


DIFFERENTIAL SURVIVAL AND SYSTEMIC STRESS IN THE ANCESTRAL
PUEBLO SOUTHWEST: A PALEOEPIDEMIOLOGICAL STUDY OF PUEBLO
BONITO AND HAWIKKU

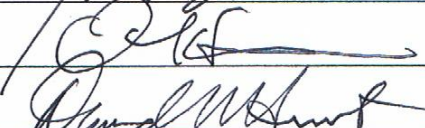
by

Allison C. Ham
A Thesis
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Master of Arts
Anthropology

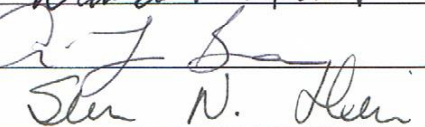
Committee:



Director



Department Chairperson



Dean, College of Humanities
and Social Sciences

Date:

May 2, 2018

Spring Semester 2018
George Mason University
Fairfax, VA

Differential Survival and Systemic Stress in the Ancestral Pueblo Southwest: A
Paleoepidemiological Study of Pueblo Bonito and Hawikku

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of
Arts at George Mason University

by

Allison C. Ham
Bachelor of Arts
The College of Wooster, 2014

Director: Haagen Klaus, Associate Professor
George Mason University

Spring Semester 2018
George Mason University
Fairfax, VA

Copyright 2018 Allison C. Ham

All Rights Reserved

DEDICATION

I dedicate this thesis to my grandmother, Marilyn Packard Ham.

ACKNOWLEDGEMENTS

This thesis would not have been possible without the support and encouragement from my loving family and friends, who have kept me sane throughout this past year. Additionally, I would like to thank my mentors at George Mason University, Haagen Klaus and Daniel Temple, who have been vital to the development of my professional career. Lastly, I would like to thank David Hunt and Christopher Dudar from the Smithsonian Institution, who were integral in the execution and completion of this study.

TABLE OF CONTENTS

	Page
List of Tables	viii
List of Figures	ix
Abstract	1
CHAPTER ONE	3
CHAPTER TWO	8
Linear Enamel Hypoplasia	8
Periosteal Lesions	13
Skeletal Growth and Development	19
The Osteological Paradox	24
Age-at-Death Estimation	28
Stationarity, Selective Mortality and Hidden Heterogeneity	31
Early Life Stress	37
Conclusion	39
CHAPTER THREE	41
Ecology of the Ancestral Pueblo Southwest	42
Modern Climate	42
Cultural Ecology and the Paleoenvironment of the Southwest	44
Paleoepidemiology and Paleodemography of the Puebloan Southwest	49
Biological Stress and Infection in the Pueblo Southwest	50
Biological and Demographic Implications of Contact	54
Case Studies	57
Pueblo Bonito	57
Hawikku	63
Conclusion	67
CHAPTER FOUR	69
Materials	69

Research Hypotheses.....	70
Methods.....	72
Sex Estimation.....	72
Age Estimation	73
Transition Analysis.....	73
Skeletal Indicators of Physiological Stress.....	75
Linear Enamel Hypoplasia.....	75
Periosteal Lesions	76
Osteometric Measurements	77
Stature Estimations	78
Body Mass Calculations	82
Statistical Analysis	83
Kaplan-Meier Survival Analysis.....	83
Skeletal Growth	85
Conclusion.....	85
CHAPTER FIVE	87
Biological Indicators of Stress Frequency Tables.....	87
Periosteal Lesions	87
Linear Enamel Hypoplasia	89
Kaplan-Meier Survival Analysis.....	91
Periosteal Lesions.....	91
Linear Enamel Hypoplasia	94
Adult Stature.....	96
Adult Body Mass.....	100
Subadult Growth Plot.....	103
Conclusion.....	105
CHAPTER SIX.....	106
Results of the Survival and Longitudinal Growth Analysis.....	107
Periosteal Lesions.....	108
Linear Enamel Hypoplasia	113
Adult Body Size – Stature and Body Mass	115
Subadult Longitudinal Growth Analysis	120

Paleodemography, Behavioral Ecology, and Physiological Stress	124
Conclusion.....	128
CHAPTER SEVEN	130
Summary of Major Findings	130
Limitations and Future Directions.....	131
Appendix A.....	133
References.....	147

LIST OF TABLES

Table	Page
Table 1 Adult Stature (cm) Equations for the Temperate Regional Group.	79
Table 2 Subadult Stature (cm) Prediction Equations for Lower Limbs.....	80
Table 3 Subadult Stature (cm) Prediction Equations for Upper Limbs.....	81
Table 4 Adult Body Mass Estimation (kg) Equations.	83
Table 5 Example of Sorted Table for LEH Kaplan-Meier Analysis.	84
Table 6 Frequencies of individuals with absent, active, mixed, and healed periosteal lesions from Hawikku sample.....	88
Table 7 Frequencies of individuals with absent, active, mixed, and healed periosteal lesions from Pueblo Bonito sample.	88
Table 8 Frequencies of individuals with absent, active, mixed, and healed periosteal lesions from both Hawikku and Pueblo Bonito samples.	89
Table 9 Frequencies of individuals with present and absent LEH from Hawikku sample.	89
Table 10 Frequencies for individuals with present or absent LEH for Pueblo Bonito sample.	90
Table 11 Frequencies for individuals with present or absent LEH for Hawikku and Pueblo Bonito samples.....	90
Table 12 Kaplan-Meier survival analysis results for periosteal lesions.	92
Table 13 Table 13 Kaplan-Meier survival analysis results for LEH.	94
Table 14 Kaplan-Meier survival analysis results for Male and Female stature.....	97
Table 15 Kaplan-Meier survival analysis results for Male and Female body mass.	101

LIST OF FIGURES

Figure	Page
Figure 1 Kaplan-Meier survival curve for periosteal lesions including Hawikku sample.	92
Figure 2 Kaplan-Meier survival curve for periosteal lesion including Pueblo Bonito sample.	93
Figure 3 Kaplan-Meier survival curve for periosteal lesions including Hawikku and Pueblo Bonito samples.	93
Figure 4 Kaplan-Meier survival curve for LEH including Hawikku sample.	95
Figure 5 Kaplan-Meier survival curve for LEH including Pueblo Bonito sample.	95
Figure 6 Kaplan-Meier survival curve for LEH including combined sample.	96
Figure 7 Kaplan-Meier survival curve for female stature (cm) including Hawikku sample.	98
Figure 8 Kaplan-Meier survival curve for female stature (cm) including Pueblo Bonito sample.	98
Figure 9 Kaplan-Meier survival curve for male stature (cm) including Hawikku sample.	99
Figure 10 Kaplan-Meier survival curve for male stature (cm) including Pueblo Bonito sample.	99
Figure 11 Kaplan-Meier survival curve for female body mass (kg) including Hawikku sample.	101
Figure 12 Kaplan-Meier survival curve for female body mass (kg) including Pueblo Bonito sample.	102
Figure 13 Kaplan-Meier survival curve for male body mass (kg) including Hawikku sample.	102
Figure 14 Kaplan-Meier survival curve for male body mass (kg) including Pueblo Bonito sample.	103
Figure 15 Skeletal growth trends for Hawikku and Pueblo Bonito.	104
Figure 16 Residual plot for skeletal growth trends at Hawikku and Pueblo Bonito.	104

ABSTRACT

DIFFERENTIAL SURVIVAL AND SYSTEMIC STRESS IN THE ANCESTRAL PUEBLO SOUTHWEST: A PALEOEPIDEMIOLOGICAL STUDY OF PUEBLO BONITO AND HAWIKKU

Allison C. Ham, M.A.

George Mason University, 2018

Thesis Director: Dr. Haagen Klaus

Recent advances in paleodemographic age estimation techniques and the integration of improved statistical methods into the bioarchaeological analysis of mortality and physiological stress has the potential to reveal levels of frailty and selective mortality within past populations. This study seeks to demonstrate how paleoepidemiological techniques can be used to advance our understanding of how behavioral and biological plasticity helped to mitigate the stressors caused by environmental perturbations in the Ancestral Pueblo Southwest. By examining two skeletal samples from the Ancestral Pueblo sites of Pueblo Bonito (A.D. 800-1200) and Hawikku (A.D. 1300-1680), this study tests the relationship between survivorship and the presence of periosteal lesions, linear enamel hypoplasia, and adult body size (i.e., adult stature and body mass). Additionally, skeletal growth trajectories are compared to adult body size to understand if smaller individuals died before reaching adulthood. Results of

the study indicate that individuals with healed periosteal lesions, no observed LEH, and males below average for body mass had an increased likelihood of survival, and therefore, a lower level of frailty. The skeletal growth analysis documented a probable stunting event occurring between the ages of 6 to 12, but does not appear to be indicative of selective mortality. These results demonstrate the advantages of applying a framework of mortality and survivorship, focusing on potential relationships with early life stressors and longevity, to the bioarchaeological analysis of skeletal indicators of stress in the past.

CHAPTER ONE

HISTORY OF PHYSIOLOGICAL STRESS IN BIOARCHAEOLOGY

In the early twentieth century, the study of archaeological skeletal remains was the domain of skeletal biology, which was mainly concerned with the description of individual cases of disease devoid of all archaeological context and classifications of humans into purported racial categories. However, by the mid twentieth century, the two fields began to depart from the predominate descriptive individualistic framework of disease, moving towards a more analytical, interpretive, and population-based approach (Armelagos, 1969; Buikstra and Cook, 1980; Cohen and Armelagos, 1984), prompting a joint consideration of biological and cultural factors in the study of health in past populations. During this period, the field of bioarchaeology developed as a regionally oriented interdisciplinary approach integrating mortuary analysis with human osteology to investigate biocultural change in archaeological populations (Buikstra, 1977).

Stress is a physiological process that has been defined and studied in numerous disciplines, including psychology, clinical medicine, and bioarchaeology (e.g., Cannon, 1934; Goodman et al., 1984a, Robert and Robert, 2015; Selye, 1950; Wright et al., 1998). It is broadly defined as the physiological disruption of an organism resulting from external perturbation (Goodman et al., 1984a; Hutchinson and Larsen, 1988). Early

definitions in bioarchaeology focused on the systemic nature of stress and its effect on the biological homeostasis of the human body. More recently, the definition of stress has been expanded to incorporate elements of evolutionary biology, life history theory, allostatic load, and anthropological theory, which have the potential to provide further insight into the relationship between stress and human behavior (Temple and Goodman, 2014). Of course, stress cannot be directly observed on the human skeleton. Pathological or otherwise altered skeletal phenotypes are the consequences of the physiological processes of stress that create the skeletal changes observed by bioarchaeologists.

To operationalize the study of health and biocultural change in archaeological populations, Goodman et al. (1984a) put forth a model of physiological stress, which suggested that stress is the product of three factors, environmental constraints, cultural systems, and host resistance. The purpose of the model was to provide a framework through which bioarchaeologists could test hypotheses about the interaction of humans with the environment as well as interpret the processes by which cultures can cause and respond to physiological stress. The model was later modified by Goodman and Armelagos (1989), which added a new output category – impact of stress on the population. This category included factors such as, decreased health, decreased work capacity, decreased reproductive capacity, and sociocultural disruptions. Additionally, the revised version demonstrated that these impacting components of stress feedback into the environmental and cultural mechanisms of the model.

The stress model developed by Goodman et al. (1984a) and Goodman and Armelagos (1989) focused on three main categories of biological stress, cumulative,

episodic, and specific disease, which encompassed skeletal indicators associated with physiological responses to stress in the human body. These well-established set of skeletal pathological conditions, along with other skeletal phenotypes such as growth and stature (e.g., Goodman et al., 1984a; Goodman and Martin, 2002) were used to measure and reconstruct the degrees of biological stress in once-living populations. Using simple frequency (or crude prevalence) data, bioarchaeologists devised quantitative studies of health, which contrasted with the prior fixation on the mere identification and description of disease.

Within this framework, the comparative study of skeletal samples and the temporal assessment of health during social, ecological, and cultural changes became the primary concentration of the discipline (Baker and Kealhofer, 1996; Cohen and Armelagos, 1984; Cook, 1981; Goodman and Armelagos, 1985; Hutchinson and Larsen, 1988; Larsen, 1994, 1995; Larsen and Milner, 1994; Merbs, 1989; Verano and Ubelaker, 1992). Furthermore, bioarchaeologists conducted cross-comparative studies using prevalence data to measure the differing “levels of health” between past populations. To accomplish population-level studies, paleodemographic evidence was used to further contextualize the data and find nuances in the results by including information on demographic variables, such as age and sex distributions, and less commonly, fertility and mortality (Armelagos, 1969; Cook, 1981; Goldstein, 1953; Goodman et al., 1984a, b; Lallo et al., 1978; Nelson et al., 1994; Palkovich, 1978, 1984a, b; Stodder, 1990).

The paleodemographic life table approach was the principle method used to conduct these cross-comparative bioarchaeological studies, but the application of the

technique received criticism for its inability to address the conceptual issues of hidden heterogeneity, selective mortality, and demographic non-stationarity (Cook, 1981; Vaupel et al., 1979; Wood et al., 1992). Hidden heterogeneity (i.e., frailty), refers to differential mortality risk expressed by individuals within a population that may not be observed in a skeletal sample, thus, hidden. Selective mortality acts on hidden heterogeneity and is the primary force involved in the formation of the death assemblage. Therefore, archaeological skeletal samples are not accurate representations of the once-living population. Demographic non-stationarity assumes that a population is open to migration and has an unfixd birth and death rate. The elucidation of these conceptual issues posed a problem to the bioarchaeological interpretation of health in once-living populations, and has recently instigated a plethora of literature and research seeking to address these conceptual and technical issues.

Within bioarchaeology, various scholars have recognized the slow pace at which the field has adopted new paradigms. Zuckerman et al. (2016) argued that the bioarchaeological delay in the adoption of epidemiological concepts and methods has compromised the field. For example, the assumption made by earlier studies that the apparent rarity of cancer in antiquity reflects its relative absence in the past demonstrates a failure to apply epidemiological concepts to analyses of frequency (Lieverse et al., 2014; Zuckerman et al., 2016). Klaus (2014b) also argued for the importance of adopting epidemiological approaches in the calculation and interpretation of lesion frequency between skeletal samples by demonstrating the effect of age-at-death on crude prevalence and the conceptual flaws of using this technique to interpret stress patterns. Although

implementation has been slow moving, bioarchaeologists have begun to more commonly apply epidemiological approaches to the study of skeletal indicators of stress, such as linear enamel hypoplasia (LEH) and periosteal lesions, along with the assessment of skeletal growth, stature, and body mass, and have demonstrated the utility for evaluating the effects of stress on mortality and survivorship in the archaeological record (DeWitte, 2014a, 2015; DeWitte and Wood, 2008; DeWitte et al., 2013; Kemkes-Grottenthaler, 2005; Reitsema et al., 2016; Sandberg et al., 2014; Temple, 2014; Usher, 2000; Vercellotti et al., 2011; Wilson, 2014; Yaussy et al., 2016).

Furthermore, use of the term 'health' in bioarchaeological analyses has been critiqued. Health is not a concept that can be investigated through the presence or absence of skeletal lesions because of its association with a self-perception of well-being along with a far more complex and holistic range of variables that contribute to health as a biocultural phenomenon. Therefore, it has been argued that bioarchaeologists should analyze skeletal indicators of stress using a framework of mortality and survivorship, focusing on potential relationships with early life stressors and longevity (Temple and Goodman, 2014). This study seeks to contribute to the recent trend in the bioarchaeological literature to address physiological stress through the consideration of early life stress and its effect on survivorship through the elucidation of heterogeneous frailty and selective mortality in two skeletal samples from the Ancestral Pueblo Southwest. Furthermore, this work contributes to the broader understanding of how Ancestral Pueblo communities mitigated the stressors of a harsh desert environment through behavioral and biological plasticity.

CHAPTER TWO

SKELETAL INDICATORS OF STRESS AND DISEASE: MORTALITY AND LIFE HISTORY INFERENCES

This chapter discusses the relevant bioarchaeological literature on periosteal lesions, linear enamel hypoplasia (LEH), body size, and skeletal growth by providing a summary of the research completed on the topics and proposed etiologies. The chapter addresses the notable conceptual and technical dilemmas faced by bioarchaeologists when evaluating mortality and physiological stress in archaeological skeletal assemblages, and the historic challenges and current improvements in age-estimation methods. Specifically, the chapter examines the issues discussed by Wood et al. (1992), and the influence of the osteological paradox on the bioarchaeological inference of physiological stress in the past. Lastly, the chapter addresses the new techniques and theoretical frameworks that have emerged capable of engaging and effectively transcending some of the shortcomings in concepts, theory, and methods faced by the discipline.

Linear Enamel Hypoplasia

Linear enamel hypoplasia (LEH) is a developmental defect that creates abnormal grooves and furrows on tooth crowns. It is characterized by a dearth in the amount or

thickness of enamel. Enamel forms by laying down a sequence of regularly spaced grooves that eventually create the crown cusps and the occlusal surface of the teeth. These grooves, also known as striae of Retzius, are called perikymata, and represent each depositional enamel event on the surface of the tooth (Goodman et al., 1984a; Hillson, 2014; Hutchinson and Larsen, 1988; King et al., 2005; Larsen, 2015). LEH is formed when insufficient enamel is deposited during the secretory phase of amelogenesis and is the result of a physiological disruption that affects the process of tooth crown formation in infancy and childhood. LEH are commonly observed on anterior teeth, specifically on the cervical and middle thirds of the tooth crowns, which is attributed to the geometric crown structures of different teeth. For example, the steep gradient in perikymata spacing on molar crown surfaces makes it difficult to observe defects on posterior maxillary and mandibular teeth (Hillson, 2014; Hillson and Bond, 1997; King et al., 2005). Ameloblasts are the cells responsible for the formation of the enamel matrix, and are highly sensitive to physiological perturbations during childhood that disrupt normal patterns of secretion (Hillson, 2014).

LEH formation is non-specific, but has three known broad categories of causative mechanisms: hereditary anomalies, localized trauma, and systemic physiological stress, such as nutritional deficiencies and infectious disease (Goodman and Rose, 1990, 1991; Hillson, 2014; Larsen, 2015; Nikiforuk and Fraser, 1981; Schultz et al., 1998). The archaeological documentation of hereditary anomalies and trauma causing LEH are rare, and can be differentiated from defects caused by metabolic disruptions based on patterning. Localized trauma tends to only affect one or a few adjacent teeth, whereas as

hereditary anomalies cause all teeth to be impacted. Defects caused by a metabolic stress event are likely to be present on most or all teeth developing at the time of the episode. (Goodman and Rose, 1990, 1991; Hillson, 1992; Hillson and Bond, 1997; Nikiforuk and Fraser, 1981). Therefore, LEH formation is frequently associated with relatively acute episodic growth disruptions caused by systemic physiological stress. In clinical studies, LEH has a high prevalence in children from underdeveloped countries, famine populations, and rural communities (Goodman and Rose, 1991; Larsen, 2015; Nikiforuk and Fraser, 1981; Zhou and Corruccini, 1998). Archaeologically, it has been demonstrated that increases in LEH prevalence correlates globally with populations undergoing dietary, settlement, and behavioral shifts (Larsen, 2015).

The relatively indelible nature of enamel has made LEH a commonly employed non-specific indicator of stress in bioarchaeological studies. Since enamel does not remodel after the disruption occurs, the defect represents a permanent sign of an episodic systemic metabolic disruption. Furthermore, bioarchaeologists can determine the frequency, age of occurrence, duration, and periodicity of each enamel defect, which can be used to compare different archaeological samples (King et al., 2002; King et al., 2005). For example, by using LEH prevalence and duration, Temple et al. (2013) demonstrated the advantages in evaluating the stress experiences of hunter-gatherer societies in relation to unique dietary and ecological conditions – rather than assuming homogeneity among these skeletal samples. Consequently, Temple et al. (2013) argued that episodes of stress cannot be solely studied through the evaluation and comparison of

subsistence strategies, and advocated for the consideration of biocultural factors and in the role of the human ability to resist stress events.

Macroscopic techniques have been commonly used in bioarchaeology to document the presence of LEH in archaeological assemblages and to compare the frequency of physiological stress by sex, social status, age, and between sample or population comparisons (Cook, 1981, 1984; Klaus and Tam, 2009, 2010; Smith et al., 2016; Temple et al., 2013; Wilson, 2014). This technique has been a crucial interpretive tool in the investigation of differential early developmental stress across archaeological samples, and has established important geographic and temporal differences in the presence of developmental stress that transpires during tooth formation. One of the major issues with the macroscopic approach, however, is that it requires the defect to be large enough to observe with the naked eye. Therefore, the macroscopic observation fails to document enamel defects that are only visible microscopically.

In recent years, microscopic techniques have been applied in multiple modern bioarchaeological studies (Hillson, 1992; Hillson and Bond, 1997; Hutchinson and Larsen, 1988; King et al., 2002; King et al., 2005; Temple et al., 2013; Temple, 2016). One benefit to the microscopic approach is the ability of the observer to accurately estimate age-at-defect formation, the duration of the episodic event, and identify more defects. The accurate estimation of these two factors allows bioarchaeologists to use LEH to establish chronologies of metabolic stress events for an individual. To determine age-at-defect and episodic duration, the microscopic technique uses perikymata groove counts to provide a chronology of the defects seen on the tooth crown and of the sequence of

crown formation. The accurate documentation of LEH duration is one of the major improvements inherent to the microscopic approach.

Hillson and Bond (1997) argued that the macroscopic method results in the overestimation of duration, because the macroscopic interpretation of duration relies on the measurement of the full defect. The authors used a microscopic technique to demonstrate that the disturbance in the perikymata only affects the occlusal wall of the defect and the disturbances in the floor and cervical wall are produced by the recovery. Therefore, only the occlusal wall of the defect is representative of the duration of the episodic stress event. Temple (2016) investigated age-at-defect formation and LEH periodicity among the Jomon peoples of Japan from the Late/Final Jomon periods, and compared the results to previous LEH macroscopic studies from other regional sites, including Coastal Honshu, Inland Honshu, and Hokkaido. The results of Temple (2016) provided important evidence for how microscopic approaches can increase the accuracy of estimating age-at-defect and periodicity.

Within bioarchaeology, one of the core touchstone research foci involves the effects of the transition from hunting and gathering to agriculture and associated trends in biological stress. Generally, comparative studies of skeletal samples drawn from populations undergoing a transition from foraging to an agricultural system reveal an increase in the frequency of enamel defects. Although, this trend is not universal, it has been observed in studies of diverse archaeological samples from around the world, including North America (Cook, 1984; Goodman et al., 1984b) and Latin America (Ubelaker, 1984). However, Hutchinson and Larsen (1988) documented no clear pattern

of frequency change between the precontact and postcontact (maize-dependent) skeletal groups at St. Catherines Island in the American Southeast. However, the results also indicated an increase in the length of duration for stress episodes between the two categories, which was interpreted as reflecting an overall decrease in the quality of life among the postcontact maize-dependent agriculturalists. The results of Hutchinson and Larsen (1988) demonstrated the value in evaluating factors other than frequency when examining LEH within archaeological samples.

The continued improvement of microscopic techniques increases the quality of the bioarchaeological interpretations of LEH. The incorporation of more accurate estimations for age-at-defect, duration, frequency, and periodicity has led to improved inferences about survivorship, mortality, and early life stress in past human groups. The chapter addresses the intersection of LEH and early life stress in a subsequent section.

Periosteal Lesions

Periostosis (i.e., periosteal lesions) is a morphological syndrome that encompasses a basic osseous response in the wake of an inflammatory process that results in new abnormal bone formation (Klaus, 2014b; Larsen, 2015). While any bone can be affected, periosteal lesions are most commonly observed in the human skeleton on the medial or lateral surfaces of the tibia. Periostosis appears as a thin plaque of highly porous, highly vascularized reactive new bone formation on the diaphysis of a long bone, which eventually becomes lamellar bone (Ortner, 2011; Ragsdale et al., 1981; Weston, 2008, 2012). In other words, the active form of periostosis presents as loosely organized bone. The inactive, or the healed form, remodels the new skeletal tissue into normal cortical

bone, resulting in the surface of the bone appearing abnormally smooth, undulating, and thickened (Larsen, 2015; Ragsdale et al., 1981).

Inflammation plays an important role in the etiology of periosteal reactions, and commonly occurs when vascularized tissue responds to trauma, neoplastic disease, or infectious pathogens. Inflammation is a protective mechanism that attempts to neutralize an invasive organism or heal tissue damage, and is vital to human survival (Kumar et al., 2018). When this occurs, the blood vessels widen, fluid exudes, and phagocyte recruitment ensues at the site of inflammation. Additionally, infection damages the cells by accelerating its normal process of cell disposal and renewal. This acceleration causes an increase in cell turnover that appears as inflammation (Ragsdale and Lehmer, 2012; Weston, 2008). In the past, many bioarchaeological studies used periosteal lesions as non-specific indicators of infection, and although infection is a common cause of new bone formation, it is not the only catalyst (Klaus, 2014b; Weston, 2008, 2012).

Periosteal lesions are ubiquitous in the archaeological skeletal record, and it is for this reason that the reactions are commonly used as a general indicator of infection and physiological stress in the bioarchaeological literature. While periosteal lesions can be caused by trauma, these lesions are differentiated by a localized, small, and non-destructive nature. Whereas, lesions produced by infectious agents tend to be more widespread and occur bilaterally (Larsen, 2015). As with LEH, bioarchaeologists have used the crude prevalence patterns of periosteal lesions as a technique through which to analyze major cultural-ecological shifts, such as the transition from foraging to agriculture within past societies. A higher prevalence of periosteal lesions may reflect a

greater exposure to infectious pathogens, which would elevate levels of biological stress, and therefore, weaken the immunocompetence of the body. The bioarchaeological research has used this connection to study the association between the shift to agriculture and an increase in the frequency of periosteal lesions within skeletal assemblages.

A classic study of lesions was conducted by Lallo et al. (1978). Lallo and colleagues interpreted the Dickson Mounds skeletal sample in the Illinois River valley, hypothesizing that cultural-ecological alterations (i.e., an increased reliance on agriculture, increased population density and sedentism, and the growth of regional trade patterns) associated with the agricultural transition impacted the biological status of the population. By examining the skeletal assemblage, Lallo et al. (1978) sought to address the effects of these cultural-ecological changes on the biological characteristics of these people, specifically focusing on the frequency of infectious disease by recording the presence of periostosis and osteomyelitis. Based on the frequency data, Lallo et al. (1978) argued that the Middle Mississippian sample possessed higher frequencies of infectious disease, contracted the diseases at a younger age, and were more severely affected by them. Furthermore, the authors applied paleodemographic techniques by using a life table approach to determine the relationship between an increase in infection and mortality. While today such an uncritical use of a life table is highly problematic, these findings still demonstrated those with lesions shared a significantly higher rate of mortality, a higher probability of dying, and a lower life expectancy in the Middle Mississippian population than that of the Mississippian Acculturated Late Woodland population.

Goodman et al. (1984b) built on this earlier work by evaluating how the cultural and ecological trends associated with the transition to agriculture impacted the health of the skeletal sample excavated at Dickson Mounds. Similar to Lallo et al. (1978), the authors documented an increase in stress between cultural periods through the documentation of an increased frequency of infection through the recording of periostitis and osteomyelitis in the skeletal assemblage. The percentage of individuals with infectious lesions almost doubled from the low-intensity agricultural skeletal sample to the high-intensity sample. The study also utilized the life table approach to assess age-at-death information. The results of the life table documented and increased risk of dying from the Late Woodland to the Middle Mississippian cultural periods, supporting the earlier conclusions of Lallo et al. (1978). Based on the evidence of stress and mortality, Goodman et al. (1984b) concluded that the cultural and ecological trends associated with the transition to agriculture resulted in an overall decrease in health at Dickson Mounds.

In the American Southeast, the Mission period followed the arrival of the Europeans. For native peoples, there was a shift in subsistence favoring a maize dominated diet as part of the colonial subsistence economy. During this time, there was also a change in settlement patterns and population density. The frequency of periosteal lesions of the tibiae increased greatly from the early to late mission periods, which has been attributed to the relocation and increased concentration of Native American populations (Larsen, 2015). The increase in infection rates could be associated with the fact that a strong relationship exists between nutritional deficiency and infection. Poor nutritional status can lead to a compromised immune system, which reduces resistance to

infection. A strong immune system requires the dietary intake of an individual to be both of a high quantity and quality (Ulijaszek, 1996).

In addition to major cultural-ecological transitions, periosteal lesions have also been analyzed by examining differences between sex and social status. The bioarchaeological evidence suggests that within a skeletal sample different cohorts are not effected by stress in the same way. These differences are explained through biocultural factors that are unique for each circumstance. For example, Klaus and Tam (2009) compared levels of systemic stress in pre-Hispanic and postcontact skeletal samples from Mórrope, Peru. The study observed an increase in periosteal lesions in the postcontact adults with females displaying a significantly higher periosteal lesion frequency compared to the men of the sample. The authors argued that the difference between the two sexes could be explained by the role Andean women played in the colonial period economy, which is supported by both bioarchaeological and historical evidence. Klaus et al. (2017) analyzed differences in periosteal lesions based on status by examining stress discrepancies between the non-elite and elite individuals from the Middle Sicán culture on the north coast of Peru. The study found an elevated level of periosteal lesions among the non-elite individuals, demonstrating the biological consequences of social hierarchy within the Middle Sicán culture.

Although periosteal lesions are widely used as a non-specific stress indicator, Weston (2008) tried to move the bioarchaeological community away from using the term non-specific indicator of infection for periosteal new bone formation, arguing that its use overestimates infectious disease prevalence within archaeological skeletal samples.

Furthermore, there is disagreement on whether periosteal lesions can be used a general indicator of stress (Weston, 2012; Klaus, 2014b). Weston (2012) argued against periosteal lesions as a stress indicator based on how glucocorticoids participate in the physiological response to stress – stress stimulates glucocorticoid secretion, which inhibits new bone formation. Therefore, periosteal lesions cannot be the result of physiological stress processes.

Klaus (2014b) questioned the argument of Weston (2012) by pointing out that when evaluating periosteal lesions, modern studies consider infection as well as other potential bone forming disorders, such as localized trauma, fluorosis, treponemal disease, scurvy, rickets, and tuberculosis. When these disorders are ruled out, however, non-specific response remains a valid option. Furthermore, the prevention of new bone formation by glucocorticoid secretion, while plausible, is only one element in the secondary regulatory axis involving stress, growth factors, hormones, and new bone formation (Klaus 2014b, p. 296). For instance, Klaus (2014b) addressed the association of periostosis with the stress hormone, leptin, and its role in the inhibition of osteoblastic activity. Klaus (2014b) argued that leptin does not terminate new bone formation, but rather restricts its location. In other words, periosteal bone can form as part of a broader stress event and perhaps as an element of the latter resolution stages of a pathologic inflammatory process that disrupts the periosteal membrane (Klaus 2014b). Larsen (2015) also argued that periosteal lesions serve as an important non-specific stress indicator, emphasizing that the biocultural contexts (e.g., declining mobility, increased

sedentism, and population aggregation) of the archaeological cultures studied suggest that the observed periosteal new bone formation is most likely related to infection.

Skeletal Growth and Development

In bioarchaeology, long bone measurements from archaeological assemblages are used to estimate stature and body mass for the interpretation of human skeletal growth and development in past cultures. When evaluating growth, it is important to recognize that subadults within a skeletal assemblage are representative of non-survivors, meaning that these individuals did not survive to adulthood and may not represent the body size of living individuals. However, it has been demonstrated that short stature in non-survivors is not necessarily reflective of an increased risk of morbidity in subadults (Saunders and Hoppa, 1993).

Human growth is a non-linear process that goes through rapid and gradual periods of activity, which is represented by the rate or velocity of skeletal growth. The first period of high velocity growth occurs during infancy and drops precipitously off after two years of age. The second phase occurs as part of adolescence. After reaching full maturity (marked by the epiphyseal fusion of the long bones), growth velocity drops to zero (Bogin, 1998). Deficits in growth are evaluated through measurements of height-for-age and weight-for-age, and are referred to as stunting/stunted and wasting/wasted, respectively (Saunders and Hoppa, 1993).

Growth curves are based on polynomial equations that develop a best-fit line of the average long bone lengths/diameters of each age group. Polynomial equations are important to the accurate study of growth, because these methods compensate for the

non-linear trend in human growth rates. Comparative studies between samples are often done to evaluate geographic, temporal, cultural, and economic variability in the growth and development of past populations. To accurately assess growth between temporally distinct groups, bioarchaeologists develop and compare sample-specific growth curves. The comparison of sample-specific growth curves can identify which group was growing faster and larger. By identifying sharp declines in growth curves, bioarchaeologists can identify stress events. Growth curves can be studied (perhaps best examined) in accordance with skeletal indicators of stress and disease such as LEH and periosteal lesions, to better interpret how the human body responds to social, ecological, and dietary changes.

The analysis of cortical bone thickness is another measurement used by bioarchaeologists to evaluate human growth in archaeological samples. Cortical bone growth can be used to indicate the nutritional environment of an individual, relying on the assumption that undernourished children experience elevated endosteal resorption as opposed to subperiosteal deposition, resulting in the thinning of the cortical section. Adequacy of nutrition and the socioeconomic status of an individual are intertwined, as demonstrated by Mays et al. (2009) and among many others in bioarchaeology and human biology. Mays et al. (2009) established a relationship between cortical thickness and the burial context of the individual, citing nutritional differences between socioeconomic statuses as a contributing factor. Similarly, Cook (1984) used radiographic data on cortical bone diameters from west central Illinois to examine the effects of changing food production practices on the health of the population. The results

of this study attributed observed bone loss (decrease in cortical thickness) to the decrease in nutrition caused by new food production practices in the region.

While Mays et al. (2009) and Cook (1984) provided important insight into the interaction between nutrition and skeletal growth, the studies failed to consider other factors that affect cortical thickness. Mechanical loads placed on the human body, through body weight or elevated physical activity loads (e.g., habitually strenuous labor) can cause cortical bone to remodel (Ruff et al., 2013). Therefore, both the biomechanical and nutritional environment of an individual has the potential to disrupt the process of bone growth and development.

Growth faltering has long been associated with limited nutrient supply. When an individual experiences nutritional and dietary deficiencies, the body compensates by reallocating energy from skeletal growth to the maintenance of tissue development. Skeletal growth is also affected by other elements, such as environmental perturbations, infection, and sociocultural factors (Bogin and MacVean, 1983; Bogin and Loucky, 1997; Cook, 1984; Eveleth and Tanner, 1990; Johnston, 1962; Klaus and Tam, 2009; Lovejoy et al., 1990; May et al., 2009; Steckel, 1986, 1995; Tanner, 1976, 1981; Tanner et al., 1966; Temple et al., 2014; Tomkins et al., 1988). A plethora of bioarchaeological literature has been produced on the effects of the increased stress loads, European infectious diseases, and undernutrition associated with major cultural-ecological transitions and its relationship to the disruption of human growth and development (Larsen, 2015). Furthermore, both clinical and bioarchaeological research has provided strong evidence to associate growth faltering during childhood to short statured adults

(Bailey et al., 1984; Bogin and MacVean, 1983; Kemkes-Grottenthaler, 2005, Larsen, 1995, 2015).

Environmental and genetic factors both play a role in the determination of terminal height. Major differences in stature between skeletal samples can be related to genetic components. For example, Becker et al. (2011) demonstrated that the major differences in average stature between African Pygmy and non-Pygmy groups is most likely due to genetic factors. However, it is difficult to separate the genetic elements from the environmental components. Similar to subadult growth, terminal stature is associated with socioeconomic and dietary circumstances (Boldsen, 1995; Kemkes-Grottenthaler, 2005; Leonard et al., 2002). Therefore, the social status of an individual influences achieved stature due to differential access to resources within the society (Vercellotti et al., 2011).

Stress events can affect skeletal growth and development, but these results are not necessarily permanent. If an individual experiences a dietary shortage and is suddenly provided with adequate resources, catch-up growth may occur. The term 'catch-up' in this scenario refers to the acceleration or prolongation of growth to correct for earlier imbalances (Stinson, 2012). This phenomenon was demonstrated by Steckel (1986) through the analysis of growth data from enslaved Africans collected from historic auction records. The results of the study demonstrated that male slaves received meat when they started performing hard labor at the age of 14, and the introduction of meat into the diet coincided with a sharp movement towards the standard growth pattern. Although faster growth occurs, almost all individuals who experience this phenomenon

never completely catch-up to the standard (Stinson, 2012). Therefore, when considering skeletal growth and development it is vital to also investigate biocultural experience.

In addition to using terminal stature, Ruff et al. (2013) argued that bioarchaeologists should also use the estimation of body mass to evaluate growth and development in skeletal assemblages. The estimation of both stature and body mass (i.e., the estimation of body size) has the potential to elucidate information on the environmental and genetic effects of these factors in the past. The relationship between social status and body size in an Italian Medieval skeletal sample was explored by Vercellotti et al. (2011). The study found a significant difference in male stature and body mass between the high and low status groups, with the low status males deviating from the expected growth patterns of the sample.

The association between terminal stature and mortality has also been examined within the bioarchaeological literature. DeWitte and Hughes-Morey (2012) observed that during the Black Death in medieval London, adult individuals who were below average stature and buried in epidemic cemeteries had an increased risk of mortality, whereas individuals buried in a non-epidemic context showed no association between risk of mortality and stature. Similarly, Kemkes-Grottenthaler (2005) established a relationship between taller individuals and an increased survival advantage using data collected from the skeletal remains of European individuals spanning from A.D. 500 to A.D. 1900. The association between shortened stature, decreased survivorship, an increased risk of mortality, and its potential relationship to the effects of early life stress on childhood development is discussed later in the chapter.

The Osteological Paradox

The publication of Wood et al. (1992) argued that there were flaws in the use of archaeological skeletal material in the interpretation of ‘health’ in once-living populations. The term the ‘osteological paradox’ was coined from the title of the article and refers to the simple fact that archaeological skeletal assemblages are biased samples, representing the frailest members of the population (i.e., the non-survivors). A skeleton with an absence of lesions cannot be interpreted in an *a priori* fashion as being ‘healthier’ than an individual with lesions. Therefore, the assumption that a high prevalence of lesions and differences in average body size within a skeletal assemblage accurately reflects the stress experience within the once-living population may be flawed.

Wood et al. (1992) had significant implications for the study of physiological stress and mortality inferences from archaeological skeletal assemblages, outlining the conceptual issues of selective mortality, hidden heterogeneity, and demographic non-stationarity. Prior to Wood et al. (1992), many paleopathologists and bioarchaeologists had recognized these conceptual flaws in the paleodemographic techniques used in the study of mortality (Bocquet-Appel and Masset, 1981; Vaupel et al., 1979; Vaupel and Yashin, 1985; Cook, 1981). However, Wood et al. (1992) had an unprecedented effect on the shaping of current approaches and new horizons in the study of mortality for paleodemography, bioarchaeology, and paleopathology (DeWitte and Stojanowski, 2015).

The critique of the bioarchaeological interpretation of the agricultural transition presented by Wood et al. (1992) was intensely debated within the bioarchaeology

community. Controversy surrounded the reevaluation of the conclusion reached by Cohen and Armelagos (1984) that the transition to agriculture commonly led to a rise in morbidity and an overall decline in health. As discussed previously, during the mid to late twentieth century the agricultural transition emerged as a primary focus of bioarchaeology. Specifically, researchers were interested in the association between the transition and cultural-ecological trends, and the effects on health and stress. Furthermore, bioarchaeologists increasingly relied on the documentation of physiological stress as a tool in the evaluation of health in past populations. As previously mentioned, Goodman et al. (1984a) outlined a model of the major causes and results of physiological stress, demonstrating its relationship with environmental constraints, cultural systems, and host resistance. The goal of Goodman et al. (1984a) was to provide a model for the bioarchaeological interpretation of patterns of stress within past populations.

Goodman et al. (1984a) also considered the relationship between stress and mortality, arguing that the establishment of sample-derived age distributions could be used to infer the relationship between stress and fluctuations in mortality. General age distribution patterns for human mortality were generated from studies completed on modern and historical industrial populations. The general pattern showed an increased level of mortality in infancy that decreased in puberty and increased again in the later ages (Wood et al., 2002). Therefore, bioarchaeologists could infer general fluctuations in mortality by comparing sample-based age distributions against the established general pattern. The evaluation of physiological stress and mortality served as an important analytical tool in the inference of general trends in health associated with major cultural-

ecological changes. The application of this technique to the assessment of the transition to agriculture culminated in the classic volume by Cohen and Armelagos (1984).

Wood et al. (1992) argued for the flaws in the interpretation of the agricultural transition by discussing the conceptual issues of selective mortality, hidden heterogeneity, and demographic non-stationarity. Specifically, Wood et al. (1992) critiqued the assertion of Cohen and Armelagos (1984) that a reduction in the average age-at-death and a rise in the frequency of skeletal indicators of stress reflected an overall decrease in health. Wood et al. (1992) conceded that Cohen and Armelagos (1984) may be correct, but argued that with the consideration of selective mortality, hidden heterogeneity, and demographic non-stationarity that an alternative interpretation was equally valid. For instance, the mean age-at-death data used by Cohen and Armelagos (1984) to argue for reduced survival, may in fact reflect an increase in fertility within the population (Sattenspiel and Harpending, 1983). Furthermore, Wood et al. (1992) suggested that the elevation in the frequency of stress indicators could be a representation of an increase in survival rather than an increase in mortality.

The controversial nature of the assertions of Wood et al. (1992), are demonstrated by the vehement rejections of the article by Goodman (1993) and Cohen (1994). Goodman (1993) reviewed the errors in the discussion of selective mortality and frailty by Wood et al. (1992), arguing that the models used in the article ignored cultural processes, contradicted biologically known processes, left out key information, and relied heavily on assumptions that were mathematically proven but biologically improbable (p. 286). Goodman (1993) even went as far as calling Wood and colleagues scientific snobs.

Similarly, Cohen (1994) denied assertion by Wood et al. (1992) that the skeletal evidence of the agricultural transition could reflect an overall improvement in health. Instead, Cohen (1994) argued that mortality is largely non-selective, and therefore, archaeological assemblages can be interpreted as accurate representations of once-living populations. In reply to Goodman (1993) and Cohen (1994), Wood and Milner (1994) restated that the purpose of the osteological paradox was not to disprove the interpretation of Cohen and Armelagos (1984), but to reveal how the assumptions made by bioarchaeologists and paleopathologists about archaeological samples have inferential implications that cannot be ignored.

Wood et al. (1992) had an unprecedented and unparalleled effect on the study of mortality for paleodemography, paleopathology, and bioarchaeology (DeWitte and Stojanowski, 2015). The article instigated a new branch of research seeking to address the issues presented and had serious implications for the interpretation of archeological assemblages. One of the major contributions of Wood et al. (1992) was the suggestion that the presence of periosteal reactions and stature can be evaluated using a framework of survivorship and mortality risk. Consequently, paleopathologists and bioarchaeologists continue to grapple with how to address and integrate these elements into the study of mortality in past populations.

Bioarchaeologists encounter various issues when interpreting and comparing biological stress patterns within and between archaeological skeletal samples. If archaeological samples are inherently biased, how can bioarchaeologists interpret markers of biological stress in the archaeological record? What are the implications of

this bias on the development of mortality patterns? In recent years, the simplistic reliance on the frequency of skeletal lesions has been heavily critiqued (Klaus, 2014b; Lieverse et al., 2014; Ortner, 1991; Wood et al., 1992; Zuckerman et al., 2016). In addition, the methodological value of the traditional paleodemographic life table approach has been reevaluated. The subsequent section reviews age-at-death estimations, stationarity, selective mortality, and hidden heterogeneity and the critical methodological challenges these topics present for the bioarchaeological interpretations of mortality patterns in the past.

Age-at-Death Estimation

Historically, paleodemographic studies commonly relied on the construction of life tables to reconstruct demographic variables from skeletal samples. Life tables were used to create age-at-death profiles to establish long-term mortality patterns for skeletal assemblages (Hoppa, 2002; Wood et al., 2002). Cohen and Armelagos (1984) defended the use of life tables for archaeological skeletal assemblages by briefly addressing the four main assumptions of the technique – (1) skeletal assemblages are representative of the population, (2) no population growth occurs, (3) there is little or no meaningful stochastic fluctuation in population size, and (4) age-at-deaths are accurately estimated. The authors stated that the benefits of the life table approach outweighed the critiques, arguing that life table analyses have frequently led to interpretable and meaningful bioarchaeological conclusions. As demonstrated prior, these assumptions formed the basis for the reevaluation of bioarchaeological inferences on stress and mortality in the past (Wood et al., 1992).

With the life table approach, age estimation is completed on an individual level through the analysis of measureable skeletal morphological features, such as cranial sutures, the process of dental wear, and the age-related degeneration of the pubic symphysis (Kemkes-Grottenthaler, 2002). Individuals are then placed into broad age categories, which are aggregated and then distributed into a life table. This distribution of age-at-death has been used to make inferences about once-living populations through the estimation of age-specific mortality rates, average age-at-death, and lifespan (Hoppa, 2002; Thomas, 2003).

As stated previously, age estimation techniques for archaeological skeletal assemblages have relied heavily on the use of morphological age markers to build broad age categorizations. The use of this method produces a high-rate of error in the estimation of age-at-death, particularly in the older age categories. This is a result of the ambiguity in morphological traits associated with senescence. Another difficulty with this technique is the tendency of age estimations to mimic the structure of the known-age reference samples used to create the age categories (Boldsen et al., 2002). The integration of statistical techniques into age estimation has provided a strategic method for handling these two issues.

Transition analysis (Boldsen et al., 2002) is one of the most recent advances in age estimation techniques within bioarchaeology and paleopathology. This technique integrates statistical modeling with age-related characteristics to create an age-at-death distribution that can expand the limit of age estimations for the skeletal sample. In addition, transition analysis can calculate the probability of the age-specific risk of dying

for each skeleton using the population density function (PDF), where a is the age of the skeleton and c_j is the set of skeletal traits observed in the j -th skeleton of the sample.

$$\Pr(a | c_j)$$

The technique differs from the traditional age estimation methods through its identification of skeletal traits that change in an age-specific manner. These traits are defined using skeletal morphological features of the cranium and pelvis taken from a reference sample. The reference sample is used to generate the probability that a skeleton will display an age-related stage of one or more skeletal traits based on the known age-at-death and is represented by the function:

$$\Pr(c_j | a)$$

$\Pr(a | c_j)$ can be derived from estimates of $\Pr(c_j | a)$ using Bayes's Theorem:

$$\Pr(a | c_j) = \frac{\Pr(c_j | a)f(a)}{\int_0^{\infty} \Pr(c_j | x) f(x)dx}$$

In the equation above, $f(a)$ is representative of the age-at-death distribution of the archaeological skeletal assemblage under investigation (Baldsen et al. 2002, p. 76-77).

The ability of transition analysis to expand the limit of age estimations has important implications to produce mortality patterns in archaeological skeletal samples.

Milner and Baldsen (2012) conducted a validation study of the technique using individuals with known-ages from the Bass Donated Collection and Mercyhurst forensic cases. The study had varying levels of success. For example, cranial sutures were found to have little to no age-related significance, the sacroiliac joint demonstrated a tendency to underestimate age, and in the absence of these two skeletal features the pubic

symphysis lacks precision and accuracy in its age estimation. However, the study showed that transition analysis improves the ability of bioarchaeologists to estimate ages of older individuals, which is critical to the deduction of age-at-death patterns for archaeological samples.

Stationarity, Selective Mortality and Hidden Heterogeneity

One of the major criticisms of the life table approach was its unrealistic assumption of population stationarity and its inability to expose selective mortality and hidden heterogeneity. A stationary population is closed to migration and has an unchanging (or fixed) birth and death rate. In other words, a life table approach assumes that the age-at-death distribution of the population is solely a product of mortality and fertility. The creation of an age-at-death distribution based on this assumption is not reflective of the once-living population, and is one of the major issues with the assumption of stationarity in a skeletal sample.

For instance, in a growing population, one would expect to see a higher number of subadults in the skeletal record due to an increase in the size of birth cohorts. In this scenario, each new birth cohort is larger than the last. Therefore, the mortality sample is comprised of more individuals, despite the mortality rate remaining the same. If a researcher assumes stationarity in this population, the increase in subadult remains may be interpreted as a reflection of an elevated rate of juvenile mortality rather than an increase in fertility (Wood et al., 2002). While stationarity is convenient for aggregate calculations, it is not realistic and does not accurately reflect most once-living populations. In addition, the life table approach is unable to manage selective mortality

and hidden heterogeneity within a skeletal sample, a flaw addressed by Vaupel et al. (1979) and Wood et al. (1992). The life table method hides the heterogeneity of risk within an archaeological skeletal assemblage, failing to capture individual levels of frailty. Not taking these factors into consideration has resulted in problematic inferences about health in the past (Wood et al., 1992; Wood et al., 2002).

The concepts of selective mortality and hidden heterogeneity are closely associated with one another. Archaeological skeletal assemblages are comprised of non-survivors within each age cohort of a once-living population, and therefore, are biased samples. In other words, age-at-death distributions for skeletal assemblages do not represent the age-specific risk of dying for the once-living population. Rather, within each age cohort the risk of dying is variable and archaeological skeletal assemblages contain a mixture of individuals with different levels of underlying frailty. Frailty here is defined as the susceptibility or relative risk of dying for an individual compared to others in the population. Therefore, selective mortality does not function in an environment with an absence of heterogeneity of risk (Wood et al., 1992).

It has been suggested that two categories of frailty exist: acquired and constant. Frailty is based on both biological and social conditions, such as genetic causes and socioeconomic inequalities. Acquired frailty fluctuates within the lifetime of an individual, whereas the constant frailty of an individual does not change (Boldsen, 2005). The average frailty of a population age cohort, however, declines with age. In other words, as an age cohort grows older, its average level of frailty decreases. This decrease

assumes that individuals with higher levels of frailty die first, resulting in a decline in the overall level of frailty in an age cohort (Vaupel et al., 1979).

The comparison of catastrophic and attritional mortality distributions is one of the main ways selective mortality and frailty has been addressed (DeWitte and Wood, 2008; Margerison and Knüsel, 2002; Yaussy et al., 2016). Catastrophic cemetery assemblages are created by events such as famines, natural disasters, and epidemics. In contrast, attritional assemblages are accumulated over long periods of time and include the full range of 'natural deaths' (Yaussy et al., 2016). As discussed above, in the absence of heterogeneous frailty, mortality is not selective. Following this logic, catastrophic events are assumed to be indiscriminate in who they kill while noncatastrophic (attritional) events are assumed to be more selective. Bioarchaeological studies of the Black Death cemeteries in London, however, have contradicted this conclusion (DeWitte and Wood, 2008).

To understand how frailty operated in past populations, bioarchaeologists must first possess a method for its measurement. One of the main ways frailty has been measured in archaeological samples is through the identification and documentation of periosteal lesions (DeWitte, 2014a; DeWitte and Wood, 2008). The presence of periosteal lesions on a skeleton may reflect previous episodes of general infection or malnutrition. As stated previously, bioarchaeologists historically used the frequency of lesions within a skeletal assemblage as a direct reflection of health within a once-living population (Goodman et al., 1984b; Lallo et al., 1978). By comparing age-distributions of lesion frequency between skeletal samples, bioarchaeologists made general inferences about

health. Framed in the context of the osteological paradox, this analytical technique poses multiple flaws (Klaus, 2014b; Wilson, 2014; Wood et al., 1992). One of its major shortcomings is the fact that only a small percentage of individuals demonstrate evidence of an infection skeletally. Therefore, individuals who possess lesions may not be an accurate representation of all the individuals with an infection in that sample.

One of the major recent contributions to the technical issues surrounding lesions as a reflection of health was the development of the Usher model (Usher, 2000). This model allows for the examination of the relationship between stress markers and risks of mortality by applying hazards analysis. Rather than relying on the frequency of stress markers as a reflection of health, the Usher model can demonstrate whether the presence of a stress marker impacts the risk of death within a population (DeWitte and Wood, 2008; DeWitte and Stojanowski, 2015; Usher, 2000). Many bioarchaeologists have used the Usher model to evaluate selective mortality and frailty in skeletal assemblages (DeWitte, 2010; DeWitte and Wood, 2008; Kreger, 2010).

Kaplan-Meier survival analysis has also been used to discern the relationship between the effect of periosteal lesion activity on survivorship. For instance, by using survival analysis DeWitte (2014a) established a relationship of survivorship between individuals with healed, active, and an absence of lesions. Those with healed lesions had a higher rate of survival than those with none or active lesions. These results indicate that in some circumstances individuals with no lesions may have a higher level of frailty than those with lesions. DeWitte (2014a) has major implications for the way bioarchaeologists interpret evidence of 'health' in the archaeological record, and reinforces the assertions of

Ortner (1991) and Wood et al. (1992) that the presence of lesions may be reflective of a good immune response, indicating a relatively 'healthy' individual.

Wilson (2014) reevaluated the interpretations of Lallo et al. (1978) and Goodman et al. (1984b) from the Dickson Mounds, considering the technical issues presented in the osteological paradox. The study utilized advancements in paleodemographic and paleoepidemiological statistical methods, obtaining age-at-death and mortality data through the application of transition analysis and Gompertz and Gompertz-Makeham hazards models. Wilson (2014) analyzed sex-specific and age-specific mortality patterns during the late Pre-Columbian period (1050-1500 A.D.) through the examination of linear enamel hypoplasia (LEH) both divorced and in conjunction with statistical analysis of lesions. In addition, the methods applied in the study examined the risk of death associated with infectious disease, warfare, and pregnancy.

The use of hazards analyses by Wilson (2014) demonstrated synchronic and diachronic difference in mortality patterning within the central Illinois River valley, largely supporting the prior conclusions of Lallo et al. (1978) and Goodman et al. (1984b). The results of the study demonstrated that female adults possessed a lower rate of survivorship than the male counterparts in the sample, showing an increased risk of death for females during reproductive years. In addition, female adults with indicators of early childhood stress (LEH) had a higher risk of death, demonstrating selective mortality and frailty within the population. Wilson (2014) argued for the utility of integrating the examination of lesions and teeth with sex and age-at-death data, stressing its potential to improve the understanding of how skeletal assemblages form within bioarchaeology.

All three studies (Lallo et al., 1978; Goodman et al., 1984b; Wilson, 2014) of the Dickson Mounds argued for diachronic differences in the mortality pattern of the population. It is important to recognize, however, the differences between the methods employed by the three studies. Lallo et al. (1978) and Goodman et al. (1984b) relied on frequency and life table data in the formation of the conclusions of the study. With the use of these earlier methods, the two studies assumed that the Dickson Mounds skeletal assemblage was representative of the once-living population, the population was stationary, and age-at-deaths were accurately estimated. As previously discussed, these assumptions are likely flawed and limited in the ability to make meaningful inferences and comparisons.

In contrast, Wilson (2014) employed more advanced statistical methods, elucidating information on the formation of the skeletal assemblage, and therefore, communicating a broader picture of population dynamics in the central Illinois River valley. By using stress indicators as a covariate of mortality, Wilson (2014) demonstrated how episodes of early life stress likely had a long-term impact on longevity. Specifically, revealing how females in the sample with evidence of early life stress events were more likely to enter the death assemblage earlier in adulthood, representing the presence of selective mortality and heterogeneous frailty. Identifying disparities in mortality rates between biological groups, offers bioarchaeologists unique opportunities to analyze how social constraints and cultural trends associated with biological sex and age can influence mortality.

Early Life Stress

Physiological trade-offs occur when allocation decisions between two or more processes compete with one another for limited resources within an individual (Stearns 1992, p. 75). For example, the differential allocation of resources could occur when a fetus receives poor nutrition, causing its physiology to reallocate energy to vital developmental processes, such as brain development. The trade-offs of this early life event may be reflected in reductions in body size, earlier maturation, and intensified mortality schedules (Giussani, 2011; Pomeroy et al., 2012; Walker et al., 2006). During this event, the plasticity of the individual allows for the refocusing of energy to the production of important tissue development, which in turn prevents immediate death. However, the future effects of this early life stress event can be observed through decreases in growth, fertility, and an increased likelihood of mortality (Armelagos et al., 2009; Temple, 2014).

In recent years, there has been an increased focus on the long-term biological consequences of early life stress events. Many of these studies are based on the Barker hypothesis, which asserts that stressful events in the life history of an individual have negative health consequences later in adulthood (Armelagos et al., 2009; Barker, 2012; Barker et al., 2002). This postulation has transformed into the Developmental Origins of Health and Disease (DOHaD) hypothesis. Medically, the DOHaD hypothesis has been studied through the documentation of a connection between low birthweight and a risk of coronary heart disease and Type 2 diabetes. Armelagos et al. (2009) argued in support of

DOHaD, and discussed its applicability within bioarchaeology by examining osteological studies that document a relationship between the presence of LEH and mortality rates.

As discussed previously, LEH are an indication of a non-specific physiological stress event, and a microscopic examination of the defect can provide a precise age-at-defect formation. Therefore, the age at which the defect formed can be analyzed in conjunction with age-at-death. This relationship is valuable to the bioarchaeological study of physiological stress, because it allows for the consideration of how early life stress may affect an acquired level of frailty. Additionally, LEH can illuminate the relationship between physiological disruption and increase in mortality rates in adulthood through three probable mechanisms: (1) the frailty levels of individuals may make them more susceptible to enamel defects, which may cause them to die earlier; (2) individuals with defects could be indicating differential exposure to cultural, social, and behavioral stressors, which may be continuing into adulthood, and; (3) the stress event that led to the defect may negatively affect the ability of an individual to handle future stressors (Armelagos et al., 2009).

One of the difficulties of applying the DOHaD hypothesis to bioarchaeological studies is the inability to control for environmental factors after ontogeny. Amoroso et al. (2014) addressed this issue by using a modern skeletal sample to test the association of LEH and adult socioeconomic information with age-at-death. The results of the study showed that socioeconomic status is more of an indicator of longevity than the presence of LEH. Other contemporaneous studies completed on LEH and mortality has demonstrated different results (Temple, 2014; Wilson, 2014). Temple (2014) examined

early life stress in the Late/Final Jomon period by applying a framework of plasticity and constraint, based on the life history theory espoused by Charnov (1991, 1993). By applying this framework, Temple (2014) found that early investments in survival, as seen through the microscopic observation of LEH, were associated with constraints in growth and maintenance, as well as an increased susceptibility to future stress events.

The application of the DOHaD hypothesis within bioarchaeology has the potential to provide an interesting framework through which to study selective mortality and frailty. Furthermore, the integration of plasticity and constraint and the DOHaD hypotheses into bioarchaeological work demonstrates an engagement with evolutionary biological concepts, which have the potential to provide a deeper understanding of the relationships between indicators of early life stress, such as LEH, and mortality and survivorship within past populations.

Conclusion

The theoretical, conceptual, and methodological issues presented by Wood et al. (1992) prompted a reevaluation of how morbidity and mortality patterns are gathered and interpreted from archaeological skeletal samples. Within the traditional life table framework, bioarchaeologists focused on comparative population studies using mortality data based upon aggregate age distributions as a reflection of health. These comparative studies were limited in the ability to provide an accurate picture of how mortality patterns were in fact structured due to a high rate of error in age estimation, an assumption of stationarity, the reliance frequency, and the conceptual issues of selective mortality and hidden heterogeneity.

The reevaluation and improvement of paleodemographic methods have led to an increased usage of age distribution statistical models within bioarchaeology. These statistical models can address the unique challenges posed by archaeological skeletal assemblages, which makes them a strong alternative to the traditional life table approach. Furthermore, the reconceptualization of physiological stress and the movement away from the concept of health has prompted an increased focus on mortality and survivorship along with a consideration of the potential relationships to early life stress and longevity. These studies have been successful in attempting to operationalize the methodological challenges posed by the osteological paradox. By focusing on the bioarchaeological study of the American Ancestral Pueblo Southwest, the subsequent chapter details the related concepts and theoretical approaches used in this work.

CHAPTER THREE

BIOARCHAEOLOGY OF THE ANCESTRAL PUEBLO SOUTHWEST

The cultural area of the Ancestral Pueblo Southwest incorporates native groups who share strong cultural similarities in ecological settings, house form, settlement configurations, pottery styles, and synchronicity in change over time (Cordell and McBrinn, 2016; Fowler and Cordell, 2005). Historically, the skeletal studies of the Ancestral Pueblo Southwest focused on the determination of so-called ‘racial’ groups within the Pueblo cultural area (Hrdlička, 1931; Seltzer, 1944). In contrast, Hooton (1930) represents one of the earliest historical examples of an integrative research design utilizing archaeological and physical anthropological information focused on addressing regional questions. The early interdisciplinary work of Hooton (1930) on the Pecos Pueblo material laid the groundwork for the foundations of modern bioarchaeology. Under the influence of cultural ecology, the bioarchaeological literature of the mid twentieth century moved away from the historical concentration on typology and towards a more regional oriented approach.

Modern bioarchaeological studies of the Pueblo Southwest have relied on the prevalence of biological stress indicators to illuminate broader trends of the biological and demographic dimensions in major cultural and ecological transitions throughout the

region. This chapter reviews the archaeological and bioarchaeological analyses of these major transitions by discussing the ecological environment of the region and its relationship to the epidemiological and demographic trends represented in the literature. Furthermore, the chapter will provide a summary of the bioarchaeological and paleodemographic studies completed on the skeletal assemblages of Pueblo Bonito and Hawikku.

Ecology of the Ancestral Pueblo Southwest

The following section examines the ecological setting of the Ancestral Pueblo peoples by documenting the patterns of regional and local environmental fluctuation, both in the past and present. Additionally, the section explores how these fluctuating conditions have been used by archaeologists and bioarchaeologists to explain major cultural and demographic shifts within the region.

Modern Climate

The Ancestral Pueblo groups of the American Southwest inhabited the Four Corners region of modern day New Mexico, Arizona, Colorado, and Utah. The Four Corners area is encompassed by the physiographic and desert region of the Colorado Plateau. The climate of this area has two major sources of atmospheric moisture, the Pacific Ocean and the Gulf of Mexico, which condition the climate by producing cyclic shifts of four air mass movements – the Polar Pacific, the Polar Continental, the Tropical Pacific, and the Tropical Gulf. The precipitation patterns of the Colorado Plateau are generated from the quantities of heat and moisture brought in by these four air masses. Each of the four air mass movements effect the precipitation levels of the area during

different times of the year with the winter season accounting for the most irregularity in annual precipitation (Dean, 1988; Vivian, 1990).

The plateau receives a relatively even spread of precipitation throughout the year, however, precipitation highs occur during the summer and winter months and the lows occur in the fall and spring (Vivian, 1990; Wright, 2010). The precipitation in the region varies with elevation. The deserts of Northeast Arizona and Northwest New Mexico are the driest portions of the plateau, receiving about 18 cm a year. The mountain regions of Central Arizona and West Central New Mexico are the wettest areas and commonly exceed 50 cm of precipitation a year (Dean 1988, p. 122). In terms of elevation, temperatures have the inverse relationship than that of precipitation – temperatures tend to decrease as elevation increases. Modern temperatures have ranged from highs of 102°F to 106°F in the summer to lows of -38°F to -48°F in the winter (Vivian 1990, p. 21).

The desert environment of the Southwest is prone to frequent climatic fluctuations linked to both short-term and long-term drought conditions. Modern droughts have been known to lead to reductions in water supply, diminished water quality, crop failure, and reduced range of productivity (Woodhouse and Overpeck 1998, p. 2693). The prehistoric Pueblo peoples of the Southwest may have experienced similar consequences associated with modern droughts. While the climate of the Colorado Plateau has been stable for the past 10,000 years (Vivian, 1990), paleoenvironmental studies have demonstrated both short-term and long-term fluctuations in precipitation and temperature that may have affected the behavior of the Ancestral Pueblo groups in the region.

Cultural Ecology and the Paleoenvironment of the Southwest

The theoretical framework of cultural ecology was proposed by Steward (1955) as a conceptual tool to evaluate the effect of the environment on human culture, and for the analysis of cultural adaptations occurring across similar environments. Within this framework, Steward (1955) argued that human behavior can be explained through culture, rather than purely biologically-derived processes such as adaptation, accommodation, and survival. The application of cultural ecology to the archaeological study of the Southwest was widespread, focusing on the relationships between the environment and culture through the analysis of social, cultural, and technological adaptations. Following the development of bioarchaeology, the framework was expanded to include the investigation of the biological effects of ecological and cultural shifts on a population level through the integration of skeletal analysis.

By establishing a prehistoric chronology of environmental variation, archaeologists have applied cultural ecological models to associate periods of major environmental change with significant cultural and demographic shifts in the Ancestral Pueblo Southwest (Berry and Benson, 2010; Cordell et al., 2007; Dean et al., 1985; Gumerman, 1988; Irwin-Williams and Haynes, 1970; Jorde, 1977; Powell, 1983). Fluctuations in the ecological conditions of the Colorado Plateau could have effected crop production and influenced the settlement patterns of the Pueblo communities (Benson and Berry, 2009; Palkovich, 1984a; Wright, 2010). Shifts in settlement patterns, such as site abandonments, relocations, and large-scale migrations are commonly documented in the archaeological record in both the prehistoric and historic periods.

These shifts have been interpreted as being representative of cultural mechanisms aimed at buffering the stressors of the desert environment (Dean et al., 1985; Palkovich, 1984a; Stodder and Martin, 1992).

The prehistoric environmental variability of the region has been documented by examining trends in hydrologic-aggradation and degradation, palynology, precipitation, temperature, and dendrochronological data in accordance with archaeological evidence from varying pueblo sites (Benson and Berry, 2009, 2010; Cordell et al., 2007; Dean et al., 1985; Euler et al., 1979; Jorde, 1977; Polyak and Asmerom, 2001; Waters and Haynes, 2001; Wright, 2010). These techniques have been used to evaluate the paleoclimate of the Southwest in terms of high and low frequency environmental processes and variability, and provide a deeper analysis of the paleoenvironmental fluctuations, rather than merely relying on the binary categorizations of favorable or unfavorable and wet or dry (Dean et al., 1985).

High and low frequency climate variations are the result of unique environmental processes that occur over different lengths of time. For example, the environmental processes responsible for high frequency variations are seasonal and annual climate fluctuations, crop yields, and natural resource productivity. High frequency climate variations are short-term events, with fluctuations lasting less than 25 years. Whereas, low frequency climate variations are long-term events lasting longer than 25 years, and are caused by fluctuations in stream flow, ground water levels, and episodes of erosion and depositions along streams. (Dean, 1988; Dean et al. 1985; Wright, 2010). High and low frequency variations in the environment have unique consequences for the regional

ecosystem, and can incite different human behavioral responses (Dean et al., 1985; Dean, 1988).

Compared to high frequency processes, low frequency processes are typically less directly observable, and therefore, are less likely to impact or otherwise actively shape human behavioral adaptation. However, depending on how close the population is to reaching its carry capacity, high frequency processes can create a varying level of adaptive responses. As a population approaches carrying capacity, it becomes more likely that major behavioral and demographic changes will occur (Euler et al., 1979; Dean, 1988). For example, the Ancestral Puebloans utilized at least seven major adaptive mechanisms to buffer themselves against environmental stressors – mobility, shifts in settlement location (movement between upland and lowland areas), subsistence mixture, exchange, ceremonialism, agricultural intensification, and territoriality (Dean et al. 1985, p. 547).

As mentioned previously, paleoenvironmental studies have sought to reconstruct the major climatic fluctuations in the region as a method through which to better understand the adaptive mechanisms of the Ancestral Pueblo groups. Archaeologists have been particularly interested in the effect of environmental variability on the demographic patterns of the area. The Ancestral Pueblo culture has been divided into four major time periods based on archaeological evidence establishing major cultural and technological changes – Pueblo I (AD 700-750 to A.D. 900), Pueblo II (A.D. 850-900 to A.D. 1050-1150), Pueblo III (A.D. 1050-1150 to A.D. 1300), and Pueblo IV (A.D. 1300 to A.D. 1540). It has been thoroughly documented that population aggregation became

increasingly common during the Pueblo I period and reached its greatest height during the middle of the Pueblo II period. Population sizes underwent a decline between A.D. 1150 and A.D. 1300, experiencing major site abandonments and the shrinking of Puebloan geographic territory (Adler et al., 1996). The depopulation of the Ancestral Pueblo area has been a major topic of discussion and debate within the archaeological study of the Southwest region (Adler et al., 1996; Benson and Berry, 2009; Cordell et al., 2007; Jorde, 1977; Kohler et al., 2010).

The archaeological evidence of the abandonment of the region coincides with the chronology of the prehistoric environmental variability. A major decline associated with a dendroclimatically-documented drought dating to around A.D. 1150 that continued until the end of the century has been established. Additionally, the period from A.D. 1275 to A.D. 1475 was marked by a significant number of droughts (Dean et al., 1985; Polyak and Asmerom, 2001). The evidence supports previous findings that a drought (commonly referred to as the Great Drought) occurred from A.D. 1275 to A.D. 1300, coinciding with archaeological evidence documenting a massive population movement during this period. The Great Drought has been viewed as one of the key explanations for the massive abandonment of the major Ancestral Pueblo sites in the San Juan Basin, including the Chaco Canyon Complex and Mesa Verde (Jett, 1964).

First proposed by Douglass (1929), the drought-abandonment hypothesis has come under scrutiny in recent years. Scholars question why this single drought may have caused abandonment in a region where droughts were common. What was unique about the Great Drought that caused the massive abandonment and migration movement? The

assumption that the depopulation of the area was produced by a direct cause and effect relationship between the climate and population movement is too simplistic (Hill et al., 2010). Archaeologists have begun to incorporate other factors into the study of the Great Drought, such as population density and mobility, length of occupation, socioeconomic organization, community relations, and the impact of humans on the environment (Hill et al., 2010; Ingram, 2017). Furthermore, within bioarchaeology the cultural ecological approach has incorporated theories of human behavioral ecology and resilience, which could provide a new and exciting avenue through which to examine the interaction of the Ancestral Puebloans with the environment.

The human behavioral ecological approach evaluates the role of socioenvironmental variables in producing behavioral diversity and similarity across a range of human populations. Human behavioral ecology and resilience theory (Campbell and Butler, 2010; Hoover and Hudson, 2016; Redman, 2005; Redman and Kinzig, 2003; Stojanowski and Knudson, 2014; Walker et al., 2004) adds another layer onto the bioarchaeological study of ecological and cultural transitions, such as cultural contact events. Unlike previous approaches (Cohen and Armelagos, 1984; Larsen, 1995), these theories integrate human agency into the interpretation of the human relationship(s) with the environment, demonstrating not only how cultural identity changes but also how it persists. In the American Southwest, the incorporation of resilience theory into the study of major prehistoric demographic and social transformations has demonstrated differing levels of severity depending on the resistance to change within a community. Through the incorporation and operationalization of the rigidity trap, (a concept in the resilience

framework that represents resistance to change within a society) archaeologists have demonstrated that communities that were more adaptable and less rigid in their behavior underwent a transformation associated with less human suffering (Hegmon et al., 2008; Nelson et al., 2011). The incorporation of agency into the study of depopulation events in the Southwest region helps to expose the behavioral intricacies present in the relationship between the Puebloan peoples and the environment.

This section has provided an overview of the ecological setting of the Ancestral Pueblo Southwest, and discussed how the cultural ecological theoretical framework has been commonly applied to explain how the environmental variability of the area caused major behavioral adaptations and demographic changes. The next section will delve further into the relationship between the environment of the Southwest and cultural and demographic change by exploring the bioarchaeological evidence for physiological stress in the region.

Paleoepidemiology and Paleodemography of the Puebloan Southwest

The idealization of the American Southwest in the late nineteenth century perpetuated the myth that prehistoric Pueblo peoples lived in a relatively healthy state free from disease. The introduction of Old World infections, brought by the arrival of the Europeans to the New World in the late fifteenth century, disrupted this so-called imagined epidemiological utopia (Larsen, 1994). Through the application of paleoenvironmental, paleoepidemiological, and paleodemographic methods, the archaeological and bioarchaeological studies of the twentieth and twenty-first centuries

demonstrated that this romanticized image of the prehistoric Pueblo biological environment is, simply put, demonstrably wrong.

To gain an understanding of the effects of major cultural and demographic shifts on the Pueblo peoples of the Southwest, bioarchaeologists have sought to reveal the diachronic trends of biological stress and disease in the region. This section provides a review of the relevant literature on the paleoepidemiological trends from the prehistoric to the historic period in the Pueblo Southwest. The integration of skeletal evidence to the biocultural study of major cultural and ecological shifts such the effects of direct and indirect cultural contact on the demographic profile of the region is also explored.

Biological Stress and Infection in the Pueblo Southwest

Goodman et al. (1984a) espoused the effect of environmental instability on human biology through the development of the ‘stress model,’ which was highly influential to paleopathologists and bioarchaeologists working in the Southwest. Within this framework, the instability of the ecological environment is reflected in the manifestation of non-specific skeletal indicators of stress, such as porotic hyperostosis, linear enamel hypoplasia (LEH), and periosteal reactions. Therefore, the framework developed by Goodman et al. (1984a) allowed bioarchaeologists to use skeletal evidence of biological stress and disease to develop a paleoepidemiological profile for sites that could quantitatively demonstrate trends over time. This paleoepidemiological approach is seen throughout the bioarchaeological literature on the prehistoric and historic Pueblo Southwest.

The prehistoric Pueblo peoples of the region had a mixed subsistence economy based on the utilization of resources acquired via both hunter-gatherer and agricultural strategies. The Pueblo diet was primarily based on crops, such as maize, squash and beans, and supplemented with amaranth, chenopodium, rabbit, deer, elk, bison and antelope (Stodder, 1990). The dietary reliance on maize within the Pueblo Southwest is reflected in a high rate of oral health indicators across a wide range of archaeological sites (Hooton, 1930; Nelson, 1938; Stodder, 1990). Stodder and Martin (1992) provided a bioarchaeological overview of the incidence of indicators of oral infection in the region, stating that the frequency of carious lesions and abscesses range from 9% to 85% and 11% to 66%, respectively. Stodder and Martin (1992) attributed the wide range of variation in these pathological conditions to differential consumption of carbohydrates at individual sites (p. 56-57).

Non-specific and specific indicators of infections are frequently documented in prehistoric Pueblo communities, with frequencies ranging from 2% to 23%. Within the late prehistoric and early contact skeletal assemblages, indicators of infection increase in prevalence (Stodder, 1990, 1996). The bioarchaeological literature has also documented the presence of both tuberculosis (El-Najjar, 1979; Hooton, 1930; Lambert, 2002; Merbs, 1989; Stodder, 1990) and treponematosi s (Baker and Armelagos, 1988; El-Najjar, 1979; Marden and Ortner, 2011; Powell and Cook, 2005) in the precontact and postcontact eras.

The presence of anemia within Pueblo skeletal samples has been repeatedly documented in the bioarchaeological literature through the observation of porotic hyperostosis and cribra orbitalia (El-Najjar et al., 1975; Lahr and Bowman, 1992;

Stodder, 1990). El-Najjar et al. (1975) interpreted the high frequency of porotic hyperostosis in Pueblo groups as an indicator of iron-deficiency anemia, caused by a heavy reliance on low iron rich foods, such as maize. In recent years, the dietary interpretation of El-Najjar et al. (1975) has been challenged (Kent, 1986; Martin and Osterholtz, 2016; Stuart-Macadam and Kent, 1992; Stodder, 1996; Stodder and Martin, 1992; Walker et al., 2009). The presence of porotic hyperostosis is more likely to have resulted from the complex interaction of multiple etiological factors, including diet, habitat structure type, infectious disease load, community ecology, and hygiene. All these factors contribute to the ability of the body to absorb nutrients and a range of anemias, because of the connection to parasitism, malnutrition, and an increased likelihood of infection (Stodder and Martin 1992, p. 58).

Parasitism has been documented using coprolite samples taken from Pueblo Bonito and other sites throughout the Colorado Plateau area (Reinhard and Clary, 1986; Reinhard, 1992). The dietary patterns of the Puebloans may have increased the risk for zoonotic parasites, because by eating the normal hosts, prehistoric peoples intruded the natural life cycles of the parasites (Reinhard et al., 2013). The connection between parasitism and anemia has been explored in the Southwest by documenting diarrhea-inducing pathogens that were likely endemic in the Ancestral Pueblo population such as *Entamoeba histolytica*, *Salmonella* sp., *Escherichia coli*, and *Shigella* sp. (Reinhard 1992, p. 250). Diarrhea in prehistoric populations was likely a cause of anemia due to its relationship with malnutrition and increased likelihood of infection.

While anemia appears to be ubiquitous within the Southwest, it is important to consider how the etiology of anemia may be unique at individual Pueblo sites. Stodder and Martin (1992) reviewed the frequencies of anemia in subadults from six Pueblo skeletal samples and documented an association between non-specific skeletal indicators of infection and the presence of porotic hyperostosis and cribra orbitalia. Stodder and Martin (1992) argued that the co-occurrence of these conditions may indicate infection as the primary cause of anemia, rather than a low-iron diet. Similarly, Kent (1986) argued that the level of porotic hyperostosis seen in the prehistoric Southwest archaeological record was related to endemic chronic infections associated with population aggregation and sedentism. Kent (1986) and Stodder and Martin (1992) provide important perspectives on the relationship between anemia and porotic hyperostosis in the prehistoric Southwest.

In addition, recent contributions to the field of bioarchaeology demonstrate a common underreporting of scurvy in the skeletal record, which is most likely due to the misidentification of porous lesions as porotic hyperostosis or cribra orbitalia (Stodder, 2012). Hooton (1930) described an osteoporotic condition on the cranium of an individual from Pecos Pueblo, which involved the wings of the sphenoid bone and the palatine roof (p. 316). Based on recent contributions to its differential diagnosis (Klaus, 2014a; Ortner et al., 2001), it appears that Hooton may have been describing a case of scurvy in the Pecos skeletal sample. Therefore, some people in prehistoric Pueblo communities may have also experienced a chronic deprivation of vitamin C (Crandall, 2014).

The bioarchaeological evidence collected from various prehistoric skeletal assemblages unambiguously contradicts the notion that the Southwest Pueblo peoples lived free from disease. Rather, the paleoepidemiological analysis of the skeletal material demonstrates a high frequency of indicators of oral health, anemic conditions, and evidence for endemic diseases, such as tuberculosis and treponematosi. Compared to the precontact period, the paleoepidemiology of the postcontact era in the Pueblo Southwest is not well understood and has not been as thoroughly studied. The work conducted on the postcontact period heavily focuses on tracing the demographic implications of the exposure of Pueblo groups to Old World contagions.

Biological and Demographic Implications of Contact

In his often-cited 1966 article, Henry Dobyns argued that a hemispheric pandemic swept the New World between A.D. 1520 and A.D. 1524, introducing the notion that Native American populations were exposed to Old World infections prior to direct contact with Europeans. The infection, most likely smallpox, would have spread through prehistoric trade routes that extended into modern-day northern Mexico. Within the framework developed by Dobyns (1966), the Pueblo groups of the Southwest would have experienced the demographic and biocultural consequences of contact without directly interacting with the Spanish (Kulisheck 2005, p. 46). Bioarchaeological and paleodemographic work supports the assertion by Dobyns (1966) that both indirect and direct contact with Old World diseases had detrimental biological and demographic effects on the Pueblo communities (Dobyns, 1993; Kulisheck, 2005; Palkovich, 1985; Ramenofsky, 1996; Upham, 1986; Verano and Ubelaker, 1992).

The role of Old World diseases in the historic depopulation of Native North America is an intensely researched and debated topic within bioarchaeology (Baker and Kealhofer, 1996; Klaus and Tam, 2009, 2010; Larsen, 1994; Larsen and Milner, 1994; Murphy and Klaus, 2017; Verano and Ubelaker, 1992). However, the timing of these epidemics cannot be determined from the archaeological and skeletal evidence in the Pueblo Southwest. The inability to identify acute infections in the skeletal record is a major challenge faced by bioarchaeologists seeking to analyze the effects of Spanish contact in the area. Bioarchaeologists have sought to overcome these challenges by utilizing paleodemographic methods (Verano and Ubelaker, 1992) to identify long-term processes that effect the age and mortality structure of a population sample (Martin and Goodman, 2002). The study of Pecos Pueblo by Hooton (1930) represents one of the earliest examples of an integrative paleopathological and demographic study, which provided the basis for subsequent demographic analyses (Goldstein, 1953; Mobley, 1980).

To better understand the magnitude of the effects of Spanish contact, bioarchaeological approaches require reliable population size estimates from prehistoric, protohistoric, and historical periods. Distinct population estimates have different implications for mortality depending on size. For example, a minimal estimate would suggest less of a mortality impact whereas a large estimate would imply a demographic collapse (Ubelaker 1992, p. 169). Upham (1992) estimated 131,750 individuals were present in the Pueblo Southwest in A.D. 1500 and by A.D. 1598 the population size was reduced to half (p. 233). The estimation formulated by Upham (1992) implies an

extremely high rate of mortality within the span of a century, but other estimates are more conservative (Palkovich, 1985). The variability and reliability of population estimates based on archaeological sites presents serious challenges to the demographic reconstruction of prehistoric Pueblo communities.

The life table approach has commonly been used in the construction of mortality profiles, which rely on age-at-death data collected from the skeletal material of the site. In the last few decades, the life table approach has been heavily critiqued by paleodemographers (Bocquet-Appel and Masset, 1981, 1996; Hoppa and Vaupel, 2002; Wood et al., 1992), but remains a frequently used method within the bioarchaeological research of the Southwest (Eckert, 2005; Nelson et al., 1994; Stodder, 1990). The flaws associated with the life table approach are addressed in the subsequent section.

The continued processes of migration and settlement shifts that occurred during the historic period hinder a clear interpretation of the effect of Spanish contact on the demography of the Pueblo Southwest. Additionally, the paleodemographic methods used in the evaluation of mortality trends between temporal periods are flawed and need to be reevaluated. Currently, there are only two primary skeletal collections that contain historical material: San Cristobal and Hawikku (Larsen, 1994). The skeletal evidence from these two sites represents different paleoepidemiological patterns of physiological stress during the postcontact period, suggesting regional variation between Pueblo groups (Stodder, 1990).

Overall, the bioarchaeological literature on the postcontact period is lacking when compared to the abundance of material on the prehistoric Pueblo Southwest. This section

has sought to provide an overview of the bioarchaeological literature using paleoepidemiological and paleodemographic methods to better understand the major cultural and ecological shifts in the region. The next section utilizes the bioarchaeological work completed on the skeletal material from Pueblo Bonito and Hawikku to further illuminate what is known about the mortality profile of the region, and to demonstrate the need for further paleodemographic and paleoepidemiological research on these two sites.

Case Studies

Pueblo Bonito

The site of Pueblo Bonito is located within Chaco Canyon, situated in modern-day northwestern New Mexico. Pueblo Bonito is recognized as being a part of the Chaco Phenomenon, a term used to distinguish a period of social complexity among the Pueblo peoples (Harrod, 2012). At its peak, the Chaco cultural system stretched across the boundaries of the San Juan Basin, extending into southwestern Colorado and southeastern Utah (Marshall, 2003; Price et al., 2017). The Chaco complex is differentiated from earlier cultural groups by archaeological evidence indicating an increased reliance on cultigens, greater sedentism, more permanent architecture (the construction of great houses and kivas), and ceramic production (Vivian, 1990). Based on architectural evidence, Pueblo Bonito was occupied from approximately A.D. 800 to A.D. 1200. The peoples of Pueblo Bonito relied on a mixed subsistence economy utilizing hunter-gathering and agricultural techniques, cultivating maize, beans, squash, and hunting large and small game, including rabbit, sheep, and elk (Vivian, 1990). The harsh climatic

conditions of Chaco Canyon would have greatly impacted the success of the farming in the area.

Modern temperatures in the canyon have ranged from a high of 102°F to a low of -38°F with an average of 49.8°F between the years of 1941 and 1970 (Vivian 1990, p. 21). From the period of 1933 to 1961, annual precipitation levels fluctuated from 8.5 cm to 45.7 cm (Vivian and Mathews 1965, p. 8). Furthermore, frost-free periods for the modern period have been estimated at about 150 days a year. As discussed previously, paleoenvironmental reconstructions of the Colorado Plateau area indicate a great amount of variability in precipitation and temperature, which was likely also the case for the localized Chaco canyon region.

Pueblo Bonito was first excavated as a part of the Hyde Exploring Expedition from 1896 to 1899, and further excavated during the National Geographic Expedition from 1920 to 1927. Two main burial clusters were found during these excavations, one located in the Northern sector of the site and the other in the Western sector. It has been argued that these two burial clusters likely represent distinct kinship groups, are multigenerational internments, and reflect differing levels of social hierarchy (Akins, 1986, 2003; Price et al., 2017). The Smithsonian Institution's National Museum of Natural History only possesses the skeletal material excavated from the burials in the Western sector of the site, which allegedly represents the lower of the two hierarchical social tiers (Akins, 2003). Therefore, the skeletal material from the Northern sector was not analyzed for this study.

The Western burial sector is comprised of four adjacent rooms and a fifth room, where 95 burials dating to roughly A.D. 1020 to A.D. 1150 were excavated by Neil M. Judd as a part of the National Geographic Expedition (Akins, 2003). The greatest burial concentration was found in rooms 320, 326, 329, and 330. These represent the largest skeletal sample excavated from Pueblo Bonito. Notes taken by Judd as well as the architectural, stratigraphic, and ceramic evidence, indicate that these rooms were converted into mortuary facilities rather than being built for that purpose (Akins and Schelberg, 1984; Palkovich, 1984b; Price et al., 2017). This assertion is supported by dendrochronological dating indicating that the construction of the Western rooms occurred around A.D. 800 to A.D. 900 (Windes and Ford, 1996).

During the excavation, Judd noted that many of the burials had previously been disturbed, which he attributed to looting (Judd, 1954, 1964; Akins, 2003; Neitzel, 2003), but it has also been suggested that this disturbance may have been caused by several other factors, including secondary burial, natural taphonomic processes, trash deposition, and the intrusion of later burials into older internments (Akins, 1986; Palkovich, 1984b). The burial descriptions recorded by Judd are often incomplete and fail to adequately describe the association of the burials with the grave goods. (Akins, 2003). Furthermore, skeletal recovery techniques used by Judd were never really described or documented which suggests that subadult remains may not have been recognized or recovered (Palkovich, 1984b). Therefore, the poor documentation of the burials from Pueblo Bonito may affect the ability of the study to establish epidemiological and demographic trends.

The bioarchaeological study of Pueblo Bonito has heavily focused on the inference of social stratification within the Chaco Canyon region, relying on the presence of biological stress indicators, such as porotic hyperostosis, cribra orbitalia, and growth patterns, as well as trauma to deduce differences between groups (Akins, 1986, 2003; Harrod, 2012; Nelson et al., 1994; Palkovich, 1984a, b). To differentiate between social strata, the mortuary contexts of great houses, such as Pueblo Bonito, have been compared to burial sites from smaller contexts in the Chaco Canyon complex. Bioarchaeologists have evaluated the level of social complexity and hierarchy within the Chaco society by using status variation, evidence of nutritional and biological stress, and paleodemographic analysis. These studies have sought to establish how individuals were uniquely buffered from the harsh desert environment, depending on status level (Akins, 1986, 2003; Nelson et al., 1994; Palkovich, 1984a, b).

The biological and paleodemographic data used to establish status as a buffering mechanism at Pueblo Bonito has been interpreted differently. Palkovich (1984a, b) sought to address whether the high-status individuals from Pueblo Bonito were buffered from nutritional stress by examining the skeletal remains of the subadults (individuals 0-10 years) excavated from the site. The life table generated by Palkovich (1984a, b) documented an underrepresentation of individuals less than 10 years of age in the sample. Of the subadults studied, 50% showed evidence of nutritional stress, as indicated by the presence of porotic hyperostosis, cribra orbitalia, and endocranial lesions. Therefore, Palkovich (1984a, b) concluded that status was not an adequate buffering mechanism against nutritional stress.

In contrast, Nelson et al. (1994) argued that the life table developed by Palkovich (1984a, b) indicated that individuals from Pueblo Bonito were of a higher status and had access to nutritional resources that adequately buffered them from stress. When the life table was corrected/smoothed for the underrepresentation of subadults, the average life expectancy increased for the Pueblo Bonito skeletal sample – rising from 25.67 to 26.46 years at age one, and from 24.95 to 25.75 years at age five. Compared to other skeletal populations from Chaco Canyon, the life expectancy at Pueblo Bonito is longer. Therefore, Nelson et al. (1994) argues that the life table data does not support the interpretation of Palkovich (1984a, b).

Due to its ability to reflect stress, the evaluation of growth patterns has also been used to assess the relationship between status and stress at Pueblo Bonito. Male and female individuals from Pueblo Bonito have been documented as having an increased stature compared to individuals from smaller sites, with males averaging 169.3 cm from Pueblo Bonito and 164.7 cm from smaller sites, and females averaging 162.0 cm from Pueblo Bonito and 157.4 cm from smaller sites (Akins, 1986). This stature differentiation has been inferred as reflecting the higher social strata having access to proper nutrition. It is important, however, to consider that the stature differentiation may also be reflective of a genetic difference in stature capacity between the two groups (Stodder, 1989).

Hyperostosis frontalis interna (HFI) was also identified in 12 out of 37 adults (mainly females) from Pueblo Bonito, and is the only documented occurrence of the condition in any Native American archaeological sample. The presence of HFI in the Pueblo Bonito sample may be indicative of a genetic predisposition, exposure to similar

environmental conditions, such as dietary phytoestrogens, or a female life cycle similar to modern populations (Mulhern et al., 2006). The etiology of HFI is not well understood but does appear to be correlated with older age, so the cause of this high incidence within the Pueblo Bonito skeletal assemblage remains unclear.

The great houses and small sites of Chaco Canyon may represent two unique biological and cultural groups. The genetic separation has been documented by evaluating phenotypic differences using methods such as craniometrics and biodistance (Akins, 1986; Corruccini, 1972; Schillaci and Stojanowski, 2003). Furthermore, Judd (1954) argued that Pueblo Bonito was occupied by two distinct groups – the Old Bonitians and the Late Bonitians – and could be distinguished by variations in architectural styles. Judd (1954) hypothesized that the Old Bonitians founded Pueblo Bonito after immigrating from somewhere beyond the San Juan Basin. However, recent isotopic evidence has demonstrated that the skeletal material from Pueblo Bonito is more likely representative of individuals from locales surrounding the Chaco Canyon area. Therefore, the construction of the Chaco Canyon complex was the product of sociocultural dynamics and not migration and population replacements (Price et al., 2017).

The skeletal assemblage of Pueblo Bonito provides a sample of high-status individuals from the Chaco Canyon cultural complex. The previous studies focusing on the relationship between stress, status, and mortality help to elucidate patterns of biological stress and disease in the Chaco region during the prehistoric period. The bioarchaeological work completed on the Pueblo Bonito skeletal collection has generated

an excellent foundation for further analysis using recent advances in paleodemography. Specifically, the integration of transition and survival analysis can produce an updated and more accurate mortality profile which may have implications for the established relationship between status and biological stress at Pueblo Bonito.

Hawikku

The Pueblo site of Hawikku is located within the modern-day Zuni Indian Reservation, east of the Arizona-New Mexico border. The peoples of Hawikku were sedentary agriculturalists who relied on a subsistence pattern mirroring that of prehistoric groups in the region, relying on corn, beans, squash, deer and other fauna (Stodder 1990, p. 33). Hawikku is one of six known settlements in the Zuni area and was established during the Pueblo IV period. Based on room estimation analysis, Eckert (2005) and Kintigh (1985) postulated that Hawikku was demographically the largest of the six settlements and remained so up until its abandonment in 1680

The excavation of Hawikku was led by F.W. Hodge and was a part of the Hendricks-Hodge expedition (1917-1923), which was co-sponsored by the Smithsonian Institution, and the Museum of the American Indian, Heye Foundation (Hodge, 1966; Kintigh, 1985; Stodder, 1990). Hodge never published a detailed archaeological report on Hawikku, contrasting with extensive literature on the excavation of Pecos Pueblo written by Alfred V. Kidder. However, a report of the excavation was published following Hodge's death in 1956 (Hodge et al., 1966).

Hawikku was established in the early Pueblo IV period (roughly around A.D. 1400) and was continuously occupied up until the Pueblo Revolt of 1680 (Stodder, 1990,

1996). During the excavation, Hodge found evidence for earlier structures that he believed were unrelated to the Hawikku occupation. The primary goal of the Hodge excavation was to document the site at the time of the Spanish arrival and through its abandonment in 1680. Therefore, Hodge did not excavate the layers belonging to the earlier occupations. Additionally, Hodge found that between the period of 1540 to 1680 the site was abandoned multiple times (Hodge et al., 1966). This stratigraphic evidence coincides with the arrival of the Spanish at Hawikku in 1540, although extended contact with the Spanish did not begin until the building of the Catholic mission in 1629. Thus, the work captured a significant protohistoric component of the site.

From 1917 to 1923, a total of 996 burials were excavated, including 317 cremations and 679 inhumations. Most burials were found in middens surrounding the site, but a few were uncovered in houses under the floors of rooms. The better preserved skeletal material was delivered to Aleš Hrdlička at the Smithsonian Institution, then referred to as the U.S. National Museum, where the skeletons were categorically aged and assigned sex estimations using the osteological methods of the time. In total, 266 individual skeletons were recorded by Hrdlička and his assistants. Of these 266 individuals, 136 were disassociated from the provenience numbers after being transferred to the Smithsonian, resulting in the loss of valuable temporal and spatial information (Hodge et al., 1966).

In addition to the loss of provenience information, the extent of mortuary context documentation recorded during the Hodge excavation of Hawikku was extremely limited. There are no maps or sketches of the burials and only generic notes were taken during the

removal. Photographs were taken, which for the time reflected good practice, but only 63 burials were photographed. Little of the non-ceramic burial goods were collected. Items such as wood and clothing were discarded as well as items deemed bulky or unattractive, such as hammerstones, metates, and cooking pots (Hodge et al., 1966). The loss of provenience and contextual information poses a challenge to the reconstruction of past demographic trends from the Hawikku population sample. Without information on spatial and temporal context, it is truly difficult to establish a diachronic analysis of demographic and epidemiological trends (Stodder, 1990).

Stodder (1990) represents the most extensive bioarchaeological study of Hawikku, examining human remains from 188 burials to establish the paleoepidemiological and demographic trends of the site. Only 165 of the 188 burials analyzed by Stodder retained the provenience numbers. Therefore, Stodder relied on artifact associations and aspects of mortuary disposition to affiliate the burials with a temporal period. The skeletal analysis of Hawikku found a higher rate of carious lesions and abscesses than in most prehistoric populations. Carious lesions were present in 53% of adults and abscesses were present in 58%. Enamel hypoplasias were recorded on canines and incisors, both permanent and deciduous, of 111 individuals. Porotic hyperostosis was present in 87% of subadults, and 33% of these individuals had an association between remodeled porotic hyperostosis and non-specific skeletal indicators of infection. As discussed previously, this association may indicate chronic infection as the primary cause of anemia at Hawikku. Furthermore, these infections may be associated with population aggregation and sedentism (Kent, 1986). The skeletal remains of

Hawikku had a 36% rate of infection, one probable case of tuberculosis, and two probable cases of treponematosiis.

Paleodemographic analysis of mortality at Hawikku has been examined using the traditional life table approach (Eckert, 2005; Stodder, 1990). For the Hawikku sample, Stodder (1990) documented a life expectancy of 21.48 years for the analyzed burial sample, which fits within the range of known prehistoric population assemblages. Furthermore, Stodder found an increase in mortality after adolescence, which was interpreted as a continued high probability of dying throughout childhood, rather than a low mortality in young adults. Overall, Stodder concluded that the paleoepidemiological and paleodemographic patterns at Hawikku do not vary significantly from the established prehistoric trend.

Eckert (2005) used age-at-death data acquired from Howell (1994) and Stodder (1990) to generate mortality curves for Hawikku. The age-at-death data used from the two separated studies generated two unique mortality curves for the historic period (A.D. 1630 to A.D. 1680). The mortality curve based on the data of Howell (1994) is identical to the protohistoric curve, implying the absence of demographic stress. Contrastingly, Eckert (2005) argued that the curve based on Stodder (1990) communicates a mortality pattern of a population effected by disease. Eckert (2005) asserted that while inconclusive, the mortality patterning of the historic period suggests a demographic disruption during the missionization period at Hawikku.

Stodder (1990) and Eckert (2005) both used the life table method to deduce temporal trends in mortality at Hawikku. By using the life table approach, both authors

assumed a stationary and/or fixed population sample. As discussed previously, the archaeological evidence in the Pueblo Southwest indicates frequent shifts in settlement and migration patterns. Therefore, it is highly unlikely that the skeletal assemblage from Hawikku is representative of a stationarity population. Furthermore, Bocquet-Appel and Masset (1981) demonstrated the tendency of life tables to mimic the mortality patterns of the reference sample on which it is based. Hence, the mortality curves for both the Pueblo Bonito and Hawikku skeletal assemblage may reflect the age structure of the reference sample used to calculate age-at-death. The critiques of the life table approach call into question the conclusions reached by Palkovich (1984a, b), Nelson et al. (1994), Stodder (1990), and Eckert (2005) about the mortality profile of Pueblo Bonito and Hawikku.

The skeletal assemblage of Hawikku is one of a few samples remaining that contains both prehistoric, protohistoric, and historic material. The temporal sequence of Hawikku presents an opportunity to elucidate the diachronic pattern of biological stress and disease in the Zuni region during the postcontact period. The bioarchaeological work completed on the Hawikku skeletal collection has generated an excellent foundation for further analysis using recent advances in paleodemography. Specifically, the integration of transition and survival analysis can produce a more detailed, precise, and confident reconstruction of age-at-death which may have implications for the established mortality patterns of Hawikku (Stodder, 1990; Eckert, 2005).

Conclusion

Considering the limitations of the previous studies and in light of current advances, this work argues that a reanalysis of the mortality patterns using updated

paleodemographic methods at Pueblo Bonito and Hawikku is warranted. The application of survival and transition analysis has the potential to elucidate new information on the epidemiological and demographic trends associated with the major cultural and ecological shifts in the region. Additionally, the reanalysis of the skeletal material from Hawikku and Pueblo Bonito using these techniques may help to overcome the conceptual, practical, and analytical challenges inherent in the traditional life table approach. The next chapter discusses the paleoepidemiological and paleodemographic methods used by this study to infer the relationship between mortality/survivorship and biological stress at Pueblo Bonito and Hawikku.

CHAPTER FOUR

MATERIALS AND METHODS

The materials and methods used to test the research hypotheses of the study are outlined in this chapter, beginning with a brief description on the requirements of the study and the selection of individual samples from the broader skeletal assemblages of Pueblo Bonito and Hawikku. Next, the chapter outlines the five hypotheses of the study, which is followed by an explanation of the methods used to estimate sex and age, identify indicators of physiological stress (i.e., periosteal reactions and LEH), and assess adult stature and body mass. The chapter concludes with a discussion on the statistical methods used to analyze survivorship and skeletal growth in the two samples.

Materials

The Ancestral Pueblo skeletal assemblages from the sites of Pueblo Bonito and Hawikku were selected for the study due to the large sample sizes and reassociated remains (Marden, 2015). To conduct a paleodemographic study, it was vital that the human remains analyzed were known to be associated with one individual. Additionally, the occupational history of the two sites has an established chronology for the Ancestral Pueblo area, Pueblo Bonito dating to A.D. 800. to A.D. 1200 and Hawikku dating to roughly A.D. 1400 to A.D. 1680. The two skeletal samples for this study were accessed

with the permission of the Smithsonian Institution's National Museum of Natural History (NMNH) and only skeletal material from the two sites possessed by the NMNH was analyzed.

For the purposes of this work, only skeletal remains identified as belonging to a single individual were analyzed. Therefore, commingled, disassociated, and cremated remains were not recorded. All subadult individuals where age could be estimated either by epiphyseal fusion or dental formation and emergence were included. For adults, the analyzed study sample was restricted to individuals that had at least one of the fourteen skeletal traits needed for transition analysis and all other adult individuals were documented but excluded from the study. In all, a total of 72 individuals were documented from Pueblo Bonito and 242 individuals were studied from Hawikku. Of those individuals, 54 from Pueblo Bonito and 173 from Hawikku met the requirements of the study.

Research Hypotheses

The bioarchaeological integration of recent advances in paleodemographic statistical methods and a research emphasis on physiological stress has the potential to reveal new social and biological dimensions through the detection of heterogeneity in frailty and selective mortality. By incorporating noteworthy biocultural, theoretical, and ecological contributions, the study examines five research hypotheses that address the role of the environment in the construction of mortality and survivorship patterns of the Pueblo Bonito and Hawikku skeletal samples, and the connection to early life stress and longevity in the Ancestral Pueblo region.

- 1) Due to a similarity in settlement environment and subsistence, the relationships between survivorship and the variables of the study (i.e., periosteal lesions, LEH, and adult body size) as well as skeletal growth, will not differ significantly between the Ancestral Pueblo sites of Pueblo Bonito and Hawikku.
- 2) The relationship between survivorship and periosteal reactions will differ based on the lesion activity category – individuals with healed lesions will have a survival advantage over those with active, mixed, or no lesions. This hypothesis is based on previous bioarchaeological evidence of survivorship advantage and healed periosteal lesion activity.
- 3) The presence of LEH will be associated with a decrease in survivorship and an increased likelihood of mortality compared to individuals with no LEH observed. This hypothesis is based on evidence that LEH represents an early investment in survival, which has been shown to be associated with constraints in growth and maintenance, as well as an increased susceptibility to future stress events.
- 4) Adult individuals with a below average body size for the sample population (i.e., stature and body mass) will be associated with a lower likelihood of survival compared to those who are above average for body size within the sample.
- 5) Evidence of stunting in longitudinal growth will be observed for both the subadult skeletal samples from Pueblo Bonito and Hawikku. This hypothesis is based on previous bioarchaeological studies documenting the relationship between growth disruption and systemic stress within past populations.

Methods

Sex Estimation

The material from Hawikku and Pueblo Bonito have both been analyzed by the NMNH and has been the subject of numerous osteological studies (Akins, 1986; Hrdlička, 1931; Palkovich, 1984a, b; Mulhern et al., 2006; Stodder, 1990, 1996; Stodder and Martin, 1992) The sex estimations assigned by the NMNH for the Pueblo Bonito and Hawikku samples were recorded (written) directly on the remains. These previous estimations were only utilized in cases of poor preservation or missing diagnostic features that prevented a sex classification.

Here, the sex estimations for individuals older than approximately 12 years were completed by scoring the sexually dimorphic morphology of the pelvis (the greater sciatic notch, ventral arc, subpubic concavity, and the ischiopubic ramus ridge) using the standards outlined in Buikstra and Ubelaker (1994) which themselves were based on Phenice (1969). Female individuals were coded as 1 and male individuals were coded as 2 for statistical data analysis.

Due to the unreliability of the skull for sex estimation, cranial morphology was only used when all morphological traits of the pelvis were absent or unobservable (Meindl et al., 1985). In these rare instances, five morphological characteristics of the skull (nuchal crest, mastoid process, supraorbital margin, prominence of glabella, and the mental eminence) were scored using Buikstra and Ubelaker (1994). A final sex estimation was generated using the cranial trait scores and the recorded sex estimation of the NMNH.

Age Estimation

The skeletal material from Hawikku and Pueblo Bonito were previously aged using traditional age estimation techniques, such as evaluating the morphological changes of the pubic symphysis (Brooks and Suchey, 1990) and the auricular surface (Lovejoy et al., 1985). To avoid the recognized flaws with traditional age estimation techniques, this study applied the statistical aging method of transition analysis to estimate age-at-death. The age estimations assigned by the NMNH for the two sample populations were not used for this study and were purposefully disregarded to avoid the injection of any biases during the application of transition analysis.

Subadult age-at-death was estimated by scoring mandibular dental development and emergence (Moorrees et al., 1963; Smith et al., 1991; Liversidge and Molleson, 2004; AlQahtani et al., 2010), and epiphyseal fusion (Buikstra and Ubelaker, 1994; Scheuer and Black, 2004). Mandibular dental development and emergence was scored for each subadult by analyzing radiographs of the individuals from Pueblo Bonito (n=27) and Hawikku (n=59) provided by the NMNH Repatriation Office.

Transition Analysis

Adults were recognized as individuals with almost or fully fused pelvic epiphyses, typically samples identified as being in the late teens to early twenties. Adult age-at-death was estimated using transition analysis, an age estimation method outlined by Boldsen et al. (2002) as an alternative to traditional osteological aging techniques. As with traditional aging methods, transition analysis requires the scoring of multiple skeletal age indicators from the pubic symphysis, the sacroiliac joint, and cranial sutures. However,

unlike traditional methods, transition analysis employs linear regression to calculate the probability that an individual will display indicators for age-specific stages for multiple age-related morphological traits.

Five age-related morphologic traits from the pubic symphysis, nine from the sacroiliac joint, and five from the ectocranial sutures were scored according to the guidelines outlined by Milner and Boldsen (2013). The left and right sides of each skeletal element were scored, so each individual sample had the potential of receiving a score for 33 traits. All skeletal elements were scored when present, but only the traits from the sacroiliac joint and pubic symphysis were used to estimate age-at-death for the study. The inclusion of cranial sutures has been shown to worsen age estimates produced by transition analysis (Milner and Boldsen, 2012). Additionally, cranial deformation was observed in both sample populations, which may have also affected the scoring of the cranial sutures. Therefore, the decision was made to remove the cranial suture scores from the final age-at-death estimations.

The transition analysis age estimation computer software, ABOU 2.1046, was downloaded from <http://math.mercyhurst.edu/~sousley/Software/>. Using this program, 95% confidence intervals and point estimates (maximum likelihood estimate) were generated for individual age-at-death. The age intervals and point estimates generated by the program differed based on the combination of observable traits present for each sample (Boldsen et al., 2002; Milner and Boldsen, 2012). The point estimates produced by the software were used to create separate and combined age-at-death distributions for the Pueblo Bonito and Hawikku population samples. In total, transition analysis was used

to estimate age for 119 individuals from Hawikku and 27 individuals from Pueblo Bonito.

Skeletal Indicators of Physiological Stress

To evaluate the effect of physiological stress on the mortality patterns of the two sample populations from Pueblo Bonito and Hawikku, linear enamel hypoplasia (LEH) and periosteal lesions were examined and documented for presence and absence. This approach was used because previous studies have shown an association between LEH and periosteal lesions and an elevated risk in mortality (DeWitte and Wood, 2008; DeWitte, 2014a; Temple, 2014; Wilson, 2014; Yaussy et al., 2016).

Linear Enamel Hypoplasia

Data on the presence and patterning of enamel defects is emerging as one of the main non-specific indicators of stress used in the interpretation of mortality within archaeological samples (Temple, 2014; Thomas, 2003; Wilson, 2014). Linear enamel hypoplasia (LEH) is a developmental defect of tooth enamel that creates grooves and furrows on tooth crowns. It forms when insufficient enamel is deposited during the secretory phase of amelogenesis and is the result of a non-specific systemic physiological disruption that affects the process of tooth crown formation. The indelible nature of the defect as well as the resilience of teeth within the archaeological record, makes LEH one of the best indicators of developmental stress.

For the study, macroscopic observations of LEH were recorded for presence and absence on the anterior permanent teeth, and were coded as 1 (absent) and 2 (present) for statistical analysis. To ensure the defect was related to a physiological disruption rather

than a hereditary condition or a traumatic event, defect presence was defined as being visible on two or more anterior teeth. A defect was only scored as absent when the enamel surface was observable, otherwise the tooth was marked as unobservable. The number of LEH observed on a tooth were recorded, but only presence and absence was used for statistical analysis.

Periosteal Lesions

Periosteal new bone formation is frequently observed within the archaeological record and has historically been used by bioarchaeologists as an indicator of biological stress to make inferences about the health of past populations. Periosteal lesions form when generalized inflammation occurs as a response to extrinsic and intrinsic pathological factors that can cause infection (Klaus, 2014b; Larsen, 1995; Weston, 2008). Additionally, the formation of periosteal lesions has also been linked to nutritional deficiencies (Brenton and Paine, 2007). For the purposes of this study, periosteal lesions were solely being used a general indicator of biological stress. Therefore, only the presence or absence of the lesion was recorded, and no attempt was made to differentially diagnosis the condition.

Periosteal lesions were recorded for presence and absence on the left and right tibia. The tibia was selected because of its sensitivity to the development of periosteal lesions. In skeletal samples, worldwide, the tibia demonstrates the greatest proclivity to manifest abnormal periosteal new bone formation (Larsen, 2015). This relates to a variety of factors, likely related to the fact that it is the least vascularized part of the body where immune and even lymphatic response to infections appears the slowest. The anterior

lower limb also has a minimal amount of soft tissue between the bone and external environment, is susceptible to repeated injury and infection which elevates periosteal osteogenic potential (Gallay et al., 1994; Klaus, 2014b; Yaussy et al., 2016). To be marked as present, the periosteal lesion must have occurred bilaterally on the tibiae.

In addition to being recorded as present, the periosteal lesions were scored as active (2), mixed (3) or healed (4) based on the standards outlined in Buikstra and Ubelaker (1994) and the research design of DeWitte (2014a). If a lesion appeared porous and disorganized, possessed sharp unremodeled edges, and looked to be sitting on top of the cortical bone it was scored as active. Whereas, a healed lesion was defined as having a more organized appearance and rounded remodeled edges (Weston 2008, p. 52). A lesion with both active and healed characteristics was scored as mixed.

Osteometric Measurements

All long bones measurements were taken three times on both the left and right sides using a standard osteometric board and were recorded over the period of a day to the nearest millimeter. The maximum femoral head diameter and the femoral head anterior-posterior breadth (FH) were measured using needle point calipers and were only taken for individuals with fully fused femoral heads. Maximum femoral length (MFL), humeral length (HL), ulnae length (UL), radial length (RL), and the maximum femoral head diameter were taken according to Buikstra and Ubelaker (1994). Tibial length (TL) was measured from the most superior portion of the lateral condyle to the most inferior point of the medial malleolus. The femoral head anterior-posterior breadth was measured perpendicular to the cervical axis, as outlined by Ruff et al. (1991).

For subadults, femoral length (FL), tibial length (TL), humeral length (HL), ulnae length (UL), and radial length (RL) were recorded for both the left and right side. Each measurement was taken three times and recorded to the nearest millimeter using a standard osteometric board and needle point calipers. There was a high occurrence of long bone epiphyses glued on to the diaphyses, preventing accurate long bone measurements. In these instances, only the long bones with no artificially attached epiphyses were measured.

Stature Estimations

Adult stature was estimated using the sex-specific equations developed by Auerbach and Ruff (2010) for indigenous North American populations from the temperate regional group, which was partially comprised of skeletal samples from the U.S. Southwest. The sex-specific calculations include three regression equations, utilizing femoral bicondylar length (FBL), maximum tibial length (TML), and a combination of the two measurements. Since only MFL measurements were taken of the samples, it was necessary to convert MFL to FBL by multiplying the MFL by 0.991 (Temple et al., 2008).

The average of the MFL and TML measurements were taken for both the left and right sides of each bone. The averages of the left and right sides were then used to calculate sex-specific adult stature using the femur equation (FE), the tibia equation (TE), and the femur and tibia equation (FTE) (Table 1). The stature estimates produced by the three equations for each side were then averaged to produce a final stature estimate (cm) for each sample from Pueblo Bonito and Hawikku.

Table 1 Adult Stature (cm) Equations for the Temperate Regional Group.

Sex	Femur Equation (FE)	Tibia Equation (TE)	Femur and Tibia Equation (FTE)
Male	$0.254 * (MFL * 0.991) + 52.85$	$0.302 * TML + 51.66$	$0.160 * FBL + 0.126 * TML + 47.11$
Female	$0.267 * (MFL * 0.991) + 55.85$	$0.296 * TML + 52.30$	$0.176 * FBL + 0.117 * TML + 41.75$

Adapted from Auerbach and Ruff (2010)

Subadult stature was estimated using the age-specific regression equations developed by Ruff (2007) for the lower and upper limbs. The three lower limb equations utilized femoral length (FL), tibial length (TL), and a combination of the two measurements. The upper limb equations utilized humeral length (HL), radial length (RL), and a combination of the two measurements. As recommended by Ruff (2007), the equations were only used for individuals aged 17 years or younger. The age-specific equations corresponding to the nearest year of the individual for both the lower (Table 2) and upper limbs (Table 3) was applied. For example, individuals aged 2.5 years were rounded down to 2 years, and individuals aged 2.6 years were rounded up to 3 years. If an individual had an age range of 4 to 6 years, the mid-point of 5 years was used to calculate stature. Total length equations were only applied when it was clear that the long bone epiphyses were fully fused and not glued on.

Overall, stature was estimated for a total 109 adults and 41 subadults from Hawikku, 67 adult females and 42 males. For Pueblo Bonito stature was estimated for 24 adults, 12 females and 12 males, and 15 subadults.

Table 2 Subadult Stature (cm) Prediction Equations for Lower Limbs.

Age	Femoral Length (mm)	Tibial Length (mm)	Femoral + Tibial Length (mm)
1 ^{d*}	0.303 * FL + 32.6	0.353 * TL + 35.4	0.175 * (FL + TL) + 31.1
2 ^d	0.294 * FL + 35.7	0.380 * TL + 33.5	0.185 * (FL + TL) + 29
3 ^d	0.310 * FL + 34.1	0.342 * TL + 39.9	0.174 * (FL + TL) + 33
4 ^d	0.295 * FL + 37.7	0.327 * TL + 43.7	0.163 * (FL + TL) + 37.7
5 ^d	0.311 * FL + 34.1	0.322 * TL + 45.3	0.168 * (FL + TL) + 35.5
6 ^d	0.287 * FL + 40.5	0.330 * TL + 44.9	0.160 * (FL + TL) + 39.5
7 ^d	0.294 * FL + 39.1	0.325 * TL + 46.8	0.162 * (FL + TL) + 38.6
8 ^d	0.284 * FL + 42.8	0.304 * TL + 52.9	0.153 * (FL + TL) + 44.3
9 ^d	0.308 * FL + 35.6	0.324 * TL + 48.9	0.165 * (FL + TL) + 38
10 ^d	0.292 * FL + 40.6	0.321 * TL + 50.1	0.160 * (FL + TL) + 40.8
11 ^d	0.306 * FL + 36.3	0.331 * TL + 47.7	0.165 * (FL + TL) + 38.2
12 ^d	0.320 * FL + 31.4	0.333 * TL + 47.9	0.148 * (FL + TL) + 38.7
11 ^{t**}	0.279 * FL + 36.4	0.296 * TL + 47.3	0.155 * (FL + TL) + 33.6
12 ^t	0.290 * FL + 31.8	0.309 * TL + 43.3	0.158 * (FL + TL) + 31.3
13 ^t	0.288 * FL + 33	0.321 * TL + 40.1	0.159 * (FL + TL) + 32.1
14 ^t	0.294 * FL + 31.5	0.307 * TL + 46.8	0.145 * (FL + TL) + 44.8

15 ^t	0.269 * FL + 43.8	0.273 * TL + 61.6	0.143 * (FL + TL) + 47
16 ^t	0.270 * FL + 43.9	0.274 * TL + 62.7	0.149 * (FL + TL) + 43.4
17 ^t	0.286 * FL + 37.4	0.281 * TL + 61.5	0.148 * (FL + TL) + 38.7

Adapted from Ruff (2007)

*d = using diaphyseal length, **t = using total length

Table 3 Subadult Stature (cm) Prediction Equations for Upper Limbs.

Age	Humeral Length (mm)	Radial Length (mm)	Humeral + Radial Length
1 ^{d*}	—	0.386 * RL +	0.131 * (HL + RL) + 49.4
2 ^d	0.437 * HL + 30	0.509 * RL +	0.264 * (HL + RL) + 26.9
3 ^d	0.393 * HL + 38.1	0.514 * RL +	0.235 * (HL + RL) + 35.5
4 ^d	0.407 * HL + 37.7	0.526 * RL +	0.236 * (HL + RL) + 36.6
5 ^d	0.394 * HL + 40.6	0.548 * RL +	0.236 * (HL + RL) + 37.4
6 ^d	0.422 * HL + 36.8	0.570 * RL +	0.254 * (HL + RL) + 32.6
7 ^d	0.445 * HL + 33.2	0.574 * RL +	0.261 * (HL + RL) + 31.1
8 ^d	0.439 * HL + 35.3	0.546 * RL +	0.255 * (HL + RL) + 33.8
9 ^d	0.448 * HL + 34.3	0.565 * RL +	0.260 * (HL + RL) + 32.8
10 ^d	0.442 * HL + 35.6	0.575 * RL +	0.259 * (HL + RL) + 33
11 ^d	0.475 * HL + 28.6	0.57 * RL +	0.252 * (HL + RL) + 36.7
12 ^d	0.433 * HL + 39.3	0.547 * RL +	0.213 * (HL + RL) + 54.5
11 ^{t**}	0.465 * HL + 21.6	0.513 * RL +	0.131 * (HL + RL) + 49.4
12 ^t	0.420 * HL + 34.3	0.532 * RL +	0.254 * (HL + RL) + 27.4
13 ^t	0.397 * HL + 41.6	0.507 * RL +	0.243 * (HL + RL) + 32.8

14 ^t	0.381 * HL + 47.7	0.483 * RL +	0.230 * (HL + RL) + 39.9
15 ^t	0.368 * HL + 52.1	0.455 * RL +	0.222 * (HL + RL) + 44.5
16 ^t	0.371 * HL + 51.6	0.463 * RL +	0.218 * (HL + RL) + 47.5
17 ^t	0.396 * HL + 44.3	0.465 * RL +	0.219 * (HL + RL) + 47.2

Adapted from Ruff (2007)

*d = using diaphyseal length, **t = using total length

Body Mass Calculations

Body mass (kg) was estimated for adults using the equations developed by Ruff et al. (1991), McHenry (1992), and Grine et al. (1995) (Table 4). All three of the authors used the femoral head anterior-posterior breadth measurement (FH) to estimate body mass. The estimation equations of Ruff et al. (1991) are sex-specific, whereas McHenry (1992) and Grine et al. (1995) combine sex. As stated previously, FH was measured only on fully fused femoral heads. Subadult body mass was not estimated for this study.

FH was measured on both the left and the right side. The FH measurements from each side were averaged to estimate body mass (kg) using the five equations depicted in Table 4. The three estimates from each side were then averaged together to create a final body mass estimation (kg). Overall, body mass was estimated for a total of 63 females and 42 males from Hawikku (n=105), and 12 females and 10 males from Pueblo Bonito (n=22).

Table 4 Adult Body Mass Estimation (kg) Equations.

Ruff et al. (1991)	$(2.741 * FH - 54.9) * .90$ (males)
	$(2.426 * FH - 35.1) * .90$ (females)
	$(2.160 * FH - 24.8) * .90$ (combined sex)
McHenry (1992)	$2.239 * FH - 39.9$
Grine et al. (1995)	$2.268 * FH - 36.5$

Adapted from Auerbach and Ruff (2004)

Statistical Analysis

Kaplan-Meier Survival Analysis

The Kaplan-Meier survival curve, developed by E.L. Kaplan and Paul Meier in 1958, has become a standard and accepted method in modern epidemiology for evaluating survival because of its ability to calculate differing survival times (time-to-event) within a sample population (Rich et al., 2010). Kaplan-Meier survival analysis is also an established method within bioarchaeology for analyzing survival within archaeological skeletal samples (Boldsen, 2005; DeWitte, 2014a; DeWitte, 2015; Wilson, 2014; Wood et al., 1992; Yaussy et al., 2016). Kaplan-Meier survival curves with log ranked tests were generated in SPSS 24 (IBM Inc., 2016) to evaluate the effect of the four variables (stature, body mass, LEH, and periosteal lesions) on survivorship for both the separate and combined Pueblo Bonito and Hawikku samples.

To evaluate adult stature (cm) and body mass (kg), sex-specific standard z-score values were calculated in Excel 2017 (Version 15.33). All individuals were coded as either 1 or 2, depending if the z-score fell above or below the sample mean. Individuals

with a z-score < 0 received a 1 and individuals with a z-score ≥ 0 received a 2. The same sex-specific coding method was used for body mass. As previously discussed, LEH were scored as absent (1) or present (2) and only scored on observable permanent anterior teeth. Periosteal lesions were scored on the tibia as absent (1), active (2), mixed (3) and healed (4), and only used if the lesion was bilaterally observed on the tibiae.

Excel 2017 (Version 15.33) was used to create tables (Table 5) containing the three key elements for Kaplan-Meier survival analysis, (1) serial time, (2) status at end of serial time (event occurrence or censored), and (3) the study group (Rich et al. 2010). For the purposes of this study, the three key elements were identified as (1) point estimate for age-at-death (years), (2) dead = 1, and (3) absence = 1, presence = 2; below average = 1, above average = 2; (1) = absent, (2) = active, (3) = mixed, (4) = healed. The status at age-at-death was the same for all individuals in the two samples populations, because archaeological samples are only representative of individuals at the point of failure (i.e., death) (Wood et al., 1992).

Table 5 Example of Sorted Table for LEH Kaplan-Meier Analysis.

Catalogue Number	Age-at Death Point Estimate	Status	Variable Score 1 = absent 2 = present
327058	36.3	1	1
327059	36.9	1	2

Skeletal Growth

The stature estimations calculated from FL, TL, HL, and RL (Ruff, 2007) were utilized as an indicator of subadult growth for the two sample populations. The relationship between age and growth was estimated using line fitting methods for the combined Pueblo Bonito and Hawikku samples. Forward selection was used in SPSS 24 to identify which model was preferable for the study. The forward selection strategy adds variables one at a time until it stops finding variables that improve the model. The adjusted R^2 value and the p-value can both be used to evaluate the effect of each variable on the significance of the model (Diez et al., 2015).

For this study, age was the independent variable (x) and stature (cm) was the dependent variable (y). Subadults that did not have stature estimates were not included in the analysis. The lower-limb stature estimations (cm) calculated from FL and TL were preferred, but if the measurements were absent then the estimations based on the upper-limb measurements, HL and RL, were used. This approach to the evaluation of subadult growth has been used by previous studies of archaeological skeletal samples (Pinhasi et al., 2005, 2006; Mays et al., 2009; Temple et al., 2014). The polynomial line produced by the model does not reflect the true growth pattern for the sample populations, rather this method is merely a tool to evaluate whether the subadult population sample is experiencing stunting in growth.

Conclusion

In this chapter, an overview was provided of the materials and methods used to test the hypotheses of the study. The skeletal material from the Ancestral Pueblo sites of

Pueblo Bonito and Hawikku were used to develop a comparative bioarchaeological study. The methods of sex and age estimation were reviewed, and the statistical aging technique of transitional analysis was briefly discussed. Additionally, the methods used for stature and body mass estimations, subadult growth, and the inference of physiological stress were explained. In the next chapter, the results of these estimations and statistical analyses are described.

CHAPTER FIVE

RESULTS

The findings of the study are presented in this chapter, beginning with a description of periosteal lesion and LEH frequency within the Pueblo Bonito and Hawikku skeletal samples. Subsequently, the association between mortality and the presence of biological indicators of stress, stature, and body mass are tested by data derived from the Kaplan-Meier survival analysis. Finally, the results of the forward selection modeling strategy for subadult growth is discussed and interpreted for the skeletal samples from Pueblo Bonito and Hawikku.

Biological Indicators of Stress Frequency Tables

Periosteal Lesions

Table 6, Table 7, and Table 8 depict the age distribution frequencies for absent, active, mixed, and healed periosteal new bone formations from the Hawikku (n=131), Pueblo Bonito (n=39), and combined (n=170) samples. The age intervals present in all three tables were only used to reveal general patterns, and were not used for the Kaplan-Meier survival analysis. The age interval 0.0-9.99 (years) represented 56% of all active lesions observed in the Hawikku sample, 64% in the Pueblo Bonito sample, and 59% in the combined sample. In the combined sample, 94% of all active lesions were observed

between the ages of 0.0 to 39.99 years, and 63% of all healed lesions were observed between the ages of 40-79.99 years.

Table 6 Frequencies of individuals with absent, active, mixed, and healed periosteal lesions from Hawikku sample.

Age (years)	Absent	Active	Mixed	Healed	Total
0.0-9.99	8	10	3	0	21
10.0-19.99	14	5	1	0	20
20.0-29.99	14	1	1	2	18
30.0-39.99	30	0	3	1	34
40.0-49.99	12	0	0	1	13
50.0-59.99	4	1	0	1	6
60.0-69.99	7	1	0	0	8
70.0-79.99	7	0	0	1	8
80.0-89.99	3	0	0	0	3
Total	99	18	8	6	131

Table 7 Frequencies of individuals with absent, active, mixed, and healed periosteal lesions from Pueblo Bonito sample.

Age (years)	Absent	Active	Mixed	Healed	Total
0.0-9.99	4	9	0	0	13
10.0-19.99	2	1	0	0	3
20.0-29.99	1	2	2	0	5
30.0-39.99	10	2	2	0	14
40.0-49.99	0	0	0	1	1
50.0-59.99	0	0	0	0	0
60.0-69.99	1	0	0	0	1
70.0-79.99	0	0	0	1	1
80.0-89.99	1	0	0	0	1
Total	19	14	4	2	39

Table 8 Frequencies of individuals with absent, active, mixed, and healed periosteal lesions from both Hawikku and Pueblo Bonito samples.

Age (years)	Absent	Active	Mixed	Healed	Total
0.0-9.99	12	19	3	0	34
10.0-19.99	16	6	1	0	23
20.0-29.99	15	3	3	2	23
30.0-39.99	40	2	5	1	48
40.0-49.99	12	0	0	2	14
50.0-59.99	4	1	0	1	6
60.0-69.99	8	1	0	0	9
70.0-79.99	7	0	0	2	9
80.0-89.99	4	0	0	0	4
Total	118	32	12	8	170

Linear Enamel Hypoplasia

Table 9, Table 10, and Table 11 provide the age distribution frequencies of individuals with absent and present LEH from the Hawikku (n=104), Pueblo Bonito (n=28), and combined samples (n=132), respectively. Only individuals aged 8.99 years and older were included because the study only examined permanent anterior teeth. As stated previously, the age intervals used were only applied to reveal general patterns, and were not used for the Kaplan-Meier survival analysis. The age intervals of 8.99-19.99, 20-29.99, and 30-39.99 represented 69% of observed (present) LEH in the Hawikku sample, 85% in the Pueblo Bonito sample, and 75% in the combined sample.

Table 9 Frequencies of individuals with present and absent LEH from Hawikku sample.

Age (years)	Absent	Present	Total
8.99-19.99	9	17	26
20.0-29.99	8	10	18
30.0-39.99	11	18	29

40.0-49.99	3	7	10
50.0-59.99	0	5	5
60.0-69.99	4	3	7
70.0-79.99	5	2	7
80.0-89.99	2	0	2
Total	42	62	104

Table 10 Frequencies for individuals with present or absent LEH for Pueblo Bonito sample.

Age (years)	Absent	Present	Total
8.99-19.99	3	4	7
20.0-29.99	3	2	5
30.0-39.99	6	5	11
40.0-49.99	1	1	2
50.0-59.99	0	0	0
60.0-69.99	1	0	1
70.0-79.99	1	0	1
80.0-89.99	0	1	1
Total	15	13	28

Table 11 Frequencies for individuals with present or absent LEH for Hawikku and Pueblo Bonito samples.

Age (years)	Absent	Present	Total
8.99-19.99	12	21	33
20.0-29.99	11	12	23
30.0-39.99	17	23	40
40.0-49.99	4	8	12
50.0-59.99	0	5	5
60.0-69.99	5	3	8
70.0-79.99	6	2	8
80.0-89.99	2	1	3
Total	45	75	132

Kaplan-Meier Survival Analysis

Periosteal Lesions

Table 12 provides the results of the Kaplan-Meier survival analysis for the Hawikku, Pueblo Bonito, and combined samples. The survival curves for the Hawikku, Pueblo Bonito, and combined samples are depicted in Figure 1, Figure 2, and Figure 3, respectively.

The results of the analyses reveal significantly different mean survival times between the four periosteal lesion activity categories. Based on these results, the activity categories can be organized from shortest to longest survival time – active, mixed, absent, and healed. For the combined sample (i.e., both Hawikku and Pueblo Bonito), the mean survival time for individuals with active lesions was 13.63 years, for mixed lesions 22.51 years, for absent (in other words, no lesions observed) 35.75 years, and for healed lesions 45.60 years.

For the Hawikku and combined analyses, the 95% confidence intervals for mean survival time of individuals with active and mixed lesions overlap, but the two categories do not overlap in the Pueblo Bonito analysis. For the Hawikku and combined samples, the 95% confidence intervals for mean survival time of individuals with mixed and absent lesions do not overlap, but they do overlap for the Pueblo Bonito sample. Lastly, the 95% confidence intervals for the mean survival time of individuals with absent and healed lesions overlap for all three analyses.

Table 12 Kaplan-Meier survival analysis results for periosteal lesions.

Sample	Periosteal Lesion Activity	Mean Survival Time	95% Confidence Interval	<i>p</i> -value
Hawikku	Absent	36.85	32.83 - 40.87	0.0
	Active	14.44	5.61 - 23.28	
	Mixed	19.01	9.73 - 28.29	
	Healed	40.98	24.76 - 57.21	
Pueblo Bonito	Absent	30.02	21.09 - 38.95	0.01
	Active	12.59	6.29 - 18.89	
	Mixed	29.50	22.47 - 36.53	
	Healed	59.45	32.30 - 86.60	
Combined	Absent	35.75	32.07 - 39.43	0.0
	Active	13.63	8.02 - 19.24	
	Mixed	22.51	15.47 - 29.55	
	Healed	45.60	31.37 - 59.83	

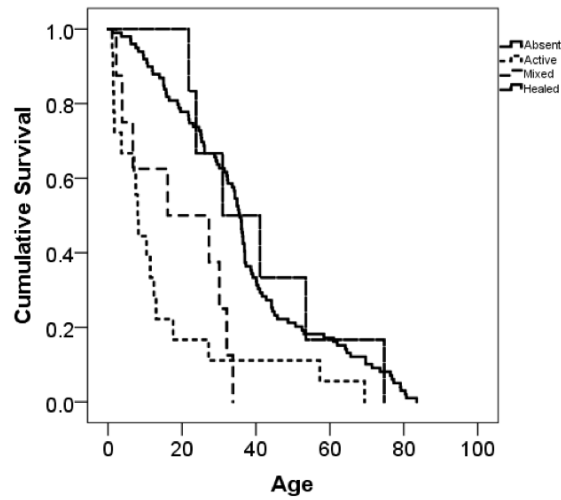


Figure 1 Kaplan-Meier survival curve for periosteal lesions including Hawikku sample.

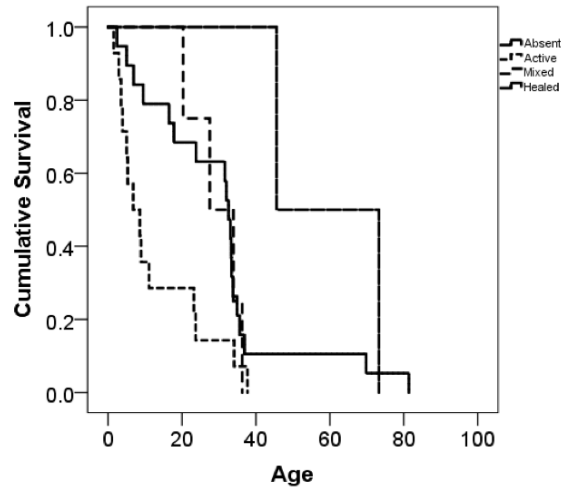


Figure 2 Kaplan-Meier survival curve for periosteal lesion including Pueblo Bonito sample.

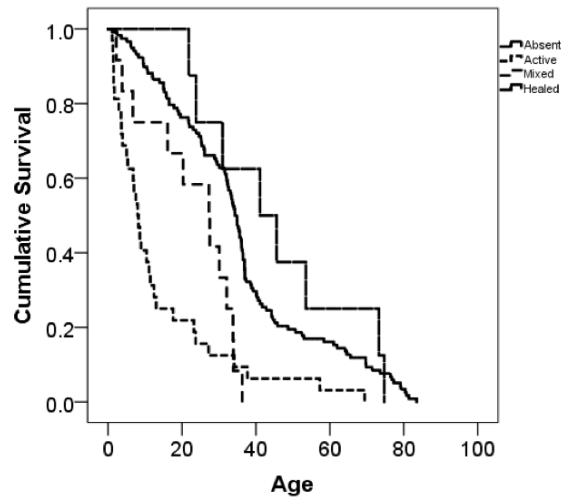


Figure 3 Kaplan-Meier survival curve for periosteal lesions including Hawikku and Pueblo Bonito samples.

Linear Enamel Hypoplasia

The results of the Kaplan-Meier survival analysis are depicted in Table 13 for the Hawikku, Pueblo Bonito, and combined samples. The survival curves for the Hawikku, Pueblo Bonito, and combined samples are depicted in Figure 4, Figure 5, and Figure 6, respectively.

The results of the analyses demonstrate statistically significant differences in the mean survival time between LEH presence and absence for the Hawikku sample, and insignificant results for the Pueblo Bonito and combined samples. For the Hawikku sample, the mean survival time for individuals with no LEH observed (defects absent) was 40.23 years, and for individuals with LEH observed (defects present) the mean survival time was 32.89 years. The 95% confidence intervals for mean survival time of individuals with absent and present LEH overlap for all three analyses.

Table 13 Table 13 Kaplan-Meier survival analysis results for LEH.

Sample	LEH Activity	Mean Survival Time	95% Confidence Interval	<i>p</i> -value
Hawikku	Absent	40.23	33.43 - 47.04	0.037
	Present	32.89	28.69 - 37.08	
Pueblo Bonito	Absent	32.9	23.28 – 42.52	0.799
	Present	30.42	20.34- 40.5	
Combined	Absent	38.27	32.64 – 43.90	0.092
	Present	32.46	28.60 – 36.32	

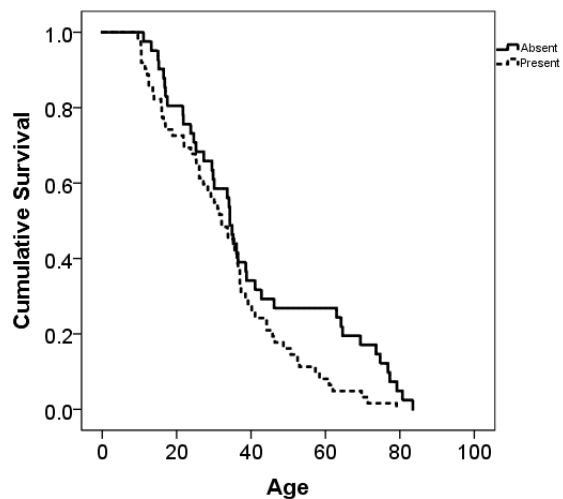


Figure 4 Kaplan-Meier survival curve for LEH including Hawikku sample.

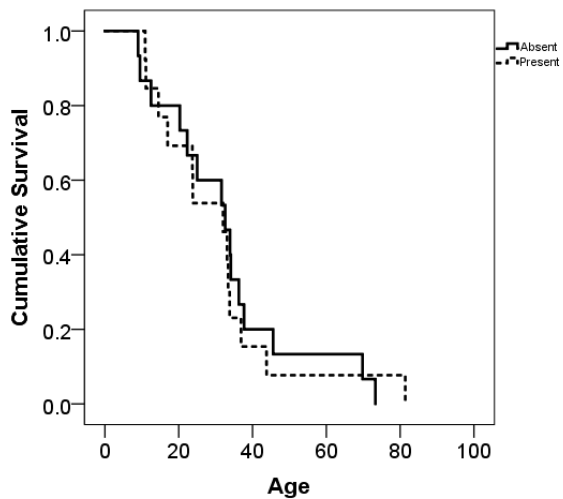


Figure 5 Kaplan-Meier survival curve for LEH including Pueblo Bonito sample.

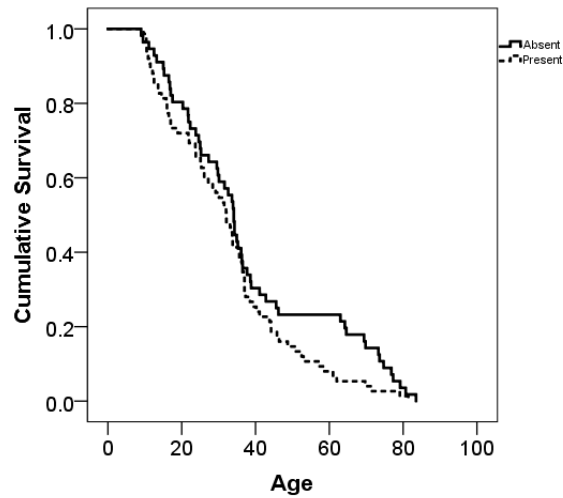


Figure 6 Kaplan-Meier survival curve for LEH including combined sample.

Adult Stature

The results of the Kaplan-Meier survival analysis for males and females are depicted in Table 14, including the Hawikku and Pueblo Bonito samples. The male and female stature (cm) survival curves for the Hawikku and Pueblo Bonito population samples are depicted in Figures 7-10. These results only include adult individuals aged using transition analysis.

The results of the analyses demonstrate statistically insignificant differences in mean survival time between below and above average stature for male and female individuals from both samples. For Hawikku females, the mean survival time for individuals below average was 46.43 years, and for individuals above average the mean survival time was 47.75 years. For Pueblo Bonito females, the mean survival time for individuals below average was 56.33 years, and for individuals above average the mean

survival time was 58.62 years. The below average male individuals from Hawikku have a mean survival time of 49.34, whereas the above average individuals have a mean survival time of 46.49 years. The mean survival time for below average male individuals from Pueblo Bonito is 61.19 years, whereas the above average individuals have a survival time of 54.3 years.

The 95% confidence intervals of female stature for the below and above average categories overlap for both Hawikku and Pueblo Bonito. These results are also seen for the 95% confidence intervals for male stature in both sample populations.

Table 14 Kaplan-Meier survival analysis results for Male and Female stature.

Sample	Biological Sex	Stature Estimation	Mean Survival Time	95% Confidence Interval	<i>p</i> -value
Hawikku	Male	Above Average	46.49	40.53 - 52.45	0.416
		Below Average	49.34	43.18 - 55.5	
	Female	Above Average	47.75	41.03 - 54.46	0.887
		Below Average	46.43	40.38 - 52.47	
Pueblo Bonito	Male	Above Average	54.3	43.35 - 65.27	0.204
		Below Average	61.19	49.54 - 72.83	
	Female	Above Average	58.62	49.06 - 68.18	0.255
		Below Average	56.33	44.17 - 68.49	

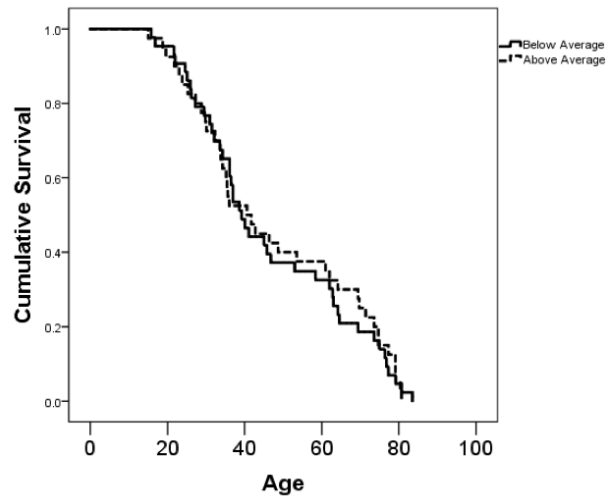


Figure 7 Kaplan-Meier survival curve for female stature (cm) including Hawikku sample.

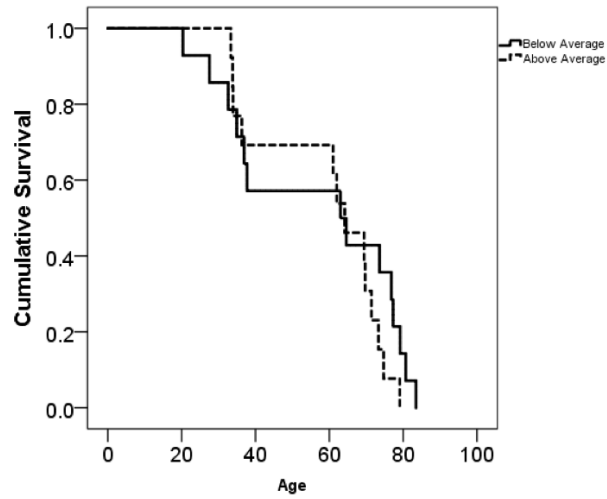


Figure 8 Kaplan-Meier survival curve for female stature (cm) including Pueblo Bonito sample.

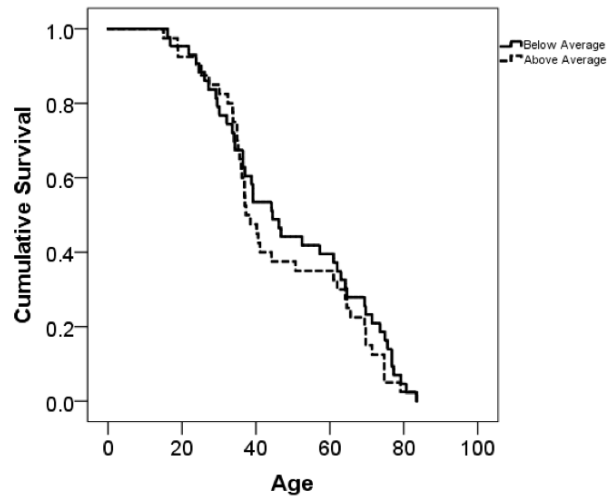


Figure 9 Kaplan-Meier survival curve for male stature (cm) including Hawikku sample.

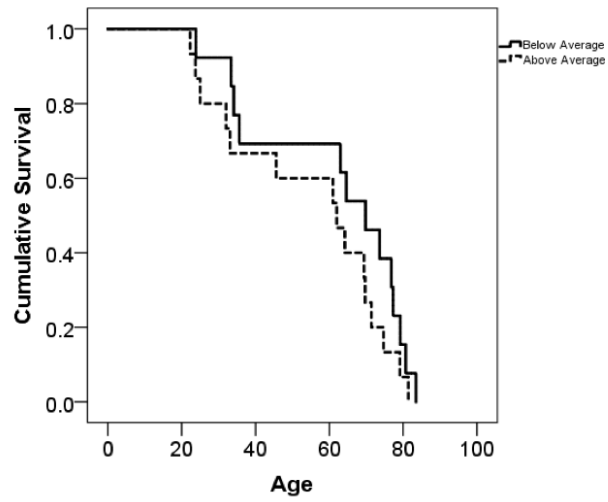


Figure 10 Kaplan-Meier survival curve for male stature (cm) including Pueblo Bonito sample.

Adult Body Mass

The results of the Kaplan-Meier survival analysis for males and females are depicted in Table 15, including the Hawikku and Pueblo Bonito samples. The male and female body mass (kg) survival curves for the Hawikku and Pueblo Bonito population samples are depicted in Figures 11-14. These results only include adult individuals with fully fused femoral heads and that were aged using transition analysis.

The results of the analyses demonstrate statistically insignificant differences in mean survival time between below and above average body mass for female individuals from both population samples. For Hawikku females, the mean survival time for individuals below average was 50.29 years, and for individuals above average the mean, survival time was 44.24 years. For Pueblo Bonito females, the mean survival time for individuals below average was 53.32 years, and for individuals above average the mean, survival time was 57.80 years.

The results of the analyses for male individuals demonstrate statistically significant differences between mean survival time. Male individuals from both Hawikku and Pueblo Bonito who were below average for body mass had a longer mean survival time than male individuals who had an above average body mass. The below average male individuals from Hawikku had a mean survival time of 55.48 years, whereas the above average individuals have a mean survival time of 44.11 years. The mean survival time for below average male individuals from Pueblo Bonito was 61.38 years, whereas the above average individuals have a survival time of 54.13 years.

The 95% confidence intervals of female body mass for the below and above average categories overlap for both Hawikku and Pueblo Bonito. These results are also seen for the 95% confidence intervals for male body mass in both sample populations.

Table 15 Kaplan-Meier survival analysis results for Male and Female body mass.

Sample	Biological Sex	Body Mass Estimation	Mean Survival Time	95% Confidence Interval	<i>p</i> -value
Hawikku	Male	Above Average	44.11	38.28 - 49.94	0.017
		Below Average	55.48	49.39 - 61.58	
	Female	Above Average	44.24	38.02 - 50.45	0.126
		Below Average	50.29	43.84 - 56.74	
Pueblo Bonito	Male	Above Average	54.13	42.73 - 65.54	0.043
		Below Average	61.38	48.81 - 73.95	
	Female	Above Average	57.8	47.46 - 68.14	0.351
		Below Average	53.32	40.68 - 65.96	

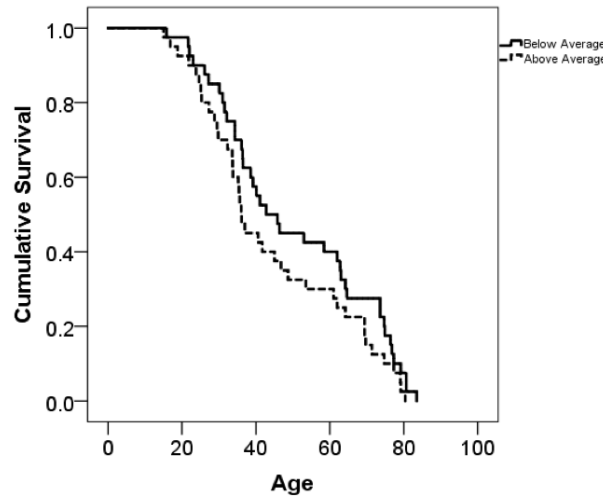


Figure 11 Kaplan-Meier survival curve for female body mass (kg) including Hawikku sample.

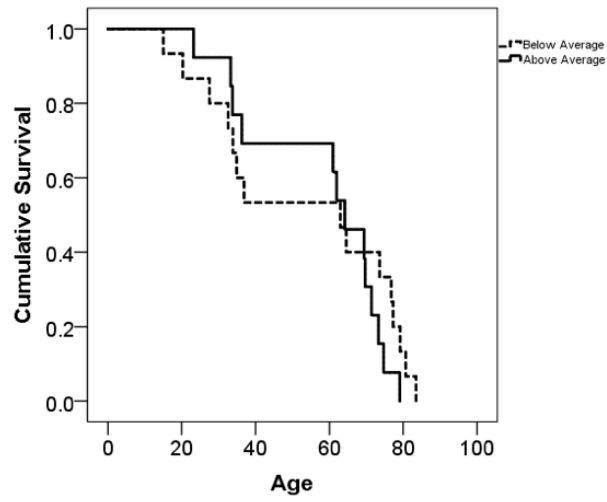


Figure 12 Kaplan-Meier survival curve for female body mass (kg) including Pueblo Bonito sample.

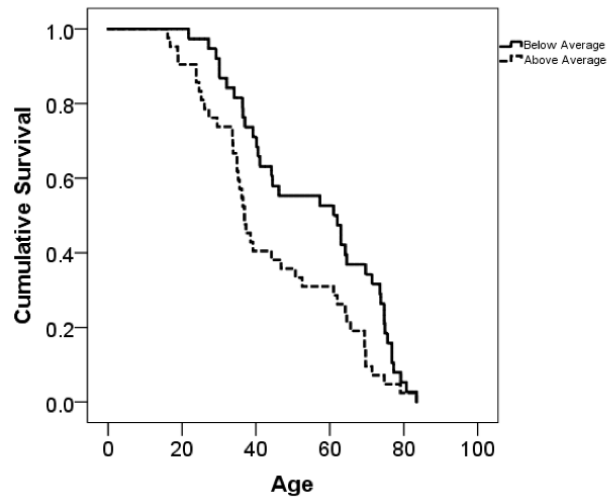


Figure 13 Kaplan-Meier survival curve for male body mass (kg) including Hawikku sample.

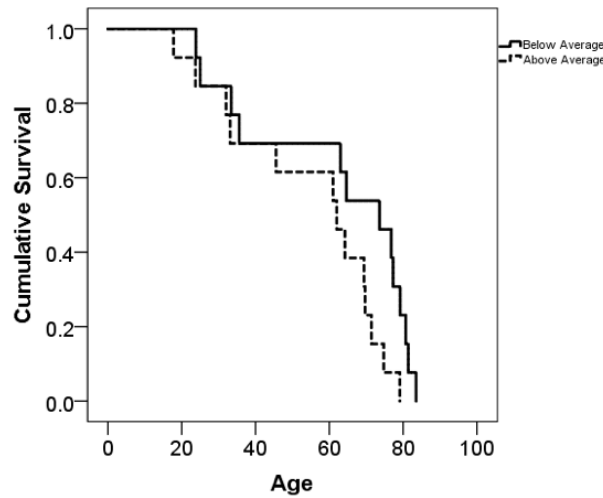


Figure 14 Kaplan-Meier survival curve for male body mass (kg) including Pueblo Bonito sample.

Subadult Growth Plot

The forward selection line fitting method designated a polynomial equation to the third order as the appropriate fit for the Hawikku and Pueblo Bonito subadult stature (cm) data. Figure 15 depicts the scatterplot for subadult stature analysis for both the population samples. The markers at the x-axis point of 18 years represents the average adult stature calculated for males and females from Hawikku and Pueblo Bonito. The adult female average from Hawikku was estimated at 152.16 (cm) and for males 160.37 (cm). For Pueblo Bonito, the female average was estimated at 158.27 (cm) and for males 161.84 (cm). The residual scatterplot (Fig. 16) illustrates that stunting is occurring around 6 to 12 years of age in the subadult samples from Hawikku and Pueblo Bonito.

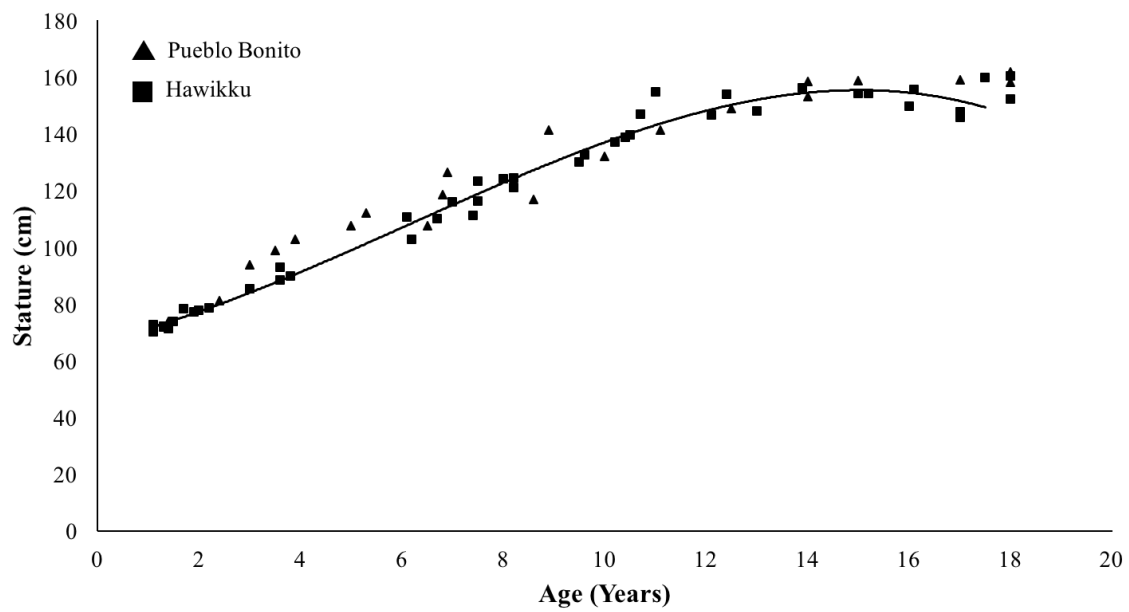


Figure 15 Skeletal growth trends for Hawikku and Pueblo Bonito.

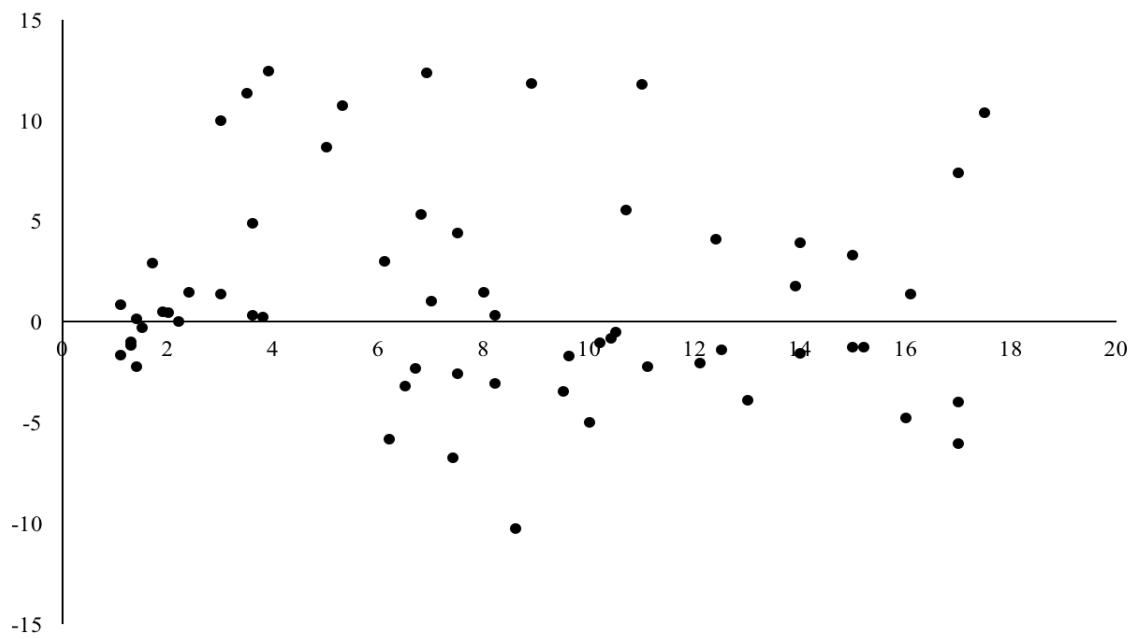


Figure 16 Residual plot for skeletal growth trends at Hawikku and Pueblo Bonito.

Conclusion

In this chapter, the results of the bioarchaeological and Kaplan-Meier survival analyses from Pueblo Bonito and Hawikku were presented. The Kaplan-Meier survival analysis demonstrated a statistically significant difference in mean survival time between categories of periosteal lesion activity, and between male individuals with above and below average body mass (kg) at both Pueblo Bonito and Hawikku. Additionally, a statistically significant difference between LEH presence and absence was observed in the Hawikku sample. The next chapter discusses the results of the study, providing possible interpretations using the background material reviewed in Chapter Two on biological stress and the conceptual challenges of paleodemography, and Chapter Three on the bioarchaeology of the Ancestral Pueblo Southwest.

CHAPTER SIX

DISCUSSION

The scholarly research of the American Pueblo Southwest represents a unique example of the advantages of a collaborative effort between archaeology, anthropology, and paleopathology. The history of shifting paradigms is reflected in the anthropological literature of the region, progressing from case descriptions to population studies, and towards an ecologically based approach. In recent years, bioarchaeological investigations of the Southwest have faced increasing logistical, practical, and ethical challenges. The implementation of the Native American Graves and Repatriation Act (NAGPRA) in the 1990s led to the repatriation and reburial of certain skeletal assemblages excavated in the Pueblo Southwest during the early twentieth century, resulting in the loss of scientific data (Stodder, 2012). The question has now shifted to how bioarchaeologists may continue to address the biological and demographic dimensions of the social and political processes of the prehistoric and postcontact eras in a region where excavation is becoming more infrequent and skeletal reburial more common. These challenges make it vital that bioarchaeologists continuously reexamine skeletal data from remaining skeletal assemblages, such as Pueblo Bonito and Hawikku, using updated age-estimation and mortality patterning methods.

The advantages of applying new methods to long-standing bioarchaeological questions about the paleoepidemiological and paleodemographic trends in the Southwest during the prehistoric, protohistoric, and postcontact periods are numerous. To gain a clearer understanding of mortality and survivorship and the potential relationships with early life stress and longevity, this study sought to reassess the age estimations and mortality patterns of Pueblo Bonito and Hawikku using transition analysis and Kaplan-Meier survival analysis. The preceding chapters reviewed the conceptual challenges faced by bioarchaeologists when interpreting physiological stress in the past, as well as the ecological, archaeological, and biological context of the Ancestral Pueblo Southwest. This chapter provides a discussion and synthesis of the results presented in Chapter Five through the integration of cultural, biological, and ecological information.

Results of the Survival and Longitudinal Growth Analysis

The results of the survival and longitudinal growth analysis documented minimal disparities between Pueblo Bonito and Hawikku. The statistical relationships between survivorship and the two variables of the study (i.e. periosteal lesions, and adult body size) were the same across the two sites. However, there was a difference in the statistical relationship between survivorship and LEH. Therefore, Hypothesis 1 is not fully rejected by the findings of the study.

The study observed comparable frequencies of LEH at Pueblo Bonito and Hawikku. LEH were present on 62 out of 104 (60%) individuals analyzed from Hawikku, and 13 out of 28 (46%) individuals from Pueblo Bonito. Of the 131 individuals analyzed for LEH from Hawikku, 24% (n=32) showed evidence of active, mixed, or healed

periosteal lesions. Pueblo Bonito had a slightly higher frequency of 51% (n= 20) of individuals showing evidence of lesion activity.

While these results are useful for a general understanding of the presence of physiological stress in the Pueblo Bonito and Hawikku skeletal assemblages, frequencies fail to demonstrate the effect of stress on survivorship and its relationship to heterogeneous frailty in the region. As discussed in Chapter Two, reliance on crude prevalence of physiological stress markers to interpret 'health' in the past has been heavily critiqued (Temple and Goodman, 2014; Wood et al., 1992). Consequently, this section interprets the results of the Kaplan-Meier survival analysis for periosteal lesions, LEH, and adult body size as well as the results for subadult growth using the conceptual considerations discussed in Chapter Two, and the contextual background considered in Chapter Three.

Periosteal Lesions

The results of the study demonstrate a significant difference between periosteal lesion activity and mean age of survival at both Pueblo Bonito and Hawikku. Furthermore, individuals with healed lesions appear to possess a survival advantage over those with active, mixed, or no lesions. Therefore, the results of the study support Hypothesis 2.

In contrast to previous studies demonstrating a relationship between older age and the presence of periosteal lesions (Grauer, 1993; Rose and Hartnady, 1991), the study documented a high occurrence of lesions (87%) between the ages of 0.0-39.99 years. Specifically, a high occurrence of active lesions (42%) was observed in the 0.0-9.99 age

range. However, of the eight healed lesions observed, all of them were present on individuals over the age of 20. What does this discrepancy between periosteal lesion activity and age communicate about longevity and the differential ability of individuals to overcome stress events in the Ancestral Pueblo region? The results of the Kaplan-Meier survival analysis can help to answer this question by elucidating the association between periosteal lesion activity and survivorship.

In the Ancestral Pueblo region, it appears that individuals with healed periosteal lesions had higher survivorship than those in the other three activity categories. Therefore, individuals with healed lesions may have had a lower level of frailty compared to those with active, mixed, or no lesions. At both Pueblo Bonito and Hawikku, the difference in mean age of survival between absent and healed lesions was statistically significant. Healed lesions have been interpreted as a representation of a good immune response (Ortner, 1991; Wood et al., 1992), which means presence may indicate both the occurrence and survival of a stress event, reflecting a low level of individual frailty. In contrast, absent lesions may indicate a failure of the immune system to mount a response, signifying an individual that was too frail to survive the stress event. Hence, the results of the analysis demonstrate that heterogeneous frailty was operating within the Ancestral Pueblo region through the documentation of survival differences between lesion activity.

The outcomes of the Kaplan-Meier survival analysis documented a significant difference between activity level and survivorship at Pueblo Bonito and Hawikku. These results are comparable to the findings of DeWitte (2014a) that showed a difference in survivorship depending on the type of lesion recorded (i.e., absent, active, mixed, and

healed) in cemetery samples from medieval London. Similar to the present study, DeWitte (2014a) observed substantial difference between healed, active, and absent lesions. The documentation of similar results across distinct temporal and geographic areas may reflect a broader trend in the relationship between frailty and periosteal lesion activity in the archaeological record.

The evidence presented using survival analysis reinforces the simplistic and binary nature of previous bioarchaeological interpretations relying on the presence or absence of periosteal lesions to reflect health in once-living populations. As discussed in Chapter Two, Lallo et al. (1978) and Goodman et al. (1984b) both documented and increase in infection during a major cultural-ecological transition at Dickson Mounds, arguing for a decrease in overall health during the shift to an agricultural based subsistence economy within the society. A consideration of lesion activity and its effect on the likelihood of survival can communicate a deeper understanding of major cultural-ecological transitions by elucidating the effect of biocultural factors on heterogeneous frailty and the formation of the skeletal assemblage.

As discussed in Chapter Two, periosteal lesions have commonly been used as a general sign of infection within the archaeological record, and there is a strong connection between infection and nutritional deficiencies. Additionally, Chapter Three established strong evidence for endemic nutritional stress in the Ancestral Pueblo region, as seen through a high frequency of porotic hyperostosis and cribra orbitalia, as well as evidence of parasitism. Therefore, the association between low survival time and active periosteal lesions may reflect a synergistic relationship between nutrition and infection at

Pueblo Bonito and Hawikku. Furthermore, Stodder and Martin (1992) found a strong association between non-specific indicators of infection and porotic hyperostosis and cribra orbitalia, arguing that infection may be the primary cause of anemia in the region. Kent (1986) proposed a similar argument, emphasizing the detrimental relationship between chronic infection and population aggregation and sedentism. Although the present study did not incorporate porotic hyperostosis and cribra orbitalia, previous bioarchaeological studies have provided strong evidence for the presence of the two conditions in the Ancestral Pueblo region.

Nutritional deficiencies can compromise the immune response, which can increase susceptibility to infection, and therefore, decrease the ability to withstand a stress event. However, the stress events experienced by the individuals within the two skeletal samples may have differed. As mentioned in Chapter Four, the present study did not perform a differential diagnosis on the periosteal lesions recorded, and therefore, it is plausible that the survivorship of individuals with lesions may have been effected by the severity of the disease. Weston (2008) was unable to link periosteal lesion response to individual disease categories, stating that the etiology of a lesion does not have a significant effect on its appearance. Hence, active lesions may reflect a more acute disease event, whereas healed lesions could be demonstrating a prolonged but less fatal disease process (DeWitte, 2014a).

The differential distribution of resources within a society generates disparities in nutrition and is one of the main indicators of social status within the archaeological skeletal record. The study refrains from using Pueblo Bonito and Hawikku as

comparative high- and low-status samples, but will briefly consider how status might have been a factor in differential survivorship in the Puebloan area. It is well established that the skeletal material from Pueblo Bonito represents a high-status group within the Chaco Canyon Complex (Akins, 1986, 2003; Nelson et al., 1994; Palkovich, 1984a, b). However, the results of the periosteal lesion survival analysis indicate that within a high-status Puebloan sample, (i.e., Pueblo Bonito) survivorship differs. How could differential survivorship be reflecting variations in diet among a high-status group in the Ancestral Pueblo region?

Using isotopic evidence, Reitsema et al. (2016) found that dietary variation is associated with differing levels of survival in medieval Italy, and interpreted these differences as selective mortality. Furthermore, Reitsema and colleagues explored the relationship between time of weaning and survival by documenting disparities in young individuals, up to 3.5 years, and breastmilk intake. Breastmilk is essential to the growth and survival of children, because it provides essential nutritional elements that help build immunity. The transition from breastmilk to solid foods, referred to as weaning, is a high-risk period. Weaning is associated with an increase in morbidities and mortality through the exposure to contaminated food and water supplies (Katzenberg et al., 1996). As parasitism was endemic in the Ancestral Pueblo region (Reinhard, 1992), it is reasonable to infer that weaning could have led to a spectrum of diarrheal diseases within the subadult sample, causing nutritional deficiencies, a weakening of the immune system, an increased chance of infection, and a reduced likelihood of survival.

Differential access to vital nutritional and caloric resources in the Ancestral Pueblo region may have predisposed some individuals for a better chance of survival. Furthermore, the age of weaning could have effected survivorship within the population, which may explain the high occurrence of infection in in the subadult sample. These notions are difficult to address without further direct evidence of diet, but are important to consider when examining the relationship between infection and survivorship, and the relationship to social status within Puebloan communities.

While the statistically significant results of the high-status skeletal sample from Pueblo Bonito are thought provoking, it is important to recognize the effects of a small sample size on the outcomes of the study. For the Hawikku sample, 131 individuals met the requirements of the study, (i.e., two observable tibiae and aged using transition analysis) whereas, only 39 individuals from Pueblo Bonito could be incorporated. Small sample sizes limited the ability to make additionally meaningful inferences regarding the skeletal material from Pueblo Bonito. Therefore, future work should be completed on other known high-status skeletal samples from the Ancestral Pueblo region to further elucidate the relationship between survivorship and periosteal lesion activity.

Linear Enamel Hypoplasia

The results of the study failed to demonstrate a significant difference between survivorship and the presence and absence of LEH in the Pueblo Bonito and combined samples. However, statistically significant results were observed between mean age of survival and LEH presence and absence in the Hawikku skeletal assemblage, and therefore, Hypothesis 3 cannot be rejected in its entirety.

Based on the results of the study, the presence or absence of LEH only appears to be associated with survivorship in the Hawikku skeletal sample. The difference in mean age of survival between the two categories was found to be statistically significant. In other words, individuals without LEH appear to have a higher likelihood of survival, when compared to those with LEH. The results of the study align with previous bioarchaeological work documenting a relationship between the presence of LEH and an increased susceptibility to future stress events (Temple, 2014; Wilson, 2014). However, significant results were not found in the Pueblo Bonito and combined samples.

As reviewed in Chapter Two, Armelagos et al. (2009) proposed three mechanisms for the study of LEH and its relationship to heterogeneous frailty, focusing on the connection between frailty and susceptibility to enamel defects, differential exposure to biocultural factors, and LEH as a reflection of the inability to handle future stress events. From the findings of the study, it appears that individuals at Hawikku who experienced early life stress, as indicated by LEH presence, have a higher level of frailty than those who showed no signs of the defect. Hence, it is likely that the metabolic event that led to LEH formation caused a physiological trade-off early in life that effected the ability to mitigate future stressors, increasing susceptibility to death.

When considering the disparity in the results between the two sites, it is important to assess the limitations of the study. The sample size for Pueblo Bonito was very small with only a total of 29 individuals meeting the qualifications of the study (i.e., the presence of anterior teeth and aged using transition analysis). Furthermore, the use of a macroscopic approach to the scoring of LEH could have resulted in the underestimation

of enamel defects within the sample. In the future, microscopic analysis should be used to study LEH within the two skeletal assemblages to better understand the relationship between early life stress and survivorship within the Puebloan communities. Specifically, age-at-defect formation should be measured to establish chronologies of metabolic stress events for individuals in the Ancestral Pueblo region.

Adult Body Size – Stature and Body Mass

The results of the study failed to demonstrate a significant difference between stature (cm) and survivorship for both male and female individuals from the Pueblo Bonito and Hawikku samples. Additionally, an insignificant difference was established between the above and below average categories for female body mass (kg) and survivorship at both sites. However, a significant difference between the above and below average categories for male body mass and survivorship was observed. The results are contrary to what was predicted by the study, and therefore, Hypothesis 4 is not supported.

The lack of statistical significance between above average body size and increased likelihood of survivorship for both males and females in the two samples is noteworthy. The advantages for increased body size in hot, arid environments has been studied in the early *Homo*, demonstrating the adaptive value of increased body size through the improved conservation of moisture and resistance to dehydration (Cartmill and Smith, 2009). Due to the desert environment of the Southwest, it was expected that individuals with an above average body size would possess an improved ability to retain water, and therefore, have a survival advantage over below average individuals.

The results of the stature estimations taken from the Pueblo Bonito skeletal sample differ from those presented by Akins (1986). The present study found a male average of 161.8 cm compared to 169.3 cm, and for females 158.3 cm versus 162 cm. This discrepancy is likely due to the requirement that individuals used in the investigation were aged using transition analysis, requiring either the sacroiliac joint or the pubic symphysis to be observable. With these restrictions in place, only 11 females and 12 males were analyzed for an association between survivorship and stature from Pueblo Bonito. The small sample size may explain the discrepancy in the stature averages between the two studies.

As mentioned in Chapter Two, previous bioarchaeological studies have established a relationship between increased stature and a decreased likelihood of survival (Kemkes-Grottenthaler, 2005; DeWitte and Hughes-Morey, 2012; Vercellotti et al., 2011). Due to the relationship of terminal stature and growth faltering during infancy, it was expected that individuals with below average stature would have a lower chance of survival. Furthermore, this expectation was based on the link between growth faltering and early life stress – reduced stature can reflect a limited or poor nutrient supply during childhood which can decrease longevity (Eveleth and Tanner, 1990). As discussed in Chapter Three, the Ancestral Pueblo region represents a harsh ecological environment that has the potential to generate stress events during growth maturation. This notion, however, was not supported by the results of the Kaplan-Meier survival analysis. The relationship between early life stress and growth and maintenance is addressed later during the discussion on the results of the longitudinal subadult growth analysis.

Based on the results of the study, male individuals in the Ancestral Pueblo region with a below average body mass had a higher likelihood of survival compared to those who were above average. Body mass estimated from skeletal samples reflects current weight rather than weight at the onset of adulthood, roughly around 18 years (Ruff et al., 1991). Therefore, the results of the survival analysis indicate that individuals who were above average in weight, at or around the time of death, within the two skeletal assemblages were dying younger than those who were below average. This result is inconsistent with the hypothesis that above average individuals, both for stature and body mass, would have a higher chance of survival.

When evaluating the potential explanations for the body mass results, it is vital to consider the small sample size of the two skeletal samples. Only 10 male individuals from Pueblo Bonito met the requirements of the study. The limited number of individuals may be effecting the results. However, significant results were also observed in the Hawikku skeletal sample that was comprised of 42 male individuals. While still relatively small, the results should still be thoroughly considered.

Previous bioarchaeological studies have shown an association between stature and survival (Kemkes-Grottenthaler, 2005; Vercellotti et al., 2011), but no known study has found a relationship between low body mass and increased survivorship. Modern-day clinical studies have documented a connection between body weight, an increase in mortality, and decreased longevity, although the results have been debated. The association between body weight and mortality is complicated by confounding factors, such as the relationship between body weight and chronic disease, cardiovascular disease,

diabetes, hypercholesterolemia, and other conditions. These confounding factors make it difficult to study body weight solely through mortality in modern clinical studies (Hu, 2008).

As discussed in Chapter Three, the desert environment of the Southwest is prone to frequent fluctuations in rainfall and extended periods of drought. These environmental conditions may have acted as a barrier to the adequate intake of calories and nutritional requirements. What would be advantageous about an individual in the Ancestral Pueblo region having a low body weight? It is unlikely that individuals from Hawikku and Pueblo Bonito were significantly obese, but there may be other potential biocultural variables that are influencing survival.

Frisancho et al. (1973) demonstrated an association between small parental body size and offspring survival in low socioeconomic status Peruvian communities. In the assessment of body size, the authors included weight and stature measurements, and found a significant relationship between offspring survival and low body size for mothers, and to a lesser extent, fathers. Frisancho and colleagues hypothesized that these results reflect a biological adaptive response to poor socioeconomic conditions, arguing that a lower caloric intake and less nutritional requirements are needed for growth and maintenance. Therefore, the results of the survival analysis may be indicating an advantage of lower nutritional requirements within the temperamental desert environment for male individuals. This explanation is supported by the thrifty gene hypothesis, developed by Hales and Barker (1992, 2001), demonstrating that there are longevity benefits to those who are born and remain undernourished throughout the post fetal life.

Hence, male individuals that underwent catch-up growth in the Ancestral Pueblo region may have had a decreased likelihood of survival compared to those who were permanently restricted in growth.

Body mass has been shown to be effected by both complex environmental and genetic factors. The biomechanical environment of an individual can mask the effects of nutrition on cortical bone thickness. Cortical bone mass and geometry responds to mechanical loads placed on the human body, such as body weight or an excess load of labor (Larsen, 2015; Ruff et al., 2006). The human skeleton possesses a remarkable plasticity, which is demonstrated through its ability to remodel based on these loading phenomenon. Therefore, in some circumstances it is the biomechanical rather than the nutritional environment of these individuals that is disrupting the process of bone growth and development. Hence, the difference in male mean age of survival at Pueblo Bonito and Hawikku could be due to variations in activity between the two categories rather than a discrepancy in nutritional or caloric intake.

Could the increased survivorship of male individuals of small body size be reflecting a biological adaptive mechanism aimed at buffering the environmental stressors of the desert Pueblo region? Further analysis is needed on the relationship between survivorship and subadult body mass to interpret how low body mass may be acting as an adaptive mechanism during growth and maintenance in the Ancestral Pueblo Southwest.

Subadult Longitudinal Growth Analysis

The results of the subadult longitudinal growth analysis indicate that the majority of deficits in stature (cm) are occurring between 6 to 12 years of age within both skeletal samples. Hence, the subadults from Pueblo Bonito and Hawikku show evidence of stunting, but are not indicative of selective mortality. Therefore, the results of the study support Hypothesis 5.

The longitudinal growth plot (Fig. 15) and the residual plot (Fig. 16) demonstrate stunting around 6 to 12 years of age within the Ancestral Pueblo samples of Pueblo Bonito and Hawikku. These results support the hypothesis that the high stress ecological setting of the Colorado Plateau would negatively impact the growth rate of the two subadult skeletal subsamples. As discussed in Chapter Two, growth tends to slow during metabolic disruptions in response to a bodily attempt to conserve energy. However, it has also been argued that stunting acts as a mechanism aimed at buffering environmental stress, which increases survival by decreasing nutritional requirements (Stini, 1971). This concept was also considered in conjunction with the discussion on adult body size, but is also appropriate to contemplate for this context.

Diarrhea is commonly linked to reductions in growth, due to its synergistic relationship with infection and malnutrition. As discussed in Chapter Three, parasites have been documented in the Ancestral Pueblo Southwest, and are thought to have been endemic throughout the region (Reinhard, 1992). Parasitism has the potential to inhibit the ability of the body to absorb nutrients and can cause diarrhea. Furthermore, parasites would have elevated the risk of mortality, making individuals more susceptible to death.

In a cross-sectional study of growth in the Ancestral Pueblo region, Schillaci et al. (2011) compared patterns of growth between Puebloan samples from skeletal assemblages and modern descendant groups. The study failed to find an association between impaired growth and the presence of porotic hyperostosis or cribra orbitalia, but argued that the results reflected a low level of mortality within the sample. The authors' conclusion is based on previous studies demonstrating the link between low mortality and evidence of stunting (Wood et al., 1992).

Wood et al. (1992) argued that when mortality is high within a community both short and tall individuals enter the death assemblage. In scenarios of low mortality only the most frail (i.e., the shortest) members of the community die. Therefore, stunting within the archaeological skeletal record represents periods of low mortality within the once-living community. Furthermore, modern studies of skeletal growth and development have shown an association between stunting and extended periods of infection as well as a higher rate of mortality from infection (Tomkins, 1988). Although disruptions in growth occur throughout childhood, the risk of mortality associated with stunting is far greater in the first few years of life (Saunders and Hoppa, 1993). The association between mortality and stunting is not casual – the relationship is dependent on its connection to malnutrition and infection.

As discussed in Chapter Two, polynomial equations are capable of compensating for multiple periods of growth or growth disruptions throughout ontogeny, and are therefore vital to the accurate study of longitudinal growth. From the results of the growth curve (Fig. 15), it is argued that a period of stunting was observed between the

ages 6 to 12 years, which is represented by the residuals falling below the predicted line generated from the polynomial growth curve (Fig. 16). As mentioned above, individuals with shortened stature are interpreted as representing the frailest member of the skeletal sample. A potential explanation for stunting with the Pueblo Bonito and Hawikku samples relies on the established relationship between growth faltering and nutrient supply. However, nutritional deficiency is not the only plausible explanation. An association between shortened stature and disruption in social, political, and environmental circumstances has also been demonstrated (Eveleth and Tanner, 1990; Leonard et al., 2002; Steckel, 1986, 1995; Temple et al., 2014; Tomkins et al., 1988).

The chapter previously contemplated the association between possible nutritional deficiencies created by weaning and an increased likelihood of infection in the desert environment of the Pueblo Southwest. However, while growth stunting in early childhood can reflect differential weaning practices, stunting during the ages of 6 to 12 in the Pueblo area may represent a limited resource supply and/or reduced dietary quality, exacerbated by the presence of parasites (Berti et al., 1988; Foster et al., 2005; Temple et al., 2014). The reasoning for limited access to nutritional and caloric resources can be related to the hypothesized environmental and demographic perturbations discussed in Chapter Three. The periods from A.D. 1150 to A.D. 1200 and A.D. 1275 to A.D. 1475 are associated with major ecological declines as indicated by strong dendroclimatic evidence documenting repeated droughts in the Colorado Plateau. Furthermore, massive demographic movements are associated with these drought periods. Therefore, the

stunting seen in the two skeletal samples may be reflecting the increased nutritional stress load of the community during these periods.

However, when considering explanations for the growth disruptions observed in the Pueblo Bonito and Hawikku samples, it is also vital to contemplate the context appropriate conception of childhood and the ontology of personhood within the Ancestral Pueblo Southwest. Schillaci et al. (2011) explored the concept of childhood in historic and modern Pueblo communities through the integration of ethnographic and skeletal evidence. The study revealed an association between growth disruptions and culturally relevant age categories, but failed to document a relationship between porotic hyperostosis and stunting, indicating that these events were likely not caused by nutritional deficiencies.

The stunting, occurring between the ages of 6 to 12 years of age, observed in the present study may reflect individuals who did not undergo the water-pouring ceremony, an important rite of passage occurring between 6 to 10 years of age in the Pueblo culture. Children who did not undergo this ceremony were not accepted as full members of the society, because they were not yet considered fully human (Schillaci et al., 2011). Therefore, the rites of passage associated with childhood may have acted as a cultural buffer to the inclusion of stressed individuals by restricting personhood within the Pueblo society. The stunting event demonstrated by the data coincides with this crucial transitional period in the Puebloan culture and potentially reflects an association between skeletal growth patterns and social institutions within the region.

The evidence of stunting is interesting to consider in the context of the Hawikku skeletal sample. In Chapter Three, the indirect effects of Spanish contact on the Puebloan peoples were briefly discussed. Dobyms (1966) proposed that prior to the arrival of the Spanish, the Southwest region was exposed to Old World diseases through well-established trade routes. If it is assumed that stunting represents a low mortality environment, then it would not appear that the skeletal sample from Hawikku analyzed for this study was experiencing an epidemic event associated with European contagions.

However, the ability of this study to register an epidemic event may be limited. While DeWitte and Wood (2008) showed that high mortality events can kill discriminately, it cannot be assumed that this occurred in this context. Furthermore, diseases, such as measles and smallpox, do not appear skeletally due to the acuteness of the infection, making it difficult to document occurrences in the archaeological record. Lastly, due to the time restraints of the study, the skeletal material from the site was not contextualized to a particular time period (i.e., prehistoric, protohistoric, or postcontact). Therefore, the interpretations of the indirect effect of European pathogens on the Ancestral Pueblo community is only speculative. In the future, the stunting of the skeletal material should be analyzed based on its associated temporal context. Although due to the loss of provenience data from the Hawikku excavation, this may be difficult.

Paleodemography, Behavioral Ecology, and Physiological Stress

The paleoepidemiological approach entrenched within the bioarchaeological study of the Southwest has been vital to the diachronic understanding of biological stress and disease within the region. However, the failure to integrate recent advancements in

paleodemographic methods, as well as the inclination for prehistoric inquiries in the bioarchaeological literature, limits the strength of paleoepidemiological interpretations. In addition, a review of the literature reveals a shortage in current research on the postcontact period in the Southwest, which is evident from the most recent studies dating to the 1990s and early 2000s. This dearth of postcontact material may be attributable to the challenges posed by federal and state regulations as well as the recent increased focus on the bioarchaeological study of prehistoric violence in the region (Stodder, 2012).

The information available within archaeological skeletal collections is limited by small sample sizes, exposure to taphonomic processes, and inherently high rates of error in age estimation. The reassessment of demographic profiles using new methods is an established practice within bioarchaeology and helps to illuminate error in the estimation of age. For example, Ruff (1981) reassessed the demographic profile generated by Hooton (1930) using updated age and sex estimation techniques. In this study, a significant difference was found between the sex and age estimates of Ruff and Hooton. Hooton (1930) tended to classify more females as male and assigned older ages to males. The discrepancies between the two demographic profiles have implications for the approximations of life expectancy within the Pecos Pueblo skeletal sample developed by Goldstein (1953). Based on the data from Hooton (1930), Goldstein estimated a life expectancy of 42.9 years, which starkly contrasts with estimation of 25 years or less by Ruff (1981). Ruff (1981) documented the importance of reanalyzing skeletal material as methods advance. Possessing accurate age estimation is especially important when analyzing mortality structures of a once-living population.

The ability of transition analysis to expand the limit of age estimations has important implications for the production of mortality patterns and the inference of survivorship in archaeological skeletal samples. As discussed in Chapter Three, Eckert (2005) generated mortality curves for Hawikku based on two sets of age-at-death data (Stodder, 1990; Howell, 1994). The variation documented by Eckert between the two historic (A.D. 1630-1680) Hawikku mortality curves may reflect discrepancies in the age estimations of Stodder (1990) and Howell (1994) based on traditional morphological techniques. Furthermore, the small number of older individuals recorded in the historic skeletal sample may be due to the common underestimating of age in archaeological populations. By applying transition analysis to the age estimation of the Hawikku and Pueblo Bonito samples, the present study extended the possible age range for the sites, which was crucial for the generation of a new age-at-death distribution.

As discussed in Chapter Two, Wood et al. (1992) heavily criticized the use of crude prevalence data in the bioarchaeological interpretation of morbidity and mortality, pointing out the key conceptual issues of selective mortality, hidden heterogeneity (frailty), and non-stationarity. At present, Kaplan-Meier survival analysis represents one of the best available statistical techniques to overcome the paradoxical challenges of archaeological skeletal assemblages, but the application of the technique within bioarchaeology has been relatively lacking (DeWitte and Stojanowski, 2015). This study sought to demonstrate the ability of survival analysis to illuminate varying levels of frailty within an archaeological skeletal assemblage using two Ancestral Pueblo case studies, Pueblo Bonito and Hawikku. Additionally, through the use of survival analysis

the study explored the relationship between survivorship and mortality, and potential associations with early life stress and longevity.

As mentioned in Chapter Three, bioarchaeologists have begun to move away from the classic cultural ecological framework developed by Steward (1955), and moving towards a human behavioral ecological approach. Furthermore, the integration of resilience theory into this approach has added a dynamic lens through which to analyze major cultural and ecological shifts in the Southwest region. This study argues for the integration of the behavioral ecological framework into future analyses of the Ancestral Pueblo region through the consideration of how socioenvironmental variables can affect behavioral adaptations. Within an ecological setting, resilience theory refers to the capacity of a population or system to absorb ecological disturbances and adapt to new environments while maintaining key aspects of previous identities and other social and biocultural constructs, which is useful for bioarchaeological interpretations of how humans use local knowledge and behavioral plasticity to mitigate stressors of environmental perturbations, while maintaining cultural identity (Temple and Stojanowski, in press).

The behavioral ecological approach has been successfully integrated into bioarchaeological analyses of hunter-gather communities. Hoover and Hudson (2016) demonstrated the usefulness of resilience theory in a study of prehistoric hunter-gatherers in northwest Kyushu, Japan, arguing that hunter-gatherer populations in this region persisted, despite disruptions in the social and ecological environments. Campbell and Butler (2010) analyzed salmon use within two sub-regions of the Pacific Northwest over

the last 7,500 years, and provided another example of the how resilience theory can provide a comprehensive approach to understanding cultural transitions. The authors documented evidence of sustainability in human use of salmon, despite evidence for social and ecological change. Hoover and Hudson (2016) and Campbell and Butler (2010) both document how during cultural and ecological transitions, groups show signs of resilience and a high level of persistence of cultural identity.

The settlement shift and large migration movements in the Ancestral Pueblo region have traditionally been interpreted within the cultural ecological framework, where cultural adaptations are viewed as mechanisms buffering the desert environment. These interpretations have relied heavily on a cause and effect relationship between the environment and human behavioral choices. Within a behavioral ecological framework, the cultural adaptations of the Puebloan peoples reflect human agency and resistance to the harsh ecological conditions of the Colorado Plateau. Ancestral Pueblo communities in the American Southwest were not passive recipients of environmental circumstances, rather they were active participants in dynamically and strategically transforming cultural practices to fit their needs. Furthermore, the resilience and persistence of these groups is evident from a continued occupation of the Colorado Plateau region by modern day descendant groups tied together by a shared cultural identity.

Conclusion

This chapter has provided a discussion on the results documented in Chapter Five using the operational, archaeological, biological, and ecological considerations addressed in Chapters Two and Three. The study demonstrated statistically significant results for

survivorship and LEH in the Hawikku sample as well as periosteal lesion activity and male body mass (kg) at both sites. From the longitudinal growth analysis, it was documented that stunting was primarily occurring in individuals between the ages of 6 to 12 in the Pueblo Bonito and Hawikku skeletal samples. Additionally, the chapter provided a brief consideration of the implementation of updated paleodemographic and theoretical frameworks to the study of physiological stress in the Ancestral Pueblo region. The next chapter concludes the analysis by briefly reviewing the scope and limitations of the study as well as discussing future directions.

CHAPTER SEVEN

CONCLUSION

The major findings of this study help to better characterize mortality and survivorship and the connection to early life stress and longevity in the Ancestral Pueblo Southwest by elucidating heterogeneous frailty within the skeletal samples of Pueblo Bonito and Hawikku. Additionally, the results communicate a complex relationship between the ecological pressures of the desert environment and the physiological response to stress.

Summary of Major Findings

1. A statistically significant difference was demonstrated between periosteal lesion activity and mean age of survival at both Pueblo Bonito and Hawikku – individuals with healed lesions appear to possess a survival advantage over those with active, mixed, or no lesions.
2. A statistically significant difference was observed between mean age of survival and LEH presence and absence in the Hawikku skeletal assemblage – individuals without LEH appear to have a higher likelihood of survival, when compared to those with LEH.

3. A significant difference between mean survival time and the above and below average categories for male body mass was observed within the Pueblo Bonito and Hawikku skeletal samples – individuals above average in weight, at or around the time of death, were dying younger than those who were below average.
4. The majority of deficits in subadult stature (cm) are occurring between 6 to 12 years of age within Pueblo Bonito and Hawikku – subadults from both skeletal samples are showing evidence of stunting.

Limitations and Future Directions

The study was limited by small sample sizes, especially in regards to the Kaplan-Meier survival analyses for the Pueblo Bonito skeletal material. The requirements of the study, as discussed in Chapter Four, restricted the number of individuals eligible in the statistical analysis. Mainly, the requirement of either an observable pubic symphysis or sacroiliac joint, needed for transition analysis, considerably reduced the number of usable individuals in the Pueblo Bonito sample. Compared to the Pueblo Bonito material, the Hawikku sample is a larger skeletal collection and is better preserved, and therefore, retained relatively large sample sizes for the survival analysis.

As discussed in Chapter Six, the difference in sample size may explain the discrepancy between the results of the Hawikku and Pueblo Bonito survival analysis for LEH absence and presence. Furthermore, the use of a macroscopic approach to the recording of LEH may have unintentionally led to the under reporting of the defect within the two samples. As mentioned in Chapter Six, future studies should concentrate on the microscopic detection of age-at-defect formation to further elucidate the complex

relationships between survival and early life stress in the Ancestral Pueblo region. The estimation of subadult body mass was outside the scope of the present study, and therefore, further analysis is needed on the relationship between survivorship and subadult body mass to interpret how low adult body size may be acting as an adaptive mechanism during growth and maintenance.

While the application of transition analysis limited the overall sample size of the two skeletal collections, it is important to recognize the benefits to applying a statistically based age estimation technique to the bioarchaeological study of once-living populations. In contrast to traditional morphological age estimation approaches, transition analysis can expand age boundaries past the previous categorical restriction of 45+. With an expanded age range, paleoepidemiological studies of mortality and survivorship can better discern complex mechanisms influencing the creation of the death assemblage, such as heterogeneous frailty and selective mortality. These conceptual challenges should not be ignored, but rather studied through the complexity of differential survivorship and systemic physiological stress. Further investigation into how frailty and selective mortality operate across temporally and geographically separated groups is needed, and therefore, future paleoepidemiological studies are required to expand bioarchaeological perspectives on the complex biocultural processes influencing mortality in the past.

APPENDIX A

RECORDING FORMS

SEX ESTIMATION

Pelvis - Trait	Left	Right
Subpubic concavity		
Ventral arc		
Ishiopubic ramus (medial aspect)		
Subpubic angle		
Greater sciatic notch		
Preauricular sulcus		

Skull - Trait	Left	Right
Nuchal crest		
Mastoid process		
Supraorbital margin		
Glabella		
Gonial angle flare		
Mental eminence		

Final estimate of sex (circle):	Not Examined	Female ♀	Probably Female	Ambiguous	Probably Male	Male ♂
--	-----------------	-------------	--------------------	-----------	------------------	--------

BASIC POSTCRANIAL MEASUREMENTS

Note that the LEFT bone is preferred over the right bone, any exception will be marked 'R'. Mark measurements taken from lightly eroded or reconstructed bone with an asterisk (*). Measurements should be undertaken twice to determine intra-observer error.

	Left	Right			
Humerus	mm				
Maximum length					
Radius	mm				
Maximum length					
Ulna	mm				
Maximum length					
Femur	mm				
Maximum length					
Maximum head diameter					
Head Breadth					
Tibia	mm				
Maximum length					
Fibula	mm				
Maximum length					

RECORDING FORM: ADULT SKELETAL PATHOLOGICAL CONDITIONS

KEY: AFTER BUIKSTRA AND UBELAKER (1994)

Humerus	Left	Right
Proximal		
Diaphysis		
Distal		

Radius	Left	Right
Proximal		
Diaphysis		
Distal		

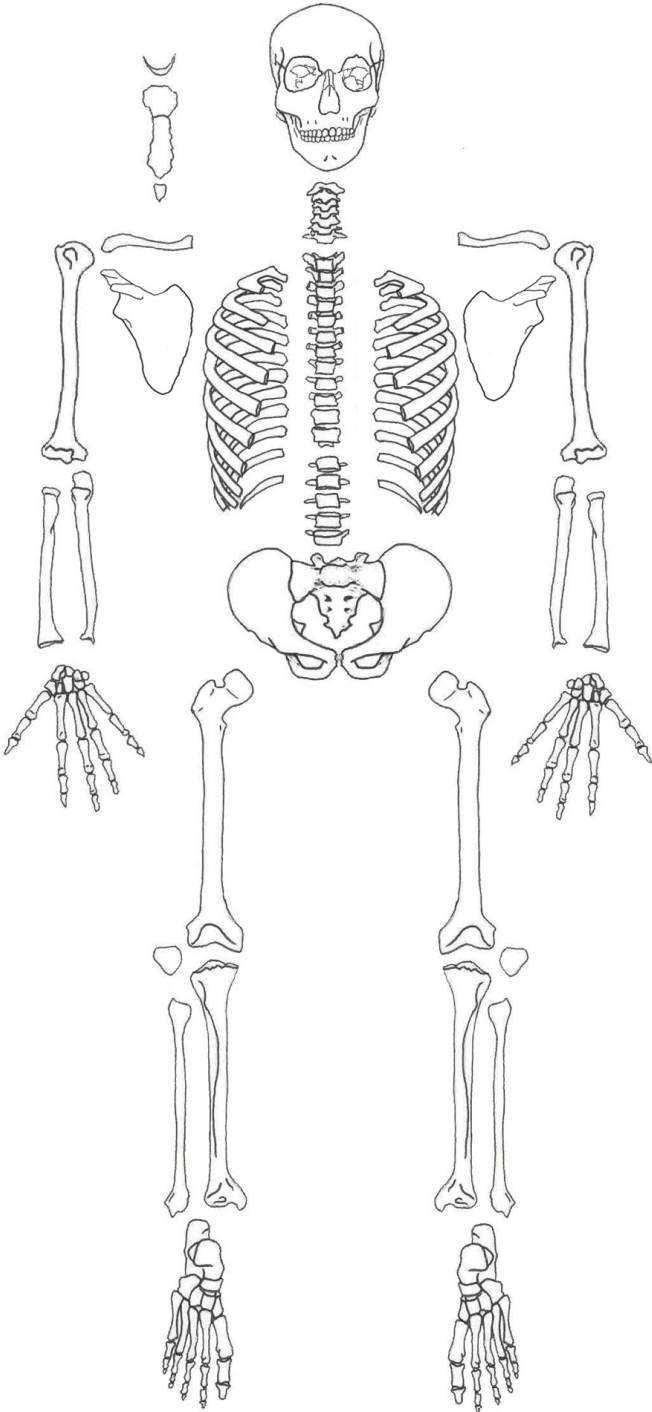
Ulna	Left	Right
Proximal		
Diaphysis		
Distal		

Femur	Left	Right
Proximal		
Diaphysis		
Distal		

Tibia	Left	Right
Proximal		
Diaphysis		
Distal		

Fibula	Left	Right
Proximal		
Diaphysis		
Distal		

VISUAL RECORDING FORM: SKELETAL PATHOLOGICAL CONDITIONS



LINEAR ENAMEL DEFECTS RECORDING FORM: PERMANENT TEETH
 (Adapted from Buikstra and Ubelaker, 1994)

Maxilla, Right

Tooth	C	I ²	I ¹
Presence			
Defect Height			
Crown Height			

Maxilla, Left

Tooth	I ¹	I ²	C
Presence			
Defect Height			
Crown Height			

Mandible, Left

Tooth	C	I ²	I ¹
Presence			
Defect Height			
Crown Height			

Mandible, Right

Tooth	I ¹	I ²	C
Presence			
Defect Height			
Crown Height			

METRIC ESTIMATION OF AGE AT DEATH

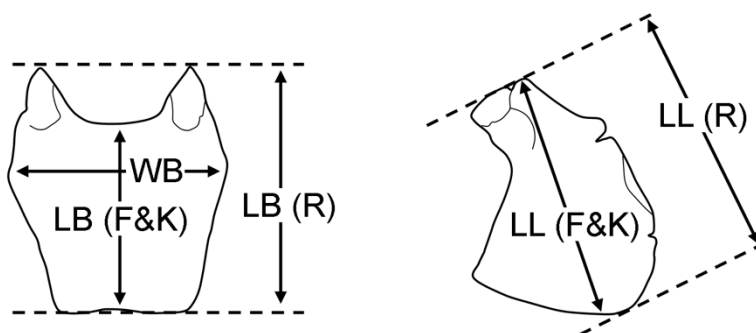
Complete as appropriate, slash the box if measurement will NOT be recorded.

Method	Maximum length LB (F&K):	Maximum length LB (R):
Pars lateralis (Scheuer and Black, 2000)	mm	mm

Method	Mid-sagittal length (F&K):	Maximum length LB (R):	Maximum width WB:
Pars basilaris (Scheuer and Black, 2000)	mm	mm	mm

Age determination

If pars basilaris is longer (mid-sagittal length) than wide <28 weeks *in utero*). If wider than long <months
If pars basilaris and lateralis are of approximately the same length <7 months *in utero*). After this the pars lateralis is longer than basilaris



From Scheuer & Black, 2000:57

Suggested age:

Bone element	Left (mm)	Age range	Right (mm)	Age range
Humerus max length				
Radius max length				
Ulna max length				
Femur max length				
Tibia max length				

For age determination, see Inforce Anthropology SOP (Assessment of age at death)

FINAL AGE ESTIMATION

Aging Method	Age Range
Dental	AlQahtani et al. (2010)
Skeletal (insert method used)	Moorees, Fanning & Hunt (1963 a,b)

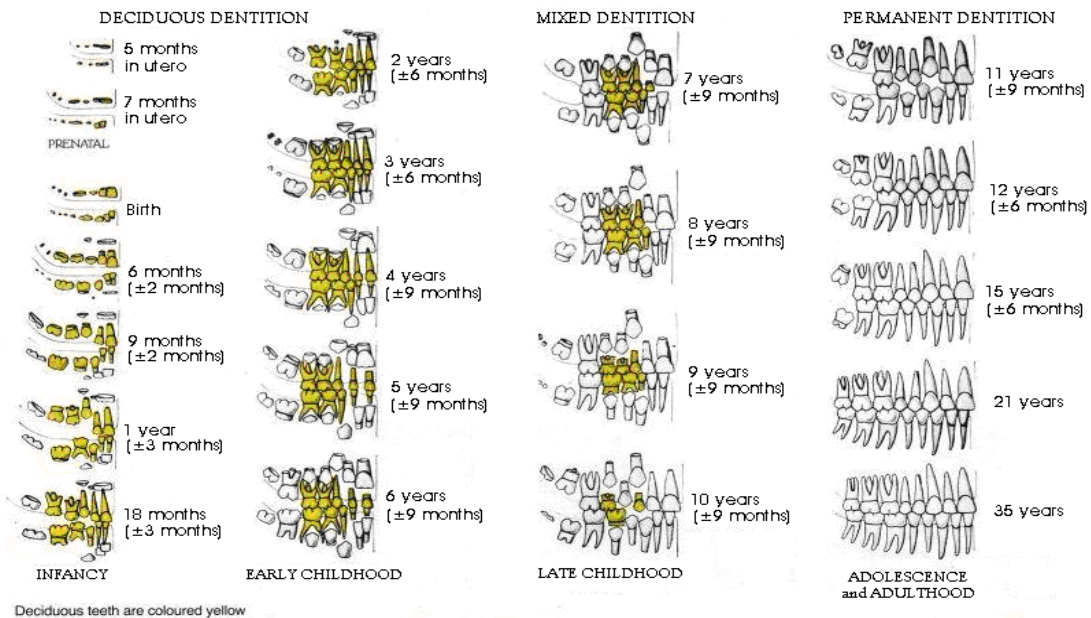
SUBADULT AGE ESTIMATION

Female	I1	I2	C	PM1	PM2	M1	M2	M3
Ci	-	-	0.6	2.0	3.3	0.2	3.6	9.9
Cco	-	-	1.0	2.5	3.9	0.5	4.0	10.4
Coc	-	-	1.6	3.2	4.5	0.9	4.5	11.0
Cr ^{1/2}	-	-	3.5	4.0	5.1	1.3	5.1	11.5
Cr ^{3/4}	-	-	4.3	4.7	5.8	1.8	5.8	12.0
Crc	-	-	4.4	5.4	6.5	2.4	6.6	12.6
Ri	-	-	5.0	6.1	7.2	3.1	7.3	13.2
Cli	-	-	-	-	-	4.0	8.4	14.1
R ^{1/4}	4.8	5.0	6.2	7.4	8.2	4.8	9.5	15.2
R ^{1/2}	5.4	5.6	7.7	8.7	9.4	5.4	10.3	16.2
R ^{2/3}	5.9	6.2	-	-	-	-	-	-
R ^{3/4}	6.4	7.0	8.6	9.6	10.3	5.8	11.0	16.9
Rc	7.0	7.9	9.4	10.5	11.3	6.5	11.8	17.7
A ^{1/2}	7.5	8.3	10.6	11.6	12.8	7.9	13.5	19.5
Ac	-	-	-	-	-	-	-	-

(From Smith, 1991)

Male	I1	I2	C	PM1	PM2	M1	M2	M3
Ci	-	-	0.6	2.1	3.2	0.1	3.8	9.5
Cco	-	-	1.0	2.6	3.9	0.4	4.3	10.0
Coc	-	-	1.7	3.3	4.5	0.8	4.9	10.6
Cr ^{1/2}	-	-	2.5	4.1	5.0	1.3	5.4	11.3
Cr ^{3/4}	-	-	3.4	4.9	5.8	1.9	6.1	11.8
Crc	-	-	4.4	5.6	6.6	2.5	6.8	12.4
Ri	-	-	5.2	6.4	7.3	3.2	7.6	13.2
Cli	-	-	-	-	-	4.1	8.7	14.1
R ^{1/4}	-	5.8	6.9	7.8	8.6	4.9	9.8	14.8
R ^{1/2}	5.6	6.6	8.8	9.3	10.1	5.5	10.6	15.6
R ^{2/3}	6.2	7.2	-	-	-	-	-	-
R ^{3/4}	6.7	7.7	9.9	10.2	11.2	6.1	11.4	16.4
Rc	7.3	8.3	11.1	11.2	12.2	7.0	12.3	17.5
A ^{1/2}	7.9	8.9	12.4	12.7	13.5	8.5	13.9	19.1
Ac	-	-	-	-	-	-	-	-

4.2 TOOTH ERUPTION PATTERNS



Age estimation (in months) from deciduous tooth eruption

Tooth	Mean	Range \pm 1 SD
Maxilla		
Central incisor	10	8-12
Lateral incisor	11	9-13
Canine	19	16-22
First molar	16	13-19♂ 14-18♀
Second molar	29	25-33
Mandible		
Central incisor	8	6-10
Lateral incisor	13	10-16
Canine	20	17-23
First molar	16	14-18
Second molar	27	23-31♂ 24-30♀

(From Scheuer and Black, 2000)

Age estimation (in years) from permanent tooth eruption

Females	Mandibular		Maxillary	
Tooth	Median	\pm 1 SD	Median	\pm 1 SD
Incisor 1	6.1	0.35	5.8	0.43
Incisor 2	7.0	0.90	6.5	0.55
Canine	9.3	1.25	8.8	0.63
Premolar 1	9.0	1.09	9.1	0.90
Premolar 2	9.5	1.37	9.2	1.64
Molar 1	5.3	0.47	5.0	0.39
Molar 2	10.3	0.90	9.9	1.06
Molar 3	17.2	2.46	17.7	2.34
Males	Mandibular		Maxillary	
Tooth	Median	\pm 1 SD	Median	\pm 1 SD
Incisor 1	6.2	0.86	5.9	0.74
Incisor 2	7.3	1.29	6.9	0.78
Canine	11.2	1.21	9.8	1.09
Premolar 1	9.8	1.41	9.6	1.29
Premolar 2	11.1	1.60	10.3	1.72
Molar 1	5.3	0.74	5.3	0.35
Molar 2	11.4	1.09	10.8	1.02
Molar 3	17.7	1.52	18.1	2.15

ANALYTICAL NOTES

FUSION OF OSSIFICATION CENTRES

Complete all boxes with the codes provided; indicate when feature is not recorded by slashing the box.

Ages shown in green are foetal weeks or months.

Where ages are indicated in both black (F) and dark red (M) then they represent females and males respectively. Where B and C are shown, B = begins fusion; C = fusion complete.

Complete the form using U = not fused; F = fusion underway; C = fusion complete.

Cranial Element	Age	Stage	Post-Cranial Element	Age	Stage
Occipital	Median sagittal suture and sutura mendosa	Birth – 1 yr	Clavicle	Medial epiphyseal flake	B 16-21yrs C 29+ yrs
	Hypoglossal canal complete	2-4 yrs		Lateral epiphyseal flake	19-20 yrs
	Pars lateralis to squama	1-3 yrs	Scapula	Coracoid and subcoracoid to body	B 13-16 yrs C 15-17 yrs
	Pars basilaris to lateralis	5-7 yrs		Glenoid epiphysis	17-18 yrs
	Spheno-occipital synchondrosis	F11-16 yrs M13-18 yrs		Acromial and coracoid epiphyses	By 20 yrs
Ear	Closure of jugular growth plate	22-34 yrs	Inferior angle and medial border	By 23 yrs	
	Malleus to goniale	<i>wk 19 f</i>	Atlas	Transverse foramen complete	3-4 yrs
Pars squama to tympanic ring	<i>wk 35 f</i>	Posterior synchondrosis		4-5 yrs	
Petro-mastoid to squamo-tympanic	1st yr	Anterior arch		5-6 yrs	
Temporal	Foramen of Huschke complete	1-5 yrs	Intradental fusion	<i>Around birth</i>	
	Lesser wing to body	<i>5 mths f</i>	Axis	Posterior synchondrosis	3-4 yrs
	Pre to post sphenoid	<i>8 mths f</i>		Dento-neural synchondrosis	3-4 yrs
	Pterygoid to greater wings	<i>8 mths f</i>		Dens to centrum	4-6 yrs
	Greater wings to body	1 st yr	Neural arches to centrum	4-6 yrs	
Sphenoid	Foramen ovale complete	1 st yr	Ossiculum terminale to dens	12 yrs	
	Foramen spinosum complete	By 2 nd yr	Cervical vertebrae 3-7	Posterior synchondrosis	1-2 yrs
	Sphenoidal conchae to ethmoid	4 yrs - puberty		Transverse foramen complete	3-4 yrs
	Anterior fontanelle closed	1-2 yrs	Neural arches to centrum	3-4 yrs	
Frontal	Metopic suture closed	2-4 yrs	Annular rings	17-25 yrs	
	Cribiform plate and crista galli to labyrinths	1-2 yrs	Post synchondrosis	1-2 yrs	
Ethmoid	Ethmoid to vomer	20-30 yrs	Thoracic	All 1° centres fused	5-6 yrs
	Palatal process	<i>18 wks f</i>		Annular rings	16-19 yrs
Mandible	Coronoid to main mass	<i>8 wks f</i>	Lumbar	Post synchondrosis in upper lumbar	1-2yrs
	Fusion at symphysis	At yr 1		Lamina of L5	4-5 yrs
				All 1° centres fused	5-6 yrs
			Sacrum	Annular rings	17-24 yrs
				Neural arch to lateral element S1-3	2-5 yrs
				Neural arch to centrum to S1-2	2-6 yrs

Post-Cranial Element	Age	Stage
Sternebra 3 to 4	4-10 yrs	
Sternebra 2 to sternebrae 3-4	11-16 yrs	
Epiphyses	B 11-16 yrs	
Sternum	Sternebra 1 to mesosternum	15-20 yrs
Sternum complete	21 yrs	
Xyphoid to mesosternum	40+ yrs	

All 1° centres fused	5-6 yrs	
Posterior synchondroses	B 6-8 yrs C 10-15 yrs	
Lateral elements	B 12 yrs	
Ribs	Epiphyses of heads	17-25 yrs

Post-Cranial Element	Age	Range
Humerus	Composite proximal epiphysis	2-6 yrs
	Distal composite epiphysis to shaft	F11-15 yrs M12-17 yrs
	Medial epicondyle to shaft	F13-15 yrs M14-16 yrs
	Composite proximal epiphysis to shaft	F13-17 yrs M16-20 yrs
Radius	Proximal epiphysis	F11½-13 yrs M14-17 yrs
	Distal epiphysis	F14-17 yrs M16-20 yrs
Ulna	Proximal epiphysis	F12-14 yrs M13-16 yrs
	Distal epiphysis	F 15-17 yrs M17-20 yrs
Hand	Base of MC1	F14-14½ yrs M16½ yrs
	Head of MC 2-5	F14½-15 yrs M16½ yrs
	Distal phalangeal epiphyses	F13½ yrs M16 yrs
	Proximal and distal epiphyses	F14-14½ yrs M16½ yrs
Pelvis	Ischiopubic ramus	5-8 yrs
	Acetabulum	F11-15 yrs M14-17 yrs
	Iliac crest	B 17-20 yrs C 20-23 yrs
	Anterior inferior iliac spine epiphysis	By 20 yrs
	Ischial epiphysis	20-23 yrs

Post-Cranial Element	Age	Stage
Femur	Proximal epiphysis	F12-16 yrs M14-19 yrs
	Distal epiphysis	F14-18 yrs M16-20 yrs
	Greater trochanter	F14-16 yrs M16-18 yrs
	Lesser trochanter	16-17 yrs
	Proximal epiphysis	F13-17 yrs M15-19 yrs
Tibia	Distal epiphysis	F14-16 yrs M15-18 yrs
	Tuberosity	12-14 yrs
Fibula	Proximal epiphysis	F12-17 yrs M15-20 yrs
	Distal epiphysis	F12-15 yrs M15-18 yrs
Calcaneal epiphysis	F	B10-12 yrs C15-16 yrs
	M	B11-14 yrs C18-20 yrs
Tarsal	Talar epiphysis	F 9 yrs M12 yrs
	Base of MT 1	F 9-12 yrs M 12-15 yrs
Head of MT 2-5		F11-13 yrs M14-16 yrs

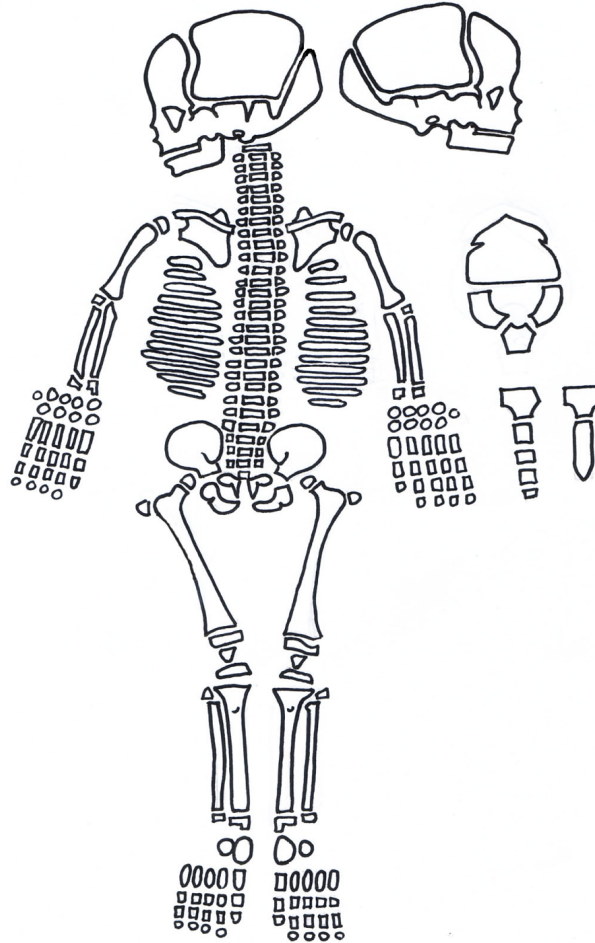
	yrs
Distal and middle phalangeal epiphyses	F11-13 yrs M14-16 yrs
<hr/>	
After Scheuer & Black, 2000	

SUBADULT ANTE-/PERIMORTEM TRAUMA AND PATHOLOGY

Highlight the description of antemortem trauma and pathology observed in the list below (use annotation as appropriate)

Complete all boxes; indicate when feature is not recorded by slashing the box.

	L	R
Humerus		
Radius		
Ulna		
Femur		
Tibia		
Fibula		



TRANSITION ANALYSIS FORM

Catalogue Number: Individual Number: Location: Site: Date:

Pubic Symphysis

Left

Right

Symphyseal Relief:	1	2	3	4	5	6	1	2	3	4	5	6		
Dorsal Symphyseal Texture:	1	2	3	4	1	2	3	4						
Superior Protuberance:	1	2	3	4	1	2	3	4						
Ventral Symphyseal Margin:	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Dorsal Symphyseal Margin:	1	2	3	4	5	1	2	3	4	5				

Sacroiliac Joint

Superior Demiface Topography:	1	2	3	1	2	3						
Inferior Demiface Topography:	1	2	3	1	2	3						
Superior Surface Characteristics:	1	2	3	4	5	1	2	3	4	5		
Middle Surface Characteristics:	1	2	3	4	5	1	2	3	4	5		
Inferior Surface Characteristics:	1	2	3	4	5	1	2	3	4	5		
Inferior Surface Texture:	1	2	3	1	2	3						
Superior Posterior Iliac Exostoses:	1	2	3	4	5	6	1	2	3	4	5	6
Inferior Posterior Iliac Exostoses:	1	2	3	4	5	6	1	2	3	4	5	6
Posterior Exostoses:	1	2	3	1	2	3						

Cranial Sutures

Coronal Pterica:	1	2	3	4	5	1	2	3	4	5
Sagittal Obelica:	1	2	3	4	5					
Lambdoidal Asterica:	1	2	3	4	5	1	2	3	4	5
Zygomaxillary:	1	2	3	4	5	1	2	3	4	5
Interpalatine:	1	3	4	5						

REFERENCES

Adler MA. 1996. Land Tenure, Archaeology, and the Ancestral Pueblo Social Landscape. *J Anthropol Archaeol* 15:337-371.

Akins NJ, Schelberg JD. 1984. Evidence for Organizational Complexity as Seen from the Mortuary Practices at Chaco Canyon. In: Judge J, Schelberg JD, editors. *Recent Research on Chaco Prehistory*. Albuquerque: Division of Cultural Research, US Department of the Interior, National Park Service. p 89-102.

Akins NJ. 1986. A biocultural approach to human burials from Chaco Canyon, New Mexico. Santa Fe: Branch of Cultural Research, U.S. Department of the Interior, National Park Service.

Akins NJ. 2003. The Burials of Pueblo Bonito. In: Neitzel JE, editor. *Pueblo Bonito: Center of the Chacoan World*. Washington, D.C.: Smithsonian Institution. p 94-106.

AlQahtani SJ, Hector MP, Liversidge HM. 2010. Brief Communication: The London Atlas of Human Tooth Development and Eruption. *Am J Phys Anthropol* 142:481-490.

Armelagos GJ. Disease in Ancient Nubia. 1969. *Sci* 163(3864):255-259.

Armelagos GJ, Goodman AH, Harper KN, Blakey ML. 2009. Enamel Hypoplasia and Early Mortality: Bioarchaeological Support for the Barker Hypothesis. *Evol Anthropol* 18:261-271.

Amoroso A, Garcia SJ, Cardoso HFV. 2014. Age at Death and Linear Enamel Hypoplasias: Testing the Effects of Childhood Stress and Adult Socioeconomic Circumstances in Premature Mortality. *Am J Hum Bio* 26:461-468.

Auerbach BM, Ruff CB. 2004. Human Body Mass Estimation: A Comparison of “Morphometric” and “Mechanical” Methods. *Am J Phys Anthropol* 125:331-342.

Auerbach BM, Ruff CB. 2010. Stature Estimation Formulae for Indigenous North American Populations. *Am J Phys Anthropol* 141:190-207.

Bailey SM, Gershoff SN, McGandy RB, Nondasuta A, Tantiwongse P, Suttapreyasri D, Miller J, McCree P. 1984. A Longitudinal Study of Growth and Maturation in Rural Thailand. *Hum Bio* 56(3):539-557.

- Baker BJ, Armelagos GJ. 1988. The Origin and Antiquity of Syphilis: Paleopathological Diagnosis and Interpretation. *Curr Anthropol* 29(5): 703-737.
- Baker, BJ, Kealhofer L, editors. 1996. *Bioarchaeology of Native American Adaptation in the Spanish Borderlands*. Gainesville: University Press of Florida.
- Barker DJP, Eriksson JG, Forsén T, Osmond C. 2002. Fetal origins of adult disease: strength of effects and biological basis. *Int J Epidemiol* 31:1235-1239.
- Barker DJP. 2012. Developmental origins of chronic disease. *Public Heal* 126:185-189.
- Becker NSA, Verdu P, Froment A, Le Bomin S, Pagezy H, Bahuchet S, Heyer E. 2011. Indirect Evidence for the Genetic Determination of Short Stature African Pygmies. *Am J Phys Anthropol* 145:390-401.
- Benson LV, Berry MS. 2009. Climate Change and Cultural Response in the Prehistoric American Southwest. *Kiva* 75(1):87-117.
- Berry MS, Benson LV. 2010. Tree-Ring Dates and Demographic Change in the Southern Colorado Plateau and Rio Grande Regions. In: Kohler TA, Varien MD, Wright AM, editors. *Leaving Mesa Verde: Peril and Change in the Thirteenth-Century Southwest*. Tucson: The University of Arizona Press. p 53-74.
- Berti PR, Leonard WR, Berti WJ. 1998. Stunting in an Andean Community: Prevalence and Etiology. *Am J Hum Biol* 10:229-240.
- Bogin B. 1998. Evolutionary and biological aspects of childhood. In: Panter-Brick C. *Biosocial Perspectives on Children*. Cambridge: Cambridge University Press. p 10-44.
- Bogin B, MacVean RB. 1983. The Relationship of Socioeconomic Status and Sex to Body Size, Skeletal Maturation, and Cognitive Status of Guatemala City Schoolchildren. *Child Dev* 54(1):115-128.
- Bogin B, Loucky J. 1997. Plasticity, Political Economy, and Physical Growth Status of Guatemala Maya Children Living in the United States. *Am J Phys Anthropol* 102:17-32.
- Boldsen JL. 1995. The place of plasticity in the study of the secular trend for male stature: an analysis of Danish biological population history. In: Mascie-Taylor CGN, Bogin B, editors. *Human variability and plasticity*. Cambridge: Cambridge University Press. p 75-90.
- Boldsen JL. 2005. Leprosy and Mortality in the Medieval Danish Village of Tirup. *Am J Phys Anthropol* 126:159-168.

Boldsen JL, Milner GR, Konigsberg LW, Wood JW. 2002. Transition analysis: a new method for estimating age from skeletons. In: Hoppa RD, Vaupel JW, editors. *Paleodemography: age distributions from skeletal samples*. Cambridge: Cambridge University Press. p 73-106.

Brenton BP, Paine RR. 2007. Reevaluating the Health and Nutritional Status of Maize-Dependent Populations: Evidence for the Impact of Pellagra on Human Skeletons from South Africa. *Ecol Food Nutr* 46:345-360.

Brooks ST, Suchey JM. 1990. Skeletal Age Determination Based on the Os Pubis: A Comparison of the Acsádi-Nemeskéri and Suchey-Brooks Methods. *Hum Evol* 5:227-238.

Buikstra JE. 1977. Biocultural Dimensions of Archaeological Study: A Regional Perspective. In Blakely RA, editor. *Biocultural adaptation in prehistoric North America*. Athens: University of Georgia Press. p 67-84.

Buikstra JE, Cook DC. 1980. Paleopathology: An American Account. *Ann Rev Anthropol* 9:433-470.

Buikstra JE, Ubelaker DH, editors. 1994. *Standards for Data Collection from Human Skeletal Remains*. Fayetteville: Arkansas Archaeological Survey Research Series (44).

Bocquet-Appel JP, Masset C. 1981. Farwell to Paleodemography. *J Hum Evol* 11:321-333.

Bocquet-Appel JP, Masset C. 1996. Paleodemography: Expectancy and False Hope. *Am J Phys Anthropol* 99:571-583.

Campbell SK, Butler VL. 2010. Archaeological Evidence for Resilience of Pacific Northwest Salmon Populations and the Socioecological System over the last ~7,500 years. *Ecol Soc* 15(1):17.

Cannon WB. 1935. Stresses and Strains of Homeostasis. *Am J Med Sci* 189:1-14.

Cartmill M, Brown K. 2009. *The Human Lineage*. Hoboken: Wiley-Blackwell.

Charnov EL. 1991. Evolution of life history variation among female mammals. *PNAS* 88(4):1134-1137.

Charnov EL. 1993. *Life History Invariants: Some Explorations of Symmetry in Evolutionary Ecology*. Oxford: Oxford University Press.

- Cohen MN, Armelagos GJ, editors. 1984. *Paleopathology at the Origins of Agriculture*. 2nd edition. Gainesville: University Press of Florida.
- Cohen MN, Wood JW, Milner GR. 1994. The Osteological Paradox Reconsidered. *Curr Anthropol* 35(5): 629-637.
- Cook DC. 1981. Mortality, age-structure and status in the interpretation of stress indicators in prehistoric skeletons: a dental example from the Lower Illinois Valley. In: Chapman R, Kinnes I, Randsborg K, editors. *Archaeology of Death*. Cambridge: Cambridge University Press. p 133-145.
- Cook DC. 1984. Subsistence and Health in the Lower Illinois Valley: Osteological Evidence. In: Cohen MN, Armelagos GJ, editors. 1984. *Paleopathology at the Origins of Agriculture*. 2nd edition. Gainesville: University Press of Florida. p 235-269.
- Cook DC. 2007. Maize and Mississippians in the American Midwest. In: Cohen MN, Crane-Kramer GMM, editors. *Ancient health: skeletal indicators of agricultural and economic intensification*. Gainesville: University Press of Florida. p 10-19.
- Cordell LS, Van West CR, Dean JS, Muenchrath DA. 2007. Mesa Verde Settlement History and Relocation: Climate Change, Social Networks, and Ancestral Pueblo Migration. *KIVA* 42(4):379-405.
- Cordell LS, McBrinn ME. 2016. The Place and its Peoples. In: Cordell LS, McBrinn ME, editors. *Archaeology of the Southwest*. 3rd edition. London: Routledge. p 17-39.
- Corruccini RS. 1972. The Biological Relationships of Some Prehistoric and Historic Pueblo Relationships. *Am J Phys Anthropol* 37(3):373-388.
- Crandall JJ. 2014. Scurvy in the Greater American Southwest: Modeling micronutrition and biosocial processes in contexts of resource stress. *Int J Paleopathol* 5:46-54.
- Dean JS. 1988. Dendrochronology and paleoenvironmental reconstruction on the Colorado Plateaus. In: Gumerman G, editor. *The Anasazi in a changing environment* Cambridge: Cambridge University Press. p 119-167.
- Dean JS, Euler RC, Gumerman GJ, Plog F, Hevly, Karlstrom TV. 1985. Human Behavior, Demography, and Paleoenvironment on the Colorado Plateaus. *Am Antiq* 50(3):537-554.
- DeWitte SN. 2010. Sex Differentials in Frailty in Medieval England. *Am J Phys Anthropol* 143:285-297.

- DeWitte SN. 2014a. Differential survival among individuals with active and healed periosteal new bone formation. *Int J Paleopathol* 7:38-44.
- DeWitte SN. 2014b. Health in Post-Black Death London (1350-1538): Age Patterns of Periosteal New Bone Formation in Post-Epidemic Population. *Am J Phys Anthropol* 155:260-267.
- DeWitte SN. 2015. Setting the Stage for Medieval Plague: Pre-Black Death Trends in Survival and Mortality. *Am J Phys Anthropol* 158:441-451.
- DeWitte SN, Wood JW. 2008. Selectivity of Black Death mortality with respect to preexisting health. *PNAS* 105(5):1436-1441.
- DeWitte SN, Bekvalac J. 2010. Oral Health and Frailty in the Medieval English Cemetery of St Mary Graces. *Am J Phys Anthropol* 142:341-354.
- DeWitte SN, Hughes-Morey G. 2012. Stature and frailty during the Black Death: the effect of stature on risks of epidemic mortality in London, A.D. 1348-1350. *J Archaeol Sci* 39:1412-1419.
- DeWitte SN, Boulware JC, Redfern RC. 2013. Medieval Monastic Mortality: Hazards Analysis of Mortality Differences Between Monastic and Nonmonastic Cemeteries in England. *Am J Phys Anthropol* 152:322-332.
- DeWitte SN, Slavín P. 2013. Between Famine and Death: England on the Eve of the Black Death—Evidence from Paleoepidemiology and Manorial Accounts. *J Interdiscip Hist* 44(1):37-60.
- DeWitte SN, Stojanowski CM. 2015. The Osteological Paradox 20 Years Later: Past Perspectives, Future Directions. *J Archaeol Res* 23:397-450.
- Diez DM, Barr CD, Çetinkaya-Rund M. 2015. *OpenIntro Statistics*. 3rd edition. https://www.openintro.org/stat/textbook.php?stat_book=os
- Dobyns HF. 1966. An Appraisal of Techniques with a Hemispheric Estimate. *Curr Anthropol* 7(4):395-416.
- Dobyns HF. 1993. Disease Transfer at Contact. *Ann Rev Anthropol* 22:273-291.
- Douglass AE. 1929. The Secret of the Southwest Solved by Talkative Tree Rings: Horizons of American History are Carried Back to A.D. 700 and a Calendar for 1,200 Years Established by National Geographic Society Expeditions. *Natl Geogr Mag* 56:736-770.

- Eckert SL. 2005. Zuni Demographic Structure, A.D. 1300-1680: A Case Study of Spanish Contact and Native Population Dynamics. *KIVA* 70(3):207-226.
- El-Najjar MY, Lozoff B, Ryan DJ. 1975. The Paleoepidemiology of Porotic Hyperostosis in the American Southwest: Radiological and Ecological Consideration. *Am J Roent Rad Therm Nuc Med* 125:918-924.
- El-Najjar MY. 1979. Human Treponematoses and Tuberculosis: Evidence from the New World. *Am J Phys Anthropol* 51(4):599-618.
- Euler RC, Gumerman GJ, Karlstrom TV, Dean JS, Hevly RH. 1979. The Colorado Plateaus: Cultural Dynamics and Paleoenvironment. *Sci* 205(4411):1089-1101.
- Eveleth PB, Tanner JM. 1990. *Worldwide Variation in Human Growth*. 2nd edition. Cambridge: Cambridge University Press.
- Frisancho AR, Sanchez J, Pallardel D, Yanez L. 1973. Adaptive Significance of Small Body Size under Poor Socio-economic Conditions in Southern Peru. *Am J Phys Anthropol* 39:255-262.
- Foster Z, Byron E, Reyes-García V, Huanca T, Vadez V, Apaza L, Pérez E, Tanner S, Gutierrez Y, Sandstrom B, Yakhedts A, Osborn C, Godoy RA, Leonard WR. 2005. Physical Growth and Nutritional Status of Tsimane' Amerindian Children of Lowland Bolivia. *Am J Phys Anthropol* 126:343-351.
- Fowler DD, Cordell LS. 2005. Introduction. In: Cordell LS, Fowler DD, editors. *Southwest Archaeology in the Twentieth Century*. Salt Lake City: The University of Utah Press. p 1-15.
- Gage TB. 1988. Mathematical Hazard Model of Mortality: An Alternative to Model Life Tables. *Am J Phys Anthropol* 76:429-441.
- Gage TB. 1991. Causes of death and the components of mortality: Testing the biological interpretations of a competing hazards model. *Am J Hum Bio* 3(3):289-300.
- Gallay SH, Yasushi M, Comisso CN, Fitzsimmons JS, O'Driscoll SW. 1994. Relationship of Donor Site to Chondrogenic Potential of Periosteum *In Vitro*. *J Orth Res* 12:515-525.
- Giussani DA. 2011. The vulnerable brain. *PNAS* 108(7):2641-2642.
- Gluckman PD, Hanson MA, Beedle AS. 2007. Early Life Events and Their Consequences for Later Disease: A Life History and Evolutionary Perspective. *Am J Hum Bio* 19:1-19.

- Godde K, Hens SM. 2012. Age-at-Death Estimation in an Italian Historical Sample: A Test of the Suchey-Brooks and Transition Analysis Methods. *Am J Phys Anthropol* 149:259-265.
- Goldstein MS. 1953. Some Vital Statistics Based on Skeletal Material. *Hum Bio* 25(1):3-12.
- Goodman AH. 1993. On the Interpretation of Health from Skeletal Remains. *Curr Anthropol* 34(3):281-288.
- Goodman AH, Armelagos GJ. 1985. Disease and Death at Dr. Dickson's Mounds: The skeletal remains of prehistoric Native Americans show that agricultural revolutions can be hazardous to your health. *Nat Hist* 94:12-18.
- Goodman AH, Armelagos GJ. 1989. Infant childhood morbidity and mortality risks in archaeological populations. *Wrlld Archaeol* 21:225-243.
- Goodman AH, Rose JC. 1990. Assessment of Systemic Physiological Perturbations from Dental Enamel Hypoplasias and Associated Histological Structures. *Yearb Phys Anthropol* 33:59-110.
- Goodman AH, Rose JC. 1991. Dental enamel hypoplasias as indicators of nutritional status. In: Kelley M, Larsen CS, editors. *Advances in Dental Anthropology*. New York: Wiley-Liss. p 279-293.
- Goodman AH, Martin DL. 2002. Reconstructing Health Profiles from Skeletal Remains. In: Steckel RH, Rose JC, editors. *The Backbone of History: Health and Nutrition in the Western Hemisphere*. Cambridge: Cambridge University Press. p 11-61.
- Goodman AH, Martin DL, Armelagos GJ. 1984a. Indicators of Stress from Bone Teeth. In: Cohen MN, Armelagos GJ, editors. *Paleopathology at the Origin of Agriculture*. Gainesville: University of Florida Press. p 13-37.
- Goodman AH, Lallo J, Armelagos GJ, Rose JC. 1984b. Health Changes at Dickson Mounds, Illinois (A.D. 950-1300). In: Cohen MN, Armelagos GJ, editors. *Paleopathology at the Origin of Agriculture*. Gainesville: University of Florida Press. p 271-305.
- Grauer AL. 1993. Patterns of Anemia and Infection from Medieval York, England. *Am J Phys Anthropol* 91:203-213.

- Grauer AL, Roberts CA. 1996. Paleoepidemiology, Healing, and Possible Treatment of Trauma in the Medieval Cemetery Population of St. Helen-on-the-Walls, York, England. *Am J Phys Anthropol* 100:531-544.
- Grine FE, Jungers WL, Tobias PV, Pearson OM. 1995. Fossil *Homo* femur from Berg Aukas, northern Namibia. *Am J Phys Anthropol* 26:67-78.
- Gumerman G, editor. 1988. *The Anasazi in a changing environment* Cambridge: Cambridge University Press.
- Hales CN, Barker DP. 1992. Type 2 (non-insulin-dependent) diabetes mellitus: the thrifty phenotype hypothesis. *Diabetologia* 35:595-601.
- Hales CN, Barker DP. 2001. The thrifty phenotype hypothesis. *Brit Med Bull* 60:5-20.
- Harrod RP. Centers of Control: Revealing elites among the Ancestral Pueblo during the "Chaco Phenomenon." *Int J Paleopathol* 2:123-135.
- Hegmon M, Peeples MA, Kinzig AP, Kulow S, Meegan CM, Nelson MC. 2008. Social Transformation and Its Human Costs in the Prehispanic U.S. Southwest. *Am Anthropol* 110(3):313-324.
- Hill BJ, Clark JJ, Doelle WH, Lyons PD. 2010. Depopulation of the northern Southwest. In: Kohler TA, Varien MD, Wright AM, editors. *Leaving Mesa Verde: Peril and change in the thirteenth-century Southwest*. Tucson: The University of Arizona Press. p 34-52.
- Hillson S. 1992. Dental enamel growth, perikymata and hypoplasia in ancient tooth crowns. *J Roy Soc Med* 85:460-466.
- Hillson S. 2014. *Tooth Development in Human Evolution and Bioarchaeology*. Cambridge: Cambridge University Press.
- Hillson S, Bond S. 1997. Relationship of Enamel Hypoplasia to the Pattern of Tooth Crown Growth: A Discussion. *Am J Phys Anthropol* 104:89-103.
- Hodge FW, Smith WW, Woodbury RB, Woodbury NF. 1966. *The excavation of Hawikuh by Frederick Webb Hodge: report of the Hendricks-Hodge expedition, 1917-1923*. Museum of the American Indian, Heye Foundation.
- Hooton EA. 1930. *The Indians of Pecos Pueblo, a study of their skeletal remains*. New Haven: Yale University Press.

- Hoover KC, Hudson MJ. 2016. Resilience in prehistoric persistent hunter-gathers in northwest Kyushu, Japan as assessed by population health and archaeological evidence. *Quatern Int* 405:22-33.
- Hoppa RD. 2002. Paleodemography: looking back and thinking ahead. In: Hoppa RD, Vaupel JW, editors. *Paleodemography: age distributions from skeletal samples*. Cambridge: Cambridge University Press. p 9-28.
- Hoppa RD, Vaupel JW. 2002. The Rostock Manifesto for paleodemography: the way from stage to age. In: Hoppa RD, Vaupel JW, editors. *Paleodemography: age distributions from skeletal samples*. Cambridge: Cambridge University Press. p 1-8.
- Howell, T.L., 1994. Leadership at the ancestral Zuni village of Hawikku. Thesis, Arizona State University.
- Hrdlička A. 1931. Catalogue of human crania in the United States National Museum collections: Pueblos, southern Utah basket-makers, Navaho. In: *Proceedings of the United States National Museum*. Washington, D.C.: US Government Printing Office. 78:1-95.
- Hu FB. 2008. *Obesity Epidemiology*. Oxford: Oxford University Press.
- Hutchinson DL, Larsen CS. 1988. Determination of Stress Episode Duration from Linear Enamel Hypoplasias: A Case Study from St. Catherines Island, Georgia. *Hum Bio* 60(1):93-110.
- International Business Machines (IBM) Inc. 2016. *IBM SPSS Statistics 24 Brief Guide*.
- Ingram SE. 2017. Settlement ecology in the precontact North America Southwest. In: Kellet LC, Jones EE, editors. *Settlement Ecology of the Ancient Americas*. London: Routledge. p 85-110.
- Irwin-Williams C, Haynes CV. 1970. Climate Change and Early Population Dynamics in the Southwestern United States. *Quatern Res* 1:59-71.
- Jett SC. 1964. Pueblo Indian Migrations: An Evaluation of the Possible Physical and Cultural Determinants. *Am Antiq* 29(3):281-300.
- Johnston FE. 1962. Growth of the Long Bones of Infants and Young Children at Indian Knoll. *Am J Phys Anthropol* 20(3):249-254.
- Jorde LB. 1977. Precipitation cycles and cultural buffering in the prehistoric Southwest. In: Binford LR, editor. *For Theory Building in Archaeology*. New York: Academic Press. p 385-396.

- Judd NM. 1954. *The Material Culture of Pueblo Bonito*. Washington, D.C.: Smithsonian Institution.
- Katzenberg MA, Herring DA, Saunders SR. 1996. Weaning and Infant Mortality: Evaluating the Skeletal Evidence. *Yearb Phys Anthropol* 39:177-199.
- Kemkes-Grottenthaler A. 2002. Aging through the ages: historical perspectives on age indicator methods. In: Hoppa RD, Vaupel JW, editors. *Paleodemography: age distributions from skeletal samples*. Cambridge: Cambridge University Press p 48-72.
- Kemkes-Grottenthaler A. 2005. The Short Die Young: The Interrelationship Between Stature and Longevity – Evidence from Skeletal Remains. *Am J Phys Anthropol* 128:340-347.
- Kent S. 1986. The Influence of Sedentism and Aggregation on Porotic Hyperostosis and Anaemia: A Case Study. *Man* 21(4):605-636.
- King T, Hillson S, Humphrey LT. 2002. A detailed study of enamel hypoplasia in a post-medieval adolescent of known age and sex. *Arch Oral Biol* 47:29-39.
- King T, Humphrey LT, Hillson S. 2005. Linear Enamel Hypoplasias as Indicators of systemic Physiological Stress: Evidence from Two Known Age-at-Death and Sex Populations from Postmedieval London. *Am J Phys Anthropol* 128:547-559.
- Kintigh KW. 1985. *Settlement, Subsistence, and Society in Late Zuni Prehistory*. Tucson: University of Arizona Press.
- Klaus HD. 2014a. Subadult scurvy in Andean South America: Evidence of vitamin C deficiency in the late pre-Hispanic and Colonial Lambayeque Valley, Peru. *Int J Paleopathol* 5:34-45.
- Klaus HD. 2014b. *Frontiers in the Bioarchaeology of Stress and Disease: Cross-Disciplinary Perspectives from Pathophysiology, Human Biology, and Epidemiology*. *Am J Phys Anthropol* 155:294-308.
- Klaus HD, Tam ME. 2009. Contact in the Andes: Bioarchaeology of Systemic Stress in Colonial Mórrope, Peru. *Am J Phys Anthropol* 138(3):356-368.
- Klaus HD, Tam ME. 2010. Oral Health and the Postcontact Adaptive Transition: A Contextual Reconstruction of Diet in Mórrope, Peru. *Am J Phys Anthropol* 141:594-609.
- Klaus HD, Shimada I, Shinoda K, Munro S. 2017. Middle Sicán Mortuary Archaeology, Skeletal Biology, and Genetic Structures in Late Pre-Hispanic South America. In: Klaus

HD, Harvey AR, Cohen MN, editors. *Bones of Complexity: Bioarchaeological Case Studies of Social Organization and Skeletal Biology*. Gainesville: University Press of Florida. p 408-449.

Kohler TA, Varien MD, Wright AM, editors. 2010. *Leaving Mesa Verde: Peril and Change in the Thirteenth-Century Southwest*. Tucson: The University of Arizona Press.

Konigsberg LW, Frankenberg SR. 2002. Deconstructing Death in Paleodemography. *Am J Phys Anthropol* 117:297-309.

Konigsberg LW, Hermann NP. 2006. The Osteological Evidence for Human Longevity in the Recent Past. In: Hawkes K, Paine RR, editors. *The Evolution of Human Life History*. Santa Fe: School of the American Research Press. p 267-306.

Kreger MB. 2010. *Urban Population Dynamics in a Preindustrial New World City: Morbidity, Mortality, and Immigration in Postclassic Cholula*. Dissertation, The Pennsylvania State University.

Kuitz, SJ, Euler, RC. 1972. *Aspects of Southwestern Paleoepidemiology*. Prescott College Press.

Kulisheck J. 2005. *The Archaeology of Pueblo Population Change on the Jemez Plateau, A.D. 1200 to 1700: The Effects of Spanish Contact and Conquest*. Thesis, Southern Methodist University.

Kumar V, Abbas AK, Aster JC. 2018. *Robbins Basic Pathology*. 10th edition. Philadelphia: Elsevier.

Lahr MM, Bowman, JE. 1992. Paleopathology of the Kechipawan Site: Health and Disease in a South-western Pueblo. *J Archaeol Sci* 19:639-654.

Lallo J, Armelagos GJ, Rose JC. 1978. Paleoepidemiology of infectious disease in the Dickson Mounds population. *Med Coll Va Q* 14:17-23.

Lambert, PM. 2002. Rib Lesions in a prehistoric Puebloan sample from southwestern Colorado. *Am J Phys Anthropol* 117(4): 281-292.

Larsen CS. 1994. In the wake of Columbus: Native population biology in the postcontact Americas. *Am J Phys Anthropol* 37:109-154.

Larsen CS. 1995. Biological Changes in Human Populations with Agriculture. *Annu Rev Anthropol* 24:185-213.

- Larsen CS. 2015. *Bioarchaeology: Interpreting Behavior from the Human Skeleton*, second edition. Cambridge: Cambridge University Press.
- Larsen CS, Milner GR, editors. 1994. *In the Wake of Contact, Biological Responses to Conquest*. New York: Wiley-Liss.
- Leonard WR, Spencer GJ, Galloway VA, Osipova L. 2002. Declining Growth Status of Indigenous Siberian Children in Post-Soviet Russia. *Hum Bio* 74(2):197-209.
- Lieverse AR, Temple DH, Bazaliiskii VI. 2014. Paleopathological Description and Diagnosis of Metastatic Carcinoma in an Early Bronze Age (4588±34 Cal. BP) Forager from Cis-Baikal Region of Eastern Siberia. *Plos One* 9(12):1-25.
- Liversidge HM, Molleson T. 2004. Variation in Crown and Root Formation and Eruption of Human Deciduous Teeth. *Am J Phys Anthropol* 123:172-180.
- Lovejoy CO, Meindl RS, Pryzbeck TR, Mensforth RP. 1985. Chronological Metamorphosis of the Auricular Surface of the Ilium: A New Method for the Determination of Age at Death. *Am J Phys Anthropol* 68:15-28.
- Lovejoy CO, Russell KF, Harrison ML. 1990. Long Bone Growth Velocity in the Libben Population. *Am J Hum Bio* 2:533-541.
- Marden K. 2015. Human Burials of Chaco Canyon: new developments in cultural interpretations through Skeletal analysis. In: Heitman CC, Plog S. *Chaco Revisited: New Research on the Prehistory of Chaco Canyon*. Tucson: Amerind Studies in Archaeology, University of Arizona Press. p 165-186.
- Marden K, Ortner DJ. 2011. A Case of Treponematosis from Pre-Columbian Chaco Canyon, New Mexico. *Int J Osteoarchaeol* 21(1):19-31.
- Margerison BJ, Knüsel CJ. 2002. Paleodemographic Comparison of a Catastrophic and an Attritional Death Assemblage. *Am J Phys Anthropol* 119:134-143.
- Marshall AL. 2003. The Siting of Pueblo Bonito. In: Neitzel JE, editor. *Pueblo Bonito: Center of the Chacoan World*. Washington, D.C.: Smithsonian Institution. p 10-13.
- Martin DL, Goodman AH. 2002. Health conditions before Columbus: paleopathology of native North Americans. *Cult Med* 176:65-68.
- Martin DL, Osterholtz AJ. 2016. *Bodies and Lives in Ancient America, Health Before Columbus*. London: Routledge.

- Mays S, Ives R, Brickley M. 2009. The Effects of Socioeconomic Status on Endochondral and Appositional Bone Growth, and Acquisition of Cortical Bone in Children From 19th Century Birmingham, England. *Am J Phys Anthropol* 140:410-416.
- McHenry HM. 1992. Body size and proportions in early Hominids. *Am J Phys Anthropol* 87:407-431.
- Meindl RS, Lovejoy O, Mensforth RP, Don Carlos L. 1985. Accuracy and Direction of Error in the Sexing of the Skeleton: Implications for Paleodemography. *Am J Phys Anthropol* 68:79-85.
- Merbs CF. 1989. Patterns of health and sickness in the Precontact Southwest. In: Thomas DH, editor. *Columbian Consequences*, vol. one. Washington, D.C.: Smithsonian Institution Press. p 41-56.
- Milner GR, Boldsen JL. 2012. Transition Analysis: A Validation Study with Known-Age Modern American Skeletons. *Am J Phys Anthropol* 148:98-110.
- Milner GR, Boldsen JL. 2013. *Transition Analysis Age Estimation: Skeletal Scoring Manual*. State College: The Pennsylvania State University.
- Milner GR, Boldsen JL. 2017. Life not death: Epidemiology from Skeletons. *Int J Paleopathol* 17:26-39.
- Mobley CH. 1980. Demographic Structure of Pecos Indians: A Model Based on Life Tables. *Am Antiq* 45(3):518-530.
- Moorees CA, Fanning EA, Hunt EE. 1963. Formation and Resorption of Three Deciduous Teeth in Children. *Am J Phys Anthropol* 21:205-213.
- Mulhern DM, Wilczak CA, Dudar CJ. 2006. Brief Communication: Unusual Finding at Pueblo Bonito: Multiple Cases of Hyperostosis Frontalis Interna. *Am J Phys Anthropol* 130:480-484.
- Murphy MS, Klaus, HD, editors. 2017. *Colonized Bodies, Worlds Transformed*. Gainesville: University Press Florida.
- Neitzel JE, editor. 2003. *Pueblo Bonito: Center of the Chacoan World*. Washington, D.C.: Smithsonian Institution.
- Nelson CT. 1938. The teeth of the Indians of Pecos Pueblo. *Am J Phys Anthropol* 23(3):261-293.

Nelson BA, Martin DL, Swedlund AC, Fish PR, Armelagos GJ. 1994. Studies in Disruption: Demography and Health in Prehistoric American Southwest. In: Gumerman G, Gell-Mann M, editors. Understanding complexity in the prehistoric Southwest. p 59-112.

Nelson MC, Hegmon M, Kulow SR, Peeples MA, Kintigh KW, Kinzig AP. 2011. Resisting Diversity: a Long-Term Archaeological Study. *Ecol Soc* 16(1):25.

Nikiforuk G, Fraser D. 1981. The etiology of enamel hypoplasia: A unifying concept. *J. Pediatr.* 98(6):888-893.

Ortner DJ. 1991. Theoretical and methodological issues in paleopathology. In: Human paleopathology: current syntheses and future options. Washington D.C.: Smithsonian Institution Press. p 5-11.

Ortner DJ, Butler W, Cafarella J, Milligan L. 2001. Evidence of probable scurvy in subadults from archaeological sites in North America. *Am J Phys Anthropol* 114(4):343-351.

Ortner DJ. 2011. What skeletons tell us. The story of human paleopathology. *Virchows Arch* 459:247-254.

Palkovich AM. 1978. A Model of the Dimension of Mortality and its Application to Paleodemography. Thesis, Northwestern University.

Palkovich AM. 1984a. Agriculture, Marginal Environments, and Nutritional Stress in the Prehistoric Southwest. In: Cohen MN, Armelagos GJ, editors. Paleopathology at the Origin of Agriculture. 2nd edition. Gainesville: University of Florida Press. p 425-438.

Palkovich AM. 1984b. Disease and Mortality Patterns in the Burial Rooms of Pueblo Bonito: Preliminary Conclusions. In: Judge J, Schelberg JD, editors. Recent Research on Chaco Prehistory. Albuquerque: Division of Cultural Research, US Department of the Interior, National Park Service. p 103-114.

Palkovich AM. 1985. Historic Population of the Eastern Pueblos: 1540-1910. *J Anthropol Res* 41(4):401-426.

Phenice T. 1969. A Newly Developed Visual Method of Sexing in the Os Pubis. *Am J Phys Anthropol* 30:297-301.

Pinhasi R, Teschler-Nicola M, Knaus A, Shaw P. 2005. Cross-Population Analysis of the Growth of Long Bones and the Os Coxae of Three Early Medieval Austrian Populations. *Am J Hum Biol* 17:470-488.

- Pinhasi R, Shaw P, White B, Ogden AR. 2006. Morbidity, rickets and long-bone growth in post medieval Britain—a cross population analysis. *Ann Hum Biol* 33(3):372-389.
- Polyak VJ, Asmerom Y. 2001. Late Holocene Climate and Cultural Changes in the Southwestern United States. *Sci* 294(5540):148-151.
- Pomeroy E, Stock JT, Stanojevic S, Miranda JJ, Cole TJ, Wells JK. 2012. Trade-Offs in Relative Limb Length among Peruvian Children: Extending the Thrifty Phenotype Hypothesis to Limb Proportions. *Plos One* 7(12):1-10.
- Powell S. 1983. *Mobility and Adaptation*. Carbondale: Southern Illinois University Press.
- Powell ML, Cook DC, editors. 2005. *The myth of syphilis: the natural history of treponematosi s in North America*, Gainesville: University Press of Florida.
- Pfeiffer S, et al. 2014. Discernment of mortality risk associated with childbirth in archaeologically derived forager skeletons. *Int J Paleopathol* 7:15-24.
- Price DT, Plog S, LeBlanc SA, Kirgbaum J. 2017. Great House origins and population stability at Pueblo Boito, Chaco Canyon, New Mexico: The isotopic evidence. *J Archaeol Sci: Rep* 11:261-273.
- Ragsdale BD, Madewell JE, Sweet DE. 1981. Radiologic and Pathologic Analysis of Solitary Bone Lesions, Part II: Periosteal Reactions. *Radiol Clin N Am* 19(4):749-783.
- Ragsdale BD, Lehmer LM. 2012. A Knowledge of Bone at the Cellular (Histological) Level is Essential to Paleopathology. In: Grauer AL, editor. *A Companion to Paleopathology*. 1st edition. Wiley-Blackwell. p 227-249.
- Ramenofsky AF. 1996. The Problem of Introduced Infectious Diseases in New Mexico: A.D. 1540-1680. *J Anthropol Res* 52(2):161-184.
- Redman CL. 2005. Resilience Theory in Archaeology. *Am Anthropol* 107(1):70-77.
- Redman CL, Kinzig AP. 2003. Resilience of Past Landscapes: Resilience Theory, Society, and the *Long Durée*. *Conserv Ecol* 7(1):14.
- Reinhard KJ. 1992. Patterns of Diet, Parasitism and Anemia in Prehistoric West North America. In: Stuart-Macadam P, Kent S, editors. *Diet, Demography, and Disease*. New York: Aldine de Gruyter. p 202-219.
- Reinhard KJ, Clary KH. 1986. Parasite analysis of prehistoric coprolites from Chaco Canyon, New Mexico. In: Akins NJ, *A Biocultural Approach to Human Burials from*

Chaco Canyon, New Mexico. Santa Fe: Reports of Chaco Canyon, No. 9, National Park Service. p 177-186.

Reinhard KJ, Ferreira LF, Bouchet F, Sianto L, Dutra JF, Iniguez A, Leles D, Le Bailly M, Fugassa M, Pucu E, Araújo A. 2013. Food, parasites, and epidemiological transitions: A broad perspective. *Int J Paleopathol* 3:150-157.

Reitsema LJ, Vercellotti G, Boano R. 2016. Subadult Dietary Variation at Trino Vercellese, Italy, and its Relationship to Adult Diet and Mortality. *Am J Phys Anthropol* 160:653-664.

Rich JT, Neely G, Paniello RC, Voelker CC, Nussenbaum B, Wang EW. 2010. A Practical Guide to Understanding Kaplan-Meier Curves. *Otolaryng Head Neck* 143(3):331-336.

Roberts CA, Powell ML, Buikstra JE. 2012. T. Aidan Cockburn (1912-1981) and Eve Cockburn (1924-2003). In: Buikstra JE, Roberts CA, editors. *The Global History of Paleopathology: Pioneers and Prospects*. Oxford: Oxford University Press. p 33-39.

Roberts L, Labat-Roberts J. 2015. Stress in biology and medicine, role in aging. *Pathol Biol* 63:230-234.

Rose JC, Hartnady P. 1991. Interpretation of infectious skeletal lesions from a historic Afro-American cemetery. In: Ortner DJ, Aufderheide AC, editors. *Human paleopathology: current syntheses and future options*. Washington: Smithsonian Institution Press. p 119-127.

Ruff CB. 1981. A Reassessment of Demographic Estimates for Pecos Pueblo. *Am J Phys Anthropol* 54:147-151.

Ruff CB. 2007. Body Size Prediction from Juvenile Skeletal Remains. *Am J Phys Anthropol* 133:698-716.

Ruff CB, Scott WW, Liu A. 1991. Articular and diaphyseal remodeling of the proximal femur with changes in body mass in adults. *Am J Phys Anthropol* 86(3):397-413.

Ruff CB, Holt B, Trinkaus E. 2006. Who's Afraid of the Big Bad Wolff?: "Wolff's Law" and Bone Functional Adaptation. *Am J Phys Anthropol* 129:484-498.

Ruff CB, Garofalo E, Holmes MA. 2013. Interpreting Skeletal Growth in the Past from a Functional and Physiological Perspective. *Am J Phys Anthropol* 150:29-37.

Sandberg PA, Sponheimer M, Lee-Throp J, Van Gerven D. 2014. Intra-Tooth Stable Isotope Analysis of Dentin: A Step Toward Addressing Selective Mortality in the

- Reconstruction of Life History in the Archaeological Record. *Am J Phys Anthropol* 155:281-293.
- Sattenspiel L, Harpending H. 1983. Stable Populations and Skeletal Age. *Am Antiq* 48(3):489-498.
- Saunders SR, Hoppa RD. 1993. Growth Deficit in Survivors and Non-Survivors: Biological Mortality Bias in Subadult Skeletal Samples. *Yearb Phys Anthropol* 36:127-151.
- Schillaci MA, Stojanowski CM. 2003. Postmarital Residence and Biological Variation at Pueblo Bonito. *Am J Phys Anthropol* 120:1-15.
- Schillaci MA, Nikitovic D, Akins NJ, Tripp L, Palkovich AM. 2011. Infant and Juvenile Growth in Ancestral Pueblo Indians. *Am J Phys Anthropol* 145:318-326.
- Scheuer L, Black S. 2004. *The Juvenile Skeleton*. Amsterdam: Elsevier.
- Schultz M, Carli-Thiele P, Schmidt-Schultz TH, Kierdorf U, Kierdorf H, Teegen WR, Kreuz K. 1998. Enamel Hypoplasias in Archaeological Skeletal Remains. In: Alt KW, Rösing FW, Teschler Nicola, editors. *Dental Anthropology: Fundamentals, Limits, and Prospects*. Austria: Springer-Verlag/Wien. p 293-312.
- Seltzer CC. 1944. *Racial Prehistory in the Southwest and the Hawikuh Zunis*. Cambridge: Peabody Museum of American Archaeology and Ethnology.
- Selye H. 1950. *The Physiology and Pathology of Exposure to Stress: A treatise based on the concepts of the General-Adaption Syndrome and the Diseases of Adaptation*. Montreal: ACTA.
- Smith BH. 1991. Standards of human tooth formation and dental age assessment. In: Kelley MA, Larsen CS, editors. *Advances in Dental Anthropology*. Wiley-Liss Inc. p 143-168.
- Smith MO, Kurtenbach KJ, Vermaat JC. 2016. Linear enamel hypoplasia in Schroeder Mounds (11HE177): A Late Woodland period site in Illinois. *Int J Paleopathol* 14:10-23.
- Stearns SC. 1992. *The Evolution of Life Histories*. Oxford: Oxford University Press.
- Steckel RH. 1986. The Nutrition, Health, and Mortality of American Slaves from Childhood to Maturity. *J Econ Hist* 46(3):721-741.
- Steckel RH. 1995. Stature and the Standard of Living. *J Econ Lit* 33(4):1903-1940.

Steward JH. 1955. The Concept and Method of Cultural Ecology. In: Steward JH. The Concept and Method of Cultural Ecology. Theory of Culture Change. Urbana: University of Illinois Press. p 30-42.

Stini WA. 1971. Evolutionary Implications of Changing Nutritional Patterns in Human Populations. *Am Anthropol* 73(5):1019-1030.

Stinson S. 2012. Growth Variation: Biological and Cultural Factors. In: Stinson S, Bogin B, O'Rourke D, editors. *Human Biology: An Evolutionary and Biocultural Perspective*. 2nd edition. Wiley & Sons. p 587-635.

Stodder ALW. 1989. Background of the Bioarchaeological Resources Survey. In: Simmons AH, Stodder, ALW, Dykeman DD, Hicks, PA, editors. *Human Adaptations and Cultural Change in the Greater Southwest: An Overview of Archaeological Resources in the Basin and Range Province*. Fayetteville, Arkansas: Arkansas Archaeological Survey. p 141-154.

Stodder ALW. 1990. Paleoepidemiology of Eastern and Western Pueblo Communities in Early Contact Period New-Mexico. *Am J Phys Anthropol* 81(2):301-302.

Stodder ALW. 1996. Paleoepidemiology of Eastern and Western Pueblo Communities in Protohistoric and Early Historic New Mexico. In: Baker BJ, Kealhofer L, editors. *Bioarchaeology of Native American Adaptation in the Spanish Borderlands*. Gainesville: University Press of Florida. p 148-176.

Stodder ALW. 2012. The History of Paleopathology in the American Southwest. In: Buikstra JE, Roberts C, editors. *The Global History of Paleopathology: Pioneers and Prospects*. Oxford: Oxford University Press. p 287-303

Stodder ALW, Martin DL. 1992. Health and Disease in the Southwest. In: Verano JW, Ubelaker, DH, editors. *Disease and Demography in the Americas*. Washington, D.C.: Smithsonian Institution Press. p 55-74.

Stojanowski CM, Knudson KJ. 2014. Changing Patterns of Mobility as a Response to Climatic Deterioration and Aridification in the Middle Holocene Southern Sahara. *Am J Phys Anthropol* 154:79-93.

Stuart-Macadam P, Kent S. 1992. *Diet, Demography, and Disease*. New York: Aldine de Gruyter.

Tanner JM. 1976. Population differences in body size, shape and growth rate: A 1976 view. *Arch Dis Child* 51:1-2.

Tanner JM. 1981. Growth and Maturation during Adolescence. *Nutr Rev* 39(2):43-55.

Tanner JM, Whitehouse RH, Takaishi M. 1966. Standards from Birth to Maturity for Height, Weight, Height Velocity, and Weight Velocity: British Children, 1965, Part I. *Arch Dis Child* 41:454-471.

Temple DH. 2010. Patterns of Systemic Stress During the Agricultural Transition in Prehistoric Japan. *Am J Phys Anthropol* 142:112-124.

Temple DH. 2014. Plasticity and Constraint in Response to Early-Life Stressors Among Late/Final Jomon Period Foragers from Japan: Evidence for Life History Trade-Offs from Incremental Microstructures of Enamel. *Am J Phys Anthropol* 155:537-545.

Temple DH. 2016. Chronology and periodicity of linear enamel hypoplasia among Late/Final Jomon period of foragers: Evidence from incremental microstructures of enamel. *Quatern Int* 405:3-10.

Temple DH, Auerbach BM, Nakatsukasa M, Sciulli PW, Larsen CS. 2008. Variation in Limb Proportions Between Jomon Foragers and Yayoi Agriculturalists from Prehistoric Japan. *Am J Phys Anthropol* 137:164-174.

Temple DH, McGroarty JN, Guatelli-Steinberg D, Nakatsukasa M, Matsumura H. 2013. A Comparative Study of Stress Episode Prevalence and Duration Among Jomon Period Foragers from Hokkaido. *Am J Phys Anthropol* 152:230-238.

Temple DH, Goodman AH. 2014. Bioarchaeology Has a “Health” Problem: Conceptualizing “Stress” and “Health” in Bioarchaeological Research. *Am J Phys Anthropol* 155:186-191.

Temple DH, Bazaliiskii VI, Goriunova OI, Weber AW. 2014. Skeletal Growth in Early and Late Neolithic Foragers from Cis-Baikal Region of Eastern Siberia. *Am J Phys Anthropol* 153:377-386.

Temple DH, Stojanowski CM. In press. Interrogating the Alterity of Hunter-Gatherers in Bioarchaeological Context: Adaptation *and* Resiliency of Hunter-Gatherers in the Past.

Thomas R. 2003. Enamel Defects, Well-Being and Mortality in a Medieval Danish Village. Thesis, The Pennsylvania State University.

Tomkins A. 1988. The Risk of Morbidity in a Stunted Child. In: Waterlow JC, editor. *Linear Growth Retardation in Less Developed Countries*, Nestlé Nutrition Workshop Series 14. New York: Raven Press Ltd. P 185-199.

Ubelaker DH. 1984. Prehistoric Human Biology of Ecuador: Possible Temporal Trends and Cultural Correlations. In: Cohen MN, Armelagos GJ, editors. 1984. *Paleopathology*

at the Origins of Agriculture. 2nd edition. Gainesville: University Press of Florida. p 491-513.

Ubelaker DH. 1992. North American Indian Population Size, Changing Perspectives. In: Verano JW, Ubelaker DH, editors. Disease and Demography in the Americas. Washington, D.C.: Smithsonian Institution Press. p 169-176.

Ulijaszek SJ. 1996. Relationships between undernutrition, infection, and growth and development. *Hum Evo* 11(3-4):233-248.

Upham S. 1986. Smallpox and Climate in the American Southwest. *Am Anthropol* 88(1):115-128.

Upham S. 1992. Population and Spanish Contact in the Southwest. In: Verano JW, Ubelaker DH, editors. Disease and Demography in the Americas. Washington, D.C.: Smithsonian Institution Press. p 223-226.

Usher BM. 2000. A Multistate Model of Health and Mortality for Paleodemography: Tirup Cemetery. Thesis, The Pennsylvania State University.

Vaupel JW, Manton KG, Stallard E. 1979. The Impact of Heterogeneity in Individual Frailty on the Dynamics of Mortality. *Demog* 16(3):439-454.

Vaupel JW, Yashin AI. 1985. Heterogeneity's Ruses: Some Surprising Effects of Selection on Population Dynamics. *Am Stat* 39(3):176-185.

Verano JW, Ubelaker DH, editors. 1992. Disease and Demography in the Americas, Washington, D.C.: Smithsonian Institution Press.

Vercellotti G, Stout SD, Boano R, Sciulli PW. 2011. Intrapopulation Variation in Stature and Body Proportions: Social Status and Sex Differences in an Italian Medieval Population (Trino Vercellese, VC). *Am J Phys Anthropol* 145:203-214.

Vivian G, Mathews TW. 1965. Kin Kletso: A Pueblo III Community in Chaco Canyon, New Mexico. *Globe, Arizona: Southwestern Monuments Association* 6(1).

Vivian G. 1990. The Chacoan Prehistory of the San Juan Basin. San Diego: Academic Press.

Walker B, Holling CS, Carpenter SR, Kinzig A. 2004. Resilience, Adaptability and Transformability in Social-ecological Systems. *Ecol Soc* 9(2):5.

Walker R, Gurven M, Hill K, Migliano A, Chagnon N, De Souza R, Djurovic G, Hames R, Hurtado AM, Kaplan H, Kramer K, Oliver WJ, Valeggia C, Yamauchi T. 2006.

- Growth Rates and Life Histories in Twenty-Two Small-Scale Societies. *Am J Hum Bio* 18:295-311.
- Walker PL, Bathurst RR, Richman R, Gjerdrum T, Andrushko VA. 2009. The Causes of Porotic Hyperostosis and Cribra Orbitalia: A Reappraisal of the Iron-Deficiency-Anemia Hypothesis. *Am J Phys Anthropol* 139(2):109-125.
- Waters MR, Haynes CV. 2001. Late Quaternary arroyo formation and climate change in the American Southwest. *Geology* 29(5):399-402.
- Weston DA. 2008. Investigating the Specificity of Periosteal Reactions in Pathology Museum Specimens. *Am J Phys Anthropol* 137:48-59.
- Weston DA. 2012. Nonspecific Infection in Paleopathology: Interpreting Periosteal Reactions. In: Grauer AL, editor. *A Companion to Paleopathology*. 1st edition. Wiley-Blackwell. p 492-512.
- Wilson JJ. 2014. Paradox and Promise: Research on the Role of Recent Advances in Paleodemography and Paleoepidemiology to the Study of “Health” in Precolumbian Societies. *Am J Phys Anthropol* 155:266-280.
- Windes TC, Ford D. 1996. The Chaco Wood Project: Chronometric Reappraisal of Pueblo Bonito. *Am Antiq* 61(2):295-310.
- Wood JW, Milner GR, Harpending HC, Weiss, KM. 1992. The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples. *Curr Anthropol* 33(4):342-370.
- Wood JW, Holman DJ, O’Connor KA, Ferrell RJ. 2002. Mortality models for paleodemography. In: Hoppa RD, Vaupel JW, editors. *Paleodemography: age distributions from skeletal samples*. Cambridge: Cambridge University Press. p 129-168.
- Woodhouse CA, Overpeck JT. 1998. 2,000 Years of Drought Variability in the Central United States. *B Am Meteorol Soc* 79(12):2693-2714.
- Wright RJ, Rodriguez M, Cohen S. 1998. Review of psychosocial stress and asthma: an integrated biopsychosocial approach. *Thorax* 53:1066-1074.
- Wright LE, Yoder CJ. 2003. Recent Progress in Bioarchaeology: Approaches to the Osteological Paradox. *J Archaeol Res* 11(1):43-70.
- Wright AM. 2010. The Climate of the Depopulation of the Northern Southwest. In: Kohler TA, Varien MD, Wright AM, editors. *Leaving Mesa Verde: Peril and Change in the Thirteenth-Century Southwest*. Tucson: The University of Arizona Press. p 75-101.

Yaussy SL, DeWitte SN, Redfern RC. 2016. Frailty and Famine: Patterns of Mortality and Physiological Stress Among Victims of Famine in Medieval London. *Am J Phys Anthropol* 160:272-283.

Zuckerman MK, Harper KN, Armelagos, GJ. 2016. Adapt or Die: Three Case Studies in Which the Failure to Adopt Advances from Other Fields has Compromised Paleopathology. *Int J Osteoarchaeol.* 26(3):375-883.

Zhou L, Corruccini RS. 1998. Enamel Hypoplasias Related to Famine Stress in Living Chinese. *Am J Hum Biol* 10:723-733.

BIOGRAPHY

Allison C. Ham graduated from Yorktown High School, Arlington, Virginia, in 2010, and received her Bachelor of Arts in Archaeology from The College of Wooster in 2014.