1984). While most of the cemetery consisted of individual burials, there were some group burials, such as Burial 36 in Mound 20 that consisted of at least 16 individuals, both adults and juveniles. There was also a wide variety of burial treatments with some skeletal remains showing evidence of postmortem processing and partial burning (Cheverud, ND; Conner, 1984; Hinkes, 1977).

Conclusion

These six skeletal samples from across the lower Illinois Valley provide an overall representation of the individuals who were living in the valley during the Middle and Late Woodland periods. Previous demographic studies of most of these sites suggest that, overall, they provide a representative group from the once living population. However, most of the paleodemographic studies completed on the skeletal remains from the lower Illinois Valley have been based on life table analysis. While the problems with this methodology will be discussed in the following chapter, more modern methods were utilized for this study.

Biological distance data using non-metric traits has suggested that there was more variability or heterogeneity between the Middle Woodland populations in the lower Illinois valley than in Late Woodland populations from the same region (Buikstra, 1976). This variability in skeletal non-metric traits between the populations in the lower Illinois valley means that there was less contact, or at least, less movement of people between groups during this time period. The three Middle Woodland sites utilized in this study also represent the entire span of the time period. The Middle Woodland component of the Elizabeth site was utilized early in the time period, while the Ray site was primarily used at the end of the Middle Woodland period. The Gibson site was used throughout most of the Middle Woodland period. One issue related to these sites is the physical distance between the groups. The Ray and Elizabeth sites are the furthest north and are over 40 kilometers from the Gibson site. However, they provide large samples of Middle Woodland burials needed for a paleodemographic study.

Several studies have shown that, in contrast to the circumstances during the Middle Woodland period, the Late Woodland period exhibited low variation among the groups within the Illinois valley, which is suggestive of high levels of gene flow, or inter-group movement. Both craniometric (Droessler, 1981) and skeletal non-metric (Conner, 1984, 1990) data from the region agree that the increased levels of gene flow, compared to the Middle Woodland period, means that there was a greater movement of people between groups in the lower Illinois Valley region. Steadman (2001) confirmed this result with a more up-to-date methodology using the RMET program developed by John Relethford, which is designed to analyze population genetics using metric traits, including craniometrics (Relethford, 1994). The Late Woodland populations' genetic make-up was much more homogenous across geographical distance than that of their successors, the Mississippians. These studies included the Ledders site, which is within the Mississippi River Valley but exhibits biological and cultural continuity with the groups living in the Illinois Valley uplands. Based on the artifacts, these three sites were primarily utilized during the latter part of the Late Woodland period, the Jersey Bluff phase. The three sites are also very close geographically in the valley, with the Helton and Hacker sites being under 10 kilometers apart. All these factors suggest that the three Late Woodland populations used in this study are representative of individuals living during the Late Woodland time period.

CHAPTER 3: REVIEW OF THE LITERATURE

A key focus within the field of bioarchaeology is the study of health in past populations. Vast amounts of literature have been devoted to evaluating dietary and skeletal data to assess whether past peoples were healthy, unhealthy, or more realistically, somewhere in between. Archaeologists have noted that changes in subsistence and settlement patterns as well as political and economic systems can lead to changes in how individuals experience their world, which includes their health (Pechenkina and Delagdo, 2006; Powell, 1991; Robb et al., 2001). Assumptions about skeletal samples and what they may and may not represent are constantly being tested (Cohen and Armelagos, 1984; Cohen and Crane-Kramer, 2007; Larsen, 2015; Steckel and Rose, 2002; Wood et al., 1992). Currently, bioarchaeologists and paleopathologists interpret these data in a more intricate fashion that incorporates both the biological and cultural evidence to gain a more holistic perspective on past groups, referred to as the biocultural approach.

No one indicator or measurement can inform researchers on the overall health status of a population or an individual, since each indicator addresses one aspect of that individual's or population's health. For example, dental caries can provide information about nutritional and dietary issues throughout an entire lifespan, while linear enamel hypoplasias specifically address stress during childhood. Archaeologists can glean information about subsistence patterns from faunal and floral data found in trash pits, including what portions of the animals were being utilized. The spatial layout of settlements can inform archaeologists about how groups organized themselves, which could reflect how resources were distributed. Therefore, to have a comprehensive view of the health of a population, multiple skeletal markers, measurements, and other environmental and social factors, like climate, settlement patterns, and gender roles need to be considered (Larsen, 2015).

Paleodemography

The field of paleodemography, the study of past populations' sex and age structures, became popular in archaeological studies during the late 1960s and early 1970s. Prior to this time, few archaeologists had felt it necessary to pursue this type of research, with the exception of Earnest Hooton. Hooton attempted a demographic study of the skeletons from Pecos Pueblo in the 1930s which, while lacking the demographic theory of the time, was well ahead of other contemporaneous archaeological researchers (Buikstra, 2006; Larsen, 2015). J. Lawrence Angel was one of the first physical anthropologists to formally delve into paleodemography. Angel and other upcoming paleodemographers of the time laid the groundwork for particular assumptions that were used in paleodemography for many years, including the association between the average population age-at-death and longevity, survivorship, and interpreting the overall health of a population based on demographics (Acsádi and Nemeskéri, 1970; Angel, 1969; Blakely, 1971). The founders of paleodemography, however, failed to consider the theoretical and methodological demography literature of the time, which led to their findings lacking in statistical rigor (Larsen, 2015; Milner et al., 2008; Petersen, 1975).

One of the biggest trends seen in the 1970s and 1980s in paleodemography was the use of life tables (Buikstra, 1976; Conner, 1984; Howell, 1982; Lovejoy et al., 1977; Moore et al., 1975). Life tables provided a mathematical way to calculate mortality and survivorship rates, like life expectancy, utilizing the data from burial samples. These mortality and survivorship rates could then be compared to model life tables based on living populations around the world. While life tables were thought to be useful, the assumptions needed to utilize them can cause several problems when interpreting the results. First, the archaeological skeletal samples used are rarely representative of the living population, due to many factors like burial practices of the group or soil acidity. Typically, the very young and old are the age groups that are the most under-represented in the archaeological record. Secondly, life tables assume that the population under study is both stable, meaning no migration, constant birth and death rates, and constant age distribution, and stationary, meaning there is no population growth or decline. It is rare to find groups that meet both of those conditions. In addition, these assumptions do not take into account heterogenous frailty among the individuals in the cemetery. Since the central mortality rate for each age interval is considered its own parameter, or variable, that means most life tables require the estimation of up to 10 parameters; one for each age interval. In order to calculate these parameters accurately, a large skeletal sample is needed (Redfern and DeWitte, 2011; Wood et al., 1992). Lastly, the fixed age intervals associated with the life tables offers the illusion that there is certainty that the age-at-death of the individuals is precise and accurate. Since adult age-at-death estimation methods are not known for their accuracy or precision, placing individuals into discrete categories can lead to problems in interpretation of the data due to the sometimes quite considerable error range around these estimates. A more in-depth discussion of adult age-at-death estimation methods can be found under the *Age-at-Death Estimation* subheading below. Most of the demographic studies completed using the skeletal remains from the lower Illinois Valley have been based on life table analysis (Asch, 1976;

Buikstra, 1976; Cheverud, ND; Conner, 1984; Flotow, 2006; Frankenberg et al.,1988; Pickering, ND), and are thus possibly flawed.

During the 1980s, paleodemography underwent many changes pertaining to the interpretation of mortality data and addressing the aforementioned issues about life table analysis. One of the catalysts for the changes seen in the field was Bocquet-Appel and Masset's (1982) paper that stated paleodemography was not a viable research arena. Their main argument focused on the lack of accuracy in age-at-death estimation methods, which causes the phenomenon known as "age mimicry" and makes the interpretation of past populations' demographics unreliable. "Age mimicry" occurs when the age-at-death distribution of the skeletal sample being studied mirrors the age distribution of the skeletal population that was originally used to develop the age-at-death estimation method. Another important development was Sattenspiel and Harpending's (1983) research that the average age-at-death of a population was more representative of the birth rate of a population, rather than the death rate or mortality of a population. As the birth rate increases, there are continually more and more individuals entering the population. With an increased number of individuals entering the population, there is usually a proportional increase in the number of deaths of young juveniles, as infants have a high risk of mortality. This increased number of infant deaths decreases the average age-at-death for the entire population. While the average age-at-death of a population can inform researchers on the population's fertility, the composition of the skeletal sample can bias the results. The under-representation of the very young in archaeological samples and the poor accuracy of estimating age-at-death of older adults can bias the outcome of the average age-at-death, and therefore the fertility estimate. Some researchers have responded to this critique by suggesting the use of ratios of very young to old individuals to remove some bias when studying fertility (Buikstra et al., 1986; Milner et al., 1989).

Since average age-at-death was found to more commonly reflect fertility, not mortality, researchers continued to explore ways to assess the mortality of populations. One method developed was pattern matching of age-at-death distributions between living populations with known fertility and mortality rates and the target skeletal sample's age-at-death distribution (Milner et al., 1989). This method allows for easy comparison and can suggest if the sample population had low or high fertility and/or mortality. Another reliable tool used in the study of population mortality patterns are hazard models (Gage, 1988, 1989; Siler, 1979; Wood et al., 1992). Hazard models allow for construction of a mortality pattern without the imposition of a set age pattern as typically seen in life table analysis, based on the types of data normally gathered from bioarchaeological investigations (Gage, 1988). The three main models used in paleodemographic studies are the Gompertz, Gompertz-Makeham, and Siler models. The Gompertz model is the simplest of these models with only 2 parameters that need to be estimated. It models the growing risk of death that individuals encounter as they progress through adulthood. The Gompertz-Makeham model adds the Makeham component to the previous model. The Makeham component addresses the risk of death from causes other than aging that everyone in the population faces, such as death from accidents, natural disasters, or interpersonal violence. The Siler model is the mortality model that best represents the entirety of the human lifespan (Gage and Dyke, 1986; Siler, 1983). In addition to the Gompertz-Makeham model, the Siler model has the added component of juvenile mortality. Juvenile mortality is modeled with high risk of death at birth and a rapid decline in mortality through infancy and a low risk of death during the remainder of childhood. These models allow for a more intricate way of assessing population structure without the inherent biases of previous paleodemographic methods.

Age-at-Death Estimation

Estimating the age-at-death of human skeletal remains is a vital component in all bioarchaeological studies. When assessing the health of the population, the age-at-death is needed to elucidate if individuals in various age groups experienced their environment differently, and what possible role the culture played in this interaction. The individual's age is especially important within paleopathology when completing a differential diagnosis since certain diseases affect various age groups differently. Juvenile remains are much easier to age since their skeleton is undergoing developmental changes that occur on a fairly regular schedule across all populations (Cunningham et al., 2016). By the end of the 2nd decade of life, most of the developmental changes in the skeleton have occurred and the aging processes shifts toward a degenerative phase (Cunningham et al., 2016; Milner and Boldsen, 2012a). The stages of degeneration are not regulated across the body like the developmental changes seen in juveniles (Milner and Boldsen, 2012a; Ubelaker, 2008). Therefore, adult age-at-death estimation is more prone to error in both accuracy and precision (Milner and Boldsen, 2012a). Another major issue with adult age-at-death estimation is that there are fewer regions of the skeleton that undergo relatively consistent degenerative changes. The four main features that are used by biological anthropologists are cranial sutures, sternal rib ends, the pubic symphysis of the pubis, and the auricular surface of the ilium. Each of these features has strengths and weaknesses associated with their use for age estimation within bioarchaeology and forensic anthropology.

The closure of cranial sutures was first used as an indicator of age-at-death by Todd and Lyon in the 1920s (Todd and Lyon, 1924, 1925a, b, c). The assumption was that as an individual aged, the cranial sutures would begin to fuse and eventually completely obliterate. While Meindl and Lovejoy (1985) produced aging criteria for the stages of closure and its association with age, some researchers have found that certain sutures' closure relationship to age is not very reliable past the age of 35 years (Hershkovitz et al., 1997), while others have found suture closures can only provide wide age ranges (Boyd et al., 2015). Within current forensic anthropology, one survey found that cranial suture closure is one of the least preferred methods used to estimate adult age-at-death (Garvin and Passalacqua, 2012). In a validation study of a new aging method called transition analysis, discussed later in this section, Milner and Boldsen (2012b) stated that cranial suture closure data provided little towards estimating either an accurate or precise age-at-death.

The sternal end of the ribs is another indicator used to estimate age in adults. Iscan and colleagues were the first to produce a standard methodology for the morphological changes associated with age in the ribs (Iscan et al., 1984, 1985). They found that the morphology of the sternal end of the ribs varied by both sex and ancestry, which required the creation of separate standards for the sexes and different populations (Iscan et al., 1987). While the ribs are quite frequently used by forensic anthropologists (Garvin and Passalacqua, 2012), bioarchaeologists do not use this technique regularly since the ribs are often fragmented in the burial context and it can be difficult to identify the 4th rib, which is the rib utilized in the Iscan method. However, one study found that the Iscan method can be used on more than just the 4th rib and produce an age estimate that does not statistically differ from the age produced from the 4th rib (Yoder et al., 2001).

The pubic symphysis is the most commonly used and reliable of the non-invasive methods available for adult age-at-death estimation (Garvin and Passalacqua, 2012). Todd first developed a methodology for the association of morphological changes in the European American male pubic symphysis in the 1920s. It comprised 10 stages with an upper limit of 50 years (Todd, 1920). He later revised his method after observing European American females and African American males and females (Todd, 1921). McKern and Stewart (1957) developed a new methodology using males who had died during the Korean War. Their system consisted of three separate components that were graded on a five-point scale. While this method was easier to use, it is biased toward younger individuals due to the demographics of the sample utilized to create it. Throughout the 1980s, Suchey worked on developing a more accurate method and refined the methodologies of both Todd and McKern and Stewart. In 1990, Brooks and Suchey published the standards still used today by most forensic anthropologists and some bioarchaeologists (Falys and Lewis, 2011; Garvin and Passalacqua, 2012). This six-stage aging method was based on a diverse sample of a wide range of ages and has different visual standards and age ranges for males and females (Buikstra and Ubelaker, 1994).

The auricular surface of the ilium is another feature of the skeleton that is highly utilized for adult age-at-death estimation (Falys and Lewis, 2011; Garvin and Passalacqua, 2012). Lovejoy and colleagues (1985) developed their method based on morphological changes of the auricular surface because it is located on a more robust portion of the os coxa and would be better preserved in the archaeological record than the pubic symphysis. They created eight stages with an upper limit of 60 years based on European American and African American individuals. Lovejoy and colleagues (1985) found that the morphological changes were neither associated nor affected by biological sex or ancestry, a conclusion validated by Osborne and colleagues (2004). Buckberry and Chamberlain (2002) revised the Lovejoy method and used a similar approach to McKern and Stewart where they observed each component of the auricular surface separately and totaled the feature scores to create a composite score. The composite score was then assigned to one of seven stages that correspond to an age range and mean and median age. Their results showed that the method provided a high correlation with true age. However, several validation studies have found the Buckberry and Chamberlain method to be less accurate than reported. Falys and colleagues (2006) reported too much variation between individuals to allow for narrow ages ranges, and their data suggested three general stages, as opposed to the seven stages, that were correlated with true age. Mulhern and Jones (2005) compared the results from the Buckberry and Chamberlain method to results from the Lovejoy method and found that the new methodology was less accurate in younger individuals but more accurate in individuals from 50 – 69 years.

While most of these methods are used in both bioarchaeological and medico-legal settings, they all are prone to the same problems when using them to estimate age-at-death: age mimicry. Age mimicry is the phenomenon where the skeletons being assessed reflect the age distribution of the skeletal sample that was used to develop the method. For example, the McKern and Stewart (1957) method was based on deceased individuals from the Korean War, which mostly consisted of young males. Certain features that were present in this population may not always be associated with young age but because there were not enough older individuals to compare the frequency of the feature, it becomes associated with a young age in this method. Bocquet-Appel and Masset (1982) stated that this phenomenon was one of the major reasons that the field of paleodemography was almost worthless. While this issue was noted in the literature, little progress was achieved until workshops in Rostock, Germany occurred in 1999 and 2000 to attempt to create a set of best practices within the field of paleodemography (Hoppa and Vaupel, 2002). The research discussed at these workshops, which was compiled into the book *Paleodemography: Age Distributions from Skeletal Samples*, included several age-at-death methods that seemingly avoided the age mimicry issues that plagued the traditional methods mentioned above.

One of these methods was transition analysis. Transition analysis, presented by Boldsen and colleagues (2002) is a multifactorial method that utilizes Bayesian statistics to calculate posterior probabilities of the age-at-death of the individual, from features on the pubic symphysis, auricular surface of the ilium, and cranial suture closure. Posterior probability is the probability that unknown individual is X years old based on the age-associated features from a known aged group. This is combined with a known prior population age-at-death distribution in order to produce a maximum likelihood point estimate, or specific age-at-death, with a 95% confidence interval, or age-at-death range. Two informative prior distributions are used in this program, a 17th century Danish cemetery sample with known ages and sexes, and a more modern sample from late 19th and early 20th century Missouri, called the Terry collection. The use of Bayesian statistics to calculate age-at-death allows researchers to circumvent age mimicry issues previously discussed and allows more than one aging feature to be factored into the equation.

Health and the Neolithic Transition

While major developments were occurring in the field of paleodemography, Cohen and Armelagos (1984) compiled and synthesized vast amounts of data and research to produce an overview of health around the world at the dawn of agriculture entitled *Paleopathology at the Origins of Agriculture*. Based on the data compiled from many researchers, Cohen and Armelagos concluded that the transition to agriculture was detrimental to the health of the majority of individuals living in these societies, as seen by increases in infectious disease and malnutrition and in some populations, a general decline in stature. The data indicated that overall age-at-death of many populations decreased following the advent of agriculture and the presence and severity of nonspecific indicators of stress increased (Cohen and Armelagos, 1984; Larsen, 2015). However, as mentioned within the *Paleodemography* section, the average age-at-death of a population is more informative about fertility than mortality, and in populations with high fertility, a calculated average age-at-death is expected to be lower. Goodman et al. (1984) briefly discuss the issues with paleodemography that Bocquet-Appel and Masset (1982) examined, but state that aging the skeletal population serially can alleviate the age mimicry issue and they argue in favor of lifetables. Goodman et al. (1984) also consider the interaction between age-at-death and stress indicators in their study but do not elaborate or consider the complexities of this interaction. Since the fields of paleopathology and paleodemography were changing in tandem, conclusions in one field should be reassessed based on the findings from the other field.

Paleoepidemiology, the interplay between paleopathology and paleodemography, came to the forefront of bioarchaeology with the publication of the "Osteological Paradox" by Wood and colleagues (1992). Prior to the publication of this paper, several other researchers had made statements cautioning bioarchaeologists about the interpretations of population health based on biased skeletal samples (Buikstra et al., 1986; Cook and Buikstra, 1979; Gage, 1989; Harpending, 1990). Ortner (1991), for example, stated that bioarchaeologists need to be careful in their interpretation of healed periosteal lesions, since it could possibly mean that the individual was robust enough to survive the illness and have a skeletal lesion form. While these scholars raised particular concerns, Wood and colleagues (1992) gathered these concerns into a cohesively laid out paper.

Wood et al. (1992) focused on three challenges that face the bioarchaeological community: demographic non-stationarity, hidden heterogeneous frailty, and selective mortality. Demographic non-stationarity refers to the assumption that past populations were under a uniform model of population growth; meaning no migration as well as no change in the birth or death rate. This assumption does not account for the effects that changes in fertility have on the interpretation of the mortality data used in paleodemographic studies (Buikstra et al., 1986). Addressing selective mortality, Wood et al. (1992) suggest the need to be aware that individuals in the cemetery or mortuary sample only represent the individuals who died at that particular age, and does not account for the individuals at that age who were at risk of death but lived longer. In other words, the people who die at a particular age are not a random sample of those who were alive at that given age.

Selective mortality is closely tied to, and acts upon hidden frailty, or as Wood et al. (1992) called it, hidden heterogeneity in risks of morbidity or mortality. In the case of hidden frailty, individuals with high frailty are more likely to succumb to death than other individuals in the population that are the same age. Consequently, the number of individuals from a cemetery in a given age group is not representative of the living population and within that specific age group it is not possible to know which individuals had low or high frailty. In terms of interpreting lesions, individuals with high frailty may die soon after exposure without having time to register any lesions on the skeleton, while individuals with low frailty could survive a health insult long enough to accumulate multiple skeletal stress markers before death. Therefore, bioarchaeologists using skeletal stress markers and age-at-death distributions to interpret past populations' health must view and consider their data and interpretations in light of these three issues.

Since the publication of the Cohen and Armelagos (1984), there has continued to be a focus within bioarchaeology on the transition to agriculture and what its effects on past populations' health. Eshed et al. (2004) constructed life tables in their study on the transition to agriculture in the Levant but they also utilized the Siler model. This technique, as discussed earlier in the chapter, is used to minimize imposing any particular mortality pattern onto the results. Large syntheses like Cohen and Crane-Kramer (2007) and Pinhasi and Stock (2011) provide more recent research on the archaeology and bioarchaeology of the transition to agriculture. Cohen and Crane-Kramer conclude that with updated data, there is a clear trend that health declined with the advent of agriculture, while Pinhasi and Stock (2011)'s volume emphasizes how regional variation of the environment and culture played important roles in the results seen by researchers. In Gage and DeWitte's (2009) article that reviews the specifically focuses on the paleodemography of the Neolithic Revolution, an important concept they point out is the lack of research focusing on transitionary period groups; as opposed to comparisons of only pre- and post-agricultural populations. Additionally, they emphasize that future bioarchaeological research focused on this important transition should be explicit in their assumptions and interpretations regarding skeletal lesions and their association with population health.

Current Work on Frailty and Selective Mortality

With the publication of the Osteological Paradox over 25 years ago, bioarchaeologists have made some progress on how they interpret health in past populations. Ten years after the Wood et al. publication, Wright and Yoder (2003) provided a review of the field considering frailty and selective mortality, which demonstrated some attempts at addressing these concerns but little else. Their review pointed out more improvements in technologies than highlighting any work that directly addressed the underlying issues. A little over a decade later, DeWitte and Stojanowski (2015) provided a more in-depth and expansive review of the seminal paper addressing topics from the initial reactionary papers in the early 1990s to current studies that are focusing on the investigation of the Osteological Paradox itself. DeWitte and Stojanowski completed a literature review of the current bioarchaeological publications to see how much the Osteological Paradox is cited and utilized in research papers. Unfortunately, they found that the majority of papers that cite Wood et al. (1992) only do so in a passive sense, by either stating it was considered or using it as a possible explanation for an unexpected result. However, there have been a growing number of papers and researchers that have focused specifically on the concerns addressed by Wood and colleagues and incorporated these concerns into their research design (DeWitte, 2006, 2014b; Gamble et al., 2017; O’Donnell, 2019; Usher, 2000; Wilson, 2010; Yaussy et al., 2016). By engaging the concepts of frailty and selective mortality in the research design of paleodemographic and paleoepidemiological studies, researchers can begin to tease out more nuanced information from the skeletal populations.

One of the main contributors to the current literature about frailty and selective mortality has been Sharon DeWitte. Her dissertation work focused on the paleodemography of the Black Death in England and her research since has been heavily focused on exploration of what the skeletal data can tell us about these concepts. There are no better skeletal populations in which to study heterogeneous frailty and selective mortality than Black Death cemeteries. Since one of the main issues with assessing the relative health of a skeletal population is the lack of knowledge of the cause of death, the Black Death cemeteries located in London, England provide an ideal sample set. There is documented evidence of several cemeteries having been created for the vast numbers of individuals who died of the plague in the 1300s, including cemetery locations and dates of use. With a definitive cause of death, DeWitte could assess and research other aspects of how the Black Death really affected the population living in London during that time. During the past 50 years, several of these cemeteries have been excavated and the skeletons have since been utilized in a number of studies (Connell et al., 2012; Grainger et al., 2008; Hawkins, 1990).

Most of DeWitte's earlier work (DeWitte, 2006; DeWitte and Wood, 2008; Redfern and DeWitte, 2011) utilized the Usher model, which shows an increased risk of death for individuals with skeletal stress markers, including periosteal new bone formation. Developed for Usher's (2000) dissertation, the three-state model (individuals with a visual skeletal pathology, individuals without a visual skeletal pathology, and dead) utilizes hazard models to assess if individuals with a skeletal lesion have a greater or less risk of dying than individuals without any skeletal lesion. Additionally, DeWitte (2010) utilized Gompertz-

Makeham models to assess age patterns of mortality which showed that selective mortality was at work during the Black Death with older individuals being at a higher risk of death. DeWitte (2014b) also compared pre- and post-Black Death populations utilizing age and skeletal lesions presence. She found that while the frequency of skeletal lesions were higher in post-Black Death populations, there was larger proportion of older individuals in the post-Black Death population which could suggest improved health following the plague as well as evidence that the individuals who survived the plague had overall lower frailty.

While most of DeWitte's work had been focused on the presence and absence of skeletal lesions, her 2014 paper in the International Journal of Paleopathology addressed a slightly over-looked aspect of the Osteological Paradox, the state of the skeletal lesion at the time of death. Periosteal lesions can be observed macroscopically and determined to be either active or healing/healed at the time of death. DeWitte found that individuals with active lesions on their tibiae had lower survivorship, and thus higher frailty, than individuals who had healed lesions. This means that since most studies lump all individuals with lesions together, there may be a loss of information about the frailty of the population being studied. DeWitte called for more bioarchaeologists to use this level of analysis to observe if this pattern is seen around the world and/or if the results change the way population health is viewed by bioarchaeologists.

While there is a considerable amount of literature written over the past 60 years about the paleodemographic patterns of the inhabitants of the Illinois River Valley, very little research has been completed recently (Asch, 1976; Buikstra, 1976; Cheverud, ND; Conner, 1984; Flotow, 2006; Frankenberg et al., 1988; Pickering, ND). A lack of current paleodemographic studies means the understanding of demographics from this region are based on studies that used methods which are now outdated, and their interpretations may be misguided. Wilson's (2010, 2014) research on the Mississippian inhabitants of the central Illinois River valley led to re-interpretations of paleodemographic patterns for this region. Wilson (2010) found that the results from his study, which used both transition analysis and hazard models, were significantly different from the life table results; individuals in the Mississippian period were living longer than previous thought. By utilizing newer paleodemographic models, and associating them with non-specific indicators of stress, Wilson (2014) feels these techniques would lead to a greater understanding of past population dynamics. He also called for bioarchaeologists who focus on the Eastern Woodlands of the United States to think and produce research that incorporates the concepts of health, age-at-death distributions and skeletal lesions, like periosteal new bone formation, and how they associated with one another.

Periosteal New Bone Formation

Periosteal new bone formation, usually referred to as periostitis in the bioarchaeological literature, is new bone that is laid down on the surface of a skeletal element by the osteoblastic layer of the periosteum (Ortner, 2003; Weston, 2012). It first appears as woven, porous bone on the cortical surface and its sharp, and sometimes spiculated, appearance lacks the organization of mature bone. Eventually, the new bone will integrate into the surrounding cortical bone and become dense, lamellar bone usually with an uneven, undulating appearance (Larsen, 2015; Ortner, 2003; Weston, 2008, 2012). While periostitis is common in the vocabulary of many bioarchaeologists, the name itself, which means "inflammation of the periosteum", implies the etiology of the lesion. The terms periosteal new bone formation or periosteal lesion do not imply a specific etiology but describes and identifies of the insult on the bone.

Periosteal new bone formation is a common skeletal lesion utilized by bioarchaeologists and paleopathologists when conducting research on past population health. Traditionally, periosteal lesions have been assumed to be associated with an infectious etiology, caused by inflammation and are therefore referred to in paleopathological assessments of community health as non-specific infectious lesions (Cook, 1984; Goodman et al., 1984; Larsen, 2015). Cohen and Armelagos (1984) provide various examples from around the world of the increase in prevalence and severity of many skeletal indicators of stress, including periostitis, during the transition to agriculture. When people began to live together in larger and larger groups, certain characteristics generally appear; one such feature is the increase of infectious disease. Therefore there has been an assumption within the bioarchaeological field that the increased frequency of periosteal lesions were due to the increase in infectious agents present in more sedentary, agricultural groups (Cohen and Crane-Kramer, 2007).

As previously stated by Wood et al. (1992), an in-depth understanding of the biological processes that create specific skeletal lesions would provide bioarchaeologists more clarity and address decades of speculation. While this information is imperative for paleopathologists' interpretations, there is little value or incentive for doctors and biomedical researchers to pursue the exact causes of specific skeletal lesions when most of their work pertains to soft tissue. However, this does not mean that the clinical and bioarchaeological literature is void of such research. More recent literature points out that periosteal new bone formation can be caused by other stimuli besides infection, such as trauma, nutritional deficiencies, and metabolic conditions (Cook, 2007; Klaus, 2014; Ortner, 2003; Weston, 2012). Therefore, periosteal new bone formation is a more encompassing term that refers to a nonspecific indicator of stress, not specifically an inflammatory response (DeWitte, 2014a). Weston (2012) goes further to suggest that previous researchers have confused the meanings of infection and inflammation, and on a molecular level, periosteal new bone formation must not be considered a stress indicator since the body cannot stimulate new bone growth while stressed. Klaus (2014) refutes Weston's point by explaining that the hormonal and molecular pathways that control the bone formation process are not a simple on/off mechanism.

Periosteal new bone formation has been widely used in different paleopathological and bioarchaeological studies (Cook, 1984; DeWitte, 2014a; DeWitte and Wood, 2008; Klaus and Tam, 2009; Novak and Slaus, 2010; Robb et al., 2001; Shuler, 2011; Yaussy 2019; Yaussy et al., 2016). Though it can be located throughout the body, periosteal new bone formation is most commonly found on the tibia (Klaus, 2014; Larsen, 2015; Weston, 2008). Due to its high prevalence on the tibia, many studies may record the presence and severity of periosteal lesions on all elements but for statistical comparisons only use the data from the tibia (Robb et al., 2001). Weston (2012), points out that there is no set standard around the world for recording and assessing periosteal new bone formation, therefore, it is extremely hard to compare the conclusions reached by different researchers. She points to a more in-depth differential diagnosis style of methodology in recording periosteal new bone formation. Also discussed in Weston (2012), as well as DeWitte (2014a), is the difficulty of assessing periosteal new bone formation in juveniles. Regular juvenile bone growth can look very similar to a periosteal reaction, especially near the metaphyses, and this misidentification can lead to an incorrect interpretation of a population's health (Weston, 2012). DeWitte (2014a) attempted to avoid this issue by only observing periosteal new bone formation at least one centimeter away from the metaphyses on un-fused tibiae, and only observed the anterior portion of adult tibiae to avoid confusion with muscle attachment sites.

Implications for the Present Study

Assessing the health of past populations requires the synthesis and interplay of many factors. As discussed in Chapter 2, there are many archaeological sites located in the lower Illinois valley that contain large numbers of burials. As paleodemographic studies need large sample sizes, the sites from this region are good candidates for this type of study. Recently, there has been little research focused on frailty and selective mortality within lower Illinois valley prehistoric populations. Utilizing transition analysis for age-at-death estimation and associating this data with periosteal lesion activity and severity should provide a broader picture of population health within the valley. Additionally, this study focuses on the transition from horticulture to agriculture which is generally not the main focus of study when researching the transition to agriculture. Therefore, this thesis is filling multiple gaps in the literature regarding methodology and regional prehistory.

CHAPTER 4: MATERIALS AND METHODS

The Skeletal Sample

The skeletal samples used for this research were excavated from six mortuary sites in the Lower Illinois Valley, located in West-Central Illinois. These sites are within approximately 70 miles (113 kilometers) of each other and as discussed at the end of chapter two, are considered to be representative of the Middle and Late Woodland populations living in the Lower Illinois Valley. Five of the six skeletal samples utilized in this study are housed at the Center for American Archeology in Kampsville, Illinois while the individuals from the Elizabeth site are housed at the Illinois State Museum Research and Collections Center in Springfield, Illinois. A total of 349 adult individuals were assessed for this study, with 271 individuals having both tibiae present for periosteal lesion assessment and os coxae from which age-at-death data could be collected.

While the soils of the Lower Illinois Valley allow for good skeletal preservation, not all tibiae and os coxae were preserved as well as might be desired. There were 120 individuals from the Middle Woodland period sites: Gibson (n=50), Elizabeth (n=30), and Ray (n=40) and there were 143 individuals from the Late Woodland period sites: Ledders (n=30), Helton (n=62), and Hacker (n=51). The demographics of the sample were approximately equal with 131 males, 132 females, and 8 individuals of unknown sex, based on the author's assessment of the skeletal remains.

Biological sex, age-at-death, and presence of periosteal new bone formation were assessed for the 349 adult individuals in this study. Juveniles were excluded due to time constraints, scope of the study, and some debate about whether periosteal new bone formation on juvenile long bones can be effectively distinguished from normal new bone growth (Weston, 2012). In order for a skeleton to be included in the study, it needed to have two well-preserved fused tibiae, so even with no other late-fusing bones present, an individual would be at least 15 years old if included in the study (Cunningham et al., 2016). Adults that were buried in a comingled context were excluded from this study to ensure that the age-at-death estimate from the ossa coxae could be directly related to the periosteal new bone formation on the respective tibiae. Individuals were also excluded from this study if the pubic symphysis and auricular surface of the ilium were absent or too damaged to provide age estimation information, or if the anterior portion of the tibial diaphysis was absent or too damaged. Due to fragmentation of the tibiae in some individuals, the sample size of individuals decreased to 278.

Sex Estimation

While most of these skeletal samples have been extensively studied and information on the sex of the individual is available from a variety of sources, the sex of each individual was assessed using morphological traits from the skull and os coxa. These features were observed macroscopically under good lighting by the author using standard indicators described below. If there was a conflicting result between the assessment of the skull and os coxa, emphasis was placed on the pelvic morphology over cranial morphology as the os coxa is more sexually dimorphic. It has been noted that morphological traits used for sex estimation, particularly from the skull, are population specific. However, the author worked with these collections for four years and is familiar with the variability present in these populations.

The Phenice method (1969) for sex estimation, which focuses on the subpubic region of the os coxa, was used to score the presence or absence of the ventral arc, subpubic concavity, and ischio-pubic ramus ridge. If a feature was present, a score of 1 was assigned, if a feature was absent, a score of 3 was assigned, if the feature was ambiguous, a score of 2 was assigned. Presence of the features are associated with an individual who is female and the absence of the features are associated with an individual who is male. The width of the greater sciatic notch was also assessed using the criteria outlined in Buikstra and Ubelaker (1994). A wide, deeper greater sciatic notch is associated with females and a narrow, shallower greater sciatic notch is associated with males. Five features on the cranium were assessed for sex estimation, using the criteria outlined in Buikstra and Ubelaker (1994). The five features are the nuchal crest, mastoid process, supraorbital margin, glabella, and the mental eminence. These features are scored on a scale from 1 to 5 with 1 being a feature that is small and gracile, which is associated with females, while a feature is scored a 5 when it is large and/or rugose, which is associated with males. Using these traits, the individuals were assessed as male, possible male, ambiguous, possible female, and female. For most statistical tests, these categories were collapsed into ambiguous, female, and male.

Age-at-Death Estimation

Age-at-death estimates were available for most of the skeletons used in this research. However, age-at-death was re-evaluated for all of the individuals since some of the age-at-death data provided for several sites were estimates based on outdated methods that were standard during the 1960s-1980s when these skeletons were initially analyzed. Methods have improved and changed during the subsequent years, therefore it was necessary to reassess the age-at-death of these skeletons. As discussed previously, lumping individuals into broad age categories can lead to a loss of information and does not provide a nuanced view of the paleopathological data. Therefore, age-at-death of each individual was estimated using transition analysis, which provides a point estimate for age-at-death.

Transition analysis, a multifactorial method that utilizes Bayes' theorem to calculate posterior probabilities, focuses on three areas of the skeleton to estimate age-at-death: the pubic symphysis, auricular surface, and cranial suture closure (Boldsen et al., 2002). This information is combined with a known prior age-at-death distribution in order to produce a maximum likelihood point estimate of the age with a 95% confidence interval. The informative prior distribution used in the program is a 17th century Danish cemetery sample with known ages and sexes. Due to the poor correlation between age-at-death and cranial suture closure, cranial suture data were not used in this study (Boyd et al., 2015; Hershkovitz et al., 1997; Milner and Boldsen, 2012b).

Five features of the pubic symphysis were observed: symphyseal relief, symphyseal texture, superior apex, ventral symphyseal margin, and dorsal symphyseal margin. Nine features were observed on the auricular surface of the ilium: superior and inferior demiface topography, superior, inferior, and apical surface morphology, inferior surface texture, superior and inferior posterior iliac exostoses, and posterior exostoses. Based on its appearance, each feature was assigned a specific score, ranging from 1 to 7 depending on the specific feature and description. Both the left and right pubic symphysis and auricular surface were scored independently. These numbers were entered into the ADBOU 2.1.046 program, along with the estimated sex of the individual, to calculate an estimated age and confidence interval. The "archaeological prior" was chosen for the hazard model and “unknown” was chosen for the ‘race’ since the database does not include individuals of Native American ancestry. Once all the data were entered, the program calculated a 95% confidence interval for age-at-death as well as a maximum likelihood estimate, or point estimate (see Appendix). This interval and point estimate take into account all the data available from the skeletal features and correct that estimate using the sex, ‘race’, and hazard previously entered.

Periosteal New Bone Formation

The anterior surfaces of the right and left tibiae were assessed for periosteal new bone formation. The posterior surface was excluded to avoid any confusion associated with surface changes related to muscle attachment sites. The metaphyses were also not assessed to avoid confusion with porosity associated with growth rather than pathology. As in DeWitte’s (2014a) study, only individuals with both the right and left tibiae present were included in the final analysis of frailty in order to focus on periosteal new bone formation that was formed from infectious or nutritional etiologies, which could imply more about the underlying immune system of the individual, rather than localized trauma or other causes.

The tibiae were first assessed for any post-mortem damage such as weathering, etching, and cortical flaking. If too much of the anterior diaphysis exhibited post-mortem damage that obscured the cortical surface, the individual was scored as unobservable and not included in the study. Tibiae that lacked periosteal new bone formation were scored as absent. Tibiae that had periosteal new bone formation present, were assessed for the stage(s) of the lesion(s). An outline of the anterior portion of the right and left tibiae were used to record the location, size, and stage of any periosteal new bone formation for each individual as well as areas of the tibiae that were absent due to post-mortem damage, as seen in Figure 4.1. Active periosteal new bone formation was denoted by diagonal lines. Active periosteal new bone formation is composed of woven bone and is identified by bony growth that is very disorganized, porous with sharp edges, and at times a grayish color. Woven bone can also manifest in the form of spiculated bony growth. Healed periosteal new bone formation was denoted by a solid shaded area. Healed periosteal new bone formation is composed of lamellar or sclerotic bone and is identified by bony growth that is more organized, with minimal porosity that exhibits round, smooth edges. Lamellar bone is usually more integrated with the surrounding cortical bone. Individuals who exhibited only active periosteal new bone formation were scored as active. Individuals who exhibited only healed periosteal new bone formation were scored as healed. Individuals who exhibited both active and healed periosteal new bone formation were scored as mixed.

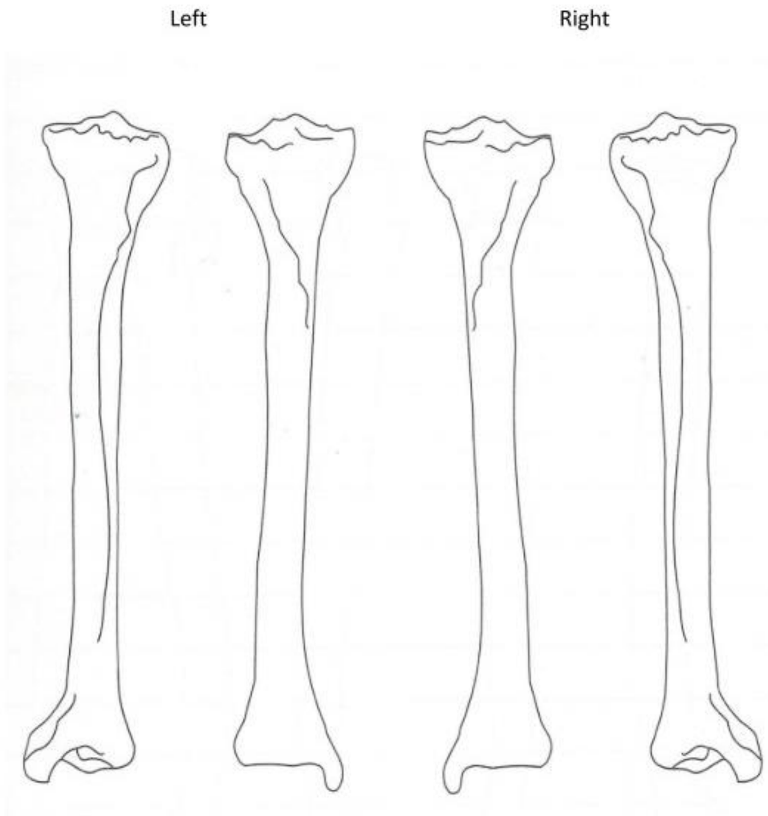

Figure 4.1. Data recording sheet for tibial periosteal new bone formation.

Periosteal new bone formation was also assessed for its severity. Periosteal new bone formation was scored as localized if the bone formation was located on less than one-third of each respective tibia. It was scored as diffuse if bone formation was located on more than one-third of each respective tibia.

Statistical Methods

Frequencies of periosteal lesion activity and severity were calculated by time period, sex, age group, and site. Individuals were placed into 4 age groups (15-25.99, 26-35.99, 36-45.99, and 46+) based on the point estimate. Comparisons between these groups were completed using Chi square in SPSS, v. 25. The Chi square analysis tests the comparison of frequencies from more than two groups at once, such as the three Middle or Late Woodland sites, or multiple stages of periosteal new bone formation.

The effect of periosteal lesion activity, severity, and time period on survival was tested using a Kaplan-Meier survival analysis with a log-rank test, utilizing SPSS, v.25. For this analysis, the age-at-death point estimates were used to show the proportion of individuals who survived to a given age with a specific type of periosteal lesion activity and severity and within a particular time period.

A two-sample Kolmogorov-Smirnov test was used to compare the age-at-death distributions of the Middle and Late Woodland samples, utilizing SPSS, v.25. The age-at-death point estimates for all individuals in each time period were compared. If there is a significant difference, it would reject the null hypothesis meaning the Middle Woodland and Late Woodland groups had different age-at-death distributions. Bioarchaeologists (DeWitte, 2014a) have used this test to observe general difference in the age-at-death distributions between populations.

CHAPTER 5: RESULTS

Descriptive Statistics

A total of 349 individuals were assessed for this study. Three hundred thirty-six (336) individuals had enough of the os coxa present to assess age-at-death using transition analysis, 271 of those had both tibiae present that were able to be scored for periosteal new bone formation. For statistical purposes, individuals that were scored as ambiguous for biological sex were excluded from the analyses; this brought the total of individuals to 263. A complete listing of all data can be found in Appendix.

Tables 5.1 and 5.2 show the frequency of the individuals in the sample by time period, site, and sex used for the frailty analysis. There is a slightly larger proportion of individuals in the sample from the Late Woodland than the Middle Woodland. Overall, the ratio of males to females in the sample is even, however the Middle Woodland sample contained more females than males while the Late Woodland sample was the reverse.

Table 5.1. Frequency of Sample by Time Period and Site.

Time Period	Sites	Count	Total
Middle Woodland	Elizabeth	30 (11.4%)	120
	Gibson	50 (19.0%)	
	Ray	40 (15.2%)	
Late Woodland	Hacker	51 (19.4%)	143
	Helton	62 (23.6%)	
	Ledders	30 (11.4%)	

Table 5.2. Frequency of Sample by Time Period and Sex.

Time Period	Female	Male
Middle Woodland	65 (49.2%)	55 (42.0%)
Late Woodland	67 (50.8%)	76 (58.0%)
Total	132	131

The frequency of periosteal lesion presence, activity, and severity by time period, sex, age group, and site can be found on Tables 5.3 – 5.14. Of the 263 individuals in the sample, there were none that only have active periosteal lesions on the tibiae. This most likely was due to the age groups that were targeted for this analysis. In DeWitte's research (2014a), 16 individuals had only active lesions and they were all under the age of 20. Of the 171 individuals that had periosteal new bone formation present, 85 individuals had acute periosteal lesions, 86 individuals had diffuse periosteal lesions, 58 individuals had periosteal lesions on only one tibia, and 113 individuals had periosteal lesions on both tibiae.

Table 5.3. Frequency of Periosteal Lesions by Time Period.

Time Period	Absent (%)	Present (%)
Middle Woodland (n=120)	32 (26.7%)	88 (73.3%)
Late Woodland (n=143)	60 (42.0%)	83 (58.0%)

Table 5.4. Frequency of Periosteal Lesion Activity by Time Period.

Time Period	Absent (%)	Mixed (%)	Healed (%)
Middle Woodland (n=120)	32 (26.7%)	28 (23.3%)	60 (50.0%)
Late Woodland (n=143)	60 (42.0%)	20 (14.0%)	63 (44.1%)

Table 5.5. Frequency of Periosteal Lesion Severity by Time Period.

Time Period	Acute (%)	Diffuse (%)
Middle Woodland (n=88)	39 (44.3%)	49 (55.7%)
Late Woodland (n=83)	46 (55.4%)	37 (44.6%)

Statistically significant differences were found between time period and periosteal lesion presence (χ^2= 6.708, df=1, p=0.010) and activity (χ^2=7.978, df=2, p=0.019). The overall presence of periosteal lesions was higher in the Middle Woodland than the Late Woodland sample, which is also reflected in the periosteal lesion activity with the presence of both active and healed lesions proportionally greater in the Middle Woodland sample than the Late Woodland. There was no statistically significant difference in severity (χ^2=2.106, df=1, p=0.147) between individuals in the Middle versus the Late Woodland.

Table 5.6. Frequency of Periosteal Lesions by Site.

Time Period	Sites	Absent	Present
Middle Woodland	Elizabeth (n=30)	4 (13.3%)	26 (86.7%)
	Gibson (n=50)	13 (26.0%)	37 (74.0%)
	Ray (n=40)	15 (37.5%)	25 (62.5%)
Late Woodland	Hacker (n=51)	21 (41.2%)	30 (58.8%)
	Helton (n=62)	28 (45.2%)	34 (54.8%)
	Ledders (n=30)	11 (36.7%)	19 (63.3%)

Table 5.7. Frequency of Periosteal Lesion Activity by Site.

Time Period	Sites	Absent	Mixed	Healed
Middle Woodland	Elizabeth (n=30)	4 (13.3%)	12 (40.0%)	14 (46.7%)
	Gibson (n=50)	13 (26.0%)	8 (16.0%)	29 (58.0%)
	Ray (n=40)	15 (37.5%)	8 (20.0%)	17 (42.5%)
Late Woodland	Hacker (n =51)	21 (41.2%)	9 (17.6%)	21 (41.2%)
	Helton (n=62)	28 (45.2%)	5 (8.1%)	29 (46.8%)
	Ledders (n=30)	11 (36.7%)	6 (20.0%)	13 (43.3%)

Table 5.8. Frequency of Periosteal Lesion Severity by Site.

Time Period	Sites	Acute	Diffuse
Middle Woodland	Elizabeth (n=26)	17 (65.4%)	9 (34.6%)
	Gibson (n=37)	11 (29.7%)	26 (70.3%)
	Ray (n=25)	11 (44.0%)	14 (56.0%)
Late Woodland	Hacker (n=30)	17 (56.7%)	13 (43.3%)
	Helton (n=34)	18 (52.9%)	16 (47.1%)
	Ledders (n=19)	11 (57.9%)	8 (42.1%)

Statistically significant differences were found between sites and periosteal lesion presence (χ^2= 11.789, df=5, p=0.038) and activity (χ^2=21.153, df=10, p=0.020). All sites had a higher proportion of individuals with periosteal lesions than without lesions, with the individuals from the Elizabeth site having the largest proportion of individuals with periosteal lesions at 86.7%. There was no statistically significant difference in severity of periosteal lesions (χ^2=10.022, df=5, p=0.075) between age groups, though the Gibson site has the largest proportion of individuals with diffuse and individuals at the Elizabeth site exhibited proportionally more acute lesions than any other site.

When comparing the Middle Woodland sites to each other, periosteal lesion presence was not significantly different (χ^2= 5.139, df=2, p=0.077) while periosteal lesion activity (χ^2= 9.840, df=4, p=0.043) and severity (χ^2= 7.868, df=2, p=0.020) were significantly different. For periosteal lesion activity, the prevalence of healed lesions is higher than for mixed lesions at all sites. The Gibson site has twice the number of individuals with healed lesions as individuals with no periosteal lesions. As mentioned above, at the Elizabeth site, over three-quarters of the individuals have periosteal lesions, so individuals with both mixed and healed lesions greatly outnumbered those without any lesions present. For severity, the Gibson site has proportionally more individuals with diffuse periosteal lesions present and the Elizabeth site has proportionally more individuals with acute periosteal lesions.

When comparing the Late Woodland sites to each other, periosteal lesion presence (χ^2= 0.619, df=2, p=0.734), periosteal lesion activity (χ^2= 3.382, df=4, p=0.496), and severity (χ^2= 0.151, df=2, p=0.927) were not significantly different. Like the Middle Woodland sites, all three Late Woodland sites had more individuals with healed periosteal lesions than mixed periosteal lesions, but the difference between the groups was not substantial.

Table 5.9. Frequency of Periosteal Lesions by Sex.

Sex	Absent (%)	Present (%)
Female (n=132)	35 (26.5%)	97 (73.5%)
Male (n=131)	57 (43.5%)	74 (56.5%)

Table 5.10. Frequency of Periosteal Lesion Activity by Sex.

Sex	Absent (%)	Mixed (%)	Healed (%)
Female (n=132)	35 (26.5%)	29 (22.0%)	68 (51.5%)
Male (n=131)	57 (43.5%)	19 (14.5%)	55 (42.0%)

Table 5.11. Frequency of Periosteal Lesion Severity by Sex.

Sex	Acute (%)	Diffuse (%)
Female (n=97)	51 (52.6%)	46 (47.4%)
Male (n=74)	34 (45.9%)	40 (54.1%)

Statistically significant differences were found between sex and periosteal lesion presence (χ^2= 8.351, df=1, p=0.004) and activity (χ^2=8.715, df=2, p=0.013). Females were more likely than males to have lesions, both healed and mixed periosteal new bone formation, on their tibia. There was no statistically significant difference in severity (χ^2=0.738, df=1, p=0.390) between males and females. When comparing Middle Woodland males and females with Late Woodland males and females, periosteal lesion presence (χ^2= 14.132, df=3, p=0.003) and activity (χ^2=18.293, df=6, p=0.006) were both significantly different. For presence, Middle Woodland females had the highest proportion of individuals with periosteal lesions and Late Woodland males had approximately equal proportions of individuals with and without periosteal lesions. When looking at periosteal lesion activity, Middle Woodland males and Late Woodland females had similar proportions in all categories, while Late Woodland males had the lowest proportion of individuals with mixed periosteal lesion activity. Periosteal lesion severity was not significantly different between the four groups (χ^2= 6.340, df=3, p=0.096). While the Middle Woodland females and Late Woodland males and females all had slightly higher proportions of individuals with acute lesions than diffuse lesions, Middle Woodland males had double the proportion of individuals with diffuse lesions than acute lesions.

Within the Middle Woodland period, a statistically significant difference in periosteal lesion presence (χ^2=4.882, df=1, p=0.027) and severity (χ^2=3.913, df=1, p=0.048) were found between the sexes. Overall, Middle Woodland females had more periosteal lesions than males, with males having proportionally more diffuse lesions and females having proportionally more acute lesions. Periosteal lesion activity did not meet the significance threshold ($p<0.05$) but is close enough to note (χ^2=5.615, df=2, p=0.06). While the Middle Woodland males and females had equal proportions of mixed periosteal lesion activity, females have proportionally more individuals with healed lesions than males.

Within the Late Woodland period, only a statistically significant difference in periosteal lesion activity was found (χ^2=6.067, df=2, p=0.048). Overall, females had a higher proportion of individuals with both healed and mixed lesion activity than males. There was no statistically significant difference between Late Woodland males and females in periosteal lesion presence (χ^2=3.013, df=1, p=0.083) or severity (χ^2=0.376, df=1, p=0.540).

Table 5.12. Frequency of Periosteal Lesions by Age.

Ages	Absent (%)	Present (%)
15-25.99 (n=53)	19 (35.8%)	34 (64.2%)
26-35.99 (n=152)	60 (39.5%)	92 (60.5%)
36-45.99 (n=37)	11 (29.7%)	26 (70.3%)
46+ (n=21)	2 (9.5%)	19 (90.5%)

Table 5.13. Frequency of Periosteal Lesion Activity by Age.

Ages	Absent (%)	Mixed (%)	Healed (%)
15-25.99 (n=53)	19 (35.8%)	4 (7.5%)	30 (56.6%)
26-35.99 (n=152)	60 (39.5%)	29 (19.1%)	63 (41.4%)
36-45.99 (n=37)	11 (29.7%)	6 (16.2%)	20 (54.1%)
46+ (n=21)	2 (9.5%)	9 (42.9%)	10 (47.6%)

Table 5.14. Frequency of Periosteal Lesion Severity by Age.

Ages	Acute (%)	Diffuse (%)
15-25.99 (n=34)	21 (61.8%)	13 (38.2%)
26-35.99 (n=92)	45 (48.9%)	47 (51.1%)
36-45.99 (n=26)	12 (46.2%)	14 (53.8%)
46+ (n=19)	7 (36.8%)	12 (63.2%)

Statistically significant differences were found between age groups and periosteal lesion presence (χ^2= 7.799, df=3, p=0.050) and activity (χ^2=17.945, df=6, p=0.006). There was a higher percentage of individuals with periosteal lesions than not in all age categories; with the most extreme difference in the 46+ age group. When considering periosteal lesion activity, the prevalence of healed lesions is much higher than mixed lesions except within the 46+ group where the prevalence of individuals with mixed lesion is almost the same as individuals with healed lesions. Additionally, in the 26-35.99 group, the proportion of individuals with healed lesions is almost the same as individuals who do not have periosteal lesions present. There was no statistically significant difference in severity of periosteal lesions (χ^2=3.390, df=3, p=0.335) between age groups.

Within the Middle Woodland, there were no statistically significant differences for periosteal lesion presence (χ^2=4.975, df=3, p=0.174), activity (χ^2=11.877, df=6, p=0.065), and severity (χ^2=1.611, df=3, p=0.657) with regard to age group. As the result for periosteal lesion activity was close to the $p<0.05$ threshold, the results are worth discussing. The youngest two age groups (15-25.99 and 26-35.99) had similar proportions of individuals with mixed and healed lesions with the percentage of individuals showing healed lesions being higher. The oldest age group (46+) was the only group that had a higher proportion of individuals with mixed periosteal lesion activity than healed.

Within the Late Woodland, there were also no statistically significant differences for periosteal lesion presence (χ^2=2.932, df=3, p=0.402), activity (χ^2=9.996, df=6, p=0.125), or severity (χ^2=5.926, df=3, p=0.115) with regard for age group.

Kaplan-Meier Survivorship

The results and survival curves of the Kaplan-Meier survival analysis for lesion presence, activity, and severity as well as time period can be found in Tables 5.15 – 5.18 and Figures 5.1 - 5.4 respectively.

Table 5.15. Kaplan-Meier Survival Analysis Results for Periosteal Lesion Presence.

Periosteal Lesion Presence	Mean Survival Time (Age)	95% Confidence Interval
Absent (n=92)	30.6	28.8 – 32.3
Present (n=171)	33.4	31.4 – 35.3

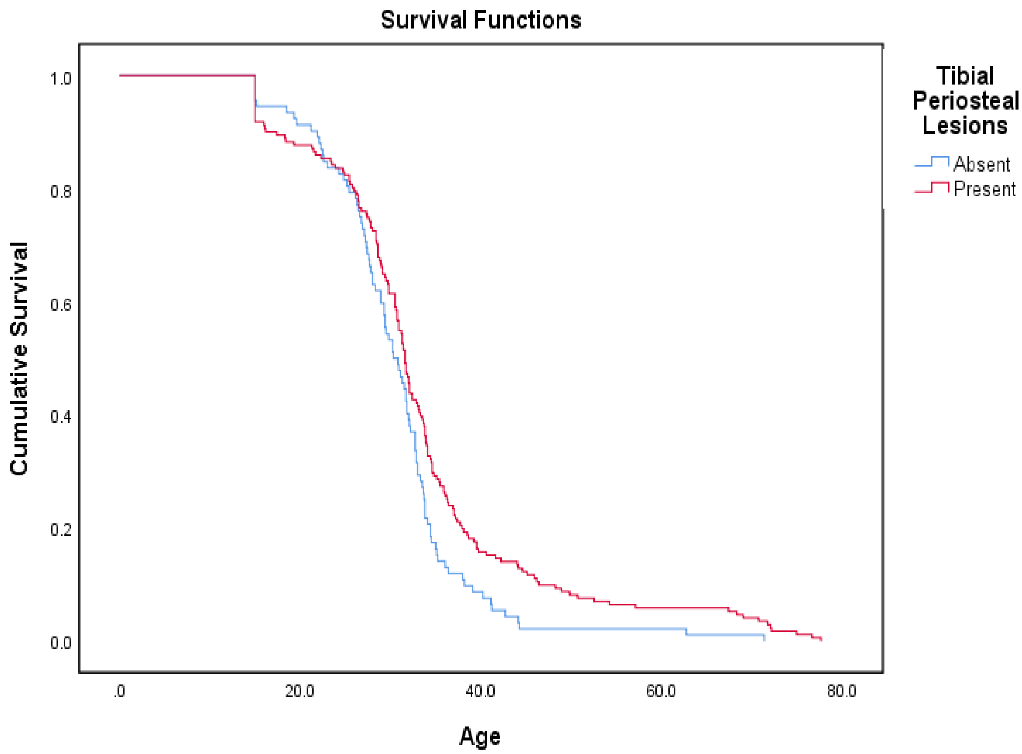

Figure 5.1. Kaplan-Meier survival curve from all sites comparing presence of periosteal lesions.

When individuals with periosteal lesions were pooled and compared with those who did not exhibit periosteal lesions, there was a statistically significant difference (χ^2=6.523, df=1, p=0.011) in mean survival time, with the individuals who had periosteal lesions present on their tibiae having higher survivorship. However, the 95% confidence interval of the mean survival time does overlap.

Table 5.16. Kaplan-Meier Survival Analysis Results for Periosteal Lesion Activity.

Periosteal Lesion Activity	Mean Survival Time (Age)	95% Confidence Interval
Absent (n=92)	30.6	28.8 – 32.3
Mixed (n=48)	37.9	33.6 – 42.2
Healed (n=123)	31.6	29.6 – 33.6

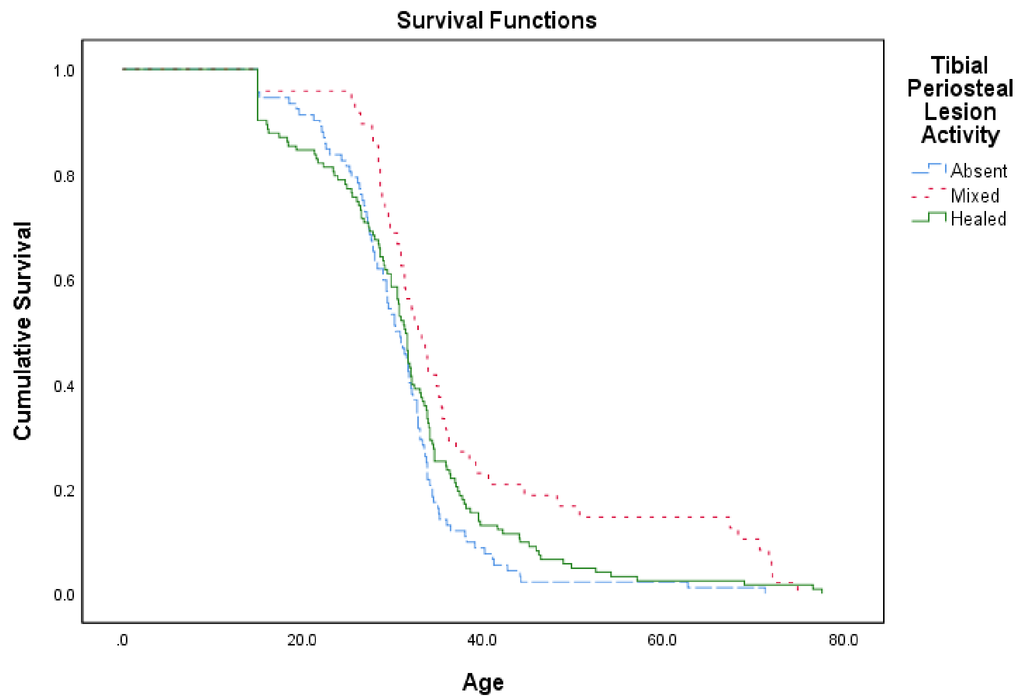

Figure 5.2. Kaplan-Meier survival curve from all sites comparing periosteal lesion activity.

There is a statistically significant difference in mean survival time between the periosteal lesion activity types (χ^2=10.469, df=2, p=0.005). Based on these results, individuals with mixed lesions had the highest survivorship, followed by individuals with healed lesions, and individuals with no periosteal lesions had the lowest survivorship. The 95% confidence interval for individuals with mixed periosteal lesions does not overlap with either the individuals without periosteal lesions or with healed lesions.

Table 5.17. Kaplan-Meier Survival Analysis Results for Periosteal Lesion Severity.

Periosteal Lesion Severity	Mean Survival Time (Age)	95% Confidence Interval
Acute (n=85)	32.1	29.5 – 34.7
Diffuse (n=86)	34.6	31.5 – 37.5

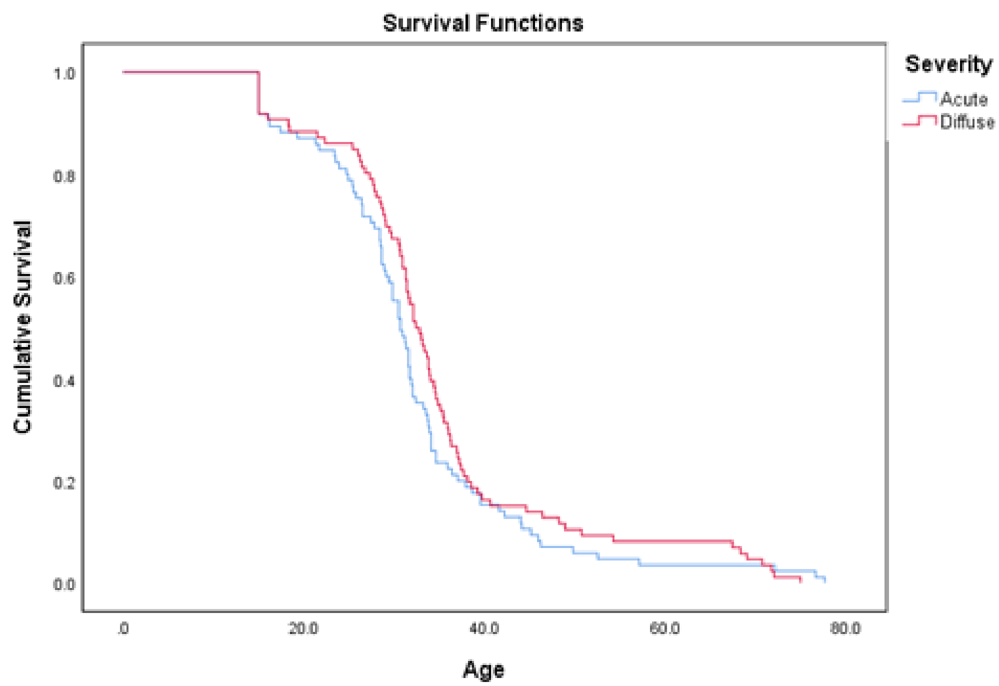

Figure 5.3. Kaplan-Meier survival curve from all sites comparing severity of periosteal lesions.

There was not a statistically significant difference (χ^2=1.127, df=1, p=0.288) in mean survival time between individuals with diffuse versus acute periosteal lesions, with their 95 % confidence intervals overlapping. Based on these results, individuals with localized or acute periosteal lesions did not have higher survivorship than individuals with chronic or diffuse periosteal lesions.

Table 5.18. Kaplan-Meier Survival Analysis Results for Time Period.

Time Period	Mean Survival Time (Age)	95% Confidence Interval
Middle Woodland (n=120)	34.5	32.0 – 36.9
Late Woodland (n=143)	30.6	29.1 – 32.2

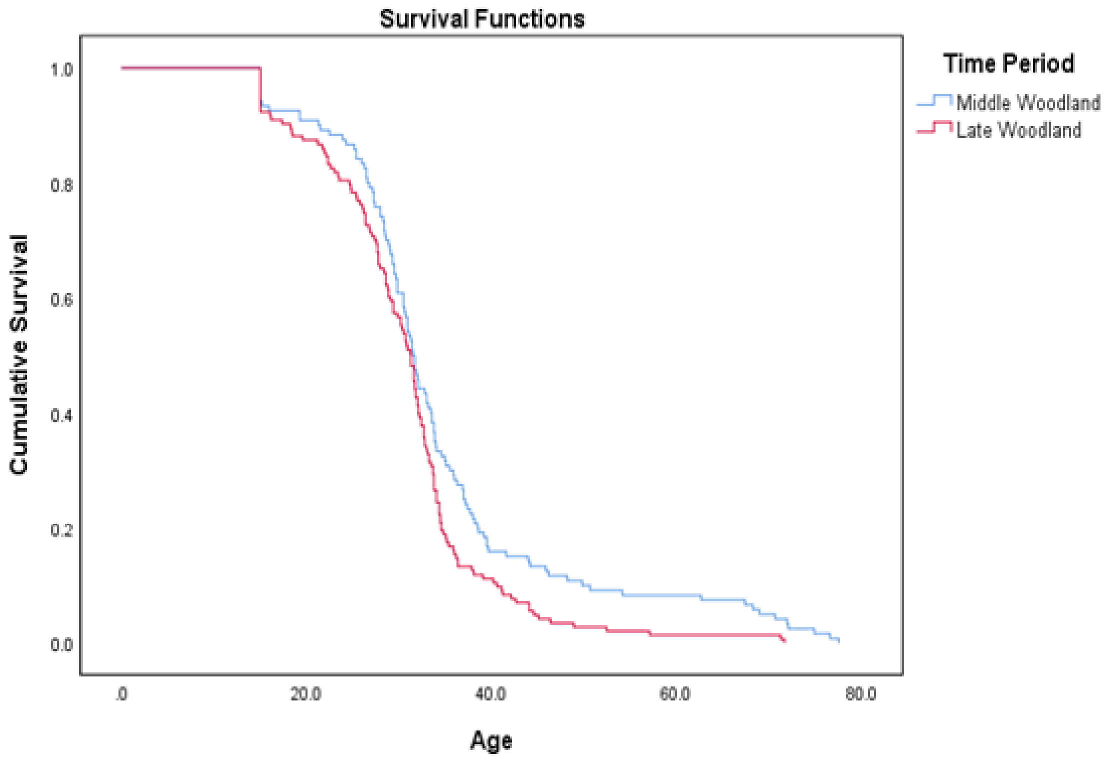

Figure 5.4. Kaplan-Meier survival curve comparing time period.

There is a statistically significant difference (χ^2=6.626, df=1, p=0.010) in mean survival time between individuals from the Middle Woodland and the Late Woodland periods, with only minimal overlap in their 95% confidence intervals. Based on these results, individuals from the Middle Woodland period had higher survivorship than the individuals from the Late Woodland period.

Table 5.19. Kaplan-Meier Survival Analysis Results for Sex Grouped by Time Period.

Sex by Time Period	Mean Survival Time (Age)	95% Confidence Interval
Middle Woodland Females (n=65)	35.2	32.0 – 38.3
Middle Woodland Males (n=55)	33.6	29.9 – 37.4
Late Woodland Females (n=67)	31.0	28.1 – 33.2
Late Woodland Males (n=76)	30.3	28.2 – 32.5

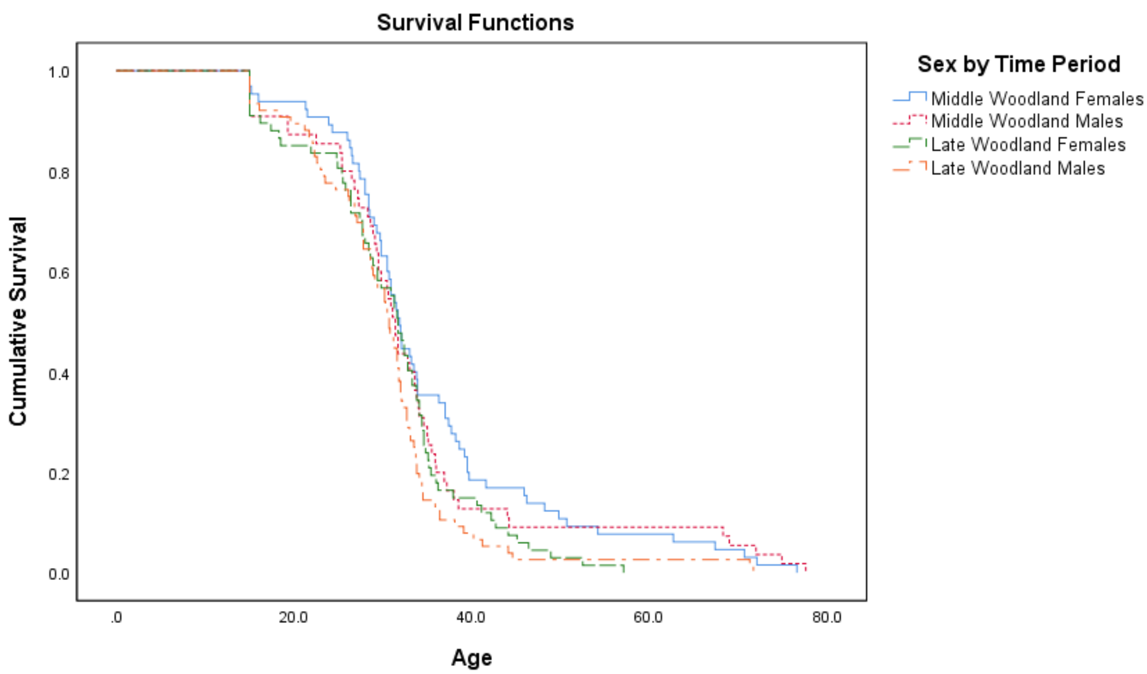

Figure 5.5. Kaplan-Meier survival curve comparing sex by time period.

There is a statistically significant difference (χ^2=8.055, df=3, p=0.045) in mean survival time between Middle Woodland females and males and Late Woodland males and females, with only minimal overlap in the 95% confidence intervals between the Middle Woodland females and Late Woodland males. Based on these results, females from the Middle Woodland period had the highest survivorship while males from the Late Woodland period that the lowest survivorship.

Table 5.20. Kaplan-Meier Survival Analysis Results for Sex Grouped by Time Period – Only Individuals with Periosteal Lesions Present.

Sex by Time Period	Mean Survival Time (Age)	95% Confidence Interval
Middle Woodland Females (n=53)	36.3	32.8 – 39.8
Middle Woodland Males (n=35)	35.4	29.8 – 41.0
Late Woodland Females (n=44)	31.5	28.5 – 34.6
Late Woodland Males (n=39)	29.6	26.7 – 32.6

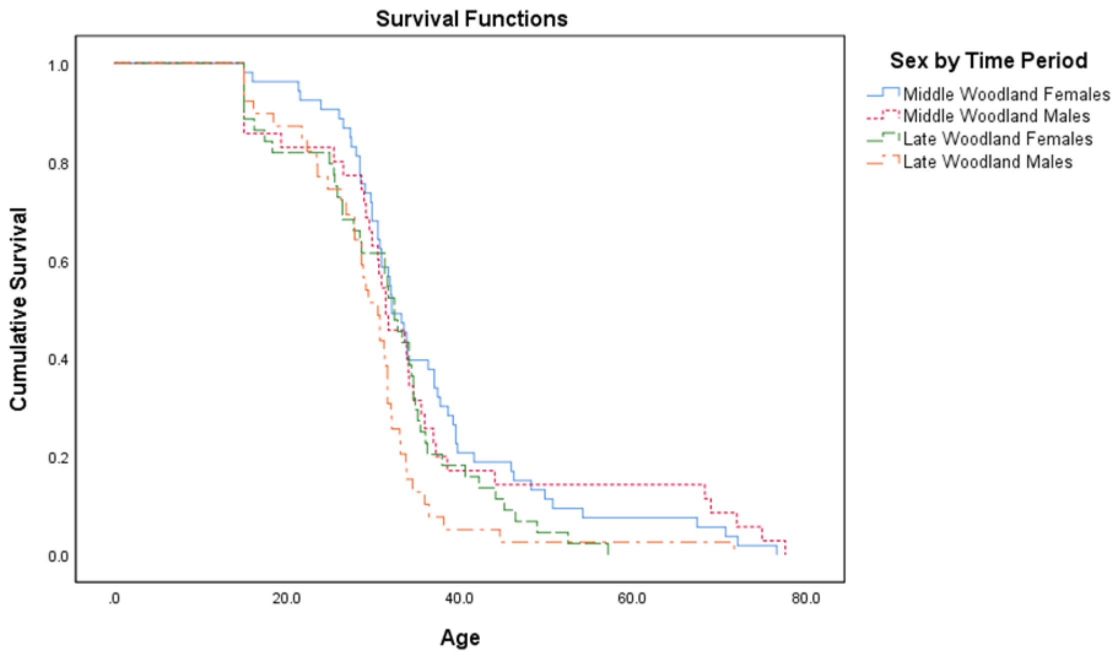

Figure 5.6. Kaplan-Meier survival curve comparing sex by time period – only individuals with periosteal lesions present.

When only using individuals with periosteal lesions present, there is a statistically significant difference (χ^2=10.435, df=3, p=0.015) in mean survival time between Middle Woodland females and males and Late Woodland males and females, with no overlap in the 95% confidence intervals between the Middle Woodland females and Late Woodland males. Based on these results, females from the Middle Woodland period with periosteal lesions had the highest survivorship while males from the Late Woodland period with periosteal lesions had the lowest survivorship.

Age-at-Death Distribution

Utilizing a two-sample Kolmogorov-Smirnov test, the age-at-death distributions of the Middle and Late Woodland populations were not significantly different ($Z=1.148$, $p=0.143$). As seen in Figures 5.7 and 5.8, both the Middle and Late Woodland populations follow a similar pattern of having more individuals between 15-20 years than the 20-25-year age bracket, and a plurality of the population being between the ages of 25-35 years. The Middle Woodland population has more individuals over 55 years than the Late Woodland populations.

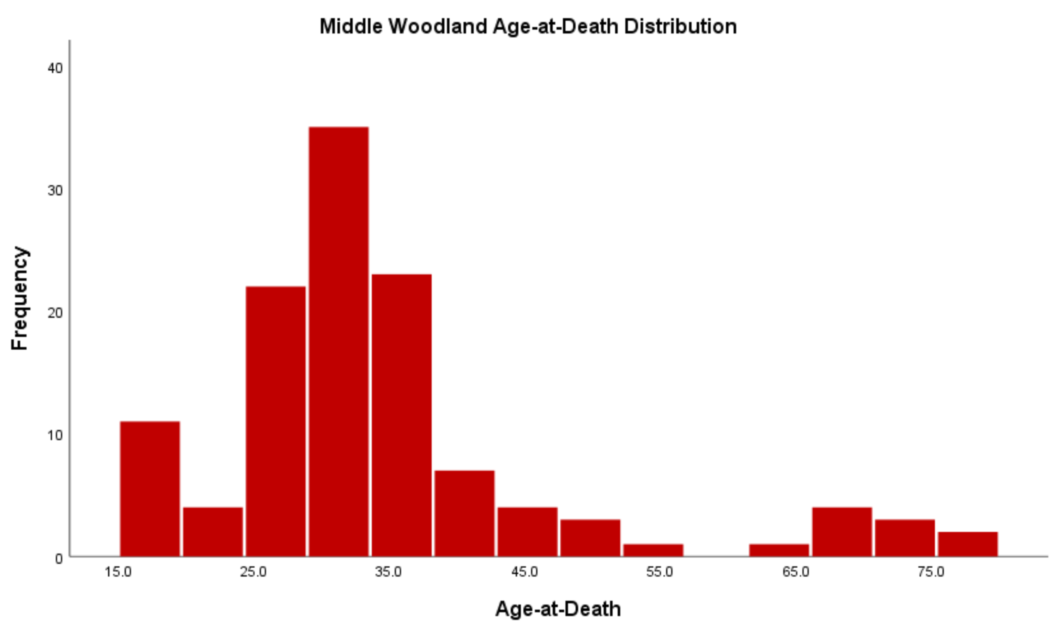

Figure 5.7. Middle Woodland age-at-death distribution.

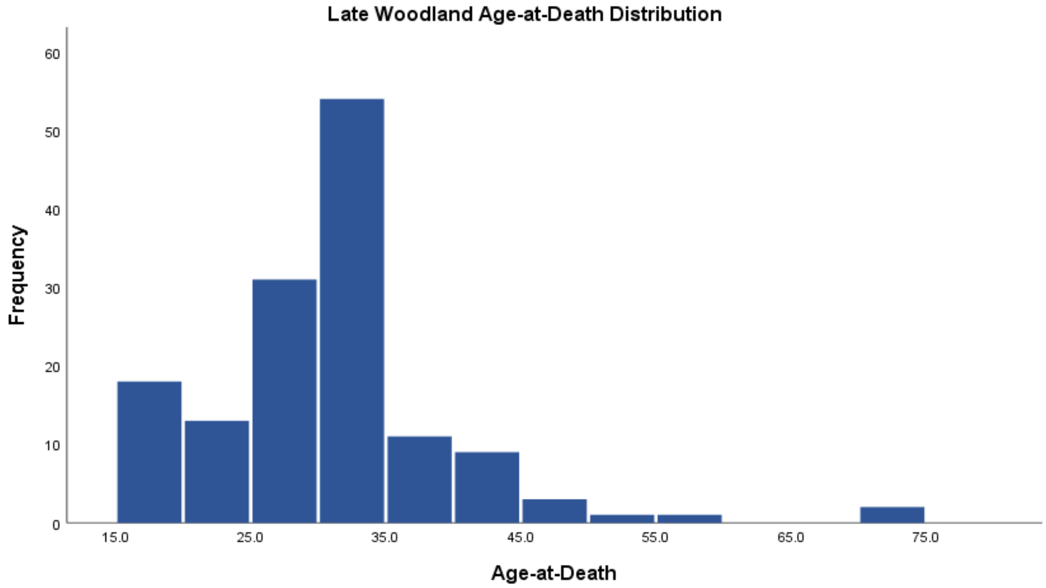

Figure 5.8. Late Woodland age-at-death distribution.

There are also some key differences in the age-at-death distribution when examined by age subgroups as represented by Table 5.21 and Figure 5.9. Proportionally, there are more individuals in the younger two age groups (15-35.99) from the Late Woodland period and more individuals in the older two age groups (36 – 46+) from the Middle Woodland period. Additionally, close to two-thirds of the individuals older than 50 years of age, are from the Middle Woodland sites. To determine if the age distribution between the time periods was affecting the results, each age group was pair-matched by age (maximum likelihood point estimate) and all statistical tests were re-run. When pair-matching the sample, only age, not sex, was considered as it would further decrease the sample size. This pair-matched sample consisted of 216 individuals. For the chi-square tests, periosteal lesion presence by sex was the only statistically significant (χ^2=5.262, p=0.022) result; meaning there was a higher proportion of females with periosteal lesions than males in the pair-matched sample. Two other comparisons, periosteal lesion activity by sex (χ^2=5.457, p=0.065) and periosteal lesion presence by time period (χ^2=2.96, p=0.085) did not reach significance in the pair-matched sample ($p<0.05$) but were close enough to be worthy of note. Failure to reach significance in this case could have been influenced by the smaller size of the pair-matched sample compared to the original sample.

Table 5.21. Age-at-Death Distribution by Time Period.

Ages	Middle Woodland	Late Woodland	Total
15-25.99	19 (15.8%)	34 (23.8%)	53 (20.1%)
26-35.99	66 (55.0%)	86 (60.1%)	152 (57.8%)
36-45.99	20 (16.7%)	17 (11.9%)	37 (14.1%)
46+	15 (12.5%)	6 (4.2%)	21 (8.0%)
Total	120 (100%)	143 (100%)	263 (100%)

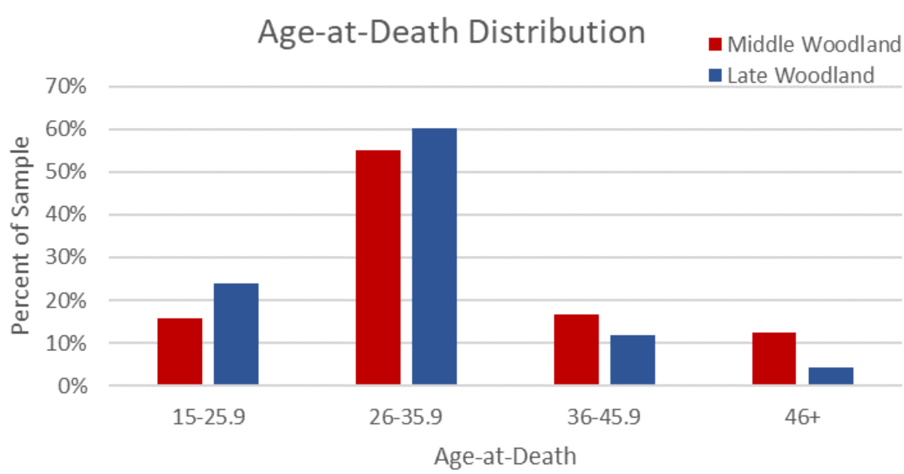

Figure 5.9. Age-at-death distribution by time period.

A similar pattern as discussed above was seen in the age-at-death distribution stratified by biological sex (Table 5.22 and Figure 5.10). Proportionally, there are more individuals in the younger two age groups (15-35.99) that were male and more individuals in the older two age groups (36 – 46+) that were female. The pair-match sample previously discussed contained an equal proportion of males to females.

Table 5.22. Age-at-Death Distribution by Sex.

Ages	Female	Male	Total
15-25.99	24 (18.2%)	29 (22.1%)	53 (20.1%)
26-35.99	72 (54.5%)	80 (61.1%)	152 (57.8%)
36-45.99	22 (16.7%)	15 (11.5%)	37 (14.1%)
46+	14 (10.6%)	7 (5.3%)	21 (8.0%)
Total	132 (100%)	131 (100%)	263 (100%)

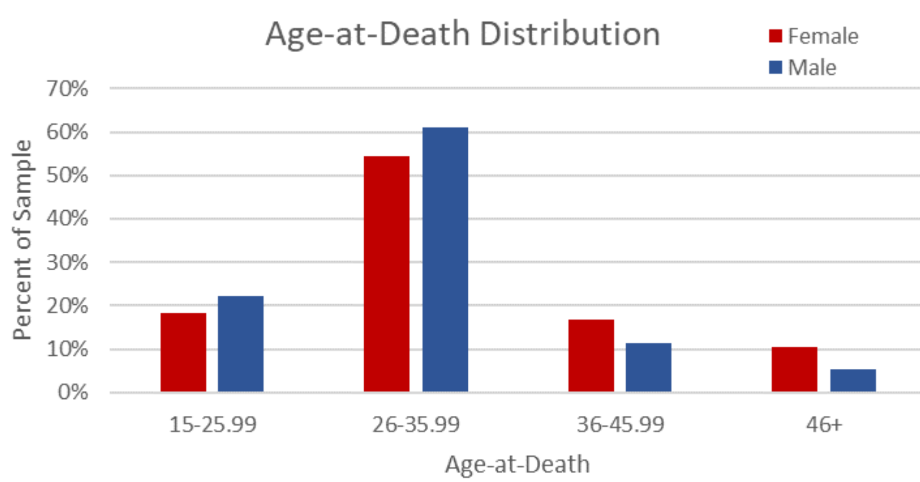

Figure 5.10. Age-at-death distribution by sex.

CHAPTER 6: DISCUSSION AND CONCLUSION

Periosteal new bone formation, or periosteal lesions, is one of several non-specific stress indicators utilized by bioarchaeologists when assessing the health of past populations. While most studies report count and frequencies of periosteal lesion presence or absence, this study attempted to parse out more information from the assessment of periosteal lesions and age-at-death data. In order to accomplish this, periosteal lesions activity (i.e. were the lesions active, healing, or healed) at time of death was assessed as was lesion severity (i.e. was the lesion acute or diffuse).

As noted in Chapter 5, there were no individuals who only exhibited active periosteal lesions on their tibiae. In DeWitte's Black Death research (2014a), only 16 individuals exhibited active periosteal lesions and they were all under the age of 20. As this study specifically targeted adults, it is not surprising that there were no individuals with only active lesions present. Comparisons of periosteal lesion presence and activity with time period, sex, site, and age group did yield some significant results while periosteal lesion severity did not. Kaplan-Meier survivor analysis also indicated statistically significant differences within these groups. A summary of these findings are as follows: Females had a significantly higher proportion of periosteal lesions than males, both in presence and activity. Individuals in the oldest age group, 46+ years, had the largest proportion with periosteal lesions present as well as mixed periosteal lesions. Individuals in the 25-35.99 years age group had almost equal proportion of individuals with healed lesions versus those without any lesions, whereas in all other age categories, the proportion of individuals with healed lesions was much higher than individuals who lacked periosteal lesions. The Middle Woodland sample had significantly more individuals with periosteal lesions present, as well as mixed and healed lesions, than individuals from the Late Woodland sample. Statistically significant differences among the archaeological sites were found. The general pattern for periosteal lesion activity by site is for the proportion of individuals with healed lesions and no lesions to be close to equal. The two exceptions, the Elizabeth and Gibson sites, both from the Middle Woodland period, have a greater proportion of individuals with healed lesions than individuals with no lesions.

Periosteal Lesion Activity and Frailty

While it is unsurprising that the results of this study did not mirror DeWitte's findings (2014a) from Black Death populations exactly, they did, however, provide an unexpected result. Individuals that exhibited both active and healed periosteal lesions, referred to as mixed activity, had higher survivorship, and therefore were less frail, than individuals with both healed lesions and no lesions. One interpretation of this result is that these individuals with both active and healed periosteal lesions were healthy enough to survive at least one health insult that caused the creation of healed periosteal lesion and they were undergoing another health insult that caused the active lesion. This latest health insult that caused the active periosteal new bone formation, however, could have been a tipping point for the individuals' immune systems and contributed to their eventual death. DeWitte's study determined that individuals with active lesions were the frailest followed by individuals with no lesions, mixed lesions, and healed lesions being the least frail. Again, there were no individuals in this study that had only active periosteal new bone formation present so there is no comparison to DeWitte's study. However, both this study and DeWitte's show that individuals with periosteal lesions, whether healed only, as in DeWitte's study, or mixed as in this study, have a higher survivorship and therefore are less frail than individuals with no lesions present.

These findings are surprising given that periosteal lesions are considered a non-specific indicator of stress. If the individuals that are the least frail have periosteal lesions present on their tibiae, what are the implications for these findings? Both studies suggest that these individuals were healthy enough to survive at least one health insult that caused the creation of periosteal new bone formation which, as discussed in Chapter 3, is not an instantaneous response to an insult. The results also suggest that selective mortality and heterogenous frailty are likely at play in this sample.

Based on the data, it appears that individuals who lived during the Middle Woodland period had higher survivorship than individuals in the Late Woodland period; specifically, females from the Middle Woodland. This can be seen in the Kaplan-Meier survivorship curve in Figures 5.4 -5.6 and Tables 5.18 -5.20 in the previous chapter. This result is consistent with the interpretation that populations were 'healthier' prior to the transition to agriculture. While one interpretation of the data is that groups that lived in the lower Illinois River valley in the Middle Woodland were 'healthier' than their counterparts in the Late Woodland, there are multiple factors that need to be considered regarding these results. The first factor to consider is the size and age-distribution of the study samples. While examining over 300 skeletons, only 263 met the specific criteria for this study (i.e. enough of the os coxa present to assess age-at-death, both tibiae able to be scored for periosteal new bone formation, and biological sex not scored as ambiguous). A reduction in over 70 individuals is quite large in terms of bioarchaeological samples and that increase in sample size would have provided more power to the statistical analyses. Another factor to consider is that the

Late Woodland period in the lower Illinois valley saw an increase in population density which began to put pressure on resources. The added stress of population increase and growing strain on resources could have weighed more heavily on the Late Woodland group's individuals with higher frailty compared to the individuals in the Middle Woodland groups who did not have the same type of stressors. Additionally, when comparing results within each time period, it is apparent that the Middle Woodland sites are more variable while the Late Woodland sites are more homogenous. This difference between the two time period's data is likely what caused some of the significant results when the data are compared as a whole. This pattern within the two time periods' periosteal lesion data, appears to match with biological distance interpretations of lower Illinois Valley populations; Middle Woodland populations are more heterogeneous suggesting less movement between groups while Late Woodland populations were more homogenous suggesting more movement between groups. Another possible reason for the difference seen within the time periods could be due to the sites' location on the landscape. The Late Woodland sites are closer geographically than the Middle Woodland sites. This could mean the individuals who were buried at the Helton, Hacker South, and Ledders sites had similar resources and stressors as well as a higher likelihood for inter-group marriage. The Middle Woodland sites have more distance between each other, and that distance could have created distinctive groups that did not seek inter-group marriages as well as slightly different environmental resources and stressors.

The results discussed above would suggest that while individuals from the Middle Woodland had proportionally more periosteal lesions, including both mixed and healed lesions, than individuals in the Late Woodland, they still had higher survivorship than individuals from the Late Woodland. This is pattern is further seen with Middle Woodland females having proportionally more periosteal lesions while having the highest survivorship. As DeWitte (2014a) discussed, there are a few studies that have previously shown a relationship between periosteal lesions presence and age-at-death (Grauer, 1993; Rose and Hartnady, 1991). While Grauer (1993) suggests this pattern is due to periosteal lesions accumulating with age, Rose and Hartnady (1991) proposed that the increased proportion of older individuals with periosteal lesions was due to increased frailty in the older adults. Once periosteal new bone formation is created, it will be evident on the bone for the rest of the person's life. Therefore, the longer a person lives, the more time and chance for them to have more periosteal lesions form; regardless of the cause. As there was a higher proportion of individuals in the Middle Woodland period from the oldest age group, 46+ years, it could be that this cohort of older individuals had a longer span of life during which either a health or physical insult that triggered the creation of periosteal new bone formation on their tibiae. Using only traditional methods of both analysis and interpretation, this discussion of heterogenous frailty and selective mortality would not occur. By only comparing periosteal lesion presence, long-held interpretations would have concluded that the Middle Woodland individuals were less healthy than the individuals from the Late Woodland. Similarly, if only considering survivorship, or average age-at-death information, it would appear that Middle Woodland individuals were living longer than the Late Woodland populations and therefore the Middle Woodland groups would be interpreted as healthier. By utilizing newer methods and applying the osteological paradox principles to this data, this study, like DeWitte's, shows how a more nuanced approach to bioarchaeological studies of population health offers a more complex view how past populations experienced their environment. In this case, it appears that the Middle Woodland groups lived longer and had more periosteal lesions because those exhibiting lesions, on average, had lower frailty than those who died without exhibiting any periosteal lesions.

Periosteal Lesion Severity

Severity of periosteal new bone formation is usually only noted when discussing specific differential diagnoses within paleopathology. Quantifying possible relationships that periosteal lesion severity may have on population health and survivorship is not typically noted in bioarchaeological assessments of health. For this study, periosteal lesion severity was defined as acute when less than one-third of the tibia exhibited any periosteal lesions, while lesions were scored as diffuse if there existed periosteal new bone formation on more than one-third of a tibia. There were no statistically significant differences ($p<0.05$) found among any of the variables at large, but differences were seen when comparing just the Middle Woodland sites ($p=0.020$) and Middle Woodland sexes ($p=0.048$). The apparent similarity could be due to how "acute" vs "diffuse" were defined – greater than or less than one-third of a tibia. A different division of the tibia might have led to a different finding, though this is unlikely given that most of the chi square tests for severity were not near statistical significance ($p<0.05$).

While the overall assessment of severity did not reach significance in the inter-site comparison ($p=0.075$), it is close enough to be worthy of discussion and can be explained by the comparison of the sites separately by time period, where the Middle Woodland sites showed statistically significant differences ($p=0.020$) by site. Four of the sites, which included all three of the Late Woodland sites and Elizabeth, had a higher proportion of individuals with acute lesions than diffuse lesions. Only two of the Middle Woodland sites, Gibson and Ray, had a larger proportion of individuals with diffuse periosteal lesions than acute lesions. Overall, this shows that the individuals with “diffuse” periosteal lesions, which could be indicative of a chronic health insult, did not show any difference in survivorship compared to individuals with “acute” periosteal lesions.

Limitations

While the methodologies used in this study are some of the most current utilized within the field of paleoepidemiology, they all have their shortcomings. Transition analysis 2.0 uses traits, specifically on the auricular surface, that can be difficult for the average observer to score consistently. While it does provide a point estimate for age-at-death, the 95% confidence intervals can be quite broad due to the nature of the features on both the auricular surface and pubic symphysis. The broad age range of a particular individual would mean that they could be grouped within more than one of the age categories in this study, thus possibly changing the age-at-death structure of the sample. Periosteal new bone formation on the tibia can be caused by a multitude of etiologies which can hinder some interpretation regarding specific health outcomes. Periosteal lesions also are age accumulative in that the older the individual is, the more opportunity they have to experience a health insult, regardless of the severity of that health insult.

Future Directions

Framing research designs around the osteological paradox, as this study has done, is the future of bioarchaeology and paleoepidemiology. Utilizing this type of framework and applying it to additional later time periods in the Lower Illinois Valley and/or additional types of non-specific stress indicators would provide a more contemporary view of the archaeology of the region. As this study focused on a stress-indicator that can occur throughout the life course, assessing early-life stressors, like cribra orbitalia and linear enamel hypoplasias, would provide a more holistic view of population health (O'Donnell 2019). However, the skeletal samples present from the Middle and Late Woodland periods have significant amounts of dental attrition which would hinder the scoring of linear enamel hypoplasias on most individuals older than 35 years of age. Without having enough enamel to assess, the results would be biased and would not provide a clear or accurate picture of the effects of early-life stress on these populations. However, other examples of early-life stress indicators, such as cribra orbitalia or porotic hyperostosis, could be assessed in these skeletal samples. Additionally, while periosteal lesions are most common on the tibia, assessing periosteal new bone formation on other skeletal elements could also provide a more in-depth view of population health.

An NIJ grant was awarded in 2014 to further develop the methodology of transition analysis, now known as Transition Analysis 3. This new methodology utilizes the standard aging features, such as the pubic symphysis and auricular surface, while adding additional features from throughout the skeleton. The updated version of the Bayesian age-at-death technique should provide a more accurate and precise age-at-death estimate, especially in older adults (Getz et al., 2015, 2017). The updated version of transition analysis will be welcomed by many bioarchaeologists and paleodemographers as the utilization of features throughout the skeleton makes the method more inclusive to skeletal collections that may not always have intact ossa coxae. Further statistical tests and models of the age-at-death data could provide additional insight into the patterns of frailty and survivorship seen in the study sample.

Conclusion

This study showed that assessing periosteal lesions in a more in-depth matter, as advocated by DeWitte (2014a), can provide a more nuanced view of population health. Similar to DeWitte's (2014a) results, prehistoric Native American populations from Illinois with both healed and active periosteal new bone formation on their tibiae were less frail, based on higher survivorship, than their counterparts who did not exhibit any periosteal lesions on their tibiae. When considered by time period, it was found that individuals from the Middle Woodland period proportionally had more periosteal lesions than their counterparts from the Late Woodland period, but they also had higher survivorship and therefore were less frail than Late Woodland individuals. More specifically, Middle Woodland females had the highest proportion of periosteal lesions and had the highest survivorship while Late Woodland males, had the lowest proportion of periosteal lesions and the lowest survivorship. This suggests that the groups from the Middle Woodland overall were less frail than their Late Woodland counterparts. When assessing the severity of periosteal lesions as either acute or diffuse, there were no statistically significant differences relative to time period, sex, site, or age group. The results from this study further reinforce the importance of what Wood et al. (1992) were advocating for regarding interpretations of health outcomes from skeletal remains.

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APPENDIX

DATA

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
EZ 1-10 SK1	Middle Woodland	Female	76.6	Yes	Healed	Acute
EZ 1-10 SK2	Middle Woodland	Probable Male	30.2	No	No Data	No Data
EZ 1-10 SK3	Middle Woodland	Probable Male	26.8	Yes	Absent	Absent
EZ 1-12 SK1	Middle Woodland	Probable Female	39.5	Yes	Healed	Acute
EZ 1-12 SK2	Middle Woodland	Probable Male	44	Yes	Healed	Acute
EZ 1-2 SK2	Middle Woodland	Female	40.6	No	No Data	No Data
EZ 1-3 SK1	Middle Woodland	Probable Male	72	Yes	Mixed	Diffuse
EZ 1-3 SK2	Middle Woodland	Female	72.1	Yes	Mixed	Acute
EZ 1-33	Middle Woodland	Probable Male	77.6	Yes	Healed	Acute
EZ 1-4	Middle Woodland	Male	30.5	Yes	Healed	Acute
EZ 3 -11	Middle Woodland	Female	37	Yes	Healed	Acute
EZ 3-1 SK1	Middle Woodland	Female	46.2	Yes	Healed	Acute
EZ 3-10	Middle Woodland	Probable Female	72.2	No	No Data	No Data
EZ 3-12 SK1	Middle Woodland	Female	31.4	No	No Data	No Data
EZ 3-13	Middle Woodland	Probable Female	30.5	Yes	Mixed	Diffuse
EZ 3-2 SK1	Middle Woodland	Female	57.3	No	No Data	No Data
EZ 3-2 SK2	Middle Woodland	Male	27.2	Yes	Absent	Absent

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
EZ 3-3 SK1	Middle Woodland	Female	70.7	Yes	Mixed	Diffuse
EZ 3-3 SK2	Middle Woodland	Probable Female	31.9	Yes	Healed	Acute
EZ 3-5 SK1	Middle Woodland	Probable Female	33.2	Yes	Mixed	Acute
EZ 3-5 SK2	Middle Woodland	Male	26.5	Yes	Healed	Acute
EZ 3-7 SK1	Middle Woodland	Female	29.7	Yes	Mixed	Diffuse
EZ 3-8	Middle Woodland	Ambiguous	No Age Data	No	Mixed	Diffuse
EZ 4-1	Middle Woodland	Male	35.1	Yes	Absent	Absent
EZ 4-2	Middle Woodland	Ambiguous	No Age Data	No	No Data	No Data
EZ 4-3	Middle Woodland	Female	29.8	Yes	Healed	Acute
EZ 6-1	Middle Woodland	Ambiguous	No Age Data	No	No Data	No Data
EZ 6-4 SK1	Middle Woodland	Probable Male	28.9	Yes	Healed	Acute
EZ 6-4 SK2	Middle Woodland	Male	20.7	No	No Data	No Data
EZ 6-4 SK3	Middle Woodland	Ambiguous	29	No	No Data	No Data
EZ 6-4 SK5	Middle Woodland	Probable Female	30.9	Yes	Mixed	Acute
EZ 7-12 SK1	Middle Woodland	Probable Female	16.9	No	No Data	No Data
EZ 7-12 SK2	Middle Woodland	Female	31.7	Yes	Healed	Acute
EZ 7-16 SK2	Middle Woodland	Female	37	Yes	Mixed	Diffuse
EZ 7-17	Middle Woodland	Probable Male	18.7	No	No Data	No Data

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
EZ 7-18	Middle Woodland	Probable Female	32.1	Yes	Mixed	Diffuse
EZ 7-19	Middle Woodland	Male	25.4	Yes	Mixed	Diffuse
EZ 7-21 SK1	Middle Woodland	Probable Female	39.2	Yes	Mixed	Diffuse
EZ 7-21 SK2	Middle Woodland	Probable Male	34.6	Yes	Healed	Acute
EZ 7-6	Middle Woodland	Probable Female	49.8	Yes	Healed	Acute
EZ 7-8 SK1	Middle Woodland	Probable Male	29.1	Yes	Mixed	Diffuse
EZ 7-9 SK2	Middle Woodland	Female	26.3	Yes	Absent	Absent
GBN 1-10	Middle Woodland	Female	33.5	Yes	Healed	Acute
GBN 1-11	Middle Woodland	Ambiguous	50.9	No	No Data	No Data
GBN 1-13	Middle Woodland	Probable Female	29.3	Yes	Absent	Absent
GBN 1-16	Middle Woodland	Probable Male	19.3	Yes	Healed	Acute
GBN 1-17	Middle Woodland	Female	50.7	Yes	Mixed	Diffuse
GBN 1-19	Middle Woodland	Female	36.3	Yes	Healed	Diffuse
GBN 1-20	Middle Woodland	Female	30.5	No	No Data	No Data
GBN 1-3	Middle Woodland	Probable Female	26	Yes	Healed	Diffuse
GBN 1-6	Middle Woodland	Male	30.6	Yes	Healed	Diffuse
GBN 1-7	Middle Woodland	Probable Female	67.1	No	No Data	No Data
GBN 1-8	Middle Woodland	Male	28.6	Yes	Healed	Acute

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
GBN 2-11	Middle Woodland	Male	22.5	Yes	Absent	Absent
GBN 2-13	Middle Woodland	Probable Female	15.2	Yes	Absent	Absent
GBN 2-14	Middle Woodland	Probable Male	15	Yes	Healed	Diffuse
GBN 2-18	Middle Woodland	Male	31.4	Yes	Mixed	Diffuse
GBN 2-19	Middle Woodland	Female	30.7	Yes	Healed	Diffuse
GBN 2-2	Middle Woodland	Female	16	Yes	Healed	Diffuse
GBN 2-22	Middle Woodland	Male	25.2	Yes	Absent	Absent
GBN 2-24	Middle Woodland	Female	67.4	Yes	Mixed	Diffuse
GBN 2-25	Middle Woodland	Female	21.5	Yes	Healed	Diffuse
GBN 2-27	Middle Woodland	Probable Male	15	Yes	Mixed	Diffuse
GBN 2-29	Middle Woodland	Male	34	Yes	Healed	Diffuse
GBN 2-3	Middle Woodland	Female	33.9	Yes	Healed	Acute
GBN 2-38	Middle Woodland	Probable Male	15	Yes	Mixed	Diffuse
GBN 2-39	Middle Woodland	Female	15	Yes	Healed	Acute
GBN 2-4	Middle Woodland	Female	26.6	No	No Data	No Data
GBN 2-40	Middle Woodland	Female	23.9	Yes	Healed	Acute
GBN 2-43	Middle Woodland	Male	27.3	Yes	Absent	Absent
GBN 2-7	Middle Woodland	Ambiguous	15	No	No Data	No Data

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
GBN 2-9	Middle Woodland	Male	36	No	No Data	No Data
GBN 3-1	Middle Woodland	Female	29	Yes	Healed	Diffuse
GBN 3-13	Middle Woodland	Female	32.1	Yes	Healed	Diffuse
GBN 3-14	Middle Woodland	Male	35.5	Yes	Mixed	Diffuse
GBN 3-15	Middle Woodland	Probable Male	33.6	Yes	Absent	Absent
GBN 3-16	Middle Woodland	Female	33.9	Yes	Mixed	Diffuse
GBN 3-17	Middle Woodland	Male	29.8	Yes	Healed	Acute
GBN 3-21	Middle Woodland	Female	31.3	Yes	Absent	Absent
GBN 3-26	Middle Woodland	Female	38.2	Yes	Absent	Absent
GBN 3-27	Middle Woodland	Female	30.9	Yes	Mixed	Diffuse
GBN 3-28	Middle Woodland	Female	39.7	Yes	Healed	Diffuse
GBN 3-4	Middle Woodland	Male	32.8	Yes	Absent	Absent
GBN 3-5	Middle Woodland	Female	21.3	Yes	Healed	Acute
GBN 3-6	Middle Woodland	Female	37.7	Yes	Healed	Diffuse
GBN 3-7	Middle Woodland	Female	27.3	Yes	Healed	Diffuse
GBN 3-8	Middle Woodland	Male	37.2	Yes	Healed	Diffuse
GBN 3-9	Middle Woodland	Male	31.1	Yes	Absent	Absent
GBN 5-1	Middle Woodland	Probable Male	No Age Data	No	Healed	Diffuse

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
GBN 5-10	Middle Woodland	Male	33	Yes	Absent	Absent
GBN 5-12	Middle Woodland	Probable Female	28.4	Yes	Healed	Acute
GBN 5-15	Middle Woodland	Female	38.6	Yes	Healed	Acute
GBN 5-18	Middle Woodland	Male	34	No	No Data	No Data
GBN 5-2	Middle Woodland	Male	30.9	Yes	Healed	Diffuse
GBN 5-20	Middle Woodland	Female	31.5	Yes	Absent	Absent
GBN 5-21	Middle Woodland	Female	41.6	Yes	Healed	Acute
GBN 5-24	Middle Woodland	Female	24.3	Yes	Absent	Absent
GBN 5-27	Middle Woodland	Probable Male	15	Yes	Healed	Diffuse
GBN 5-30	Middle Woodland	Male	31.8	No	No Data	No Data
GBN 5-7	Middle Woodland	Female	28	Yes	Healed	Diffuse
GBN 5-8	Middle Woodland	Ambiguous	69.5	No	Healed	Acute
GBN1-4	Middle Woodland	Female	37.4	Yes	Healed	Diffuse
HN 20-1-1	Late Woodland	Female	26.4	No	Absent	Absent
HN 20-14-1	Late Woodland	Female	28.6	Yes	Mixed	Diffuse
HN 20-24	Late Woodland	Female	18.5	Yes	Absent	Absent
HN 20-27-1	Late Woodland	Male	30.5	Yes	Healed	Acute
HN 20-29-1	Late Woodland	Male	34.5	Yes	Absent	Absent

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HN 20-30-1	Late Woodland	Probable Female	68.7	No	No Data	No Data
HN 20-31-1	Late Woodland	Female	46.4	Yes	Healed	Diffuse
HN 20-32-1	Late Woodland	Male	35.5	No	Absent	Absent
HN 20-34-1	Late Woodland	Female	34.4	Yes	Absent	Absent
HN 20-37	Late Woodland	Male	32.7	Yes	Absent	Absent
HN 20-4-1	Late Woodland	Probable Female	29.9	No	No Data	No Data
HN 20-45-1	Late Woodland	Male	27.1	Yes	Absent	Absent
HN 20-47-1	Late Woodland	Probable Male	30.8	Yes	Absent	Absent
HN 20-49-1	Late Woodland	Male	41.2	Yes	Absent	Absent
HN 20-56	Late Woodland	Female	34.6	Yes	Healed	Diffuse
HN 20-57-1	Late Woodland	Male	40.2	Yes	Absent	Absent
HN 20-6-1	Late Woodland	Female	35.1	Yes	Mixed	Diffuse
HN 20-64-1	Late Woodland	Probable Male	29.5	No	Absent	Absent
HN 20-66-1	Late Woodland	Female	40.6	Yes	Mixed	Diffuse
HN 20-7-1	Late Woodland	Male	28.6	Yes	Healed	Acute
HN 20-9-1	Late Woodland	Male	21.4	No	Absent	Absent
HN 21-7	Late Woodland	Male	15	Yes	Healed	Diffuse
HN 21-8	Late Woodland	Probable Female	21.9	Yes	Absent	Absent

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HN 22-15	Late Woodland	Ambiguous	33.6	No	No Data	No Data
HN 22-27	Late Woodland	Probable Male	31.3	Yes	Healed	Acute
HN 22-32	Late Woodland	Probable Female	32.8	Yes	Mixed	Diffuse
HN 22-7	Late Woodland	Female	45.1	Yes	Healed	Acute
HN 46-1-1	Late Woodland	Probable Female	42.2	Yes	Healed	Acute
HN 46-12	Late Woodland	Male	30.2	Yes	Absent	Absent
HN 46-13	Late Woodland	Male	27.8	Yes	Healed	Acute
HN 46-14	Late Woodland	Female	32.1	Yes	Absent	Absent
HN 46-23	Late Woodland	Probable Female	41.7	No	Absent	Absent
HN 46-25	Late Woodland	Female	16.2	Yes	Healed	Acute
HN 46-30	Late Woodland	Male	34.1	Yes	Absent	Absent
HN 46-31	Late Woodland	Probable Male	21.7	Yes	Healed	Acute
HN 46-34	Late Woodland	Male	31.6	Yes	Healed	Acute
HN 46-37	Late Woodland	Probable Male	36.4	Yes	Absent	Absent
HN 46-54	Late Woodland	Male	23.5	Yes	Healed	Acute
HN 46-57	Late Woodland	Probable Female	29.4	Yes	Absent	Absent
HN 46-6	Late Woodland	Ambiguous	15	No	Absent	Absent
HN 46-64	Late Woodland	Male	34.5	Yes	Healed	Diffuse

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HN 46-66	Late Woodland	Female	52.5	Yes	Healed	Acute
HN 46-69	Late Woodland	Female	33.8	Yes	Absent	Absent
HN 46-73	Late Woodland	Probable Male	15	Yes	Absent	Absent
HN 46-75-2	Late Woodland	Female	34.4	Yes	Healed	Diffuse
HN 46-9	Late Woodland	Probable Male	15	Yes	Absent	Absent
HN 47-1	Late Woodland	Male	38.1	Yes	Healed	Diffuse
HN 47-12	Late Woodland	Probable Female	28.9	Yes	Absent	Absent
HN 47-13	Late Woodland	Female	32.8	Yes	Absent	Absent
HN 47-16	Late Woodland	Female	28	Yes	Absent	Absent
HN 47-20	Late Woodland	Male	18.4	Yes	Healed	Diffuse
HN 47-25	Late Woodland	Male	23	Yes	Absent	Absent
HN 47-28	Late Woodland	Female	42.7	Yes	Absent	Absent
HN 47-33	Late Woodland	Probable Male	33.1	Yes	Healed	Diffuse
HN 47-37	Late Woodland	Male	33.7	Yes	Absent	Absent
HN 47-38	Late Woodland	Probable Female	32.2	No	No Data	No Data
HN 47-39	Late Woodland	Probable Female	26.4	Yes	Absent	Absent
HN 47-44-1	Late Woodland	Female	35.4	Yes	Mixed	Diffuse
HN 47-47	Late Woodland	Probable Female	15	Yes	Healed	Acute

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HN 47-50	Late Woodland	Male	33	Yes	Healed	Diffuse
HN 47-51-1	Late Woodland	Male	27.6	Yes	Absent	Absent
HN 47-53	Late Woodland	Probable Female	15	Yes	Healed	Acute
HN 47-54	Late Woodland	Female	25.5	Yes	Healed	Acute
HN 47-58	Late Woodland	Probable Male	33.7	Yes	Healed	Acute
HN 47-6	Late Woodland	Male	22.6	Yes	Absent	Absent
HN 47-60	Late Woodland	Ambiguous	29.4	No	Healed	Acute
HN 47-61	Late Woodland	Male	22.3	Yes	Healed	Diffuse
HN 47-63	Late Woodland	Male	24.7	Yes	Healed	Acute
HN 47-69	Late Woodland	Ambiguous	20	No	No Data	No Data
HN 47-7	Late Woodland	Female	34.1	Yes	Healed	Acute
HN 47-70	Late Woodland	Male	32.1	Yes	Healed	Diffuse
HN 47-76	Late Woodland	Male	30.7	Yes	Healed	Acute
HN 47-77	Late Woodland	Female	35.2	Yes	Absent	Absent
HN 47-79	Late Woodland	Probable Male	32.8	No	No Data	No Data
HN 47-80	Late Woodland	Probable Male	34.2	No	No Data	No Data
HN 47-9	Late Woodland	Female	29.4	Yes	Absent	Absent
HRS 1-1	Late Woodland	Male	27.8	Yes	Absent	Absent

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HRS 1-2	Late Woodland	Probable Male	26.8	Yes	Healed	Diffuse
HRS 1-24	Late Woodland	Ambiguous	28.1	No	Healed	Acute
HRS 1-28	Late Woodland	Male	44.1	Yes	Absent	Absent
HRS 1-39	Late Woodland	Male	42.6	No	No Data	No Data
HRS 1-41	Late Woodland	Female	34.1	Yes	Healed	Acute
HRS 1-48	Late Woodland	Male	28.9	No	No Data	No Data
HRS 1-57	Late Woodland	Male	39.1	Yes	Absent	Absent
HRS 1-58	Late Woodland	Ambiguous	70.3	No	No Data	No Data
HRS 2-10	Late Woodland	Male	32.7	Yes	Absent	Absent
HRS 2-100	Late Woodland	Probable Female	36.2	Yes	Mixed	Diffuse
HRS 2-102	Late Woodland	Female	48.9	Yes	Healed	Diffuse
HRS 2-103	Late Woodland	Female	57.1	Yes	Healed	Acute
HRS 2-104	Late Woodland	Probable Male	35.2	No	No Data	No Data
HRS 2-105	Late Woodland	Male	20.5	No	No Data	No Data
HRS 2-106	Late Woodland	Male	30.2	No	No Data	No Data
HRS 2-108	Late Woodland	Female	26.8	No	No Data	No Data
HRS 2-110	Late Woodland	Probable Male	28.8	Yes	Mixed	Diffuse
HRS 2-112	Late Woodland	Female	30.9	Yes	Absent	Absent

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HRS 2-113	Late Woodland	Probable Male	30.2	Yes	Absent	Absent
HRS 2-115	Late Woodland	Ambiguous	15	No	Absent	Absent
HRS 2-116	Late Woodland	Male	23.4	Yes	Healed	Acute
HRS 2-118	Late Woodland	Male	15	No	No Data	No Data
HRS 2-119	Late Woodland	Male	30.3	Yes	Absent	Absent
HRS 2-120	Late Woodland	Ambiguous	66.5	No	No Data	No Data
HRS 2-121	Late Woodland	Female	33.3	Yes	Healed	Diffuse
HRS 2-13	Late Woodland	Male	28.6	Yes	Mixed	Acute
HRS 2-14	Late Woodland	Probable Male	39	No	No Data	No Data
HRS 2-15	Late Woodland	Male	28.9	Yes	Absent	Absent
HRS 2-16	Late Woodland	Male	22.1	Yes	Absent	Absent
HRS 2-17	Late Woodland	Probable Male	35.9	Yes	Healed	Acute
HRS 2-18	Late Woodland	Male	30.7	Yes	Healed	Acute
HRS 2-19	Late Woodland	Male	31.8	Yes	Absent	Absent
HRS 2-20	Late Woodland	Probable Female	22.7	No	No Data	No Data
HRS 2-22	Late Woodland	Male	21.2	Yes	Absent	Absent
HRS 2-27	Late Woodland	Probable Male	24.9	No	No Data	No Data
HRS 2-28	Late Woodland	Male	34.4	Yes	Absent	Absent

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HRS 2-29	Late Woodland	Male	32	Yes	Absent	Absent
HRS 2-34	Late Woodland	Female	31.3	Yes	Mixed	Diffuse
HRS 2-36	Late Woodland	Female	32.4	Yes	Mixed	Diffuse
HRS 2-38	Late Woodland	Female	33.3	Yes	Absent	Absent
HRS 2-42	Late Woodland	Female	27.7	Yes	Absent	Absent
HRS 2-43	Late Woodland	Female	24.9	Yes	Healed	Acute
HRS 2-46	Late Woodland	Male	30.7	No	No Data	No Data
HRS 2-47	Late Woodland	Female	34.8	Yes	Mixed	Diffuse
HRS 2-49	Late Woodland	Male	31.2	Yes	Healed	Acute
HRS 2-5	Late Woodland	Male	33.8	Yes	Mixed	Diffuse
HRS 2-50	Late Woodland	Female	44.1	Yes	Healed	Acute
HRS 2-51	Late Woodland	Probable Male	31.6	Yes	Healed	Acute
HRS 2-57	Late Woodland	Female	31.7	Yes	Absent	Absent
HRS 2-6	Late Woodland	Probable Male	23.1	No	No Data	No Data
HRS 2-62-1	Late Woodland	Probable Male	71.3	Yes	Absent	Absent
HRS 2-63	Late Woodland	Probable Female	26.4	Yes	Mixed	Diffuse
HRS 2-67	Late Woodland	Female	37.9	Yes	Healed	Acute
HRS 2-68	Late Woodland	Probable Female	26.4	Yes	Healed	Acute

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HRS 2-7	Late Woodland	Male	19.6	Yes	Absent	Absent
HRS 2-70	Late Woodland	Probable Male	26.2	Yes	Healed	Diffuse
HRS 2-72	Late Woodland	Female	41.1	Yes	Absent	Absent
HRS 2-73	Late Woodland	Probable Male	30.4	No	No Data	No Data
HRS 2-74	Late Woodland	Female	23.6	No	No Data	No Data
HRS 2-8	Late Woodland	Male	27.8	Yes	Mixed	Diffuse
HRS 2-82	Late Woodland	Female	40.4	No	No Data	No Data
HRS 2-84	Late Woodland	Female	15	Yes	Absent	Absent
HRS 2-85	Late Woodland	Ambiguous	28.3	No	No Data	No Data
HRS 2-89	Late Woodland	Female	34.6	Yes	Healed	Acute
HRS 2-9	Late Woodland	Male	29.4	Yes	Healed	Acute
HRS 2-90	Late Woodland	Probable Male	16.1	Yes	Healed	Acute
HRS 2-91	Late Woodland	Female	36	Yes	Healed	Diffuse
HRS 2-92	Late Woodland	Female	31.4	No	No Data	No Data
HRS 2-94	Late Woodland	Female	31.6	Yes	Healed	Acute
HRS 2-95	Late Woodland	Male	15	Yes	Healed	Acute
HRS 2-98	Late Woodland	Female	34.6	No	No Data	No Data
HRS 3-1	Late Woodland	Ambiguous	19	No	No Data	No Data

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
HRS 3-2	Late Woodland	Female	18.9	No	No Data	No Data
HRS 5-2	Late Woodland	Probable Female	29.8	Yes	Absent	Absent
LD 1-10	Late Woodland	Female	33.8	Yes	Absent	Absent
LD 1-105	Late Woodland	Female	24.8	Yes	Absent	Absent
LD 1-109	Late Woodland	Ambiguous	No Age Data	No	Mixed	Acute
LD 1-116	Late Woodland	Female	18.3	Yes	Healed	Diffuse
LD 1-121	Late Woodland	Female	31.3	Yes	Mixed	Diffuse
LD 1-122	Late Woodland	Male	32	Yes	Healed	Acute
LD 1-130	Late Woodland	Ambiguous	32.6	No	No Data	No Data
LD 1-132	Late Woodland	Probable Female	15	Yes	Healed	Diffuse
LD 1-135	Late Woodland	Male	26.1	Yes	Absent	Absent
LD 1-137	Late Woodland	Ambiguous	15	No	Mixed	Diffuse
LD 1-138	Late Woodland	Probable Female	27.7	Yes	Mixed	Diffuse
LD 1-142	Late Woodland	Male	31.6	Yes	Healed	Diffuse
LD 1-145	Late Woodland	Female	15	No	No Data	No Data
LD 1-146	Late Woodland	Female	27.4	Yes	Absent	Absent
LD 1-147	Late Woodland	Probable Female	15	No	No Data	No Data
LD 1-151	Late Woodland	Probable Female	17.4	Yes	Healed	Acute

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
LD 1-16	Late Woodland	Probable Male	31.8	Yes	Absent	Absent
LD 1-17	Late Woodland	Probable Male	29.1	Yes	Healed	Acute
LD 1-20	Late Woodland	Ambiguous	29.5	No	Absent	Absent
LD 1-24	Late Woodland	Probable Male	71.7	Yes	Mixed	Diffuse
LD 1-25	Late Woodland	Male	15	Yes	Healed	Acute
LD 1-28	Late Woodland	Female	32.4	Yes	Healed	Acute
LD 1-30	Late Woodland	Ambiguous	No Age Data	No	Mixed	Diffuse
LD 1-37	Late Woodland	Male	22.3	Yes	Absent	Absent
LD 1-38	Late Woodland	Male	20.4	No	No Data	No Data
LD 1-4	Late Woodland	Probable Female	24.9	No	No Data	No Data
LD 1-5	Late Woodland	Probable Male	33.5	Yes	Absent	Absent
LD 1-54	Late Woodland	Male	32.7	Yes	Absent	Absent
LD 1-56	Late Woodland	Male	32.2	Yes	Absent	Absent
LD 1-58	Late Woodland	Ambiguous	33.8	No	Absent	Absent
LD 1-60	Late Woodland	Ambiguous	No Age Data	No	Absent	Absent
LD 1-61	Late Woodland	Probable Male	83.3	No	No Data	No Data
LD 1-63	Late Woodland	Probable Female	28.4	Yes	Mixed	Diffuse
LD 1-69	Late Woodland	Probable Female	15	Yes	Healed	Acute

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
LD 1-78	Late Woodland	Ambiguous	No Age Data	No	No Data	No Data
LD 1-79	Late Woodland	Female	15	Yes	Healed	Acute
LD 1-8	Late Woodland	Female	31.7	Yes	Healed	Acute
LD 1-81	Late Woodland	Male	33.8	Yes	Absent	Absent
LD 1-91	Late Woodland	Male	26.9	Yes	Absent	Absent
LD 1-96	Late Woodland	Male	36.4	Yes	Healed	Acute
LD 1-98	Late Woodland	Probable Male	No Age Data	No	Absent	Absent
LD 1-99	Late Woodland	Ambiguous	No Age Data	No	Healed	Acute
LD 2-10	Late Woodland	Probable Female	25.6	No	No Data	No Data
LD 2-12	Late Woodland	Probable Female	25.4	Yes	Healed	Acute
LD 2-34	Late Woodland	Probable Male	44.6	Yes	Mixed	Diffuse
LD 2-36	Late Woodland	Probable Female	25.8	Yes	Mixed	Acute
Ray 1-29	Middle Woodland	Probable Male	33.8	Yes	Healed	Acute
Ray 1-3	Middle Woodland	Probable Male	46.1	No	No Data	No Data
Ray 1-30	Middle Woodland	Male	35	Yes	Absent	Absent
Ray 1-31	Middle Woodland	Probable Male	19.3	Yes	Absent	Absent
Ray 1-32	Middle Woodland	Probable Female	45.9	Yes	Healed	Acute
Ray 1-52	Middle Woodland	Probable Female	No Age Data	No	Absent	Absent

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
Ray 1-54	Middle Woodland	Male	38.5	Yes	Mixed	Diffuse
Ray 1-59	Middle Woodland	Male	29.5	Yes	Absent	Absent
Ray 1-60	Middle Woodland	Male	34.1	Yes	Healed	Acute
Ray 1-63	Middle Woodland	Male	74.9	Yes	Mixed	Diffuse
Ray 2-10	Middle Woodland	Probable Female	15	Yes	Absent	Absent
Ray 2-15	Middle Woodland	Probable Male	15	Yes	Healed	Diffuse
Ray 2-57	Middle Woodland	Female	26.5	Yes	Healed	Acute
Ray 2-6	Middle Woodland	Male	44.2	Yes	Absent	Absent
Ray 2-65	Middle Woodland	Ambiguous	42.8	No	Healed	Acute
Ray 2-69	Middle Woodland	Probable Male	35.9	Yes	Mixed	Diffuse
Ray 2-74	Middle Woodland	Female	32	Yes	Healed	Acute
Ray 2-77	Middle Woodland	Male	31.7	Yes	Healed	Diffuse
Ray 2-8	Middle Woodland	Probable Male	68.3	Yes	Mixed	Diffuse
Ray 2-81	Middle Woodland	Probable Female	22.8	No	No Data	No Data
Ray 2-82	Middle Woodland	Female	29.8	Yes	Healed	Acute
Ray 2-83	Middle Woodland	Male	31.4	Yes	Healed	Diffuse
Ray 3-18	Middle Woodland	Probable Female	No Age Data	No	Mixed	Diffuse
Ray 3-19	Middle Woodland	Male	36.9	Yes	Healed	Diffuse

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
Ray 3-36	Middle Woodland	Female	54.2	Yes	Healed	Diffuse
Ray 3-37	Middle Woodland	Male	31.7	Yes	Absent	Absent
Ray 3-38	Middle Woodland	Female	48.2	Yes	Mixed	Diffuse
Ray 3-39	Middle Woodland	Female	27.4	Yes	Healed	Acute
Ray 3-42	Middle Woodland	Probable Male	29.3	Yes	Absent	Absent
Ray 3-43	Middle Woodland	Probable Female	62.7	Yes	Absent	Absent
Ray 3-47	Middle Woodland	Female	33.8	Yes	Healed	Diffuse
Ray 3-48	Middle Woodland	Female	39.5	Yes	Healed	Acute
Ray 3-50	Middle Woodland	Probable Male	33.6	Yes	Mixed	Diffuse
Ray 3-71	Middle Woodland	Male	29.5	Yes	Mixed	Diffuse
Ray 3-76	Middle Woodland	Male	21.6	No	No Data	No Data
Ray 4-21	Middle Woodland	Male	36	Yes	Absent	Absent
Ray 4-22	Middle Woodland	Female	28	Yes	Absent	Absent
Ray 4-66	Middle Woodland	Probable Male	28.3	Yes	Absent	Absent
Ray 5-23	Middle Woodland	Male	25.4	Yes	Absent	Absent
Ray 5-24	Middle Woodland	Probable Female	30.5	Yes	Healed	Acute
Ray 5-25	Middle Woodland	Probable Male	15	No	No Data	No Data
Ray 5-26	Middle Woodland	Ambiguous	79.5	No	No Data	No Data

ID	Time Period	Sex	Transition Analysis Point Estimate	Used in Frailty Analysis?	Periosteal Lesion Activity	Periosteal Lesion Severity
Ray 7-34	Middle Woodland	Probable Male	69	Yes	Healed	Diffuse
Ray 75	Middle Woodland	Ambiguous	32.7	No	Healed	Acute
Ray 85	Middle Woodland	Female	33	Yes	Absent	Absent
Ray 86	Middle Woodland	Probable Male	No Age Data	No	Absent	Absent
Ray 90	Middle Woodland	Probable Male	38	Yes	Absent	Absent
Ray 92	Middle Woodland	Probable Female	28.4	Yes	Mixed	Acute
Ray 94	Middle Woodland	Female	26.6	Yes	Absent	Absent
Ray 95	Middle Woodland	Probable Female	28.5	Yes	Healed	Acute