EXPRESSIONS AND SEVERITY OF DEGENERATIVE JOINT DISEASES: A COMPARATIVE STUDY OF JOINT PATHOLOGY IN THE LAMBAYEQUE REGION, NORTH COAST PERU

by

Michelle L. Yockey

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: __________________________________ Spring Semester 2019
George Mason University
Fairfax, VA

“Expressions and Severity of Degenerative Joint Diseases: A Comparative Study of Joint Pathology in the Lambayeque Region, North Coast Peru”

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

By

Michelle L. Yockey
Bachelor of Arts
Ball State University, 2016

Director: Haagen D. Klaus
Department of Sociology and Anthropology

Spring Semester 2019
George Mason University
Fairfax, VA

DEDICATION

This work is dedicated to extremely supporting and loving partner, Anthony.

ACKNOWLEDGEMENTS

I would like to thank everyone who had a part in supporting me through this process. My supporting partner, Anthony, helped me immensely by talking though ideas with me and helping me through the writer's block. My parents, Douglas and Nancy, for loving and pushing me to get this far. My colleague, Liz, for being a great friend and listener throughout the drafting of this thesis. Dr. Haagen Klaus, for helping me throughout every process of this paper and mentoring me through this process. I'd also like to thank my committee members, Dr. Daniel Temple and Dr. Cortney Hughes Rinker.

TABLE OF CONTENTS

Chapter Page

Dedication .... **ii**

Acknowledgements .... **iii**

List of Tables .... **vii**

List of Figures .... **viii**

Abstract .... **iv**

1 – Introduction **1**
Conclusion **6**

2 - The Biology and Bioarchaeology of Degenerative Joint Disease **7**
Joint Pathology **7**
Degenerative Joint Disease and the Joint 8
Synovial Joint Degeneration 11
Degenerative Joint Disease in Review: Global Perspectives over the Last 10,000 Years **14**
Prehistoric Patterning 17
Early Works and the Development of a Modern Paradigm 18
Early Life Dietary Stress and DJD Predisposition 22
Mobility and Adaptive Shifts 27
Labor Systems 30
Comparing Populations in North America 32
Perspectives Beyond the Americas 33
DJD in Settings of New World Spanish Colonization 35
South American Populations 37
Conclusion **43**

3 – Culture History **45**
The Lambayeque Valley Complex **45**
Culture History **51**
The First Settlers 51
The Origins of Social Complexity and Farming 52
The Preceramic Period 52
The Cupisnique 54
The Salinar and Gallinazo Traditions 56

The Moche ... 57
The Sicán ... 59
The Chimú ... 62
The Rise of the Inka ... 63
Pre-Hispanic power Structures ... 64
Shifting Labor Systems ... 66
Effects of the Spanish Colonization of the Lambayeque and its People ... 68
Conclusion ... 72

4 – Materials and Methods ... 73
Materials ... 73
Archaeological Context ... 73
Eten ... 73
Mórrope ... 78
The Skeletal Samples ... 84
Methods ... 88
Expressions of DJD ... 88
Scoring Expressions of DJD ... 93
Statistical Procedures ... 95
Conclusion ... 98

5 – Results ... 99
Introduction ... 99
***Z*-Tests ... 100**
Odds Ratio Results ... 101
Mann-Whitney U ... 104
Types of Expression: Osteophytosis ... 104
Severity of Osteophytosis ... 107
Types of Expression: Porosity ... 110
Severity of Porosity ... 113
Types of Expression: Eburnation ... 115
Severity of Eburnation ... 118
Conclusion ... 120

6 – Discussion ... 121
Introduction ... 121
Results Analysis ... 122
Comparing Joint Systems ... 122
Interpretations of DJD Prevalence Variation between Mórrope and Eten ... 125
Diet and Nutritional Factors ... 125
Diet and Nutritional Factors as a Window on Degenerative Joint Lesions? ... 128
Association between Body Mass and DJD Variation? ... 131
Ecological Factors ... 132
Physical Activity ... 134
Conclusion ... 144

7 – Conclusion **148**
References **153**
Biography **164**

LIST OF TABLES

Table Page
4.1 Joint Systems as defined in this work, based n Klaus et al. (2009) ……………86
4.2 Age Class Structures, based on Klaus et al. (2009) ………………………......87
5.1 Univariate Data for Samples for any type of DJD ……………………………100
5.2 - Odds Ratio Results: for age classes 3-6 between Mórrope and Eten………..103
5.3 - Univariate Data of Samples: Osteophytosis Presence………………………104
5.4 – Mann-Whitney U Test Results: Osteophytosis..……………………………106
5.5 - Mann-Whitney U Test Results: Osteophytosis Severity …………………....109
5.6 - Univariate Data for Samples: Porosity Presence……………………………110
5.7 - Mann-Whitney U Test Results: Porosity …………………………………...112
5.8 – Mann-Whitney U Test Results: Porosity Severity ……………………...…..114
5.9 Univariate Data of Samples: Eburnation Presence…………………………....115
5.10 – Mann-Whitney U Test Results: Eburnation ………………………………117
5.11 – Mann-Whitney U Test Results: Eburnation Severity ……..…………...…191

LIST OF FIGURES

Figure Page
3.1 – Archaeological Map of the North Coast of Peru………………………..45
3.2 – Archaeological Map Depicting the Lambayeque Valley Complex, including Mórrope and Eten……………………………………….….….…......50
4.1 – Church of Santa Maria de Magdalena de Eten……………………….…75
4.2 – CNS Plan Map from Eten Site…………………………..…………....77
4.3 – The Chapel of San Pedro de Mórrope…………………….………..…79
4.4 – CSPM Plan Map from Mórrope Site……………………..………...81
4.5 – Example of Eburnation found on the Superior Epiphysis of a Humerus found in Eten……………………………………………………………….…89
4.6 – Examples of Osteophytosis (or Lipping) Found on Various Bones in Mórrope (Superior Epiphysis of the Ulna, Superior Epiphysis of the Radius, and Humeral Head)……………………………………………………90
5.1 - Pedal Phalange from Eten Sample………………………………..…..102
6.1 - Comparing Mórrope and Eten's Bone Degeneration in the Inferior Epiphyses of the Femur. Morrope's Femur is on Top, showing clear signs of Osteophytosis…………………………………………………………123
6.2 - Glenoid Fossa of the Scapula and Humeral Head from an Individual in the Mórrope Sample……………………………………………………140
6.3 - Glenoid Fossa of the Scapula and Humeral Head from Individuals in the Eten Sample……………………..………………………………………141
6.4 - Inferior Epiphysis of the Humerus and Superior Epiphysis of the Radius from an Individual from the Mórrope Sample Showing Complete Destruction of the Joint Surfaces……………………..………..……………………141
6.5 - Inferior Epiphysis of the Humerus from an Individual from the Eten Sample……………………..………..……………….……..…142

ABSTRACT

EXPRESSIONS AND SEVERITY OF DEGENERATIVE JOINT DISEASES: A COMPARATIVE STUDY OF JOINT PATHOLOGY IN THE LAMBAYEQUE REGION, NORTH COAST PERU

Michelle L. Yockey, M.A. George Mason University, 2019 Thesis Director: Haagen D. Klaus

Degenerative joint disease (DJD) is one of the most common categories of pathological conditions found in archaeological and clinical medical contexts. DJD and is characterized by the progressive erosion of the articular cartilage of the synovial joint systems throughout the human body. Subsequent pathological joint alterations include osteophytosis, porosity, and eburnation. Bioarchaeologists have previously studied DJD linking wear-and-tear of joints to broad patterns and intensities of long-term habitual physical activities to shed light on lifeways, mobility, gender roles, and forms of economy. In the Lambayeque region of northern Peru past research has demonstrated while the biological effects of conquest were variable, DJD has not been studied in particular depth. This thesis analyzed data from 331 individuals from Mórrope and 148 from Eten –two Colonial era skeletal samples from Lambayeque. Here, the prevalence of multiple types of DJD as well as the severity of each pathological manifestation were examined between Mórrope and Eten using odds ratios and Mann-Whitney U tests.

Results show that the manifestation and severity of each type are statistically different between the two samples in most comparisons, demonstrating that people in Mórrope sample were experiencing an elevated if not excessive level of physical activity than in Eten. These findings point to local differences in Colonial Peruvian economy as mediated by microenvironments, the possible role of early life nutritional stress on later predisposition to DJD, and the literal embodiment of multiple forms of social inequality among the native Muchik peoples of historic Peru.

CHAPTER ONE:

INTRODUCTION

Degenerative joint diseases are among the most common pathological conditions found in ancient human remains. This broad category of disease continues to afflict a large number of individuals in the modern world, especially as lifespans increase in the developed and developing world. Therefore, it is vital to understand this condition in both its archaeological context and the modern clinical setting. Many bioarchaeologists and paleopathologists argue that understanding how degenerative joint diseases (DJD) manifests in the human skeleton can help scholars reconstruct and interpret the lifeways, physical activity patterns, adaptations, human-environment interplays, and political economies of past societies. This approach involves inferences based on DJD patterning to reconstruct the long-term habitual motions of the afflicted joints and the mechanical strain that such endured as well as the intensity of the activity. However, additional factors are involved in the manifestation of DJD that must be considered, including environmental and topographic factors, age-at-death, early life nutritional stress, and genetic predisposition to the condition. Studies of degenerative joint diseases patterns can provide vital insights on the interaction between different economies and patterns of routine physical activity, including a better understanding of how the European conquest of the Americas transformed (and in some ways, radically altered) lifestyle, activity, economy, and skeletally biology among many Native American peoples.

Previous research has found a temporal increase in the prevalence of degenerative joint disease among the indigenous Muchik population of the Lambayeque region located on the northern coast of Peru between the late pre- Hispanic and Historic, or postcontact eras. This examination of two skeletal samples of Muchik peoples from Lambayeque, Peru, aims to understand how degenerative joint disease may have differed across the postcontact adaptive transition. Work conducted by Klaus et al. (2009) demonstrated that the indigenous Muchik population living in one settlement in the Lambayeque region on the northern coast Peru experienced a striking rise in mechanically stressful activity during the Colonial period. They found that there were statistically significant patterns of elevated DJD prevalence in the indigenous population in Mórrope, Peru, after Spanish conquest in multiple joint systems, including the shoulder, elbow, wrist, and knee (Klaus et al., 2009). These changes were interpreted as reflecting an intensification of labor among the indigenous peoples of the Lambayeque after the Spanish occupied the area.

While Klaus et al. (2009) and Klaus and Alvarez-Calderon (2017) both focused on the prevalence of DJD among pre- and postcontact sites in Lambayeque, there has yet to be an examination of the differential severity of DJD found in this ancient population. Further, the broad-stroke nature of the past work in Lambayeque lumped *all* expressions of DJD together as dichotomized present/absence data in the calculation of prevalence only. This effectively treated osteophytosis, porosity, and eburnation equally. In addition, there had been no further analysis of the severity of DJD in each of the joint systems found between the samples.

Using additional data, this thesis expands on the previous study of Klaus et al. (2009) by focusing on the different expressions of degenerative joint disease separately as well as examining the differences in severity between Mórrope and Eten, two Muchik colonial towns that were relatively neighboring settlements on the Peruvian north coast within the Lambayeque Valley Complex. The work used data previously collected by Klaus et al. (2009) along with data from nearly 500 additional adult individuals excavated by the Lambayeque Valley Biohistory Project over the intervening decade to examine the differences of the types of DJD expression and severity found in pre-Hispanic and Colonial sites in the Lambayeque region in Peru. Given that the people of Mórrope and Eten lived in the same valley, at the same time, and under the same form of Spanish colonial administration and economy, I test the hypothesis that similar expression and severity of DJD lesions will be documented between Mórrope and Eten.

This thesis contains seven chapters. Following this introduction, Chapter 2 explores the biological aspects of joint pathology and the manifestations of DJD on dry bone. Here, it becomes apparent that there is no specific single cause of DJD that lead to some individuals developing DJD while others do not. Genetics, age, physical activity and intensity, body weight, nutritional and dietary stress, and mobility can all play a role in synovial joint degeneration. However, the deeper pathogenesis of the process itself is still widely unknown. Indeed, DJD is a multifactorial disease. In addition, Chapter 2 also explores previous literature that is key in understanding DJD and its manifestations. A global survey of the literature demonstrates a general lack of DJD studies in the South American region.

Chapter 3 establishes the historical context of both the Mórrope and Eten samples by exploring previous literature and primary written records describing how Spanish control over the Lambayeque valley affected the lifeways of these communities. An in depth overview of the Lambayeque Valley Complex area is also provided, including a discussion of the many different microenvironments and their ecologies. This is followed by a contextual historical overview of northern Peru, including examination of the first settlers of the Paijan tradition, the Preceramic period, the Cupisnique era, the rise and fall of the Salinar and Gallinazo traditions, the introduction of the Moche, Sicán, and Chimú states and empires, and lastly, the rise of the Inka empire. A discussion on Spanish conquest is then given as a background for the shifting power structures as well as the transformative effects on Lambayeque's native peoples.

Chapter 4 describes the materials and methods used in this study as well as their archaeological context. This includes historical and archeological backgrounds on the Church of Santa Maria de Magdalena de Eten (CSMME), Chapel of the Nino Serranito (CNS), and Chapel of San Pedro de Mórrope (CSPM), previous bioarchaeological findings, and information regarding their local microenvironmental variation. Also in this chapter, explanations of the different expressions of DJD and how they are identified, (including osteophytosis, bone porosity, and eburnation) and the severity scoring systems are described. Finally, a discussion of the different statistical tests and methods used for this study are explained in Chapter 4, including Odds Ratios, *z*-tests, and Mann-Whitney U tests.

Chapter 5 presents the results of these statistical tests, which show a higher prevalence of DJD, each expression type, and severity among the one of the samples over the other sample. *Z*-tests demonstrated there is not a significant differences in the size or proportions of their age class structures between the two samples. This allows for direct comparison of the data from Mórrope and Eten. Odds ratios were calculated using SAS 9.3 and showed that individuals from Mórrope had higher prevalence and greater odds of being affected by DJD in multiple joint systems than those people represented in the Eten sample. Finally, Mann-Whitney U tests were conducted using SPSS 21. All three types of DJD expressions, as well as the severity of those expressions, were examined using a Mann-Whitney U test to identify whether the distribution of these characteristics was the same between the Mórrope and Eten samples. While there were a many non-statistically significant results, all statistically significant results acquired showed an increase in the Mórrope sample. The people of Mórrope appear to have been experiencing higher rates of DJD in general, in every type of expression in nearly every joint system, and in greater severity of DJD in joints that possessed arthritic expressions.

Finally, Chapter 6 discusses possible conditions that may help to explain the increased prevalence, expression types, and severity in Mórrope. By exploring topics of nutritional stress, ecological differences, and physical labor intensities, this study of DJD in the Lambayeque region shows that the lived experience of the colonized shows how humans are both biological organisms affected by their environments as well as social beings affected by the cultural constructs of nutritional stressors and physically intense labor conditions that can all mold the human body and be expressed in many different ways. Not only is this increased prevalence, expression, and severity of DJD among the Mórrope sample illustrating the strenuous labor conditions as they were habitually employed in economic gain for their leaders, but it can also give insight into the structural violence of the times.

1.1 – Conclusion

Archaeological and paleopathological examination of degenerative joint disease prevalence, expression types, and the severity of each type of expression among the Muchik populations of Eten and Mórrope will provide a new and unique look at DJD in postcontact South America. By examining this combination of factors, which have been unstudied until now, this work aims to gain new insight into the lifeways and conditions in which these people lived and the transformations they endured following the conquest.

CHAPTER TWO:
THE BIOLOGY AND BIOARCHAEOLOGY OF DEGENERATIVE JOINT DISEASE

2.1 – Joint Pathology

Degenerative Joint Disease, or DJD, is one of the most common categories of pathological conditions found in skeletal remains of many different ancient archaeological contexts and modern forensic settings. DJD is considered an umbrella classification that encompasses many different pathological conditions. Some of the conditions that are included under the DJD classification include rheumatoid arthritis (RA), diffuse idiopathic skeletal hyperostosis (DISH), spondyloarthropathies (including ankylosing spondylitis, reactive arthritis, and psoriatic arthritis), and osteoarthritis (OA). This chapter first defines and explores the nature and characteristics of osteoarthritic bony abnormalities. Second, the chapter provides an overview of key contributions to the anthropological and bioarchaeological study of the distribution and patterning of DJD lesions. Ultimately, these can be informative as to the nature of habitual physical activities, nutritional stress, environment, and the nature of human economies – in other words, how human bodies are often used in economic activities (e.g., food production and other kinds of labor). In this chapter, the overall explanation of DJD will be explained as well as how the joint degenerates on a molecular level. In addition, a comprehensive synopsis of past works and studies focusing on DJD will be evaluated and explored to give contextual background for the subsequent study on Mórrope and Eten.

2.1.1 – Degenerative Joint Disease and the Joint

Osteoarthritis (OA) is a disease characterized by the progressive erosion of articular cartilage. OA is considered to be an inherent disease of cartilage in which biochemical and metabolic alterations in individuals with genetic or mechanical susceptibility result in its breakdown, even though inflammatory cells may be present (Robbins et al., 2010). OA has traditionally been seen primarily as a disorder of the articular cartilage, however, there is increasing evidence that has suggested that OA should be considered a disease of the whole joint unit rather than just a cartilage-centered view (Aho et al., 2017). The disease itself is multifactorial and can be affected by elements of both the environment and the genetic predisposition of an individual. Of the joint types found in the human body, synovial joints are the most susceptible to arthritic changes. Synovial joints are characterized by a joint space that allows for a wide range of motion and degrees of mechanical loading. Such joints include the ball-and-socket joints (as found in the shoulder and hip joints) and hinge joints (as found in the elbow and knee joints). Along with these types of synovial joints, the temporomandibular joint (TMJ) is similar to the other synovial joints in terms of how it may be affected by DJD. In other words, the TMJ is a modified-hinge type of synovial joint. The TMJ is made up of the condylar process of the mandible and the mandibular fossa of the temporal bone. When it comes to DJD research in synovial joints, studies were initially undertaken to define histopathologic and microstructural changes (observed via scanning electron microscopy) in osteoarthritic cartilage in humans. Focus has since shifted to the biochemical, molecular signaling, and metabolic changes in cartilage affected by degenerative joint diseases (de Bont, 1995). Mankin and Brandt (1992) suggested that DJD was a result of an imbalance between anabolic and catabolic processes controlled by chondrocytes that are characterized by the progressive degeneration of ECM components of the articular cartilage, along with secondary inflammatory components. This thinking still underscores basic clinical and bioarchaeological approaches to DJD today.

Synovial (or diarthrodial) joints feature the articular cartilage on the bones, a thin layer of synovial fluid, and a synovial membrane. The articular cartilage is comprised of chondrocyte cells and the extracellular matrix (ECM), which itself is made of collagen fibrils (mostly type II), proteoglycans (predominantly aggrecan), and glycoproteins. The EMC is synthesized and maintained by the chondrocytes (Poole et al., 2007). The proteoglycan in the ECM aggregates, or form a cluster, that is situated between the collagen fibrils and interstitial spaces of the joint. These proteoglycan clusters are hydrophilic and form a gel that can swell, however, the collagen network in the joints prevents the widespread swelling of these aggregates (du Bont, 1995). Thus, the articular cartilage operates as a super-low-friction, wear-resistant surface for load support, load transfer, and motion between the bones of the synovial joint (Poole et al., 2007).

The synovial membrane holds the joint surfaces and the synovial fluid within the joint. The synovial fluid separates the two cartilage-covered surfaces of the bones, lubricates them, and provides nutrition to the articular cartilage. The cartilage of joints is not directly connected to the circulatory system, so it cannot receive the nutrition that it needs directly from the bloodstream. However, cartilage receives its nutrients from the synovial fluid, which contains the necessary nutrition for cartilage and removes waste product through passive diffusion through cell membranes. Synovial joints are the most susceptible to arthritis due to the range of motion that these joints provide.

Osteoarthritis and other forms of DJD involve the whole synovial joint, including the cartilage, synovium, and underlying bones. The cells within these different tissues found in joints have different ways of responding to joint injury that eventually result in the degeneration of the joint cartilage. In a normally functioning synovial joint, the external loading pressure from physical activities will be in equilibrium with the internal cartilage pressure (de Bont, 1995). In other words, the normally functioning cartilage that is with these structures is submerged in the synovial fluid and is able to withstand millions of cycles of loading each year while exhibiting little to no wear or degradation (Poole et al., 2007).

The biochemistry and metabolism of both normal and osteoarthritic cartilage involve interplays between proteases (proteolytic enzymes), cytokines, growth factors, and arachidonic acid metabolites (de Bont, 1995). Proteolytic enzymes are responsible for maintaining the turnover of normal tissues and the degradation of ECM components of articular cartilage in OA. Tissue inhibitor of metalloprotease (TIMP) is often found in large quantities in normal articular cartilage, as it is a protease inhibitor that helps balance the turnover and degeneration of tissue caused by proteolytic enzymes. Under normal physiological conditions, the components of ECM are involved in a state of slow turnover that is preserved in a homeostatic equilibrium between catabolic and anabolic events (Poole et al., 2007). This is controlled through the processing of genetic and environmental information, ECM composition, and physical factors such as mechanical stress. The cytokines and growth factors are polypeptides that are capable of regulating cellular growth, differentiation, and metabolic activity. Cytokines induce the production of proteolytic enzymes, this results in the reduction of proteoglycans in the cartilage, decreases the synthesis rate of proteoglycan and other EMC components, as well as increases the rate of cartilage degeneration (de Bont, 1995). Conversely, growth factors exert an anabolic effect. These include the insulin-like growth factor, transforming growth factor, and fibroblast growth factor. Finally, the arachidonic acid metabolites are released from the membrane phospholipids and mediate inflammation.

2.1.2 – Synovial Joint Degeneration

When chondrocytes are disturbed by a mechanical, biochemical, inflammatory, or immune stimulus, the balance between the synthesis and degeneration of the extracellular matrix (EMC) components results in the deterioration of cartilage. This deterioration is met with efforts of repair through the increased synthesis of EMC components. Repair efforts result in the loss of proteoglycan, clustering of chondrocytes, and the proliferation of cells that become active in an attempt to repair the degenerating matrix (de Bont, 1995). The maintenance of homeostasis in cartilage is parallel to that in bone, that is, there is a loss of cartilage matrix in areas where there is decreased pressure and necrosis of chondrocytes in areas of increased pressure (Hough, 2001). Subchondral bone remodeling of microfractures of the calcified cartilage may promote cartilage destruction by increasing the stiffness of the underlying bone. When the degeneration of the cartilage begins to take place, the breakdown is discharged into the synovial fluid and synovial membrane, which elicits an inflammatory reaction. “When the cartilage degradation continues, the tissue loses its integrity, resulting in blistering, fibrillation, horizontal splitting, adhesion formation, cartilage thinning, and responses in adjacent tissues” (de Bont, 1995, 6). Some of these responses can be seen on dry bone, including eburnation, porosity, and osteophytosis/osteophytes. These three expressions will be explained in more detail in the following chapters.

Cornelius Celsius first documented redness and swelling with heat and pain in a joint system in the first century A.D. Later, the term “osteoarthritis” was officially defined by physicians in the 17th century (Attur et al., 2002) Following this, with the help of microscopic radiographic imaging in living patients, 20th century physicians were first able to observe changes in the articular cartilage and its effects on bones. From these observations, two different kinds of changes were seen in individuals with joint problems. The first type of DJD recognized through radiography and was termed atrophic arthritis and it affected younger people. Many joints were involved and there was a tendency to observe inflammation of the soft tissues of the joint with the erosion of the joint margins and loss of bone density (Rogers and Waldron, 1995). The second type was designated as hypertrophic joint disease, as “the hypertrophy or overgrowth of marginal and articular bone manifested by osteophytosis and sclerosis” (Rogers and Waldron, 1995, 3). These terms were later changed at the beginning of the twentieth century to rheumatoid arthritis, or RA for the atrophic form, and osteoarthritis, or OA, for the hyperopic form. The definition of OA has evolved into the most recent consensus definition:

> "OA diseases are a result of both mechanical and biologic events that destabilize the normal coupling of degradation and synthesis of articular cartilage chondrocytes and extracellular matrix, and subchondral bone. Although they may be initiated by multiple factors, including genetic, developmental, metabolic, and traumatic, OA diseases involve all of the tissues of the diarthrodial joint. Ultimately, OA diseases are manifested by morphologic, biochemical, molecular, and biomechanical changes of both cells and the matrix which lead to a softening, fillibration, ulceration, loss of articular cartilage, sclerosis, and eburnation of subchondral bone, osteophytes, and subchondral cysts. When clinically evident, OA diseases are characterized by joint pain, tenderness, limitation of movement, crepitus, occasional effusion, and variable degrees of inflammation without systemic effects" (Sharma and Kapoor, 2007, 3).

Eburnation, osteophytosis, and bone porosity are the three principle expressions of DJD on the surface of dry bones that can be observed in an archaeological context. Eburnation occurs when the synovial joint breaks down over time, and the two bone surfaces once separated by the synovium come into contact with one another. As the two bones of the joint are allowed to come in contact with one another without any barrier, the interaction causes their surfaces to become polished. Osteophytosis is the growth and presence of often-irregular bony growths or lipping on the joint's anatomical margins. Osteophytosis can be expressed through the growth of osteophytes or the presence of marginal lipping on the joint surface. These irregular outgrowths are indeed indicative of a pathologic process at play but can be best understood as a kind of reparative mechanism that in many cases attempts to stabilize a chronically comprised or inflamed joint (Gosman, 2012). Bone porosity is the presence of a porous, or pitting, feature to the bone, or a non-continuous surface of the subchondral bone. Porosity is abnormal and it is included in standard bioarchaeological observations of DJD as it is understood especially in terms of molecular signaling mechanisms to represent inflammation-mediated subchondral bone death (Gosman, 2012). As degeneration of the joint system progresses in OA, the subchondral bone histology undergoes distinctive changes, including an increased thickness and ruggedness of the bone plate depicted by an uneven fibrillating surface pattern on the bone (Aho et al., 2017). Still, there is some debate about whether porosity should be an indicator of osteoarthritis and degenerative joint diseases. Unfortunately, the term "bone porosity" has been often conflated with anemia, exclusively. Frequently, the distinction in the kind of porosity is not made between cranial porosity caused by marrow hypoplasia and porosity that could potentially be caused by other disorders, such as DJD (Ortner, 2012). Here, all three of these expressions of DJD will be further discussed in Chapter 4.

2.2 – Degenerative Joint Disease in Review: Global Perspectives over the Last 10,000 Years

From the origins of life on Earth, organisms have become the subject to the forces of natural selection determined by their environments. Humans are no different. One of the most defining characteristics of human adaptation involves how our bodies move in certain circumstances and physical/cultural environments involving the strain that movement puts on different areas of our bodies and our overall intensity and patterns of physical activity. As humans, our physical activity forms and shapes our bodies. These changes are seen on the exterior and but the interior as well. Our bones and joint systems are constantly changing and being shaped by the physical activity we place on them. Human adaptive systems are highly variable, and it is not possible for studies to make broad statements about any kind of universal or biologically predictive nature of workloads based on their lifestyle alone (Larsen, 2015). In fact, there are a large number of different variables that dynamically affect the lifestyle of individuals, communities, and societies, as well as how human skeletal systems may varyingly portray activity patterns through musculoskeletal modifications. The workload and lifeways of communities are influenced greatly by not only physical activity, but also by the kinds of resources in the area, how each community accesses those resources, the climate of the area in which they live and work, and by other ecogeographic circumstances. Learning about structural adaptation through cross-sectional geometry and the activity patterns of communities through articular degeneration and other musculoskeletal modification can not only help elucidate the physical conditions in which these communities lived, but also help inform other aspects of their lives, including birthrates, fertility, food acquisition and processing, socioeconomic inequality, genetic factors, and much more (Farmer, 2003; Felson et al, 1988; Klaus et al., 2009, 2017; Merbs, 1983; Ortner, 1968; Pickering, 1984). While the focus on the evaluation of articular degenerative conditions, the structural adaptation and cross-sectional geometry are just as important to understating the lifeways of past populations. However, it is outside the scope of this work but represents an untapped future direction of the research on the north coast of Peru. The focus will remain on understanding individuals and communities through examination of the articular degeneration of joints (degenerative joint diseases). Arthritic conditions under the umbrella term of degenerative joint disease (DJD) are some of the most common diseases that affect the human population, in modern communities as well as prehistoric times. The most familiar of these expressions of DJD is osteoarthritis (OA), which is caused by "wear and tear" on the different joint systems. Since OA and other DJD are the results of activities involving the joint, it is often used as an indicator of activity levels or that prevalence of activities in prehistoric societies (Bridges, 1992).

Current and future research on degenerative joint disease in archaeological contexts must first look to the previous global literature as a foundation in which to further the understanding and ground current understandings that DJD may arise in an individual’s skeletal system. In the early phases of research into DJD, description – and only description – of lesions was the primary goal of studying arthritic joints. This reflected the primary ethos and conception of the field at the time. As paleopathology and bioarchaeology matured, research on DJD and arthritic joints began to focus more on what these pathological conditions could reveal about an individual’s behavior or the broader social structures and adaptions of human populations. By the 1970s and 1980s, some physical anthropologists argued that DJD could reveal specific information about labor via the habitual movements, activities, or mechanical stress placed on joints. However, as paleopathological and bioarchaeological research continues, it has become quite clear that there are many different factors that contribute to DJD in a skeletal sample beyond what was previously imagined.

2.2.1 – Prehistoric Patterning

Patterns of osteoarthritis and other degenerative joint disease are not a new disease phenomenon. In fact, some of the earliest hominins show signs of joint degeneration – the most famous being the three-million-year-old australopithecine "Lucy" (A.L. 288-1). Examination of Lucy's vertebral column carried out by Cook et al. (1983) found that there were signs of joint degeneration. New bone formation, marginal lipping, wedging of vertebral bodies, and reduced intervertebral disk space all characterize the vertebral degeneration of the A.L. 288-1 specimen. Cook et al. (1983) concluded that A.L. 288-1's vertebral column shows signs of "compression resulting from heavy loading or forceful ventral flexion" and suggests that many different and diverse activities could have caused this, including "arm-swinging, bridging, crutch-walking, or any climbing activity including forced ventral flexion of the trunk, as well as a whole repertoire of lifting and carrying activities" (Cook et al., 1983, 99).

Expressions of DJD can also be seen in a large number of Neanderthal adults. In fact, the first reconstruction of Neanderthal locomotion was created using an individual that was misidentified as a "normal" Neanderthal, the La Chapelle-aux-Saints skeleton (Larsen, 2015). This reconstruction branded Neanderthals with the completely inappropriate image of being brutish, possessive of poor posture, and less than human. After closer inspection by William L. Straus, Jr. and A. J. E. Cave in 1957, this individual was actually diagnosed with severe osteoarthritis that prevented the individual from having a normal posture and movement pattern (Straus and Cave, 1957). Analysis revealed that there was a widespread presence of degenerative pathology of the TMJ, occipital condyles, cervical vertebrae, and thoracic vertebrae of the La Chapelle individual. However, this is not the only Neanderthal individual found to have had signs of joint degeneration. Other Neanderthals from Iraq have also been found with the condition. "The widespread nature of articular pathology in these individuals reflects a highly physically demanding lifeway for these archaic *Homo sapiens*" (Larsen, 2015, 188). Suggesting that OA is not only widespread in modern human populations, but in other archaic *Homo sapiens,* such as the Neanderthals, too.

2.2.2 – Early Works and the Development of a Modern Paradigm

In the early days of modern bioarchaeology and paleopathology, it was thought that DJD could be attributed to only habitual movements and mechanical stress placed on a joint. In some ways, today, we have come full circle back to this point. In 1968, Donald J. Ortner attempted to provide a descriptive and classificatory foundation to provide a clearer understanding of degenerative changes in one joint: the distal portion of the humerus that composed part of the elbow joint. Ortner focused on this joint in particular because it does not usually bear weight unlike those joints in the lower appendicular skeleton. Ortner's analysis focused on two samples: a sample of Peruvian natives and a sample of Alaskan Inuits. In this work, two general issues when studying this distal humeral joint were examined. One involved the problem of using the distal humeral joint surface to make comparisons of mechanical stress between different skeletal samples or populations. The second concern focused on the unique morphology and biomechanics of the distal humeral joint surface. Ortner argued that the type and degree of mechanical stress exerted on the elbow joint depended on three different factors: handedness (whether a person's dominant hand was their left or right), sex, and cultural practices. "Careful analysis of degenerative changes in the elbow of human skeletons is, potentially, a very useful tool in studying the degrees and types of joint stress in ancient populations" (Ortner, 1968, 139). Ortner first discusses the anatomy and function of the elbow joint including how it moves and its operations (throwing, reaching, flexion/extension, and pronation/supination). He found that there were three areas where degenerative changes take place on the distal humerus, the joint surface, areas peripheral to the joint, and the coronoid, radial, and olecranon fossae (Ortner, 1968). Ortner then argued that there are four different factors that contribute to the appearance of degenerative changes of a joint, including the degree and amount of pressure and mechanical motion placed on the joint, how the stress is dissipated, the duration of the stress, and the frequency of stress (Ortner, 1968). All of the factors have to do with habitual movement and mechanical stress placed on the joints, there is no mention of genetic factors, age, sex, or other factors (which is due to the to the time this paper was published).

One of the earliest and most complete bioarchaeological studies of degenerative joint disease in a hunter-gatherer community was the investigation completed by Merbs using a skeletal sample of Sadlermiut Inuits. In 1983, Merbs published a now-classic monograph that studied a group of Sadlermiut individuals from Alaska to examine if their physical activity patterns – which reflected unique adaptations to the Arctic ecology and geography – were reflected in pathological expressions of osteoarthritis, osteophytosis, vertebral compression injuries, spondylolysis, and anterior tooth loss. With these conditions, Merbs identified 20 different activity categories (including sewing, erect posture, throwing a harpoon or dart, riding on a sled or toboggan, and more) as having probable and possible bearing on degenerative pathology among Sadlermiut peoples (Merbs, 1983). By comparing the patterning of traumatic and degenerative skeletal changes among the group, Merbs found significant differences between the males and females in the population based on the sexual division of labor: men showed greater prevalence and severity of osteoarthritis and DJD, vertebral osteophytosis, and spondylolysis while women exhibited greater prevalence of anterior tooth loss and vertebral compression fractures. When it came to the men in the sample, he argued that the degenerative changes that left their mark on the skeleton were largely due to two habitual activities – harpoon throwing and kayak paddling – due to an extreme habitual loading of the upper arm and the shoulders. As one example, arthritic patterning more commonly involved the right shoulder and elbow that correlates with sites of mechanical stress when the arm is at full extension at the end of a harpoon throw (Merbs, 1983). Among the Sadlermiut women, skeletal changes were attributed to patterns of habitual clothing making and sewing (Merbs, 1983). This conclusion focused mostly on the prevalence of degenerative changes in the TMJ of females in the sample, being twice the amount found in males of the same population.

By 1989, the idea of specific forms of habitual activity leaving a lasting and distinctive mark on the skeleton reached its conceptual apex with the publication of K.A.R. Kennedy's chapter, "Skeletal Markers of Occupational Stress," in *Reconstruction of Life from the Skeleton,* which Kennedy co-edited with Yasar Işcan. In this work, Kennedy described 140 markers of occupational stress, arguing that it is possible to reconstruct the lifeways and activity patterns of an individual from skeletal markers of DJD (Kennedy, 1989). Kennedy developed these markers of specific occupational stresses from published medical and anthropological sources from forensic anthropology cases from the Cornell University Human Biology Laboratory. Kennedy's Table 1 lists 114 distinctive stress markers on various bones and claimed each as a consequence of a specific occupational activity (following in the tradition of previous workers such as Angel, Kostick, Ortner, and Wells). The concept Kennedy proposed was as fascinating as it was enticing to those interested in trying to connect habitual movements of joints due to occupational activities with the physical appearance of DJD on bone. Kennedy claimed that one of the main reasons for osteoarthritis is attrition, or the "abrasion of osseous tissue is involved when bones are in direct contact at joint surfaces because of deterioration of intervening structures under severe osteoarthritic conditions" and identifies how he recognizes osteoarthritis "[resulting in] eburnation of the bones at the points of articulation" (Kennedy, 1989, 136). Unlike other researchers, Kennedy did not focus on porosity or osteophytosis but solely focused on the presence or absence of eburnation on the joint surfaces. In the discussion portion of his chapter, the Kennedy wrote "there has been a tendency to isolate a single occupational activity as the cause of a given enthesopathic lesion, as is seen in the literature about spear throwing, slinging, baseball pitching, and related behaviors," however, in reality, many different factors contribute to osteoarthritis and DJD, not just occupational activities (Kennedy, 1989, 156).

Kennedy (1989) concludes his chapter by declaring that there has been no systematic organization of the data on occupational stress markers and that the information is usually anecdotal and rarely finds its place in published work. Kennedy looks at other factors aside from occupational stress, but not in much detail. As the basis of an individual's ability to attain full and proper skeletal development, the author attributes nutrition as a factor in skeletal maturity, body size, and stature. "The markers of occupational stress…are seldom the consequence of a single stress factor. Sex, age, social status, nutritional quality and quantity, lifestyle, and general health profile are critical components in the genesis of a specific marker" (Kennedy, 1989, 137). Kennedy argues that nutritional deficiency due to the availability of resources, food quality, social status, environment, and lifestyle can leave markers of occupational stress on a skeleton. In addition to his argument that nutrition attributes to DJD, Kennedy discusses that ecological conditions and the sexual dimorphism (including institutionalized divisions of labor) also are attributed to allocating different stresses on the human skeleton. The idea that a bioarchaeologist could examine DJD-related skeletal markers and determine exactly what physical activity caused remained en vogue in the literature for only a short time. By the early 2000s, subsequent research and critical analyses from in a variety of fields have demonstrated this is not the case.

2.2.3 – Early Life Dietary Stress and DJD Predisposition

Another 1988 publication concluded just as Kennedy that early life nutritional stress could predispose individuals to greater risk of DJD later in life. Peterson's (1988) study focused not on humans, but on a moose population found in the Isle Royale

National Park in Michigan. Beginning in the 1950s, this moose population suffered a several-fold increase in the prevalence of DJD and before this study, the effect of nutritional stress considered in the context of DJD. To understand the unexpected increase in DJD prevalence amongst this moose population, Peterson examined skeletal remains of individuals that were at least seven years old at the time of death. In this work, moose born during the early 1970s showed the highest prevalence of joint lesions (Peterson, 1988). The population density of this moose population and snowfall amounts both increased during the 1960s and 1970s. This produced significantly elevated nutritional stress on the moose population in the area. In young moose during the 1970s, the increase in nutritional stress was indicated by fat-depleted bone marrow and delayed epiphyseal closure in their appendicular skeleton (Peterson, 1988). The conclusions of this study found that fluctuations in moose density and marrow fat levels rejects the idea that under-nutrition is the primary cause of the increased DJD prevalence in the population, however, cohorts with the highest prevalence of DJD were those who were severely undernourished early in their lives due to the increased snowfall in the area (Peterson, 1988). The under-nutrition of moose early in their lives was at the very least associated with developmental abnormalities in cartilage, which would increase the prevalence of DJD later in their lives. Peterson (1988) describes this model as the "early nutrition hypothesis."

Peterson continued his research into the "early nutrition hypothesis" and in 2010, Peterson and colleagues published a new study that may be pivotal in understanding early life dietary stress in moose (and other large mammals) and later predisposition for DJD in those that were affected by early dietary stress. Again, Peterson et al. focused their study on the moose population found on Isle Royal, where population density fluctuated drastically between 1959 and 2008 in response to weather, food availability, and predation on the moose population by the island's wolf population. It was originally hypothesized that the primary cause of death in the moose population consisted of predation by the grey wolves and malnutrition during the winter months. To measure the effects of forage abundance, weather, and predation risk on maternal condition and early growth of offspring, metatarsal lengths was measured (Peterson, 1977; Peterson et al., 2010). Metatarsal length is representative of perinatal nutrition as the metatarsus has a high growth priority early in life among ungulates. In fact, when a moose is born, their metatarsal length is about half of its adult length. So, if there is a lack of nutrition during gestation, the metatarsal length will be shorter than in a moose whose mother had adequate nutrition during pregnancy. In general, in moose populations, poor nutrition and slow early development can be associated with small stature in grown adults (Peterson et al., 2010). Therefore, it was possible to see if there was any trend associated between early nutritional stress in the moose population and later predisposition to DJD.

To measure the hypothesis about whether the presence of DJD in a moose at the time of its death was correlated with nutritional conditions early in their lives, the team used a logistic regression model that showed that the odds of dying with arthritis were significantly higher in moose with shorter metatarsal bones. These smaller moose had a 32% greater chance of dying with arthritis than moose larger than the 66th percentile (Peterson et al., 2010). In addition, metatarsal length is also a predictor of longevity in moose, meaning that some of the smallest moose with the greatest risk for DJD tend to die before they are old enough develop DJD on their remains. In conclusion, the Isle Royale moose were more likely to develop DJD if they experienced poor nutritional conditions early in their lives.

Taken one step further, this work may reflect one of the deep etiological triggers for the development in DJD in vertebrates and mammals. Indeed, there are at several examples of this phenomenon (at least associationally) documented from different human groups in history. Larsen et al. (2001) noted that the skeletal remains of Guale peoples in the Georgia Bight showed an increase in DJD expression over a 500-year period. This time period is associated with an adaptive shift involving native economies changing from one where they heavily relied on wild plants and animals to an economic regime that focused on farming and lower-quality cultigens during the late pre-Historic and Spanish colonial eras. Goodman et al. also noted a similar transition in another group of Native Americans as the population began to rely more and more on maize in the American mid-west (Goodman et al., 1984). In this example, DJD increased by about 65%, which was originally attributed to an increase in joint stress due to mechanical stress from an increase in agricultural activities. However, adults and children in this population also experienced a reduction in growth as well as a shortened life span, suggesting that the group encountered nutritional deficiencies early in their lives, just as the Isle Royale moose population. Of course, the challenge is figuring out how to understand and detangle cause, causation, and association between the varied and complex nutritional and mechanical inputs that ultimately produce DJD.

In a similar vein, Jordan et al. in 2005 explored novel risk factors surrounding lumbar vertebral osteoarthritis in adults. More specifically, the team investigated if and how polymorphisms of the vitamin D receptor gene (VDR) and birth weight affected the chances of OA later in life. To do this, Jordan et al. studied radiographs of the lumbar vertebrae taken from 392 individuals and scored the vertebrae for osteophytosis and narrowing of the disc space. Historical records of each individuals birth weight and weight (as a proxy of biological stress and nutrition) at one year of age. In addition, VDR gene allelic variation was analyzed in 291 of these individuals. They found that 66.7% of men had an osteophytosis grade greater than or equal to 2, while 59.5% of women had had a grade greater than or equal to 2 ($p = 0.33$). As for narrowing of the disc space, 15.6% of men and 12.7% of women had a grade greater than or equal to 2 ($p = 0.76$) (Jordan et al., 2005). They also found that the presence of osteophytes was higher in men with lower weight at year one ($p = 0.02$). In addition, Jordan et al. found a significant interaction between birth weight and the VDR genotype as determinants of osteophytosis (Jordan et al., 2005). This interaction was not seen between narrowing of the disc space and the VDR genotype. They concluded that there was an association between variation of alleles in the VDR gene and vertebral osteophytosis, and that there was a significant interaction between birth weight and the VDR gene as a determinant of vertebral osteophytosis.

Degenerative joint disease is of course not the only chronic adult disease to be linked with early life nutritional stress. In humans, low birth weight has been consistently shown as a link to coronary heart disease (CHD), hypertension, and type II diabetes due to the rapid weight gain in childhood (Barker et al., 2002). Some phenotypic changes produced *in utero* allow the organism to adapt so that it may have a greater chance of survival into reproductive age (Gluckman and Hanson, 2006). In this case, natural selection favors the conservation of the organism earlier in life up to reproductive age, even if there is a cost to the individual's life later in life after the organism passes reproductive age. This is why many chronic diseases such as DJD, hypertension, CHD, and type II diabetes often show up later in an organism's life. "In response to a maternally determined environment perceived as inadequate, the fetus makes irreversible changes to aspects of its development," thus, somatic growth and conservation of energy after the organism's birth may allow the offspring a better chance of survival in a postnatal environment where nutrition is poor (Gluckman and Hanson, 2006, S47-S48). In short, this alteration due to a stimulus or insult on the developing organism during a sensitive and critical time in its development can cause lasting and lifelong effects on the organism (Jordan et al., 2005).

2.2.4 – Mobility and Adaptive Shifts

One of the major (if not popular) foci of bioarchaeological DJD studies involves reconstruction of mobility vis-à-vis adaptive transitions, particularly in North America. To understand if DJD could point to whether a population took part in a limnosedenary (sedentary) exploitive strategy (one where food and other resources were obtained mainly in the wetland areas surrounding the desert landscape) or a limnomobile exploitive strategy (one of high mobility where much of the foragers' time was spent collecting and transporting goods from the nearby mountains) Larsen and colleagues (1995) examined skeletal samples from the Stillwater Marsh area of western North America. In these samples, a high prevalence osteoarthritic joint systems were observed and a majority of the individuals above the age of thirty had at least one joint affected by DJD. The high degree of DJD suggested that there was a high habitual intensity of heavy lifting and carrying. This is consistent with these populations as highly mobile and gathering resources from many different areas. Unfortunately, that is as detailed as bioarchaeological data can safely get when it comes to research involving DJD data, as it is not possible to say for certain whether these populations were sedentary or mobile from evidence of osteoarthritis or DJD alone. The DJD data contributed a key dimension to the work, but studies of cross-sectional geometry would further explore the research question (Bass et al., 2002; Bridges, 1989; Craig et al., 1995; Larsen, 1981, 2015; Lorentzon et al., 2005; Ruff, 2008).

Additional studies of modern foragers have found that the mobility versus sedentary issues appears to be an individual, group-level phenomenon, suggesting that there are not only different kinds of mobility but different intensities of mobility that engender disparate levels of physical demand on the body. In addition, these studies have also revealed the many different strategies employed by modern foragers are used to achieve successful adaptation and meet the differences in distribution, quality, and seasonal availability of resources (Hemphill, 1999). Perhaps this differentiation of foraging behaviors rose in popularity among the populations of the Great Basin wetlands due to the local variations in resources. This variation would have been a driving force behind the adaptive shift in foraging strategies among hunter-gatherers. This would lead to the different forms and intensities of habitual of activity. Examination of three important skeletal series uncovered in the Great Basin marsh in the American West, Hemphill (1999) aimed to evaluate the impact of local distinctions in the distribution, quality, and seasonality of different resources on the patterns and intensities of physical activity experienced by those individuals. In sum, this study examined the overall degrees of osteoarthritic affliction and whether females and males of each skeletal sample had similar exposure and levels of repetitive mechanical stress on their joint systems.

Hemphill's (1999) study examined human remains in the large Stillwater Marsh and Great Salt Lake samples along with the Malheur Lake sample. The frequency of DJD in the different joint systems in the Malheur Lake individuals was compared by measures of crude prevalence (frequencies) obtained from other skeletal samples (Stillwater Marsh and preagricultural and agricultural samples of the Georgia coast) to try and determine whether the Great Basin hunter-gatherers were sedentary or highly mobile. Forty-seven bilateral joint systems were examined in the Malheur Lake sample, 21 (44.7%) of which showed DJD on one side (which was more common in the lower limbs) and 26 (55.3%) showed bilateral affliction (Hemphill, 1999). Males and females from the two Great Basin samples were more similar to one another than they were to the Georgia coast samples. Results of this examination suggest that the populations occupying the Great Basin were not on either side of the mobility spectrum. In other words, they were not exclusively mobile or sedentary. Given that all of the major joint systems were affected, and that prevalence was generally high among both males and females in the sample, it is suggested that there was some form of high mobility among these groups occupying the Great Basin (Hemphill, 1999).

2.2.5 – Labor systems

The concept that DJD could illuminate mobility regimes is also a frequent topic in bioarchaeological approaches that involve assessment of human labor systems. One recent example by Austin (2017) analyzed a sample of individuals from the Deir el-Medina area of ancient Egypt and found that commuting attributed to the formation expression of DJD in the lower limbs as a part of their labor system. It is, of course, difficult to link the use of a joint with any form of DJD, whether the focus is on a modern sample or an ancient one. Some studies have found a correlation between DJD and activities such as farming and weightlifting, but others have found no similar correlations. Still, Austin (2017) argues that studies of DJD and arthritic joints are often hindered or otherwise limited by three factors: (1) some clinical studies are based on symptomatic DJD when an individual reports joint pain which is impossible observe or define in a non-living population; (2) many studies of DJD are dominated by individuals of advanced age where it is difficult to separate cases of DJD due to occupation from those of advanced age and body mass, and; (3) in many studies, individuals begin their occupations as adults and are only engaged in a specific occupation for a few years (Austin, 2017). Along these lines, Austin examined the patterns and prevalence of osteoarthritis in the lower limbs of individuals from the Deir el-Medina region in Egypt from the Ramesside period, which lasted from circa 1300 to 1069 BCE. Austin aimed to compare the joint health of those individuals with previous studies of other ancient

Egyptian and Nubian populations. Austin also incorporated contextual data from historical texts and the landscape and topography to establish if and how occupation influenced the high rates of osteoarthritis. "The duration, intensity, and frequency of the workmen's hikes are reconstructed based on the surrounding landscape and 42 texts recording work days" (Austin, 2017, 537). The results of this study yielded signs of DJD, but they did not appear to be qualitatively severe in Austin's evaluation. Eburnation was only found in two distal joints of femora in the knee with no indication of eburnation found in the femoral heads, both belonging to older women, and one proximal tibia end of a male in the knee. Her analysis found "men at Deir el-Medina were experiencing disproportionally higher levels of joint strain at the knee and ankle than either women or comparable populations of the middle class and elite Egyptians… it is critical to understand how occupational activities of males at Deir el-Medina would have impacted the knees and ankles specifically" (Austin, 2017 543). One element that the workmen at Deir el-Medina faced daily was the hikes that they had to endure through the Theban hills to travel between their homes and their jobs. Regardless of their position within the crew, all workmen hiked through these hills to get to their work site and back home again. This would explain why the DJD of the knees and ankles were more prevalent in men, as women and others not working in Deir el-Medina would not have been taking these hikes. “Data from both modern and historical populations support the assertion that hiking in a heterogeneous landscape would increase rates of DJD at the knee and ankle specifically. Injuries to the knee and ankle are known to be correlated with higher levels of DJD in modern clinical studies, and injuries have even been cited as the most common cause of DJD in the ankle," constantly climbing the hills would have placed more stress and force on both the knee and the ankle compared to solely walking on a flat landscape (Austin, 2017, 543). While not a direct function of occupation, the commute of the Deir el-Medina workmen placed different stressors on them compared to the women in the same group. This is a case where the environment has a correlation on the symptoms and expressions of DJD in a population as they move across a landscape.

2.2.6 – Comparing Populations in North America

Uncovering and understanding the many different aspects of life that DJD can reveal about a specific population can also be applied in a comparative perspective. Since DJD has the potential of being so variable, it is necessary to compare many different skeletal samples to predict, interpret, or infer general patterns and variations of physical activities in the past.

One classic broad-scale analysis that attempted to compile and review published studies of osteoarthritis of the appendicular and axial skeleton in populations of Native Americans of North America was written by Patricia Bridges (1992). In this synthesis - style analysis, Bridges (1992) argues that because of the role that activities have in the etiology of osteoarthritis and other forms of DJD, the pathology of joints is often used as an indication of the patterns and intensity of activities in prehistoric societies, as well as the prevalence of specific activities. In addition, the analysis infers the prevalence and differences of the level and type of activities in the samples understudied. Age and physical activity (including trauma) are the most common factors that affect the etiology of osteoarthritis (Bridges, 1992). In her analysis, the knee joint has the highest prevalence of DJD, with OA being found among 17 of the samples. The elbow joint has the second highest prevalence with 15 samples affected. However, Bridges could not identify clear associations between OA and subsistence mode between the comparison of hunter-gatherers and agriculturalists. Still, agriculturalists tended to have a lower prevalence of lesion in their hands and wrists, however, not all foragers had high levels of DJD in the same joints, with ankles and feet being the least affected in most samples (Bridges, 1992; Larsen, 2015). "The comparisons of different populations in published findings contribute to an understanding of variation in work burdens and activity. However, these comparisons are limited by the variable nature of the methods of data collection used by the variety of researchers," which may prevent investigations from presenting clear trends or population difference in DJD prevalence (Larsen, 2015, 189-190). This issue may be evaded by using comparisons and data collected by the same researcher(s) or researchers using the same methods of comparison and collection.

2.2.7 –Perspectives Beyond the Americas

Further insights into DJD are gained from samples across the world. In Korea, for instance, significant work that resonates broadly has been done by Woo and Pack (2014). They examined the relationship between two different types of vertebral DJD among people living in the Joseon Dynasty in Korea during the mid-15th and early 20th centuries. In this study, Woo and Pak hypothesized that vertebral DJD reflecting general activity-related stress would have a higher correlation with Schmorl's nodes (SNs) (Woo and Pak, 2014). The results showed that the relationship between the two kinds of vertebral DJD were varyingly functions of individual's sex, the vertebral region being examined (i.e., cervical, thoracic, and lumbar), and the joint type. Results were statistically significant at the cervical and lumbar vertebral regions among males in the sample and SNs appeared independent of the pattern of DJD in almost all joints aside from the intervertebral joints and SNs of the lumbar vertebrae in females (Woo and Pak, 2014). In another study, Woo and Pak (2013) used the same Joseon Dynasty skeletal sample to examine more broadly whether DJD can indeed reflect activity levels of individuals in past populations (Woo and Pak, 2013). Woo and Pak documented the occurrence of DJD in six different joint systems (the shoulder, elbow, wrist, hip, knee, and ankle). Their results show that DJD is positively correlated in specific joint systems suggesting that DJD manifests in different ways to different etiological factors (Woo and Pak, 2013). This means that that the distribution and patterning of DJD can be more nuanced than previously envisioned and as such, be discussed cautiously and *contextually* when used to reconstruct activity.

Another highly influential study on DJD in a population was conducted in Siberia's Cis-Baikal region by Lieverse et al. (2007). This work aimed to reconstruct the mobility and activity patterns of regional inhabitants during the mid-Holocene era. Specifically, the authors investigated osteoarthritis prevalence and patterning among the pre-hiatus Kitoi culture and the post-hiatus Serovo-Glaskovo culture samples. The examination yielded results that suggested that levels of activity among these samples remained relatively consistent throughout the mid-Holocene, however, mobility and specific activity patterns did change owing to the shifting adaptive strategies of the two cultures (Lieverse et al., 2007).

2.2.8 – DJD in Settings of New World Spanish Colonization

Frequently, one area of study when it comes to North and South American studies of health concerns focuses on the effect on Native Americans due to European contact. The arrival of Europeans into the New World had lasting effects on the native peoples that inhabited the Americas, and the consequences of contact are still playing out. New diseases found their way to the natives, such as cholera, influenza, malaria, and smallpox. In addition, malnutrition and demanding labor also put a strain on the native bodies, both of which can be seen in their skeletal systems. Larsen et al., 2001 describe the biological impact that occurred with the arrival of Europeans on native populations by studying the pre- and postcontact skeletal remains found in Spanish Florida, which today is located in an area marked by coastal Georgia and northern Florida. In this examination of native health consequences of the European invasion, Larsen et al. were able to isolate several different instances where indigenous health was impacted. By using stable isotope analysis, it became clear that there was a temporal shift from foraging to maize agriculture in some areas of Spanish Florida, as well as a clear homogenization of the diet across a whole of the region, leading to an impact on native health. Larsen et al. also examined several different indicators of stress on the native population found in Spanish Florida, including growth disruption (defects on the enamel surface), iron status (porotic hyperostosis and cribra orbitalia), and infectious diseases (both specific and nonspecific). When comparing the early and late mission samples (samples taken from a period where European missions were in the area) were compared with the late prehistoric sample, there was a marked increase in pathological lines in the enamel of the natives between the prehistoric and mission samples, pointing to a decrease in overall native health (Larsen et al., 2001).

Larsen et al. also found evidence of a lifestyle shift in via degenerative joint disease and structural adaptation on the part of the skeleton. Examination of DJD in the early prehistoric Georgia sample, late prehistoric Georgia sample, and late mission Florida sample found that there were two distinct temporal trends in the frequency of DJD. This first trend showed a moderate reduction of DJD from the early prehistoric Georgia sample to the late prehistoric Georgia sample. The second trend showed a dramatic increase in DJD prevalence into the late mission Florida sample (Larsen et al., 2001). Larsen et al. suggest that these trends could reflect a reduction/increase in workload, commute, or physical demands. As for the structural adaptation of the skeleton in native samples, Larsen et al. examined a sample of precontact and contact-era femora and humeri from Spanish Florida. By using methods of cross-sectional geometry, the team was able to compare the two groups and found very clear temporal trends for the prehistoric and mission samples and found a general reduction in sexual dimorphism among the individuals in the sample. Ultimately, Larsen et al. attribute this general reduction in sexual dimorphism to the types of work being done, suggesting that men and women in these samples were increasingly engaging in similar kinds of activities, especially during the mission period.

When used in conjunction with archaeological, ethnographic, and historical data, the study of human remains can offer a documentary record from which it is possible to interpret details of human biocultural adaptation (Larsen et al., 2001). Larsen et al.'s biological examination of the effects of colonization and European contact in Spanish Florida sets up the framework for our Eten and Mórrope examination, as these communities also experienced the effects of European contact and Spanish control.

2.2.9 – South American Populations

Unfortunately, studies of osteoarthritis represent a relatively poorly developed focus in the bioarchaeology of both pre-and postcontact South American populations. Rojas-Sepúlveda et al.'s (2008) investigation into vertebral DJD in a pre-Columbian Muisca population from Columbia. This study aimed to look at the documented manifestations of vertebral DJD from the Soacha Cemetery in Colombia dating back to about the 11th and 13th centuries CE. This population was an agricultural society of the Cundiameracy and Boyaca plateau and who exhibited significant manifestations of DJD on their vertebral column. Excavated in 1987 by archaeologists of the Instituto Colombiano de Anthropologia, 1,646 total vertebral elements of 83 individuals were examined in terms of age-at-death, sex, preservation, and manifestations of DJD which included osteophytosis, joint surface contour change (referred to as lipping), pitting, and eburnation. The frequency of DJD by both the individual and the vertebra were used in the calculation of prevalence. The results showed that abnormal porosity (or pitting as they refer to it) was the most frequently found manifestation of DJD in the sample, which was calculated affect 68.7% of individuals in the sample. However, there were no significant differences found when pitting was compared to any other the other manifestations examined (Rojas-Sepúlveda et al., 2008). As for manifestations on the individual vertebrae, eburnation was the most common manifestation (20.1%). Overall, 83% of the individuals and 32% of vertebrae were identified as having at least one of the aforementioned manifestations of DJD. In addition, there were no significant differences found between males and females in the samples. Interestingly, osteoarthritic involvement of the vertebral column of individuals in this sample appears to have begun early in the individual's lives. The high frequency of young adults (aging from 15 to 30 years of age) suggests that habitually strenuous activity that loaded their vertebral columns began early in the Soacha Muiscas' lives. Rojas-Sepúlveda et al. attempted to compare their population with samples from central and southern Mexico, as well as one from the Dickson Mounds population in Illinois. Rojas-Sepúlveda et al. (2008) calculated that the frequency of DJD in Soacha was lower than the central and southern Mexican samples. When compared to Dickson Mounds, there was a higher frequency of osteophytosis occurring earlier in male lumbar regions in the South American individuals. Differences between many populations and samples have previously supported the relationship between DJD and physical activity. With this positive correlation is accepted, the Soacha population can be interpreted as experiencing intense levels of physical activity throughout their lives (Rojas-Sepúlveda et al., 2008). Rojas-Sepúlveda et al. speculated that these individuals experienced a somewhat accelerated aging process, with an early onset of DJD and no differences in quantity of manifestations between males and females.

On the north coast of Peru, there is a paucity of studies that focus on the appearance of DJD. However, the few that have been conducted have led to some interesting observations. For example, Verano studied the physical characteristics and skeletal biology of a Late Moche population in the Jequetepeque valley at the Pacatnamú archaeological complex at the mouth of the Jequetepeque valley. Verano's sample came from the only intact cemetery at Pacatnamú: H45CM1 (Huaca 45 Cemetery 1). This sample consisted of 84 burials and about 590 isolated skeletal elements from the Late Moche period (ca. 550-750 CE). Here, degenerative changes in the joints were moderate. Further, there were no advanced patterns of DJD, including eburnation and remodeling or the articular surface observed in the sample, However, there is no doubt that these individuals were experiencing clinical physical suffering and pain from their DJD lesions. It should be noted that Verano used the terms DJD and OA interchangeably. DJD is not used to as an umbrella term in Verano's work on the Pacatnamú sample. The frequency of DJD among Verano's Pacatnamú sample correlated strongly with the age of the individual, which is expected since the older the individual, the more time they have to develop DJD. Degenerative manifestations in joints of the articular skeleton were found in all older adults, as well as in several younger adults, with the hips, knees, and shoulders being the most frequently affected systems (Verano, 1997). Verano associates the degenerative changes in the hip and knee joints with wear-bearing stress, while the degenerative changes in the shoulders are associated with wear and tear from activities using the upper limbs. The Pacatnamú sample also exhibits signs of rheumatoid arthritis (RA) as well. Verano (1997) distinguishes RA as having involvement of specific joints that occur on both sides of the body (bilaterally), which tends to result in joint fusion. There were several examples of vertebral fusion in the surface materials, but only one example of vertebral fusion found in the H45CM1 cemetery, which was identified as being consistent with either RA or ankylosing spondylitis. Verano (1997) concludes that the patterns of DJD found in this sample suggest an active lifestyle among the individuals that involves a great deal of wear and tear on the upper body and limbs of the individuals found in the sample.

In Mórrope (two valleys further north on the Peruvian coast), Klaus et al. (2009) the impact of European conquest on labor systems and physical activity among Muchik peoples (ethnically Moche descendants). This work examined 11 different load-bearing joint systems (the shoulder, elbow, wrist, hand, cervical vertebrae, thoracic vertebrae, lumbar vertebrae, hip, knee, ankle, and foot) and scored as present or absent based on the principle expressions of DJD. Periarticular osteophytic lipping, porosity, and eburnation were all included as expressions of DJD. The analysis found that there was a statistically significant increase of DJD in the upper limbs observed from the pre-Hispanic to the Colonial periods among these Muchik peoples. The postcontact shoulder joint was twice as likely to be affected by DJD than the late pre-Hispanic population's shoulder joint system, elbow prevalence increased by nearly three times, and DJD was 5.6 times greater in the wrist, in the lower limbs, only the knee was found to have a significant change in DJD prevalence, around 3.6 times greater in postcontact samples (Klaus et al., 2009). In addition, it was observed that males were by far most frequently affected by the elevated rates of DJD. The only joint where DJD risk was greater in pre-Hispanic women was in the hip joint system. These findings of elevated DJD in the joint systems of the individuals found in Mórrope are consistent with ethnohistoric evidence that describe the workings of the colonial Spanish economy and its mandatory labor system.

Following Klaus et al.'s (2009) work in Mórrope, Klaus and Alvarez-Calderón (2017) questioned if the patterns of health, stress, and cultural responses to conquest in Mórrope was common to other groups on the north coast of Peru who lived under Spanish colonial rule. To test this notion, skeletal samples corresponding to Muchik peoples from Eten were compared with the contemporaneous and geographically nearby sample from Mórrope. DJD lesions were among a broader suite of non-specific childhood and adult biological stress indicators such as enamel hypoplasias, porotic hyperostosis, and periostosis. Again, data on DJD in several different joint systems (shoulder, elbow, wrist, hand, cervical vertebrae, thoracic vertebrae, lumbar vertebrae, hip, knee, ankle, and foot), and Schmorl's depressions were again compared. Specifically, Klaus and Alvarez-Calderón hypothesized that negative health outcomes in Mórrope were also experienced in Eten (2017). Surprisingly, this was not the case.

Odds ratio comparisons between the Eten and Mórrope samples found that the prevalence of nearly every pathological condition was consistently lower in the Eten sample when compared to the Mórrope sample. The only comparison that was found to be more common among the Eten sample was DJD of the foot but this finding was not statistically significant. As for the other comparisons of DJD, all were more common in the Mórrope sample and half of which were statistically significant. DJD of the shoulder joint system was found to be about 3.8 times more common in Mórrope, as about 68.3% of the sample was affected by DJD of the shoulder in Mórrope. DJD of the shoulder in Eten was found in only 36.4% of the sample. In the elbow, the Mórrope sample was found to be 2.17 times more common, with about 69.6% of the sample being affected in

Mórrope as opposed to 50.4% being affected in Eten. Wrist DJD was found in about 43.4% of the Mórrope sample and 17.3% of the Eten sample, making it 4.02 times more common in the Mórrope sample. The lumbar vertebrae in the Mórrope sample were affected by DJD in 61.8% of the individuals, which is 2.68 times more common than the 46.0% of individuals in the Eten sample with the same condition. Finally, DJD of the knee was 3.73 times more common in Mórrope, with 61.8% of the sample being affected. Some 34.7% of the Eten population was affected by DJD of the knee (Klaus and Alvarez-Calderón, 2017). In addition, porotic hyperostosis and nonspecific periostitis were also more common in Mórrope when compared to Eten, with these measurements being statistically significant.

2.3 – Conclusion

Degenerative joint disease is a complex and highly variable pathological condition and includes a range of different pathological joint phenomena. As one of the most common pathological condition found in both the archaeological context and modern clinical assessments, DJD is a biologically elaborate degenerative condition that begins as a gradual wearing of the synovial joint capsule and a breakdown of the cartilage protecting the skeletal elements involved in the movement of the joint. This can produce many different downstream manifestations in the skeletal system, including lipping and osteophytes, pitting and porosity, and eburnation that can eventually or even completely obliterate the joint system. Although the exact etiologies of DJD require further clarification, bioarchaeologists can use the condition in a conservative fashion to interpret and understand many different aspects of prehistoric, and modern lifeways. DJD can provide essential clues to activity patterns when used in addition to other lines of evidence such as structural adaptation and cross-sectional geometry. DJD can also be a function of surrounding ecogeography, labor systems, gender roles, mobility patterns, and more. This idea of trying to understand the lifeways of different groups around the world has not been applied extensively to South American cultures and especially the north coast of Peru.

In this work, the two samples of postcontact Muchik populations in the Lambayeque region (Mórrope and Eten) that have previously been examined for the prevalence of DJD are once again the focus of study. Here, severity and manifestation of the types of DJD is compared to delve deeper into the effects upon life, society, and history as Spanish took hold and reshaped the Peruvian north coast. To best contextualize these changes, the next chapter turns to an overview of the archaeological and ethnohistoric backgrounds of the north coast of Peru.

CHAPTER THREE:

CULTURE HISTORY

3.1 – The Lambayeque Valley Complex

The Lambayeque Valley Complex is located on the northern coast of Peru. Taking its name from the pre-Hispanic name of a river and an eponymous pre-Hispanic idol known Llamapayec in local ethnohistoric lore, the Lambayeque Valley consists of five rivers that all connect to one another to create Peru's largest river valley and the largest integrated hydraulic valley system found in the Americas. These rivers include the La Leche, Motupe, Lambayeque, Reque, and Zaña. The territory consists of wide plains that are irrigated by these rivers that flow from the Andes Mountains. The Lambayeque Valley Complex encompasses around 150,000 hectares of arable land with diverse natural resources including terrestrial and marine resources. This area was also home to about a third of the total late pre-Hispanic era population of the entire Peruvian coast (Kosok 1965).

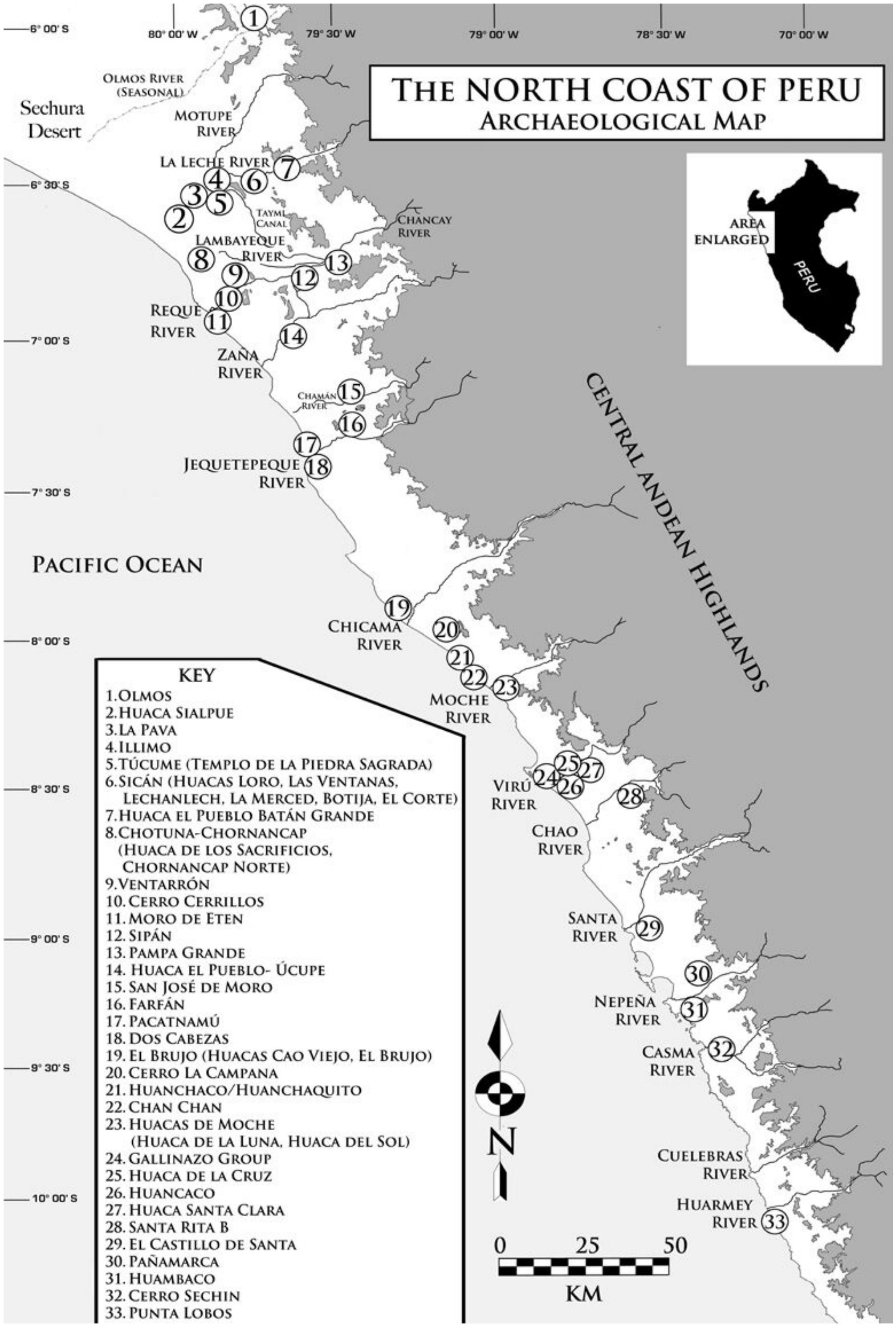

Figure 3.1 - Archaeological Map of the North Coast of Peru. Map by and courtesy of Haagen Klaus.

The Peruvian landscape is divided, at the very least, into three main topographical areas: the coast (*costa*), the highlands (*sierra*), and the eastern rainforests (*selva*). The focus of this study will remain on the examination of the northern coast of Peru. Along the Pacific coast, in an area that the inhabitants named *vallle nuevo* (or "new valley"), dense fog and heavy mist tend to slow the growth of agricultural crops due to the diminished sunlight and increased amount of harmful fungi and insects (Ramírez, 1996). Further inland lays a more semitropical climate that is home to nearly year-round sunlight, termed the *valle viejo*, or "old valley". In this area of Peru, the climate makes it possible for farmers to harvest between two and three crop groups a year. The pre-Hispanic indigenous populations were more concentrated in these upper, old valleys due to the agricultural richness of the land. However, these populations were later resettled into the lower valleys around the 1560s and 1570s, for the sole purpose of freeing up the most productive areas for the expanding Spanish agriculture (Ramírez, 1996). Between AD 100 and 1100 AD, these resources and economies underwrote the unprecedented economic power of the Middle Moche and Late Moche societies and the Middle Sicán theocratic state.

The Lambayeque Valley Region also consists of many different types of microenvironments. Microenvironments of the Lamabayeque Valley cover an immense range of different biomes and ecologies. Microenvironments range from coastal deserts, forests, cultivated plains and pastures, and arid, treeless *pampas* can all be found among the lowlands and mountains of Northern Peru (Netherly and Dillehay, 2017). Areas near Morro de Eten, Caleta de San José, Santa Rosa, and Pimentel are all considered to be apart of the littoral zone. The littoral zone microenvironment is an area of land characterized by its lack of trees and includes a narrow stretch of shore. This microenvironment is quite variable in of itself, not all littoral zones look the same. For example, the littoral zone surrounding Morro de Eten consists of a rocky landscape, however, the littoral zone surrounding Caleta de San José is more sandy and beach-like rather than rocky. Most communities and individuals found in the littoral zone environments partake in a maritime fishing economy that also includes the collection of mollusks and the hunting of seals and other sea mammals (Netherly and Dillehay, 2017). To the east of the littoral zone is a zone that contains sand dunes that can reach up to twenty kilometers inland; this is the coastal desert zone. In this area, vegetation and water are sparse and the soil contains deposits of clay, salt, and gypsum. Cultivation in this zone would be very difficult due to the poor quality of the soil. Mórrope is found in this microenvironment. The *monte* zone is a microenvironment that characterized by the growth of different shrubs, including types of *algarrobo, faique*, *vichayo*, *zapote,* and *palo verde.* This zone is thought to most closely resemble what the vegetation coverage would have been like when indigenous communities were forming. After the Inka conquest, much of the *monte* environment fell into disuse. However, when the Colonial era began to take place, this zone began to be exploited for animal feed due to the large amounts of shrubbery. Subsequently, the *monte* zone was reduced once again by intensive sugar cane production (Klaus, 2008). Near the La Leche River is a microenvironment that encompasses a large area of the Lambayeque River Valley, the semi-tropical forest. The semi-tropical forest forms the Poma Forest National Historic

Sanctuary, which is home to a vast number of birds, mammals, insects, and other various creatures. The riverine microenvironments include strips of continuously alluvial floodplain and terraces and can vary in size but are generally smaller than two kilometers (Klaus, 2008). Communities found in this microenvironment often practice cultivation and farming due to the availability of water and rich soil that can support a wide range of plants. The final microenvironment is referred to as the valley flanks, which embodies the transition between the fertile bottomlands and the Andean foothills. Areas in the valley flanks microenvironment appear to be where pre-Hispanic communities and settlements generally appeared and settled. Characteristics of this microenvironment include areas of sloping and barren surfaces with a mixture of subtropical trees and shrubs. Livestock and herding are two of the main economic endeavors. Due to a large number of microenvironments and how each microenvironment widely differs from all of the other microenvironments, it is understandable that the people inhabiting each different area would be adapted to different conditions and experience widely different advantages and disadvantages than those inhabiting other microenvironments.

Later conquest of the Lambayeque region, its resources, and its peoples by the Chimú and Inka proved to be an immense boon to both imperial treasuries (Klaus et al., 2009). While archaeological cultures rose and fell, one ethnic group endured under the surface of all of these changes well into the historic people: the Muchik. The Muchik arose in the Lambayeque Valley region sometime during the Middle to Late Moche eras. In addition, the Muchik appear to be the descendants of even earlier, local Lambayeque peoples (Klaus, 2013). The Muchik ethnic group is most commonly defined by their burial rituals which lasted up until Hispanic contact in the Lambayeque Valley region. In addition to this, the Muchik also conducted prolonged primary burials, the manipulation of skeletal remains, and secondary burials that would maintain the links between the living Muchik population to their dead ancestors. This ethnic group developed and shared a wide variety of mortuary rituals, technologies, art, labor system, language, and traditions.

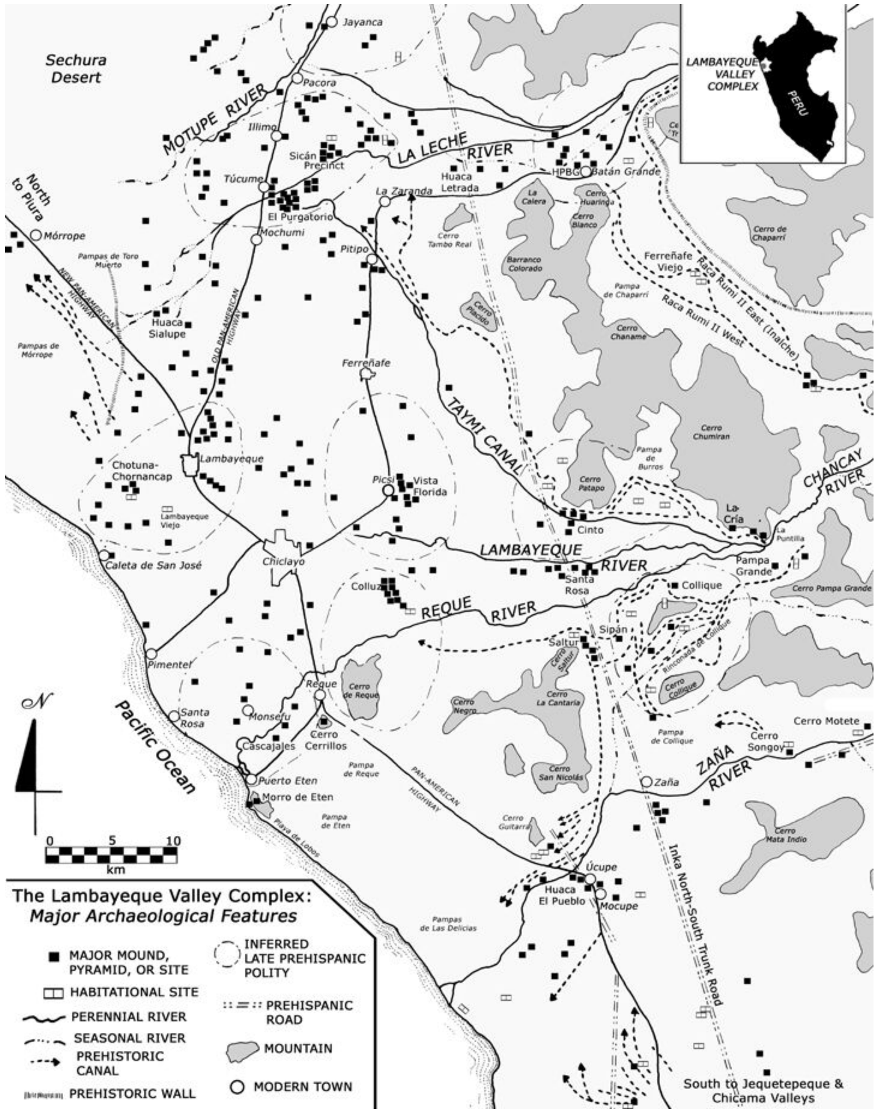

Figure 3.2 - Archaeological Map depicting the Lambayeque Valley Complex, including Mórrope and Eten. Map by and courtesy of Haagen Klaus.

3.2 – Cultural History

In 1532, Spanish conquistador Francisco Pizarro and his mercenaries first entered the Lambayeque region of northern Peru on their way to Cajamarca, where the historic confrontation between the Spanish band and the Inka emperor Atahualpa, leading to Spain's claim to the land. The small Muchik fishing village of Ätim (eventually renamed as Eten) rested adjacent the route which Pizarro and his assemblage took to the Inka Empire (Klaus and Alvarez-Calderón, 2017). This may have been an interesting sight for the locals of the lower Lambayeque Valley Complex, Ätim locals while Pizarro was passing through, yet, in a year's time, the Inka empire would fall to the Spanish, leaving the land under permanent European control and the colonization of the Andes would begin to take place. Understanding the culture of both precontact peoples and their history as well as the transition into post contact settlements following the arrival and conquest of the Spanish can lead to a better understanding of what exactly happened to these native peoples when the Europeans arrived and how it affected not only their cultural systems but their bodies as well. The Lambayeque Valley Complex was a center of influential pre-Hispanic cultures and key developments focused on technology, sociopolitics, and economics for at least 3,500 years before the Spaniards arrived.

3.2.1 – The First Settlers

Around 15,000 years ago, people began to populate the area in and around the Andes. Though the exact route of migration remains unknown, dental analysis has found that the first settlers of the Andes came in a couple of waves of migration. The first settlers are believed to have been decedents of an ancestral sinodont population as gene flow into the Andes from other areas of Central America appear to parallel the adoption of agricultural practices and sinodont replacement from the earlier populations (Klaus, 2008). Permanent colonization of the northern coast of Peru was completed between 11,000 and 9,000 years ago. The economy and subsistence of these early communities focused mainly on marine resources, unlike the highlands, which focused on terrestrial resources. The Paijan sites, a tradition carried out by paleoindians in the area, suggest that settlements during the first inhabitants were centrally located in middle or upper valley regions that reached as high as 1800 meters above sea level. Between 8700 and 5900 BCE, groups began to decrease their movement, create permanent settlements, and established seasonal patterns. These peoples are also credited as some of the first in the area to claim control over plants and animals, leading to more consistent plant and animal domestication later. This would be the foundation upon which more complex societies would later build.

3.2.2 – The Origins of Social Complexity and Farming:

3.2.2.1 – The Preceramic Period

Developments that occurred after the Paijan tradition are not often studied. In fact, there is a large portion of history that seems to be missing from the timeline: the transition from foraging to farming and sedentism on the north coast of Peru (Klaus, 2008). However, there is some evidence of the nature of the transition on the coast found in the Zaña Valley. Hunter-gatherers in this region experienced a shift in lifeways by around 5500 BCE. Organized communities, the ritual processing and burial of their dead, social stratification, and small-scale food storage were all aspects that characterized their new lifeway (Rossen and Dillehay, 2001). By 1500 BCE, many of the main cultural shifts that lead to the building blocks of cultural complexity along the northern coast of Peru. Seasonal cultivation began to take place along the rivers, crops consisting of carbohydrates and sugars became dominant in the economy and diet, and reciprocal trading between the coastal peoples and those living inland began to take place (Ramirez, 1996).

With the foundations of cavitation built by the first settlers in place, the Preceramic period continued to build upon the foundations. Large platform mounds, U-shaped plazas, and sunken circular courts all characterize the Preceramic period of the Peruvian coast (Burger, 1995; Klaus 2008). Burger (1995) suggested that this type of structure showcases the power that a small number of elite individuals that would have been responsible for organizing and directing labor without the help of state-level organization or socioeconomic stratification. In addition, the northern Peruvian coast became one of the first major centers for the early construction projects, including Sechín Alto, built in the late Initial Period, Alto Salaverry in the Moche Valley, and Pampa de las Llamas-Moxeke and Huayuná in the Casma Valley, all constructed in the Late Preceramic era.

During the Preceramic era, one of the most powerful polities during this era could be found in Caral of the Supe Valley on the central coast. This organization was most likely powered by trade networks that ran between the coastal and highland peoples. Caral continued to thrive in the area from about 3000 to 1800 BCE when it then began to decline under reasons unknown. The Caral polity is quite important, as it was one of the first powerful influences found on the Peruvian north coast and most likely continued to influence the area for many years. In fact, it would be centuries before any other peoples would surpass the power and achievements of the Caral people.

Even though Peruvians were in contact with other societies that commonly used and created pottery, it wasn't until 2000 BCE that the people of Peru began to utilize ceramics and pottery in their everyday lives, and only began to produce pottery on the north coast between 1800 and 1500 BCE. Not only was ceramics used for the production of food, as well as its storage, but ceramics also provided a new medium for economic ventures and ideological and artistic activities. Thus, this was the end of the long Preceramic period.

3.2.2.2 – The Cupisnique

After the implementation of ceramics and pottery into the lives of the Peruvians on the north coast, a new designation was created to describe a type of ceramic style and technology that was found in funerary contexts of the Chicama Valley that dated from 1500 to 700 BCE. The Cupisnique is most commonly identified in ceramics by their representation of various subject matters, including plants, animals, humans, stylized felines, and supernatural beings, as well as geometric, patterned designs and stamping on gray and black ceramics. Cupisnique mythology was often centered around these felines and human-like spiders found on their ceramics, who were often shown holding a decapitated human head. This scene is often found in association with plant growth, which severed hands, trophy heads, and other body parts grow (Burger, 1995). Excavations in the Poma National Historic Sanctuary have previously uncovered a large-scale ceramic production center consisting of 57 kilns. After this discovery, there were tests to try and better understand how these kilns may have been used by placing sensors within a replica of the kilns as well as one of the 2,700-year-old kilns found in the Poma National Historic Sanctuary.

It is thought that the Cupisnique populations partook in a tribal or chiefdom level governing system that connected many populations in the area. The Cupisnique were capable of not only creating but directing and operating large-scale civic and ceremonial centers, such as the Huaca de los Reyes and Huaca Lucia to name a couple. These civic and ceremonial structures displayed low-tiered platforms, inset stairways that could reach 16 meters wide, rectangular forecourts, and colonnades, which are rows of columns that support a roofing structure (Burger, 1995; Klaus, 2008). These Colonnades were the most unique feature found in these structures. Metallurgy, or the manufacturing of precious metals, also rose in popularity sometime during the late Cupisnique phase, which can be seen through the creation of golden crowns and other jewelry appearing for the first time in the Andes region (Klaus, 2008). The inclusion of such goods in funerary contexts has become evident that social inequality and social elites both existed in the Cupisnique society. These golden objects were most likely used to show the status and authority an individual possessed, those with more golden objects having a higher status and authority over those with fewer or no evidence of golden objects in their burials. The Cupisnique phase appears to have declined around 700 BCE. It is not well understood how the decline took place, but it may have been due to so environmental perturbations, such as an El Niño event or some sort of impact from a tropical storm.

3.2.2.2 – The Salinar and Gallinazo Traditions

After the fall of the Cupisnique phase came a new dominant style, one that is often understudied: the Salinar tradition style. Salinar populations generally centered around the mid-valley and hillside regions of the coast. The Salinar tradition also brought about the first evidence for strongholds and fortifications of any type on the north coast of Peru, which may indicate some sort of increasing social tensions or organized warfare.

Around the time of the Salinar decline, a new tradition began to arise and gain prominence in the north coast region, the Gallinazo tradition. This tradition is often credited for their role in the origins of Moche culture and the developments of other cultural groups. The Gallinazo tradition stretches from Chicama all the way to Santa on the north coast and maintained their former governing style of a chiefdom-level society with clusters of villages. These villages were not the only areas populated by people, some communities were settled in areas that some would consider more "urban" than the villages.

What is remarkable about the Gallinazo is that this style seems to have persisted throughout the Moche era and into eras beyond the Moche. This is unlike other traditions before, which terminated before the rise of a new tradition. Most of the polities of the Gallinazo were incorporated into Moche culture. On the other hand, the Gallinazo populations and artistic traditions continued among the common people in the area, where they outlived even the polities of the Gallinazo.

3.2.3 – The Moche

During the first millennium AD, there was one cultural development on the Peruvian north coast: the Moche culture. The Moche culture has yielded many different art forms that were previously used as the only source of information about their culture. However, this is problematic for archaeological research, as most of these art forms found their way to archaeological researchers after first being looted from their original resting place. This means that there was no context about where it came from, whom it was buried with, how it was placed within the burial, and so many more contexts, completely disembodied form and context that may lead to a better understanding of the Moche culture (Klaus, 2008).

The Moche culture is often divided into five different chronological phases, which were first defined by Larco Hoyle in 1948. It is unknown how the Moche culture came to be, however, the Moche I and Moche II art styles seemed to have emerged around 0 AD while the polities emerged from sociopolitical changes in the already established Gallinazo government. Most developments in the early phases of Moche culture happened in the north between the La Leche and Lambayeque valley. After the early phases, a second polity in the south rose to power in the Chicama-Moche region. These two groups were discovered from inside the tombs found at the Huaca Rajada complex in Sipán. These tombs were decorated with goods made of various metals, making it one of the most valuable burials that managed to escape looting documented in the Western Hemisphere.

The Moche culture and style use to be lumped into one continuous polity, however, this categorization fails to show how dynamic the relationships were between the very different sociopolitical centers that are found throughout northern Peru. During this time, there is a clear north-south bipartition of the north coast. One of the differences between the northern and southern Moche can be seen in their ceramics. Even though there can be a broadly assigned "Moche style," the way in which the pottery is created and decorated varies between the north and south. The northern Moche ceramics display fine, small decorations while the southern Moche ceramics depicted portrait styles. Nonetheless, there are similarities that can be seen between the northern and southern Moche polities. Both areas maintained a small valley, which had limited amounts of run-off water, which was politically linked with a larger valley that had a mostly stable water supply throughout the year. These smaller valleys were the central political powers of the area. The smaller valley sized allowed for there to be a high degree of political, economic, and social centralization, while the larger valleys the more of a stable water supply were used as an agricultural area for growing a majority of the food for both valleys (Kosok, 1965). Social organization during the Moche era is thought to have involved a very ridged stratified class system that was ruled by a small number of elites. These elites are not just political leaders, but religious leaders as well. The elite are thought to have had control over large construction projects and the laborers who built them. Upward social mobility and a growing middle class are also believed to have been consistent with the Moche (Ramírez, 1996; Klaus, 2008). The social stratification can be seen in the different variations of burial treatments, with different classes being interred and treated differently than others.

By around 450 to 550 AD, over 350 kilometers of the Peruvian coastline was in the hands of the southern Moche. Social and political transformations and reorganizations began to come about as a result of an extended period of intense El Niño and environmental events. Despite efforts to maintain the Moche, the final fall of Moche power occurred around 700 to 750 AD.

3.2.4 – The Sicán

After the collapse of the Moche era (which ended with the Moche V), a new society rose from a small local polity and grew into an administration that held a large dominance over the region, the Sicán culture. The term "Sicán" is used to describe the archaeological culture found in the Poma Forest between 800 and 1375 AD. The Sicán culture is divided into three distinctly different eras, the Early Sicán (750 to 800-900 AD), the Middle Sicán (900-1100 AD), and the Late Sicán (1100-1375 AD). The Early Sicán era continues the same ceramic style as the Moche V had previously left behind. Though the origins of the Sicán are unknown, oral folklore may have left some hints about the Early Sicán. Spanish colonial administrators recorded legends of a society that was founded before the Chimu dynasty in the Lambayeque region that was ruled by a foreign leader named Naymlap (Klaus, 2008). Although this folktale has yet to be verified and clues regarding Naymlap have yet to be discovered, its hard to tell whether there is some truth to this legend, but a pre-Chimu civilization in the Lambayeque region is consistent with the archaeological documentation of the Sicán culture. However, Early

Sicán occupation left behind no readily recognizable large corporate structures and is still poorly understood (Shimada, 2000).

The Middle Sicán period was home to a plethora of cultural developments, including a distinct religious art style and ideology as well as developments in construction and craftsmanship that involved the large-scale use of fire. The Middle Sicán period also displayed new characteristics of state-level organization: the control and deployment of many different types of resource exploration, distinct social classes that had different accesses to goods, services, and information, and a centralized government with a form of hierarchical administration (Shimada, 2000; Klaus, 2008). Middle Sicán communities had an economy that focused on self-sufficient strategies that used resources found in their local environments (for example, marine resources) and their own agricultural products. The Middle Sicán also participated in a long-distance trade route that expanded nearly 1000 kilometers (Shimada, 2000; Klaus, 2008). In fact, Shimada (2000) describes how many of the items and grave goods found within elite tombs were actually items that were imported into the Middle Sicán communities, including marine shells from contemporaneous Maneño and Milagro populations from south-central Ecuador.

Using evidence from archaeological data, mortuary patterns, and data on skeletal biology and molecular genetics, reconstruction of the Middle Sicán social organization appears to have been a complex, multiethnic, hierarchical society that consisted of at least three different social classes consisting of three or more different cultural traditions and ethnic groups. Individuals that were considered "commoners" were those who were manual laborers, agriculturalists, fishers, and artisans, the vast majority of the Middle Sicán society. These individuals were mostly local populations who settled in a sedentary community that may even be traced back for many eras. In fact, a large number of individuals in the Middle Sicán population were likely to be ethnically Muchik, individuals who were descendants of the early Moche culture. Despite the cultural and political world changing around them, the Muchik ethnic group continued to partake in their original practices and identity from the earlier Moche period. While some of the original Moche artistic style remained, the most significant mark of the persistence of their culture can be seen in the Muchik burial practices. Even after the fall of the Moche, the Muchik continued to inter their dead in the same manner: an extended corpse aligned on a north-south axis in a simple pit with no more than two meters in any dimension and accompanied by ceramic, metal, or camelid offerings, as well as a prolonged primary burial, subsequent manipulation of the skeletal remains, and a second burial to maintain the connection between the living and the dead (Klaus 2008).

Around 1020 AD, another devastating El Niño event took place, this time leading to a decades-long drought in the area. This devastation brought about an abrupt collapse to the Middle Sicán communities. Many believed that this devastation was brought about by the leaders lack in ability, leading to the destruction of many temples in an effort to remove the leadership in power. Whether or not this was due to the ethnicity of the leaders or the leader's inability to "effectively mitigate the supernatural elements of the crisis," the exact reason is unknown; whatever the reason, it is clear that this was an effort on the part of the commoners to remove the extant political and religious leadership in

Sicán (Shimada, 2000, 61). This destruction and restructuring of the Middle Sicán is what lead to the beginning of the Late Sicán period. The Late Sicán period is often described as a reorganization resembling the Moche V rather than a complete collapse.

3.2.5 – The Chimú

In the Southern portion of the region, a new power began to reach out from its homeland and establish itself as a predatory imperial polity in the Moche Valley. The Chimú Kingdom began to expand around 1325 AD. The capital of the Chimú, Chan Chan, offered the most insight into what it was like living under the rule of the Chimú. Chan Chan is considered one of the largest pre-Hispanic cities in the Andes. The capital contained nine hierarchically organized *Cuidadelas*, which were large royal compounds, 35 smaller elite compounds, and neighborhoods dispersed throughout the remaining area. The actual origins of the Chimú remain unknown, but oral folklore tells of a great leader coming from the north, around the same time of the collapse of Middle Sicán, named Tacaynamo. Tacaynamo was rumored to have been the founder of the Chimú. At the height of their expansion, the Chimú controlled a number of different territories that encompass at least five modern South American countries (Mackey, 2006).

The Lambayeque region was a goldmine for the Chimú Empire. The Lambayeque region contained about a third of the north coast's total population, a large amount. The Chimú government pushed to have the Lambayeque land be cultivated as much as possible. Shimada (2000) argues that the amount of cultivated land in the Lambayeque region under the Chimú was about 30 percent greater than the extent of farmland during modern times. Socially, the Chimú did not interfere with the social organization and institutions of the Lamb. The administration followed the standardized, three-tiered hierarchy and used a range of strategies, ranging from state-imposed resettlement or the co-option of local lords (Shimada, 2000; Klaus, 2008).

3.2.6 – The Rise of the Inka

The Chimú was not unmatched the when it came to expansion of their kingdom. Eventually, the Chimú came into contact with a large power that it had never encountered before, the Inka state. During their expansion, the Inka would first initiate diplomatic discussions with the local lords of the communities in their path. If the lords were accepting of the Inka, then the lords were honored by the Inka state and given gifts, of metals, cloth, and women. If they were accepting, the lords would also be able to maintain their ruling position over their community. This tactic did not work on the Chimú ruler, which lead to conflict between the two empires. The Chimú were defeated around 14690 AD and Inka expansion then proceeded along the Peruvian coast. Communities on the coast were incorporated into the Inka province once their previous rulers were either defeated or were they themselves transitioned by the Inka.

All in all, the impact that the transition to the Inka state was probably quite easy and not as stark as one might think. In fact, impacts were probably limited. Firstly, the north coast was only subjected to Inka control for less than a century. Secondly, the coast did not endure the same control as the Inka heartland since they were on the outskirts of the Inka province. Thirdly, since the customs and traditions of many on the north coast could be traced as far back as the Moche era, the imperial mandate could not quickly change the practices of those on the north coast (Klaus, 2008).

In 1530, Francisco Pizarro and his crew landed on the coast of South America and by 1532, they encountered the Inka. This caused a struggle between the two powers, and by November 15th of 1533, Cuzco fell to the Spaniards and the new power began to seize control over its new colony.

3.2.7 – Pre-Hispanic Power Structure

Before Spanish colonization, the north coast of Peru was home to a lord-subject power dynamic. The chief or paramount lord (called the *curaca*) would have control over thousands of native subjects and would also manage the land and the natural resources to support them and their subjects. Societies found on the north coast of Peru were considered status-based societies, and even *curacas* were not immune from the grips of social status. The rank, position, and prestige of each curaca were equated with the number of subjects which he had control over. "Many contemporary authors have commented on the fact that the rank and status of a native leader were correlated with the size of the population he controlled, no only in the north, but throughout the wider Inka empire" (Ramírez, 1996, 15). In addition, it was found that each ranked official, including *curacas*, had to have a certain amount of native tributaries to achieve and maintain his status in the Inka administration. This status and reputation directly related to the number of subjects under their control, and their status and reputation would increase as their numbers grew. While the exact geographical reach of each curaca would be difficult to assess, oral traditions recorded by observers in the early sixteenth century suggest that the land was, indeed, divided and recorded by the Inka empire. "The Inka or his agents and surveyors divided and marked each lord's domain when the coast was incorporated into the empire … the Inka divided the highlands from the coast …[and] delegated, entrusted, and assigned land and other recourses to a curaca and his followers" (Ramírez, 1996, 16). This means that each *curaca* was delegated control over specific resources and lands that could have been scattered across multiples ecological zones. This land tenure was one of the most significant impacts on the north coast after being incorporated into the Inka province. Having control over land in this sense was not the same as private property. *Curaca's* land rights depended on the delegation of land from Inka authority. In addition, land was often set aside for centrally-controlled state production and exclusive access to hunting grounds, fishing waters, forest, and mines (Klaus, 2008).

While the lands "belonged" to the *curacas*, they would entrust these lands to the lesser lords under him, who would pass land down below them, on and on until the hierarchy reached the individual heads of households (Ramírez, 1996). In return for the right to the access of resources, the subjects customarily gave the lord a gift and the lesser lord would pay a sort of "rent" to the *curaca*. This "rent" or "gifts" came in the form of goods, such as corn, pepper, or cloth. This is a reflection of expected reciprocity between the subjects and the lord in terms of items or goods, but usually in the form of labor services and time in the Inka Empire.

The *curacas* were considered the authority of justice over their local land, meaning they would police the people whom they had control over. For example, if a commoner were guilty of a minor infraction or a grave offense, the *curaca* would determine the means of torture or punishment that the commoner must face, in addition, the *curaca* had the power to take the life of the offender (Ramírez, 1996). In areas under stricter Inka control, *curacas* were supposed to get the permission of Inka rulers before inflicting capital punishment onto his subjects. However, this did not include areas of the north coast of Peru. It is likely that *curacas* were more lenient when it came to capital punishment, however, since decreasing their number of subjects would also have a negative impact on their status and reputation.

3.2.8 – Shifting Labor Systems

The Muchik also had developed their own labor system as well. "Pre-Hispanic Lambayeque labor organization involved a system that appears to date back at least to the Moche V period [between 550 and 750 AD]" (Klaus et al. 2009, 205). This labor system consisted of a "dualistic segmentary organization" based on the rules of reciprocity and where the economy consisted of guild-like specialties, such as fishers, agriculturalists, weavers, crafters, and more (Klaus et al., 2009). These craftspeople had reciprocal obligations to a lord (or *curaca*) who was the center of the economic production and distribution of wealth, as the craftspeople were the subjects of the lord. As mentioned before, *curaca's* would give their subjects access to land and resources, and in return, the subjects would "repay" their *curacas* in the form of reciprocal exchange of goods or labor service and time.

As the Spanish began to take hold of the Peruvian land, it did not take long for them to notice the sunny, warm climate, the expansive land that was perfect for agricultural production, and the many coastal areas that had great potential to become seaports for exportation of goods. Because of this, Lambayeque became one of the key centers for agricultural production for the Spaniards in the New World. The Spanish plan for this area was to extract the maximum amount of natural resources, manipulate native labor, and convert the native people into taxpaying Christians, with the agricultural production focusing on sugarcane, alfalfa, cattle, and swine (Klaus and Alvarez-Calderón, 2017).

The native labor-system did not last very long after the Spanish Inquisition. When organized colonization of the Lambayeque region began in the 1560s, the *curacas* were manipulated or forced into ceasing the ruler-subject obligations. Local peoples began to work by authorization for the colonial administration, which allowed the higher powers to abuse the labor force (Ramírez, 1996; Klaus et al., 2009). The focus of the economy shifted away from craftsmanship and guilds to an economy concentrated on ranching pigs, goats, cattle, and sheep. As small ranches began to evolve into large plantations, the demand on the colonized workers increased as they became more powerless and embedded in poverty. The previous native economy was replaced by a system that gave all the power to the Spaniards and focused largely of the production of a few cash crops (such as alfalfa and sugar cane) on an industrial scale. This labor system, as opposed to the pre-Hispanic system of reciprocal exchange and lord-subject system, can best be described as a one-way extractive relationship of labor flowing from indigenous people into the coffers of the colonial state in Lima (Klaus et al., 2009).

3.2.9 – Effects of the Spanish Colonization on Lambayeque and Its People

With the Spanish now in control of their new colonial land, both the landscape and the native population and their society began to mono-crop. Because of the mono-crop agriculture and overgrazing, the local Lambayeque ecology began to suffer. In addition, the many peripheral irrigation canals of the Lambayeque Valley were damaged, allowing much of the lush land and forests to become reclaimed by a desert climate.

Following the dismantling of the local pre-Hispanic labor systems focusing on socioeconomic reciprocity, the Muchik were forced into the lowest strata of a new economy that demonstrated proto-capitalist characteristics with from feudalistic roots (Klaus and Alvarez-Calderón, 2017). These native communities were also forcibly moved off of the lush land and resettled into marginal locations. The local population was placed into a structural poverty trap and escape from poverty was made to be as difficult as possible for the natives (Klaus and Alvarez-Calderón, 2017). As stated before, native populations once populated the *valle viejo* and moved forcefully onto less viable lands. These native populations were resettled into extremely crowded *reducciones*, new settlements created by the Spanish to house native populations. These *reducciones* was to give the ruling government the greatest amount of control of those living inside the settlement, to give the Spanish a great amount of control over the natives. *Reducciones* were also usually located on less sustainable land with "sickly" terrain. "A hidden agenda of the *reducciones* was to open up land coveted by the Spanish" (Ramírez, 1996, 31). While the Spanish took all the good agricultural land for themselves, the natives were left with the nearly uncultivable land. The *reducciones* were not in the best interest of the natives who were forced from their homes. Due to the high population density of the *reducciones*, the native's low socioeconomic standing, and the unhealthy terrain, many natives perished. One *encomendero* (a Spaniard who held the trust of the natives, or, a native advocate) criticized the *reducciones*, saying that natives were removed to land that was too sickly and swampy to cultivate, leading to the deaths of 200 native individuals (Ramírez, 1996). Deaths of native individuals lead to the abandonment of some *reducciones.* However, it was not long before the *encomenderos* began to take advantage of some of the native peoples. "Unregulated *encomenderos* began to exact increasingly large tribute demands from their now politically powerless and poverty-stricken subjects," these tributes included large amounts of crops, fowl, sheep, handmade goods (such as blankets), and tribute cloths (Klaus, 2009, 205).

After the relocation of native populations into the *reducciones,* a large depopulation of native peoples began to take place. There are numerous reasons for the rapid population loss along the north coast of Peru, one of which is the population density. "Population density is a major determinant in the spread of epidemic disease. The immunity of a population is another factor" (Cook, 2004, 143). Among the native individuals' population the Americas in the late 1400s, there was virtually no natural immunity to the diseases that Europeans brought into the New World. Coastal regions are the most ideal areas for an endemic disease, as the population is concentrated around waterways and diseases could easily travel along a coast through a carrier. An entire valley, such as the Lambayeque Valley Complex, could be infected by a disease carrier traveling along the coast (Cook, 2004). In addition, diseases spread through insects spread more quickly in warmer environments such as the *valle viejo,* where a majority of the native population lived before their relocation by the Spaniards. While the comprehensive north coast census data points to a nearly 93% drop in population, populations in the Lambayeque region began to stabilize and rebound around the 1630s after losing about 40% of its indigenous peoples (Cook, 2004; Klaus and Alvarez-Calderón, 2017).

Spanish colonization of the Lambayeque region is often characterized by an increase in native labor extraction. Before the Spanish arrived in the New World, the Inka empire had developed and employed a labor system called the *Mit'a.* The *Mit'a* in the Inka empire was a kind of tribute system in which labor would be given to the Inka government; it was mandatory public service. Citizens, and generally males between the age of 15 and 50, were required to perform this mandatory labor for the Inka empire for a set number of days throughout the year while the rest of the year was devoted to the individuals own land and family obligations. In return for their labor, the Inka state reciprocally provided food, land rights, water usage rights, and so forth. While the term *Mit'a* is used to describe this system used by the Inka, the term *Mita* is used to describe a similar labor system with a very different intent used by used by the Spanish colonial government in a one-way extraction labor from the native population.

The Spanish used the *Mita* labor system to abusively extract free labor from the indigenous population, characterizing it as a form of tribute to the Spanish crown. Under the *Mita* system, indigenous peoples would provide agricultural labor, work in textile mills, or work in the mines. Working in the mines was the most common form of labor for natives under the *Mita* system. The main difference is that under the Inka controlled *Mit'a*, workers were only required to participate in the mandated labor for a set number of days and then they could return home and work their own land, which would provide them with a steady income for their family. However, under the Spanish run *Mit'a*, while individuals were also mandated to only work for a set number of days, the conditions in which they were working changed Unlike under the *Mit'a*, workers in the *Mita* system were required not only to give up days working on their farm or land for an income, but they were also required to pay taxes and were responsible for purchasing their own food while on the job. While they were working for next to nothing in the mine, mill, or Spanish-owned farm, they were required to pay out of pocket for these expenses that they could not afford, leaving them in debt. Workers could often not pay off their debt and could not leave the job until they were able to pay, making it impossible for workers to leave their *Mita* job and return home to their families and land, where they previously were able to make a living under the old *Mit'a* system. By 1540, the stress of the colonial reality began to assert itself among the Muchik (Klaus, 2008, 313). As the Spanish population continued to increase in the Lambayeque Valley Complex region, native labor extraction continued to increase in demand as well. In addition, the "free" native labor began to run into ever increasing mandated tribute quotas that natives could never achieve. The work that natives experienced under Spanish rule was very different from anything they were use to in terms of physical labor, so it is expected that the prevalence of DJD and trauma would be elevated in adults who found themselves trapped in this new

Mit'a system. In addition, men will more often be affected than women in these situations, as men were often the ones being drafted into the labor system.

3.3 – Conclusions

The Lambayeque Valley region covers an expansive area of the includes north coast and include many different and unique microenvironments that make any area unlike any other in the region. The Lambayeque Valley and its surrounding territories have experienced several different sociopolitical climates that built upon one another to get to where we are today with modern Peru. Along the sociopolitical change route came the colonization of the area. Seeing how expansive the region is and how each environment is unlike any other, it would be interesting to see how different areas consisting of different environments were affected by one similar event: colonization by the Spanish. Some might think that Spanish colonization would affect each area similarly; they are all being affected by the same political climate after all. But where each of the different areas and communities affected in a similar way? In the next chapter, there will be a close examination of the archaeological context of the two Muchik samples of Mórrope and Eten. In addition, explanations of the statistical tests used to compare Mórrope and Eten will be described.

CHAPTER FOUR:

MATERIALS AND METHODS

This chapter presents a description of the materials and methods used in this study exploring how degenerative joint disease may have differed across the postcontact adaptive transition in Mórrope and Eten. First, archaeological and bioarchaeological backgrounds on the sites and skeletal assemblages are provided. Second, scoring and data collection protocols are described. Third, the mathematical bases of the statistical procedures used in the data analysis are detailed.

MATERIALS

4.1 – Archaeological Contexts

4.1.1 – Eten

Eten, likely known as Ätim in the late pre-Hispanic era, is located in the southwest corner of the Lambayeque region on the Reque river. Local lore states the town started out as a small economically specialized fishing village, and around the late 1530s or so, the construction of a small mission church was undertaken. In the late 1500s, Eten's population reached nearly a thousand individuals, and ethnohistoric sources characterize it as one of the more demographically and economically stable communities found in the Lambayeque region (Cook, 2004; Ramírez, 1996; Klaus and Alvarez-Calderón, 2017). The area surrounding Eten contains several thousands of years of human presence, beginning in the Preceramic era all the way to the Chimú occupation. While there are few records of the area, the primary source of information about Eten comes in the form of aforementioned oral history and local lore from people in the area. These histories state that around 1533, a missionary encountered the settlement of Ätim (soon to be renamed Eten) and later established a mission in the area. Over several decades, it outgrew the small mission church and upgraded to a larger church called the Church of Santa Maria de Magdalena de Eten (CSMME) in the mid-1600s. Eten was subsequently abandoned sometime between 1740 and 1760 due to the northward expansion of sand dunes into the area, forcing locals out of the area.

Figure 4.1 - Church of Santa Maria de Magdalena de Eten. Photo by and courtesy of Haagen Klaus.

A popular traditional narrative states that in 1647, when the CSMME church was still in use, three divine apparitions of the Christ Child appeared to church officials. Word spread of this divine event, making CSMME a pilgrimage site for many worshipers, even into modern times. After the area was abandoned, another church was constructed around 1776 to commemorate a supposedly miraculous rescue of the Spaniard Miguel Castillo's ship just off the Eten coast (Klaus and Alvarez-Calderón, 2017). This apparition of Christ Child is said to have saved a vessel that was in peril in a sudden storm just off of the beach. The ship's captain, Castillo, constructed a new church on the site as thanks for sparing his life and commemorating the miraculous experience that Castillo claims took place that day. This new structure was named the Chapel of the Nino Serranito (CNS). CNS was abandoned around 1900 but was never officially consecrated as a church by the bishop of Chiclayo. Subsequent excavations of the CNS by Klaus and colleagues in 2010-11 intended to document the mortuary sample of a Late Colonial/Republican era sample. However, excavators soon realized that the CNS had the ruins of a smaller, Early Colonial church hidden below its structure. "Multiple and independent lines of stratigraphic, architectural, temporally linked stylistic variation of grave goods and other evidence indicate that this was the first mission church of Eten," Captain Castillo had in fact built the CNS atop the mission church ruins in the 1770s (Klaus and Alvarez-Calderón, 2017). This site was home to three distinctly different occupational time periods that were able to be archaeologically documented in Eten: an Early/Middle Colonial phase, a Middle/Late Colonial phase, and a Terminal Colonial and Republican era phase.

Excavations of the CNS level yielded 243 single-inhumation burials. The entire sample contains at least 450 individuals when the isolated bones, disturbed contexts, and commingled assemblages containing at least an additional 197 individuals are added. Excavations of the CSMME yielded 256 funerary contexts, plus an additional 52 individuals in the form of secondary burials, commingled remains, and disturbed contexts, providing an MNI of 308 individuals found in the Middle/Late Colonial sample. These disturbed contexts were produced as the population in Eten was reusing the land and cemetery space throughout history. Additionally, there were no pre-Hispanic burials found in Eten (Klaus and Alvarez-Calderón, 2017). These samples were examined for standard macroscopic signs of systemic biological stress or other pathological conditions, including examinations of linear enamel hypoplasias (LEHs), porotic hyperostosis, nonspecific periostitis, female fertility, DJD prevalence, traumatic injury, and oral biology (such as dental carries and antemortem tooth loss prevalence). Findings of these examinations are detailed below.

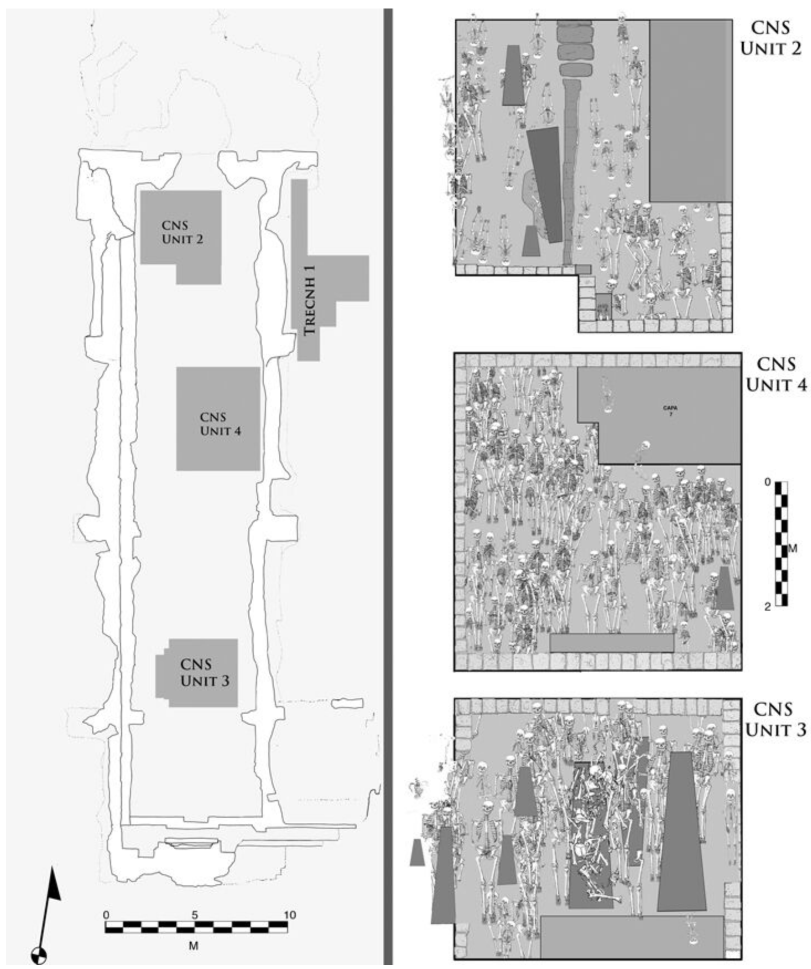

Figure 1.2 - CNS Plan Map from Eten Site. Map by and courtesy of Haagen Klaus.

4.1.2 – Mórrope

Located 803 km north of Lima on the northwest perimeter of the Lambayeque Valley Complex lies the modern town of Mórrope. Here, large-scale excavations and analysis took place by Haagen Klaus and Manuel Tam between 2004 and 2006 at the ruins of the Chapel of San Pedro de Mórrope. Three hundred and twenty-two burials were recovered with the remains of at least 867 individuals documented (Klaus et al., 2009). Stratification of the Early/Middle and Middle/Late Colonial periods was observed and further validated using seriation and correspondence analysis of mortuary pattern variation. Occupation of the immediate area surrounding Mórrope goes back to at least the Late Moche era between 550 and 800 AD and is currently still inhabited by individuals of Muchik descent (Klaus and Alvarez-Calderón, 2017). Mórrope was established quickly as a colonial town as early as 1536. The location of Mórrope was quite advantageous for the Spanish colonists, as the town was located at one end of a trading route in which goods, information, and people traveled the desert between Lima, Lambayeque, and Piura (Klaus and Alvarez-Calderón, 2017).

Established in June of 1536, the Chapel of San Pedro de Mórrope was constructed during the 16th-century occupation of the Peruvian Colonial period. The Chapel was created to assist the Spanish effort to convert the indigenous Muchik people into Christians. Architecturally, the Chapel of San Pedro de Mórrope was constructed using pre-Hispanic methods and traditional materials, such as adobe, reeds, and *quincha*. The most interesting element of the Chapel of San Pedro de Mórrope is considered to be the stepped-pyramid style alter found inside the chapel. "Unlike standard altar designs that involve a pedestal base and large flat table facing to the west, the north-facing alter takes the form of a 3.5 meter tall, three-dimensional stepped pyramid that abutted the south wall of the chancel and has no recognizable base or table" (Klaus, 2008, 413). The stepped pyramid motif had a supernatural significance during the Moche period and Middle Sicán era. It is believed that the stepped pyramid possibly represents an abstracted mountain or *huaca* (sacred object or monument). The pyramid motif is believed to embody the supernatural supremacy connected to the forces of ancestors, nature, and draw the powerful mountain realm into human agency and authority (Klaus, 2008). The site was subsequently abandoned between the 1720s and 1750s.

Figure 4.3 - The Chapel of San Pedro de Mórrope. Photo by and courtesy of Haagen Klaus.

Excavations of the Chapel of San Pedro de Mórrope took place between 2004 and 2006 as a part of the Lambayeque Valley Biohistory project headed by Haagen D. Klaus. This investigation sought to define the effects of contact and colonization on the Muchik in Mórrope, including their biological stress patterns, physical activity, genetic diversity, and mortuary rituals (Klaus, 2008). These individuals were buried sometime between the 1530s and 1750s, spanning the Early/Middle and Middle/Late colonial periods of the Lambayeque region. Bioarchaeological analysis of the individuals buried at the Chapel was conducted by Klaus and Tam (2009, 2010) and Klaus et al. (2009) by using a subsample of 139 individual adult skeletons. Their findings showed a large range of statistically significant differences between the sample at Mórrope and regional pre-Hispanic patterns.

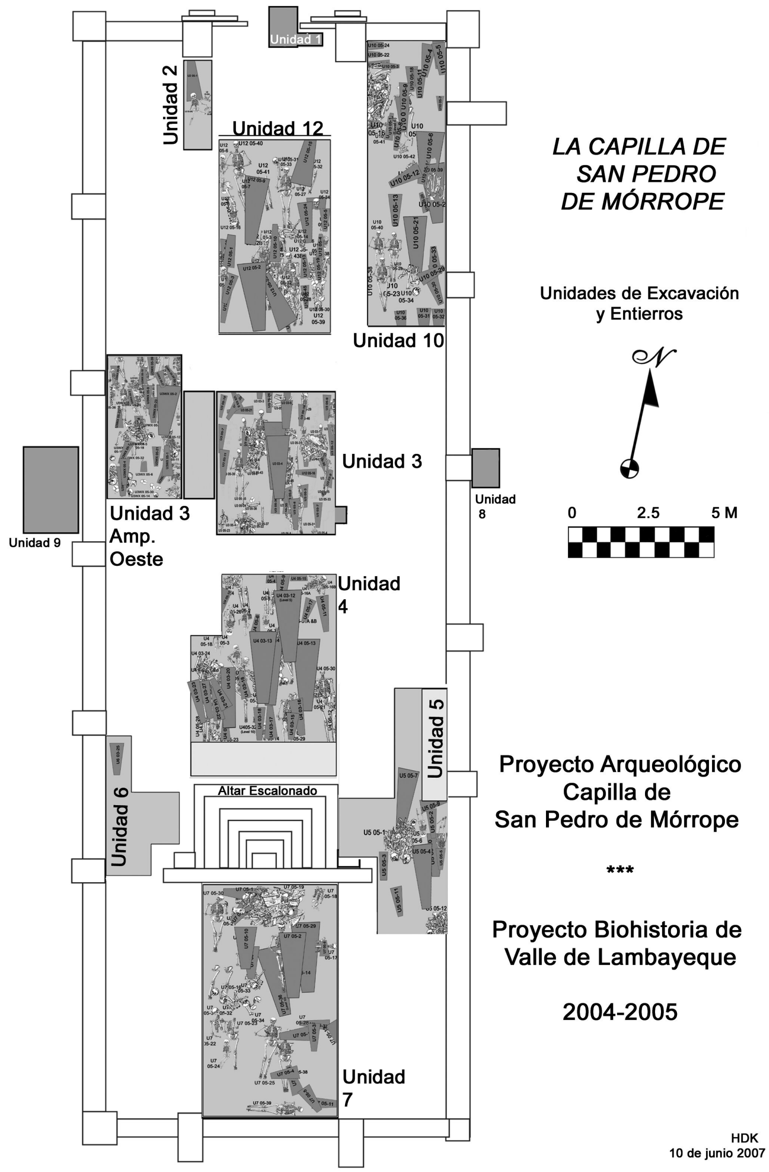

Figure 4.4 – CSPM Plan Map from Mórrope Site. **Map by and courtesy of Haagen Klaus.**

In terms of biological stress and other pathological abnormalities, the Mórrope sample from the Chapel demonstrated very high morbidity. Rates of nonspecific periosteal infection and childhood anemia were very high among the Mórrope sample, as well as the stunting of subadult growth in the younger population. Female fertility also appeared to decline among the women found in the Mórrope sample. In surprising contrast, enamel hypoplasia (EH) prevalence among the population seemed to decline rather than increase, which would be expected considering all of the other pathological responses found in the sample. However, Klaus and Alvarez-Calderón (2017) argue that this increase in EH prevalence is not a reflection of better health among the young in this sample but may have been produced by a shift towards new forms of acute childhood stress driving elevated childhood mortality. In short, the infants and children in this sample may not have lived a long enough time or survived biological stress events for EHs to develop on their dentition. In addition to the lowered prevalence of EHs on the dentition, Mórrope exhibits all over poorer oral health when compared to other areas of the same time period. This decline in oral health could be caused by a shift in diet to one that had a great reliance on starchy foods, such as maize. Finally, the prevalence of DJD was also elevated in this sample among many different joint systems of individuals. This is consistent with the ethnohistoric descriptions of the intense physical labor extraction of the native populations by the Spanish in the Lambayeque Valley Complex.

Previous work by Klaus et al. (2009) demonstrated that the indigenous Muchik population of the Lambayeque region on the northern coast of Peru experienced a rise in mechanically stressful activity during the Colonial period. They found that there were statistically significant patterns of elevated DJD prevalence in the indigenous population in Mórrope, Peru after the Spanish conquest in multiple joint systems, including the shoulder, elbow, wrist, and knee (Klaus et al., 2009). These changes are interpreted as reflecting an intensification of labor among the indigenous peoples of the Lambayeque after the Spanish occupied the area. "A statistically significant elevation of DJD in the joint systems of the upper lib is observed: the post-contact shoulder joint is 2.2 times more likely to be affected by DJD than the late pre-Hispanic population, elbow prevalence increases 2.7 times, and DJD is 5.6 times greater in the wrist," in the lower limbs, only the knee was found to have a significant change in DJD prevalence, around 3.6 times greater in postcontact samples (Klaus et al., 2009, 210). In addition, it was observed that males were by far most commonly affected by the elevated rates of DJD. The only joint where DJD risk was greater in pre-Hispanic women was the hip joint.

While Klaus et al. (2009) focused on the prevalence of DJD among pre- and postcontact sites in Lambayeque, there has yet to be an examination of the differential severity of DJD found within this ancient population. Further, the broad-stroke nature of the past work in Lambayeque lumped different expressions of DJD together as presence and absence data. This effectively treated osteophytosis, porosity, and eburnation equally.

This work uses data previously collected by Klaus et al. (2009) along with data from nearly 500 additional adult individuals excavated by the Lambayeque Valley Biohistory Project over the intervening decade to examine the differences of the types of DJD expression and severity found in two different Colonial sites in the Lambayeque region in Peru. Given the hypotheses outlined in Chapter 1, greater prevalence and the severity of DJD will be found in the Mórrope sample when compared the Eten sample. This hypothesis is based on previous analyses, which found that Mórrope has an increased prevalence of several different pathological conditions. It is possible to test this using several different types of statistical analyses. By analyzing results from *z*-tests, odds ratio results, and Mann-Whitney U statistical testing, the type of DJD and the severity of these expressions between the Mórrope and Eten samples can be evaluated.

4.2 – The Skeletal Samples

For this study, skeletal data was collected from three different colonial Muchik samples in the Lambayeque Valley Complex of Peru: the Chapel of San Pedro de Mórrope (CSPM), the Chapel of the Nino Serranito (CNS), and the Church of Santa Maria de Madalena de Eten (CSMME). Haagen D. Klaus and Peruvian co-director Manuel Tam recovered the Mórrope sample between 2004 and 2006 while Haagen D. Klaus, Peruvian co-director Rosabella Alvarez-Calderón, and Klaus's students excavated the Eten samples between 2009 and 2011. While information has been collected at each site concerning the presence, type of expression, and severity of DJD, only presence and absence has been closely evaluated. Klaus et al. (2009) and Klaus and Alvarez-Calderon (2017) have both previously examined at the DJD prevalence between two the different Muchik communities of Mórrope and Eten.

The Chapel of San Pedro de Mórrope (CSPM) investigation sought to define the effects of contact and colonization on the Muchik in Mórrope, including expressions of biological stress, physical activity, genetic diversity, and mortuary rituals (Klaus and Alvarez-Calderón, 2017). During this excavation, 322 burials were recovered using a representative cemetery sample strategy (Klaus et al., 2009). These burials yielded at least 867 individuals dated to the Early/Middle Colonial and Middle/Late Colonial periods (between the 1530s and 1750s) and appear to represent individuals of a low-status Colonial Muchik population. Analyses of DJD lesions buried at the Chapel were conducted by Klaus et al. (2009) by using a subsample of 139 individual adult skeletons. Their findings show a large range of statistically significant differences between the sample at Mórrope and other regional health patterns found in the Lambayeque Valley Complex in the late pre-Hispanic era.

In this study, data from 867 individuals collected from the Mórrope sample were assessed. Individuals with complete joint systems were studied to see if there was a presence of DJD found in any of the joint systems. These joint systems include the shoulder, elbow, wrist, hands, cervical spine, thoracic spine, lumbar spine, hips, knees, ankles, and foot, which can be seen in Table 1. Of the individuals accounted for in this study, 263 individuals with any number of complete joint systems were found to have evidence of DJD. While 263 of these individuals have DJD present in their joint systems, it is impossible to infer the exact number of individuals with DJD present, as many individuals were missing various joint surfaces that may or may not have had evidence of DJD. Individuals were classified into six standard different age classes (Table 2) including those whose age could not be estimated. The age of each individual was estimated using the summary age statistic (Lovejoy et al., 1985), which is calculated based on a principle component analysis of an internally consistent seriation of pubic symphysis, auricular surface, cranial suture closure, and dental wear indicators for the pre- and postcontact Lambayeque populations (Klaus, 2008; 2009). Because DJD is a disease in which new cases arise for the first time in an individual's adult life and the probability of affliction steadily increases with age, only age classes 3 and above were considered in this examination (Waldron, 1994). After the data was winnowed down to only include those with at least one joint system and within the specified age categories, 70 individuals remained in the CSPM sample of which are suitable for analysis.

Table 4.1: Joint Systems as defined in this work, based on Klaus et al. (2009)

Joint System	Consists of:
Shoulder	Proximal end of the Humerus; the Glenoid Fossa
Elbow	Distal Humerus; Proximal Radius; Proximal Ulna
Wrist	Distal Radius; Distal Ulna; Carpals
Hand	Metacarpals; Manual Phalanges
Cervical Spine	Vertebrae C1-C7
Thoracic Spine	Vertebrae T1-T12
Lumbar Spine	Vertebrae L1-L5
Hip	Proximal Femur Bone; Acetabulum
Knee	Distal Femur Bone; Patella; Proximal Tibia
Ankle	Distal Tibia; Distal Fibula; Tarsals
Foot	Metatarsals; Pedal Phalanges

The Eten sample contains two different skeletal assemblages from two immediately adjacent church ruins. Additional examination of the Eten site found that there were no indications of pre-Hispanic burials found in Eten (Klaus and Alvarez-Calderón, 2017). These skeletal remains were examined for systemic biological stress and related pathological conditions, including of linear enamel hypoplasias (LEHs), cranial porotic hyperostosis, nonspecific periostitis, female fertility, DJD lesions, traumatic injury, and oral biology (such as dental carries and antemortem tooth loss prevalence). After data winnowing, 126 individuals were left in the CNS sample and 24 remained in the CSMME sample for examination.

Table 4.2 - Age Class Structures, based on Klaus et al. (2009)

Age Class	Approximate Age Range (Years)
1	Newborn – 4.9
2	5.0-14.9
3	15.0-24.9
4	25.0-34.9
5	35.0-44.9
6	45+

4.3 – Expressions of DJD

This work uses three basic biological and morphological categorical expressions to define DJD used to identify the disease in an archaeological human skeleton: joint surface eburnation, marginal osteophytosis, and abnormal joint surface porosity. Of these three expressions, eburnation is the most pathognomonic of degenerative joint diseases since it represents the wearing away and destruction of the cartilage that separates the two bones forming the joint. Osteophytosis is also quite common in DJD, as it is often referred to as a reparative measure where the body tries to stabilize a chronically inflamed joint by making the surface wider and, therefore, more stable. However, the third expression, porosity, is often excluded from the criterion for DJD, but this will be explained further below. For the purpose of this study, all three expressions are assessed so as to obtain the most complete picture of the differences in the skeletal samples examined.

Eburnation occurs when the synovial joint breaks down over time, and the two bones, once separated by the synovium, come into contact with one another. As the two bones of the joint are allowed to come in contact with one another without any barrier, the interaction causes their surfaces to become polished. The effect of the two bones rubbing against one another is eburnation and is representative of the most mechanically severe form of joint disease. Aufderheide and Rodriguez-Martin (1998) define eburnation as a smooth and shiny, polished surface produced by bone-to-bone contact in cartilage-free areas during joint movement. The eburnation of a joint surface can be described as having a polished ivory-like appearance, a shining of the bone, or a mirrored surface. Rogers and Waldron (1995) classify eburnation as pathognomonic of osteoarthritis, and that there is no excuse to miss this characteristic on the bone because eburnation is so blatant and recognizable.

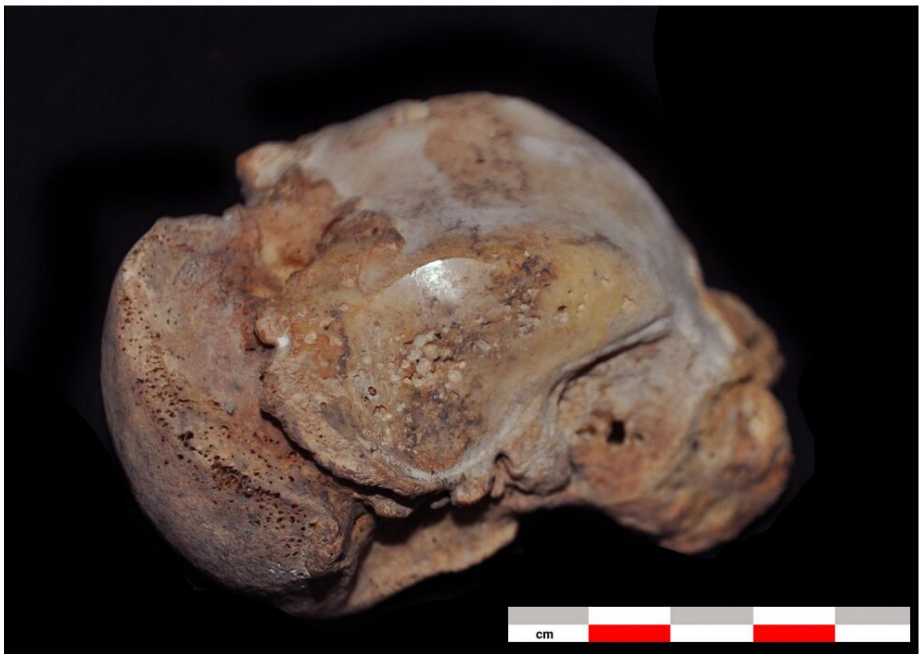

Figure 4.5 - Example of eburnation found on the left talus found in an individual from Eten. Photo by and courtesy of Haagen Klaus.

Osteophytosis is the growth and presence of boney growths or lipping on the bone. Osteophytosis can be expressed through the growth of osteophytes or the presence of marginal lipping on the joint surface. Osteophytes, which are often called colloquially referred to as bone spurs, are irregular growths of new abnormal bone that form around the margins of a joint and may vary in size and shape (Rogers and Waldron, 1995).

Osteophytosis appears to be a way for the joint to try and stabilize itself as a reparative phenomenon associated with joint soft tissue inflammation. While osteophytes can be found in any joint affected by osteoarthritis, they appear more commonly in some areas rather than others. For example, they are seen more often present around the hip and knee joints rather than the ankle. In the hands, osteophytes are seen more commonly in the distal interphalangeal joints than the proximal interphalangeal joints (Rogers and Waldron, 1995). One area of the body that osteophytes are especially common and easy to identify is in the margins of cervical and lumbar vertebral bodies of the vertebral column in both dry bones and in radiographs. This new bone formation at the margins of bone can also be linked with the abnormal calcification of cartilage from the joints affected by arthritis (Aufderheide and Rodriguez-Marin, 1998).

Figure 4.6- Examples of extreme Osteophytosis (or Lipping) Found on Various Bones in Mórrope, from left to right: distal humerus extensive lipping and joint modification; proximal ulane, and; a significantly modified radial head). Photo by and courtesy of Haagen Klaus.

Abnormal joint surface porosity is a final manifestation of osteoarthritis in joint surfaces. Porosity is the presence of an abnormal focus or foci of porous bone loss, a pitting feature to the joint surface, or a non-continuous surface of the subchondral bone. However, there is some debate as to whether porosity should be an indicator of osteoarthritis and degenerative joint diseases or not. This idea is echoed in the work of Ortner (1968; 2003), who has made previous assertions about the use of porosity as a means to identify DJD as well. In his 1968 analysis describing and classifying the presence of DJD in the elbow of two separate sample populations, Ortner described the process that he believed lead to the development of eburnation of the joint surface in individuals with "Atlatl elbow." This process occurs when the superficial layer of the hyaline cartilage begins to break down. As the superficial layer continues to break down, continued motion of the joint leads to the further splitting of the degenerating cartilage along the radially arranged fibers; this act slowly clears away the degenerated cartilage through attrition, making the subchondral bone sclerotic and eburnated (Putschar, 1960; Ortner, 1968). This explains the development of eburnation found in atlatl elbow, but not the development of bone porosity found in the same condition. Ortner explains that porosity almost always occurs with eburnation, yet porosity can be found in joints with no signs of eburnation. Because eburnation is almost always accompanied by some sort of bone porosity, it is possible that the process leading to the development of bone porosity occurs before the process that generates eburnation. Perhaps bone porosity is associated with increased vascularity in the subchondral bone as a response to the destruction of cartilage (Ortner, 1968). As both medical and bioarchaeological research has progressed, Ortner has continued his efforts in trying to explain the root cause and the role of bone porosity in DJD. In the early 2000s, clinicians and researchers alike were still unable to pinpoint the exact cause of this phenomenon. Ortner reiterates in his canonical 2003 work, *Identification of Pathological Conditions in Human Skeletal Remains,* that the arthritic destruction of bone surfaces often expressed as porosity, which is often found with eburnation of the disturbed bone surface, though this is not always the case. However, research of the time suggested that newly formed cartilage strands penetrate through the gaps in subchondral bone that suffers from eburnation. Perhaps this new cartilage formation is what is being seen when porosity is observed (Hough, 2001; Ortner, 2003). Whether or not porosity is used as a criterion for the presence of osteoarthritis, diagnosis of the condition should not be conducted underneath only one of these criterions, multiple measures should be used to identify any condition. It is also possible that multiple conditions can manifest simultaneously in a comorbid fashion and represent different pathogenic processes. If porosity is, in fact, the process of new cartilage formation taking form on subchondral bone or the antecedent to eburnation, it would be important to observe and note bone porosity as a continuation of the degeneration of joint surfaces in the examination of DJD. Therefore, all three expressions of DJD (eburnation, osteophytosis, and porosity) will be used in this study to examine the presence and severity of DJD in the different Colonial sites.

4.4 – Scoring Expressions of DJD

For the data used in this and previous research, the different expressions of DJD were recorded using the standards provided by Buikstra and Ubelaker in their 1994 work *Standards for Data Collection from Human Skeletal Remains.* In this work, Buikstra and Ubelaker developed their classic and widely adopted descriptive scoring system so that workers could categorize with minimal interobserver error the degree to which a joint surface was affected by the three different kinds of DJD expression. Buikstra and Ubelaker (1994) refer to as lipping marginal to the articular surface (osteophytosis), porosity of the surface, and eburnation. In addition to the identification of the presence of these expressions of DJD, Buikstra and Ubelaker (1994) suggest that observers record the extent that a joint surface is affected by these traits or the severity of DJD expression.

Standards provides the following scale: 1, indicating that less than one-third of the joint surface is affected; 2, one-third to two-thirds of the joint surface is affected, or 3, more than two-thirds of the joint surface is affected to indicate the maximum expression of arthritic change in the joint (Buikstra and Ubelaker, 1994). For the sake of this study, the focus remained on the degree of arthritic changes found in the different joint systems of Muchik individuals living in Colonial sites. The following standards created by Buikstra and Ubelaker (1994) were applied: lipping degree, surface porosity degree, eburnation degree. There are different degrees found in each category:

Degree of Osteophytosis (or Lipping):

8.1.1 – Barely discernible

8.1.2 – Sharp ridge, sometimes curled with spicules

8.1.3 – Extensive spicule formation

8.1.4 – Ankylosis

Degree of Surface Porosity:

8.3.1 – Pinpoint

8.3.2 – Coalesced

8.3.3 – Both pinpoint and coalesced present

Degrees of Eburnation:

8.5.1 –Barely discernible

8.5.2 – Polish only

8.5.3 – Polish with grooves

For the data point collected, columns were created in an excel spreadsheet for each joint system followed by an expression (e.g., shoulder porosity, knee eburnation), if that expression was found in that joint system, a value of 1 was given to that category. Then, severity was measured using different columns specifically looking at each joint system and expression, similar to the previous measurements (i.e., elbow osteophytosis severity, ankle porosity severity). Depending on the severity of the expression noted on the inventory sheets, the maximum expression was recorded using a numerical system from 1 to 3. For instance, if 8.1.2 was recorded for the proximal humerus of an individual on the inventory for an individual, then osteophytosis would be marked as present (1) for the shoulder of the individual with a severity value of 2.

4.5 – Statistical Procedures

To explore the presence of DJD between the two different colonial sites, the joints of load-bearing joint systems were scored where at least half of the joint surface was present following Buikstra and Ubelaker (1994). The systems examined included the shoulder, elbow, wrist, hand, cervical spine, thoracic spine, lumbar spine, hip, knee, ankle, and foot joint systems. Data on the joint systems was recorded as present or absent of each system. DJD was scored for a system if any one or combination of the three principle expressions of DJD were observed (osteophytosis, porosity, or eburnation). Once all of the information on the joint systems was collected in a Microsoft Excel spreadsheet, *z*-tests were ran to evaluate whether the number of individuals in each age class (3-6) were proportional between the two groups. Using the common pooled proportion to estimate the variance between the two samples, *z*-tests use an analysis of independent samples to compare the independent proportion of the samples. *Z*-tests can explain whether the two populations being compared differ significantly, in this case, by their age class. *Z*-scores were found by using an online *z*-score calculator (https://www.socscistatistics.com/tests/ztest/Default2.aspx), which used the formula:

$$z = \frac{(x - \mu)}{\sigma}$$

Odds ratios (ORs) were then calculated in order to quantify the differences between the two postcontact populations. An odds ratio is a summary statistic that expresses the overall prevalence difference between two different populations as a proportion relating to their age structures. An odds ratio was chosen over crude prevalence rates as crude prevalence can often alter the true prevalence by either artificially increasing or decreasing the measurement in cases of samples having non-identical age structures. If the two populations being compared have different distributions of determinants of disease (in this case, age-at-death), this difference in distribution can cause a misrepresentation in the comparison of the population, a confounding distortion. Odds ratios are calculated using the following equation provided by Waldron (2007):

$$OR = \frac{p_1/(1-p_1)}{q_1/(1-q_1)} + \frac{p_2/(1-p_2)}{q_2/(1-q_2)}$$

ORs were calculated between the Mórrope and Eten samples, comparing all individuals that fell into the four older age classes (3, 4, 5, and 6). As mentioned in the materials section above, younger individuals categorized in age classes 1 and 2 were not used in this study, the more chronic nature of DJD would not have enough time to have developed by the age in which these individuals died, and thorough examination of their joint showed no signs of articular abnormalities. In addition, those whose age was unknown were also omitted from the OR analysis. Four hundred and forty-two individuals were omitted from the Mórrope site while 384 individuals were omitted from the Eten site for being in age classes 1-2. In terms of interpretation of results, if the prevalence is higher in the first population of Mórrope, then the OR would be greater than or equal to 1, and if the prevalence is higher in the second population of Eten (CNS and CSMME), then the OR would be less than or equal to 0.99 (Klaus et al., 2009). The ORs for each joint system was calculated separately by age cohort using a custom program in SAS 9.4 (SAS Institute, 2003). From here, the common odds ratio was calculated. The common odds ratio is a summary statistic that indicates the overall prevalence differences between two different populations as an age-related proportion and considers age-related proportional prevalence patterns in the data (Waldron, 1994; Klaus et al., 2009).

The final step involves the calculation of nonparametric Mann-Whitney U tests on both of the samples to compare the type of DJD expression and severity. A Mann-Whitney U test is used to compare the differences between two independent samples when the dependent variable (in this case, variables) is either ordinal or continuous and is not normally distributed. Since the data in this study is labeled in ordered categories and the distances between the categories is not known, the data are considered ordinal. To compare how the samples differ, the data for each site was imported into SPSS 21. Six different Mann-Whitney U tests were run, the first three consisting of the types of expression compared between the two samples (osteophytosis, porosity, and eburnation) and the final three comparing the severity of each type between Mórrope and Eten (osteophytosis severity, porosity severity, and eburnation severity). The Mann-Whitney U test formula can be found below, where U=Mann-Whitney U test, N_1 stands for the first sample size, N_2 stands for the second sample size, and R_i is the rank of the sample size.

$$U = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - \sum_{i = n_1 + 1}^{n_2} R_i$$

4.6 – Conclusion

Statistical procedures can empirically document the differences (if any) in the type of expression and severity of DJD in the Mórrope and Eten skeletal samples. While there have been previous debates about which types of osteoarthritic expressions are viable to understanding the occurrence of DJD in a sample, all three expressions (osteophytosis, porosity, and eburnation) all are important factors in understanding the DJD of the individuals with the condition. In fact, forgoing study one of these expressions could lead to a flawed and incomplete analysis. Archaeological contexts are helpful in gaining information about how individuals in each sample lived, as well as their surrounding environments. This is vital to interpreting how and why the two samples could differ in their types and severity of DJD. The z-test demonstrates whether or not the two samples have significant proportions differences between their age class structures. The odds ratios demonstrate overall prevalence patterns between two different populations in terms of the presence and absence of DJD. Finally, Mann-Whitney U tests can evaluate if there are statistically meaningful variations between each individual joint system between the two samples in terms of both type and severity. Next, Chapter 5 presents the results of these tests.

CHAPTER FIVE:

RESULTS

5.1 – Introduction

This chapter presents the results of the three different statistical analyses that were run using both SPSS 21 and SAS 9.3. The first that was used was the Z-test, which was used to determine if the two samples possessed proportional age classes. The second was an odds ratio (OR) test. The OR test was used to compare DJD prevalence, or more precisely, understand if the two samples had the same chances of having DJD. Finally, Mann-Whitney U tests were used to compare the distribution of DJD expressions and severity patterns across the Mórrope and Eten skeletal samples. Univariate data is presented in Table 5.1 below depicting the total percentage affected by DJD, in any of the three expressions tested. Table 5.1 shows that over 50% of individuals from both sites are affected by DJD in some way and, surprisingly, the Eten sample has a higher percentage affected than the Mórrope sample.

Table 5.1 – Univariate Data for Samples for any type of DJD

Site	Unaffected	Affected	Total	% Affected by DJD
Mórrope	136	195	331	58.91%
Eten	59	89	148	60.14%

5.2 – *Z*-tests

Z-test scores were calculated by using an online *z*-score calculator located at <https://www.socscistatistics.com/tests/ztest/Default2.aspx>. Age classes 3, 4, 5, and 6 were compared between Mórrope and Eten. Each age classes in both samples was tested to see if there was a significant difference at the $p \leq 0.05$. The *z*-test shows whether or not the two samples have significant differences in the size or proportions of their age class structures that could skew or even disallow direct comparison.

Age class 3 was the first to be calculated and achieved a *z*-score between Mórrope and Eten samples of 1.3915 ($p = 0.16452$). Age class 4 comparisons generated a *z*-score of -0.004 and the probabilities of identical proportions was the same ($p = 1.0$). Comparisons between age class 5 featured a *z*-score of 1.1232 ($p = 0.26272$), and again, no significant difference was present. Similarly, age class 6 comparisons produced a *z*-score of 0.3438 ($p = 0.72786$), showing no significant proportional difference between Mórrope and Eten. The final age class (those whose ages could not be estimated) had a calculated *z*-score of -0.5807 ($p = 0.61006$).

In short, all *z*-tests found that there was no significant difference between the two skeletal samples in any of the age classes used in the analysis. This means that the age distributions in both of samples are proportional and that there is no significant difference between the age categories between the Mórrope and Eten collections. This allows for the direct statistical comparison of the two samples.

5.3 – Odds Ratio Results

Common odds ratio results show that in nearly every joint system, individuals from Mórrope had higher prevalence and greater odds of being affected by DJD in multiple joint systems than those people represented in the Eten sample (Table 5.2). DJD in Mórrope shoulder joints yielded a higher OR in every age category. However, since there were no individuals in the Mórrope sample that did not have DJD in the fifth age class, the program could not run a mathematically valid calculation for that age class. Overall, all age classes with DJD in the shoulder produced a common odds ratio of 4.37. As with the shoulder DJD, both the elbow and wrist ORs for each age class in Mórrope also yielded higher results in each age category, producing common odds ratio results of 2.09 and 4.02 respectively, which is statistically significant. DJD in the hand joint system is the first instance of age categories having a higher OR in the Eten sample (categories 4 and 5). This, too, is statistically significant. However, the common odds ratio remains high and shows a higher comparative prevalence in the Mórrope sample ($\hat{O}R = 2.49$). All three vertebral column joint systems demonstrate ÔRs that show higher odds of DJD occurring in the Mórrope sample. In addition, all inferior appendicular joint systems, excluding the joint systems of the foot, produce common odds ratios demonstrating that individuals in Mórrope have higher odds of having DJD in their lower limb joint systems. In contrast, ÔRs for the joint system of the foot (including metatarsals and pedal phalanges) have relatively higher chance of DJD lesion presence in Eten when compared to the Mórrope sample.

Figure 5.1 – First right metatarsal from an individual in the Eten Sample displaying abnormal osteophytosis of the distal joint surface. Photo by and courtesy of Haagen Klaus.

Table 5.2 - Odds Ratio Results: for age classes 3-6 between Mórrope and Eten

Joint System	OR - Age Class 3	OR - Age Class 4	OR - Age Class 5	OR - Age Class 6	ÔR*	Interpretation:
Shoulder	5.7	3.5	.	1.44	4.37	Statistically significant higher prevalence in Mórrope
Elbow	2	2.83	1.11	2.5	2.09	Statistically significant higher prevalence in Mórrope
Wrist	.	1.6	2	11.4	4.02	Statistically significant higher prevalence in Mórrope
Hand	.	0.51	0.48	11.11	2.49	Statistically significant higher prevalence in Mórrope
Cervical Vert.	1.58	1.03	1	3.42	1.62	Statistically significant higher prevalence in Mórrope
Thoracic Vert.	3.45	0.65	2.63	3.29	1.62	Statistically significant higher prevalence in Mórrope
Lumbar Vert.	.	2.42	1.5	1.47	2.39	Statistically significant higher prevalence in Mórrope
Hip	.	1.47	1.18	1.14	1.07	Statistically significant higher prevalence in Mórrope
Knee	.	2.64	1.04	4.15	2.12	Statistically significant higher prevalence in Mórrope
Ankle	.	1.4	1.5	2.4	1.88	Statistically significant higher prevalence in Mórrope
Foot	.	0.28	1.03	0.9	0.74	Statistically significant higher prevalence in Eten

***ÔR represents the common odds ratio for each joint system.**

5.4 – Mann-Whitney U

All three types of DJD expressions, as well as the severity of those expressions, were examined using a Mann-Whitney U test in SPSS 21 to identify whether the distribution of these characteristics was the same between the Mórrope and Eten samples. The Mann-Whitney U results can be found in tables 5.3-5.8 below.

5.4.1 – Type of Expression: Osteophytosis

Mann-Whitney U tests were used to identify if the distribution of osteophytosis in each of the joint systems was the same across the Mórrope and Eten samples. The univariate data of osteophytosis presence can be found in Table 5.3. This table shows that 57.14% of individuals in the Mórrope sample were affected by osteophytosis from DJD while 47.30% were affected from the Eten sample.

Table 5.3 - Univariate Data of Samples: Osteophytosis Presence

Site	Unaffected	Affected	Total	% Affected by Osteophytosis
Mórrope	39	52	91	57.14%
Eten	78	70	148	47.30%

All superior joint systems differed in osteophytosis distribution expression across the samples. Distribution of osteophytosis in the shoulder joint systems was different across the two samples, with manifestations of osteophytosis greater and strongly significant in the Mórrope sample ($p < 0.001$). Osteophytosis occurring in the elbow joint systems was also different across the two samples, again, with manifestations of osteophytosis being more common in the Mórrope sample ($p = 0.001$). Osteophytosis of the wrist was a third system that differed between samples, with Mórrope again demonstrating greater prevalence than the Eten sample ($p < 0.001$). The final superior appendicular joint system, the hand joints, demonstrates Mórrope individuals possessing greater proportional manifestations of osteophytosis in these joint systems as well ($p = 0.001$). This shows a greater expression in the Mórrope sample.

As with the superior joints, the joint systems of the vertebral column also all differed in their distribution of osteophytosis between the two samples. The cervical vertebrae joint system distribution of osteophytes demonstrated that the Mórrope sample possessed significantly greater osteophytic expressions ($p = 0.019$). Osteophytosis of the thoracic vertebrae also differed between the two samples with significantly greater expression in Mórrope ($p = 0.037$). Finally, the lumbar vertebrae differed in osteophyte expression, with higher prevalence in Mórrope ($p= 0.002$).

The joints of the lower limb differed little in osteophyte prevalence and the patterns were mostly equivalent between the Mórrope and Eten. The knee was the only joint system that differed with significantly greater osteophytic expressions in Mórrope, showing that expression of osteophytosis was greater in Mórrope ($p < 0.001$). The hip, ankle, and foot joint systems all demonstrated statistically insignificant variation of osteophyte expression across all samples (respectively, $p = 0.480$; $p = 0.260$; $p = 0.646$).

Table 5.4 – Mann-Whitney U Test Results: Osteophytosis

Null Hypothesis	Significance	Results
The distribution of shoulder osteophytosis is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope
The distribution of elbow osteophytosis is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope
The distribution of wrist osteophytosis is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope
The distribution of hand osteophytosis is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope
The distribution of cervical vertebrae osteophytosis is the same across both sites	0.019	Statistically significant difference of greater expression in Mórrope
The distribution of thoracic vertebrae osteophytosis is the same across both sites	0.037	Statistically significant difference of greater expression in Mórrope
The distribution of lumbar vertebrae osteophytosis is the same across both sites	0.002	Statistically significant difference of greater expression in Mórrope
The distribution of hip osteophytosis is the same across both sites	0.480	No statistically significant difference in expression between sites.
The distribution of knee osteophytosis is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope
The distribution of ankle osteophytosis is the same across both sites	0.260	No statistically significant difference in expression between sites.
The distribution of foot osteophytosis is the same across both sites	0.646	No statistically significant difference in expression between sites.

5.4.2 – Severity of Osteophytosis

The patterning of osteophytosis severity between the two samples differed in every joint system in the superior appendicular skeleton, with Mórrope individuals reflecting a higher degree of severity in every instance. The distribution of the severity of osteophytosis was different between the two samples ($p < 0.001$). This shows severity was greater in Mórrope when compared to the Eten sample. The same is true for the severity in the wrist joint systems ($p = 0.001$). The severity of osteophyte expression was distributed differently ($p < 0.001$). Osteophyte expression severity in the wrist was also different between Mórrope and Eten, with severity being greater in Mórrope ($p < 0.001$).

Two of the three systems in the vertebral column joints were also found to have a different distribution of osteophyte expression severity between the two samples. The cervical vertebrae had a different distribution of osteophyte expression severity between the samples, with Mórrope having a higher patterning of severity ($p = 0.034$). In addition, the lumbar joint system also differed between samples in terms of the severity of osteophytosis, again with Mórrope having a higher degree of severity ($p = 0.002$). Severity of osteophytosis in the thoracic joint system was found to be the same across both of the samples ($p = 0.077$).

The last class of joint systems examined was the inferior appendicular joints, which only had one instance of having the severity of osteophytosis differ between the Mórrope and Eten samples. This difference was again found in the knee joints, with Mórrope individuals demonstrating a greater degree of severity than the Eten sample ($p < 0.001$). The hip, ankle, and foot, had statistically equivalent distribution of osteophytic severity patterning (respectively, $p = 0.504$; $p = 0.355$; $p = 0,687$) and thus did not differ between Mórrope and Eten.

Table 5.5 - Mann-Whitney U Test Results: Osteophytosis Severity

Null Hypothesis	Significance	Results
The distribution of shoulder osteophytosis severity is the same across both sites	0.581	No statistically significant difference in expression between sites.
The distribution of elbow osteophytosis severity is the same across both sites	0.066	No statistically significant difference in expression between sites.
The distribution of wrist osteophytosis severity is the same across both sites	1	No statistically significant difference in expression between sites.
The distribution of hand osteophytosis severity is the same across both sites	1	No statistically significant difference in expression between sites.
The distribution of cervical vertebrae osteophytosis severity is the same across both sites	0.04	Statistically significant difference of greater expression in Mórrope.
The distribution of thoracic vertebrae osteophytosis severity is the same across both sites	0.585	No statistically significant difference in expression between sites.
The distribution of lumbar vertebrae osteophytosis severity is the same across both sites	0.493	No statistically significant difference in expression between sites.
The distribution of hip osteophytosis severity is the same across both sites	0.494	No statistically significant difference in expression between sites.
The distribution of knee osteophytosis severity is the same across both sites	0.523	No statistically significant difference in expression between sites.
The distribution of ankle osteophytosis severity is the same across both sites	0.32	No statistically significant difference in expression between sites.
The distribution of foot osteophytosis severity is the same across both sites	0.562	No statistically significant difference in expression between sites.

5.4.3 – Type of Expression: Porosity

The expression of abnormal joint porosity between the two samples demonstrated broadly similar patterning with the results for osteophytosis. That is, a majority of the differences between Mórrope and Eten are present in the superior appendicular joint systems. The univariate data of porosity presence can be found in Table 5.6. This table shows that 36.26% of individuals in the Mórrope sample were affected by porosity from DJD while 17.57% were affected from the Eten sample. Both of these percentages are significantly less than those found from osteophytosis presence.

Table 5.6 - Univariate Data for Samples: Porosity Presence

Site	Unaffected	Affected	Total	% Affected
Mórrope	58	33	91	36.26%
Eten	122	26	148	17.57%

The distribution of porosity in the shoulder joint systems is clearly unequal between the two samples, with Mórrope having greater expressions of porosity ($p < 0.001$). In addition, distribution of porosity in the hand joint systems differs across samples ($p = 0.039$) with greater expressions of porosity in the hands of people in Mórrope. The elbow and wrist joint systems, however, had the same distribution of abnormal porosity between Mórrope and Eten (respectively, $p = 0.713$; $p = 0.176$). The only other Mann-Whitney U test that produced a statistically significant difference between the two samples is the expression of abnormal porosity found in the cervical vertebral joints ($p < 0.001$) where Mórrope demonstrated more expressions of degeneration-related porosity than the Eten sample.

All other joint systems that were tested for the distribution of porosity between the two samples showed that porosity patterning between Mórrope and Eten were not statistically distinct. These included thoracic and lumbar joint systems ($p = 0.955$; $p = 0.093$) and all joint systems in the inferior appendicular skeleton including the hip, knee, ankle, and foot systems (respectively, $p = 0.778$; $p = 0.417$; $p = 0.225$; $p = 0.562$).

Table 5.7 - Mann-Whitney U Test Results: Porosity

Null Hypothesis	Significance	Results
The distribution of shoulder porosity is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope.
The distribution of elbow porosity is the same across both sites	0.713	No statistically significant difference in expression between sites.
The distribution of wrist porosity is the same across both sites	0.176	No statistically significant difference in expression between sites.
The distribution of hand porosity is the same across both sites	0.039	Statistically significant difference of greater expression in Mórrope.
The distribution of cervical vertebrae porosity is the same across both sites	0.001	No statistically significant difference in expression between sites.
The distribution of thoracic vertebrae porosity is the same across both sites	0.944	No statistically significant difference in expression between sites.
The distribution of lumbar vertebrae porosity is the same across both sites	0.093	No statistically significant difference in expression between sites.
The distribution of hip porosity is the same across both sites	0.778	No statistically significant difference in expression between sites.
The distribution of knee porosity is the same across both sites	0.417	No statistically significant difference in expression between sites.
The distribution of ankle porosity is the same across both sites	0.225	No statistically significant difference in expression between sites.
The distribution of foot porosity is the same across both sites	0.562	No statistically significant difference in expression between sites.

5.4.4 – Severity of Porosity

When the degree or severity of porosity was compared between the Mórrope and Eten samples, there were more similarities found than when the osteophytic severity was compared between the two samples. In the superior appendicular skeleton, half of the joint systems were found to have had a different distribution of porosity severity. The distribution of the severity of porosity in the shoulder was found to be different across the samples, with the patterning of porosity severity being higher in the Mórrope sample than in the Eten sample ($p < 0.001$). The same observation was found regarding the distribution of porosity severity in the hand ($p = 0.039$). In contrast, the elbow and wrist joint systems had statistically indistinguishable patterns of porotic severity between Mórrope and Eten ($p = 0.955$; $p = 0.174$).

The cervical vertebral joints had different distributions of porotic severity between the samples, with Mórrope demonstrating more severe abnormal porosity ($p < 0.001$). However, the thoracic and lumbar vertebral joints had the same distribution of severity between Mórrope and Eten ($p = 0.732$; $p = 0.240$). The inferior appendicular joints shared no differences in the distribution of severity between the samples spanning the, the hip, knee, ankle, and foot joint systems between Mórrope and Eten ($p = 0.778$; $p = 0.443$; $p = 0.738$; $p = 0.949$).

Table 5.8 – Mann-Whitney U Test Results: Porosity Severity

Null Hypothesis	Significance	Results
The distribution of shoulder porosity severity is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope.
The distribution of elbow porosity severity is the same across both sites	0.955	No statistically significant difference in expression between sites.
The distribution of wrist porosity severity is the same across both sites	0.174	No statistically significant difference in expression between sites.
The distribution of hand porosity severity is the same across both sites	0.039	Statistically significant difference of greater expression in Mórrope.
The distribution of cervical vertebrae porosity severity is the same across both sites	0.001	Statistically significant difference of greater expression in Mórrope.
The distribution of thoracic vertebrae porosity severity is the same across both sites	0.732	No statistically significant difference in expression between sites.
The distribution of lumbar vertebrae porosity severity is the same across both sites	0.240	No statistically significant difference in expression between sites.
The distribution of hip porosity severity is the same across both sites	0.778	No statistically significant difference in expression between sites.
The distribution of knee porosity severity is the same across both sites	0.443	No statistically significant difference in expression between sites.
The distribution of ankle porosity severity is the same across both sites	0.738	No statistically significant difference in expression between sites.
The distribution of foot porosity severity is the same across both sites	0.949	No statistically significant difference in expression between sites.

5.4.5 – Type of Expression: Eburnation

Eburnation was generally quite rare, and only one of the joint systems examined was found to have had a different distribution of eburnation: cervical vertebral joints (p = 0.040). The univariate data of eburnation presence can be found in Table 5.9. This table shows that 3.30% of individuals in the Mórrope sample were affected by eburnation from DJD while 5.40% were affected from the Eten sample. Both of these percentages are significantly less than those found from osteophytosis and porosity presence.

Table 5.9 Univariate Data of Samples: Eburnation Presence

Site	Unaffected	Affected	Total	% Affected
Mórrope	88	3	91	3.30%
Eten	140	8	148	5.40%

Interestingly, eburnation presence is the only percentage where Eten has more percent than the Mórrope sample. Every other joint system had statistically non-significant variations of eburnation patterning in their joints between both of the samples. For the superior appendicular skeletal joints, the shoulder, elbow, wrist, and hand joints, distribution was the same across both skeletal samples (respectively, p = 0.581; p = 0.066; p = 1.000; p = 1.000). The thoracic and lumbar joint systems also demonstrated values that showed no difference between the samples (p = 0.585; p = 0.493). Finally, all four joint systems in the inferior appendicular skeleton, the hip, knee, ankle, and foot joints did not differ in eburnation distribution (respectively, $p = 0.494$; $p = 0.523$; $p = 0.320$; $p = 0.327$).

Table 5.10 – Mann-Whitney U Test Results: Eburnation

Null Hypothesis	Significance	Results
The distribution of shoulder eburnation is the same across both sites	0.581	No statistically significant difference in expression between sites.
The distribution of elbow eburnation is the same across both sites	0.066	No statistically significant difference in expression between sites.
The distribution of wrist eburnation is the same across both sites	1.000	No statistically significant difference in expression between sites.
The distribution of hand eburnation is the same across both sites	1.000	No statistically significant difference in expression between sites.
The distribution of cervical vertebrae eburnation is the same across both sites	0.040	Statistically significant difference of greater expression in Mórrope.
The distribution of thoracic vertebrae eburnation is the same across both sites	0.585	No statistically significant difference in expression between sites.
The distribution of lumbar vertebrae eburnation is the same across both sites	0.493	No statistically significant difference in expression between sites.
The distribution of hip eburnation is the same across both sites	0.494	No statistically significant difference in expression between sites.
The distribution of knee eburnation is the same across both sites	0.523	No statistically significant difference in expression between sites.
The distribution of ankle eburnation is the same across both sites	0.320	No statistically significant difference in expression between sites.
The distribution of foot eburnation is the same across both sites	0.327	No statistically significant difference in expression between sites.

5.4.6 – Severity of Eburnation

Variation in the severity of eburnation represent the most statistically insignificant series of observations in this work. Only the cervical vertebral joint system differed between Mórrope and Eten (p = 0.040) with Mórrope individuals demonstrating a greater degree severity of eburnation severity.

In the superior appendicular skeleton, the shoulder, elbow, wrist, and hand joint systems had the same distribution of eburnation severity (respectively, p = 0.571; p = 0.072; p = 1.000; p = 1.000). The same was true for the hip, knee, ankle, and foot joint systems of the inferior appendicular skeleton (respectively, p = 0.500; p = 0.156; p = 0.224; p = 0.329). The severity of eburnation also is the same thoracic and lumbar vertebral joint systems between samples (p = 0.588; p = 0.500). In all of these systems, the Mórrope and Eten samples cannot be distinguished in their patterning of eburnation severity.

Table 5.11 – Mann-Whitney U Test Results: Eburnation Severity

Null Hypothesis	Significance	Results
The distribution of shoulder eburnation severity is the same across both sites	0.571	No statistically significant difference in expression between sites.
The distribution of elbow eburnation severity is the same across both sites	0.072	No statistically significant difference in expression between sites.
The distribution of wrist eburnation severity is the same across both sites	1.000	No statistically significant difference in expression between sites.
The distribution of hand eburnation severity is the same across both sites	1.000	No statistically significant difference in expression between sites.
The distribution of cervical vertebrae eburnation severity is the same across both sites	0.040	Statistically significant difference of greater expression in Mórrope.
The distribution of thoracic vertebrae eburnation severity is the same across both sites	0.588	No statistically significant difference in expression between sites.
The distribution of lumbar vertebrae eburnation severity is the same across both sites	0.500	No statistically significant difference in expression between sites.
The distribution of hip eburnation severity is the same across both sites	0.500	No statistically significant difference in expression between sites.
The distribution of knee eburnation severity is the same across both sites	0.156	No statistically significant difference in expression between sites.
The distribution of ankle eburnation severity is the same across both sites	0.224	No statistically significant difference in expression between sites.
The distribution of foot eburnation severity is the same across both sites	0.329	No statistically significant difference in expression between sites.

5.5 – Conclusion

These data provide new insights and novel observations regarding the details and nuances present within the DJD lesions present in these two Colonial Andean communities and the upon the lives of their peoples. A majority of the results consistently demonstrate that people in Mórrope had a greater prevalence and manifestations of severity when compared to those people in the Eten sample. Many different factors could be the cause of the elevated DJD manifestations and severity among the people who lived in Mórrope in the 200 years following colonization. In the next chapter, I aim to interpret these patterns and consider them in light of variations of ecology, economy, and the physical labor demands placed upon the local Muchik peoples of the Lambayeque valley region.

CHAPTER SIX:

DISCUSSION

6.1 – Introduction

Bioarchaeological methods and theory open unique and meaningful windows upon the human past, including opportunities to examine and reconstruct the lifestyle of past peoples and populations. By looking back in history using skeletal markers such as what has been done here with the examination of DJD lesions the lifeways of both the Mórrope and Eten samples can be examined. It is appears an argument can be made for differences in biomechanical environments between Mórrope and Eten. This differentiation appears around and shortly after the time in which the Lambayeque area was colonized by the Spanish conquistadors. By examining the prevalence of DJD, the different types of DJD expression, and the severity of degenerative lesions, a specific picture of how colonization can differentially affect life and labor among native Andean peoples takes shape.

The data allow for the rejection of the hypothesis presented in Chapter 1. The people of Mórrope appear to have been experiencing higher rates of DJD in general, in every type of expression in nearly every joint system, and an in elevated severity of DJD in joints with arthritic expressions. So what could have driven such differences in DJD expression in two different groups of Muchik people who lived at the same time, in the same valley, and under the same form of Spanish colonial political economy? This chapter will explore several different working hypotheses as to why Mórrope's colonial experience seemed to have been more physically strenuous than that of Eten. The discussion considers dimensions involving nutrition, ecology, genetic disposition, and extent and types of physical activity to try and reconstruct what may have been happening to the people of Mórrope and Eten.

6.2 – Results Analysis

6.2.1 – Comparing Joint Systems

Examination of the eleven different joint systems in their respective categories (superior appendicular skeleton, vertebral column, and inferior appendicular skeleton), shows there are many different patterns involving specific joint systems. As described in the previous chapter, common odds ratio (OR) results show that all instances in the superior appendicular skeleton and vertebral column have a higher risk of DJD lesion presences in the Mórrope skeletal sample when compared to the Eten skeletal sample. DJD prevalence in Eten is higher only is a single comparison: the foot joint system. In all other joint systems of the inferior appendicular skeleton, Mórrope has a higher risk of DJD lesions. In sum, the Muchik people of Mórrope had a higher chance of DJD lesions in the superior appendicular skeleton and vertebral column in every comparison. The same held true for the majority of inferior appendicular joint systems. Therefore, we can conclude that the overall prevalence or risk of DJD presence in the Mórrope sample is meaningfully and systematically greater than that of Eten.

Figure 6.1 - Examples of differing DJD severity affecting the distal femur (knee joint) in an individual from Mórrope (top) and Eten (bottom). Photo by and courtesy of Haagen Klaus.

Mann-Whitney U test results demonstrate that there are no instances of Eten possessing a statistically significant higher prevalence of either the presence or severity of osteophytosis, porosity, or eburnation. Every instance where there is a statistically significant result in the Mann-Whitney U test, those results demonstrate a higher prevalence of the lesion presence/severity in Mórrope. The superior appendicular skeletal sample of both Mórrope and Eten reveal a higher prevalence of osteophytosis in every joint system in the Mórrope sample while the shoulder and hand joint systems have a higher prevalence of porosity in the Mórrope sample. Eburnation shows no statistically significant difference in any joint system of the superior appendicular skeleton. The superior appendicular skeletal joint systems have the highest degree of statistically significant results, meaning that the prevalence of joint degeneration is more often found in the arms of the individuals found in the Mórrope sample. These findings independently demonstrate the people of Mórrope experienced lives and lifestyles that contrasted clearly with the people of nearby Eten.

When the vertebral column is examined, Mórrope demonstrates a higher prevalence of lesions in the cervical joint systems of the vertebral column in the Mórrope sample. In the examination of the lumbar vertebrae, only the presence of osteophytosis has a significant result, showing that Mórrope had higher osteophytosis prevalence in these lumbar vertebrae. Presence of porosity and eburnation, as well as the severity of all three expressions in the thoracic vertebrae yielded non-statistically significant results. Unlike the thoracic and lumbar vertebrae, the Mann-Whitney U tests comparing the cervical vertebrae between the two samples show that the presence and severity of all expression types of DJD are statistically significantly higher in the Mórrope sample.

Mann-Whitney U results of the inferior appendicular skeleton show the most similarities between the two samples, with only the knee joint system having osteophytosis presence statistically significant in the Mórrope sample. All other expressions and severities of the hip, ankle, and foot joint systems show no difference between the two samples.

So what does this mean for Mórrope? The immediate implications are that people in Mórrope were engaged in long-term, habitual patterns of physical activity that affected their upper bodies in ways that were different from the people of Eten. In addition, nutritional and ecological factors differed significantly between the two Muchik colonies, which may have also played a role in the increased DJD prevalence in Mórrope.

6.3 – Interpretations of DJD Prevalence Variation between Mórrope and Eten

6.3.1 – Diet and Nutritional Factors

Diet and nutrition are crucial factors that shape the development and growth of individuals. Nutritional stress early in a mammalian organism's life has been shown to cause an increase in a number of different chronic illnesses in a population later in life, including DJD prevalence (Goodman et al., 1984; Peterson, 1988; Larsen et al., 2001; Jordan et al., 2005; Peterson et al., 2010). It is possible that one input in these broader prevalence differences involves signs of early nutritional stress that sewed the seeds for increased prevalence and severity of DJD in Mórrope as opposed to Eten.

Bioarchaeological, archaeological, and ecological data leave little doubt that there were dietary differences between the Eten and Mórrope communities, as both sites occupy very different microenvironmental zones. These zones (mentioned both in Chapter 4 and below) can either hinder or help adaptations in this generally hostile environment as it relates to how its inhabitants to maintain food sources. Klaus and Alvarez-Calderón (2017) argue that this is related to the statistically significant differences in oral health patterning between Mórrope and Eten. This could also be a factor as to why expression of osteophytosis, porosity, and eburnation presence and severity was elevated in the Mórrope individuals.

In their conclusion, Klaus and Alvarez-Calderón (2017) state that the Muchik people of Eten appeared to have been skeletally healthier than those in the Mórrope community. The Eten population probably endured less childhood and adult stress, higher birthrates, higher female fertility, and less strenuous forms of physical activity (discussed below). It appears that life for the Muchik people of Mórrope was more physically challenging than their neighbors in Eten. These results make strong case regarding how differing social realities and lived experiences can be incorporated in skeletal tissues (Klaus 2012; Klaus and Alvarez-Calderón, 2017). It also shows how Colonial outcomes can be highly variable, even in the same coastal Peruvian river valley.

Any realization that these degenerative lesions indicate how different life and experiences between the two sites can be linked to Nancy Krieger's 2004 work "Embodiment: A Conceptual Glossary for Epidemiology." Krieger focused on how the theoretical construct of "embodiment" can be used in the analysis of how the human body can reveal different aspects of human life. The bodies of these individuals can reveal the story of the experience of a human's existence and match or empirically test accounts that have previously been recorded. Embodiment theory allows permits us to tell the story of the life of an individual(s) who cannot, or will not, tell their own story – whether it be because they are unable, prohibited, or chose not to tell their experience (Krieger, 2004). Bodies, dead or alive, can articulate the story of an individual's social life and reality down to one's bones and archaeological remains. The key is to know how to read these signs in skeletal phenotypes.

Both poverty and privilege can produce distinctive forms of biological outcomes (Krieger, 2004). In a place such as Colonial Peru, inadequate sanitation, lack of water, discrimination, abuse, exposure to toxic materials or disease, and inadequate healthcare all can leave their mark on the human skeletal system, giving an inside perspective on any sort of structural violence an indigenous community may have encountered (Klaus, 2012). Structural violence refers to normalized differences of unequal social structures that act to suppress agency and prevents an individual or group of people within a population from reaching their social, economic, or biological potential, impairing human rights and needs. In colonial Peru, a majority of structural violence centered around the distribution of wealth and sociopolitical capital and was often justified on the biologically deterministic views of race of the time period (Klaus, 2012). Historic Peruvian society was extremely stratified following colonization, with white European elites on top and native laborers on the bottom. Those on the bottom were manipulated for physical labor. The embodied effects of such a socioeconomic system allows bioarchaeologists and paleopathologists to understand critical aspects of the conditions of people's lives from the state of their bodies (*sensu* Krieger, 2004). Indeed, the Mórrope sample shows a life full of suffering in the form of lack of a reliable food and water sources as well as increased labor demands (described below).

6.3.1.1 – Diet and Nutritional Factors as a Window on Degenerative Joint Lesions?

Early life nutritional stress could be a previously under-recognized and under-conceptualized factor when it comes to the prevalence and severity of DJD in the joint systems of the Muchik population in Mórrope. It is hard to test, but it represents a heuristically and theoretically worthwhile discussion. As mentioned in Chapter 2, early life nutritional stress can predispose vertebrate mammals to greater risk of several different chronic conditions including DJD later in life (Peterson, 1988; Barker et al., 2002; Jordan et al., 2005; Gluckman and Hanson, 2006; Peterson et al., 2010; Temple, 2019). This concept and its related evidence articulates with the Developmental Origins of Health and Disease (DOHaD) paradigm. The DOHaD framework examines how early life stress can affect the health of individuals much later (and in seemingly unconnected manners) over their life course. Temple's synthesis describes the evolutionary mechanism involved when chronic stress events can affect the life of an individual long after the event has taken place. Short-term investments are made in survival of these stressful events early in life to promote survival, but these occur at the costs of decreased allocation of energetic resources used for growth and maintenance of the individual later in their lives (Temple, 2019). This can result in increased risk of chronic infection and other forms of morbidity for an individual as well as a permanently reduced lifespan. Evidence of these stressful events can be found in the form of skeletal (i.e., adult stature and skeletal growth) and dental indicators (i.e., linear enamel hypoplasias and crypt fenestration enamel defects).

Given the bioarchaeological data of elevated expressions of childhood and material stress in Mórrope (see Klaus and Tam, 2009) it is likely that many people in Mórrope experienced nutritional strain early in their development (*in utero* and in infancy). In light of the work of Peterson et al. (2010), this well could have predisposed bodies in Mórrope to develop later degenerative conditions given their economic environment. Deficiencies in vitamins including vitamin C and D, other antioxidant vitamins, and vitamin K have all been found to have some bearing on the presence of DJD later in life (Johnson and Hunter, 2014). When regular availability of foods rich in these vitamins is restricted, there could be an increase in overall DJD prevalence. These include foods such as kale, spinach, parsley, Brussels sprouts, broccoli and cauliflower, fish, milk products, and more. In Mórrope, during the implementation of the *reducciones,* many traditional and generally sufficient food sources were restricted from the inhabitants or otherwise lost to be replaced with "cash crops" such as cotton, corn, and alfalfa. Good agricultural land, which is at a premium in this coastal desert setting, was set aside for their production. In addition, pastoralism transformed and restricted to increase the amount of space for agriculture of these crops. Access to traditional meat sources such as camelids were completely eliminated from Mórrope and the north coast of Peru in general (Klaus and Tam, 2009). The general scarcity of water was another factor that could be putting stress on the material intrauterine environments as well as infants in Mórrope. Mórrope did not have a single reliable water source, unlike their neighbors in Eten who had access to fresh water year-round thanks to the high-volume Reque river. Without a reliable water source and a fresh food source, mother-fetus interfaces could well have been suboptimal.

Going back to Peterson et al.'s (2010) exploration into the ecology of arthritis, nutritional factors had a pivotal impact on the prevalence of DJD in the moose population they examined. Their work suggested that the vulnerability of an older age class depended on the nutritional status those individuals experienced early in life. Furthermore, the Isle Royale moose were more likely to develop late-onset DJD if they had previously experienced poor or limited nutritional conditions early in their lives. This finding could hold the key to what happened to the Mórrope Muchik population sample. The nutritional burden placed upon them could play a role in the increase DJD prevalence, type of expression, and severity when compared to the Eten Muchik sample.

For the children of Mórrope, the consequences of contact can be seen in many different conditions, including porotic hyperostosis and nonspecific periostitis. Klaus and Tam (2009) found statistically significant patterns of increase of porotic hyperostosis and periosteal inflammation, as well as subadult growth decreases and depression in female fertility following postcontact, indicating an increase in stress among the Mórrope Muchik. Analysis of femoral growth in children in Klaus and Tam's sample population showed that by age 2, the postcontact children were growing at a slightly accelerated rate as opposed to the precontact children. However, by age 5, the pattern flips, with the postcontact children's growth slowing behind the precontact sample. This slower postcontact femoral growth continues until around age 12 (Klaus and Tam, 2009). Klaus and Tam attribute this change in growth velocity with the cessation of breastfeeding and an introduction of a contaminated solid food diet. This shows that there was an increase in nutritional stress among the Mórrope sample and, following this thinking, the decline in nutrition towards the beginning stages of growth could relate to an increased predisposition of DJD among those individuals later in life.

Epidemiologists and auxologists have long recognized that there are critical periods of growth during mammalian development. During these critical periods, specific environmental stimuli are required in order to produce the "normal" development of different anatomical structures and their functions in the mammal (Cameron and Demerath, 2002). These periods are considered "critical" because stressful life events taking place in these timeframes can cause a developmental process to unfold differently producing permanent change in the growth of these anatomical structures as well long-term outcomes. In general, Cameron and Demerath (2002) define four different growth periods: the intra-uterine period (fetal development), infancy (two months to two years of age), mid-childhood (begins after age two, but endpoint is not commonly defined in literature), and adolescence (end of adolescence to puberty).

6.3.1.2 – Association between Body Mass and DJD Variation?

Wiess and Jurman (2006) considered some of the confounding factors in the epidemiology of DJD. Body mass represents another area of study that is often overlooked in ancient South American bioarchaeology. It may be argued that, since the Eten population was overall more nourished than the Mórrope sample due to their ability to produce food, the Eten individuals had a larger body mass overall when compared to

Mórrope. However, following European conquest, average body mass values show a 7% increase in Colonial Eten (4.0 kg) and a 5.4% increase in Colonial Mórrope (3.0 kg) (when compared to a precontact sample). These results were not statistically significant and all fell within a rather narrow range of variation. This rules out the possibility of body mass differences between Eten and Mórrope (Ball, 2017). In addition, the joints most commonly affected by DJD in the Mórrope sample are not of weight-bearing joint systems, which is another important indication that body mass is not the cause of these differences. If this were the case, Mórrope would have a higher prevalence in expression types as well as severity in the inferior joint systems and vertebral joint systems than the results demonstrate. Klaus et al. pointed out this discrepancy in his 2009 paper as "Changes in body mass are a poor explanation [for the increase in DJD prevalence] as most weight-bearing joint systems of the lower body are not significantly affected" (Klaus, 2009, 210). This work found the same pattern and in fact, it is the superior appendicular skeleton and cervical vertebral joint systems that are the most affected in the Mórrope sample, not the inferior appendicular joint systems.

6.3.2 – Ecological Factors

Some factors that could be contributed to Mórrope's greater overall biological stress include the differences in environment, conflict, and Spanish hegemony. Mórrope was located on nutrient-poor soils that make it difficult (and still does today) to grow diverse food or other products to make a living for their families and keep them well fed. In addition, the area was also susceptible to water shortages, making drinking water unavailable periodically. Similarly, Mórrope is often depicted as a neglected, rural area that was often in conflict with neighboring groups, many of which they lost. These conflicts were often over water rights, property rights, severe droughts, and heavy labor demands of the Spanish (Klaus and Alvarez-Calderón, 2017). Such obstacles were not encountered in the community of Eten as they were located in a comparatively rich environment with adequate drinking water and food resources for their people.

The economic basis of daily life appears to have been different in Mórrope and Eten. Much of this dimension can be related to the ways in which ecological variation shapes the local formation of political economies. This extended directly to how Spanish administrators maintained tribute to the Spanish crown in two very different microenvironmental zones. As mentioned in Chapter 4, Mórrope was in the middle a microenvironment that was beneficial to maintaining "typical" tribute to their Spanish leaders. Mórrope is in an inland coastal desert environment. Here, vegetation and water would have been extremely sparse and the soil contains deposits of that were problematic for most forms of agriculture. These factors made cultivation in this zone very difficult due to the poor quality of the soil. In addition, Mórrope is for all intents and purposes one of the last areas to receive any water from the La Leche River, making water even sparser in the area. Water in Mórrope is only sufficient for the cultivation of crops every six to seven years when corn and alfalfa are grown. During the drier years when water is sparse, cotton would have been the primary crop cultivated. On the other hand, to the advantage of the Spaniards, Mórrope's surroundings contained plentiful deposits of phosphorus, salt, and gypsum.

In contrast to Mórrope, Eten sits on a unique combination of multiple different environments. While it is considered to mostly encompass a littoral zone, Eten actually straddles many different microenvironments on an ecotone. These include marine, coastal, riverine, and lagoon microenvironments. This area contains a unique lagoon-marsh microenvironment, which supports a diverse range of littoral flora and fauna, making it quite a fruitful area to cultivate crops and raise livestock as tribute for their new leaders as opposed to the Mórrope (Shimada 1976). The different experience at Eten is linked to two different factors: the microenvironmental variation and the economy. The Eten population also had access to a larger amount and better foodstuffs due to the soil in which it was located. Maize, beans, gourds, squashes, and a wide assortment of other crops were able to be cultivated in Eten, with the additional inclusion of many different animals being raised as well (Klaus and Alvarez-Calderón, 2017).

The differentiation between the two environments described could have deeply shaped each settlement's ability to provide tribute to and keep up with the demands of their new Spanish leaders, as well as providing for the dietary and water demands of their own people. The Muchik people inhabiting Mórrope likely had a harder time keeping up with the demands of their new leaders, especially when compared to Eten. It might seem like there was less they could offer, least on the surface.

6.3.3 – Physical Activity

As the Spaniards colonized the New World, they sought economic reward and material gain. Little did they know at the beginning of their colonial project how just how alien a western European proto-capitalist system would be when compared to the complex tribute systems they found in Peru. Spaniards did not quite understand the tribute system of the natives, nor did they care much beyond understanding how they could transform of manipulate those structures to their own ends. Perhaps their expectations of New World economic systems were prefigured by the tribute system which they encountered amongst the Aztecs in Mexico. The Aztec tribute system was based on specific quantities of goods rather than the work put into the labor service (Ramírez, 1996). This misunderstanding would eventually lead Spanish administrators to introduce a new link between the lords and the commoners. Initially, settlers began to purchase land, construct buildings, and create other investments. However, this was not quite the economic gain they had hoped they would find. Those who were left feeling as though they needed more material wealth faced the problem of how to convert the wealth of northern coastal Peru into products from which they could make a profit. Rather than completely scrapping the tribute system that natives had in place at the time of European contact, Spaniards began to build upon and manipulate native systems of labor obligations in which commoners provided labor and services to their lords. By 1533-4, the *encomienda* became an institutionalized medium that made it possible to mobilize indigenous peoples into a labor force that provided commodities for a European-style market (Ramírez, 1996). This way, Spaniards were able to control labor and exact tribute. This type of tribute is what forced native Peruvians into a market economy - something they had never had to deal with before. Under the Inka tribute system, if a laborer completed the task that they were assigned, whether or not their work yielded any actual products, their obligation was considered fulfilled and the individual owned nothing more to their lords than the labor provided (Ramírez, 1996). For example, if a laborer was tasked with planting and caring for crops, whether or not the crops they planted thrived and produced goods or failed, their task was considered complete if they put the effort into the productive activity. Records indicate that after Spain took control of the area, the conditions of labor extraction began to leave their mark on commoners. Under Inka control, labor extractions were considered “mild” compared to what happened after the Spanish conquest. Key differences in the precontact tribute system involved systems of socioeconomic reciprocity and mutual obligations between lords and subjects when compared to the Spanish tribute system, which was a one-way, physically excessive, and intensely extractive form of manipulation of resources and human capital (Ramírez, 1996).

By 1535, Spanish *encomenderos* were granted control over many different native communities, essentially making these Spaniards the new lords (of a kind). The same land grants that ordained the encomenderos as the new leaders of the natives were considered to be unregulated, as the grants did not specifically state what it was that the subjects must provide as tribute. Unlike the Inka tribute system, the new Spanish *encomenderos* were not only able to demand labor and services that the commoners used to provide for their leaders, but due to the unregulated manner of the new order, laborers were also given a high quota of goods that they had to meet in order to complete the tribute. This extra labor commoners and workers had to generate in to keep up with ever-increasing demands of their new *encomenderos* may have led to the increased number of degenerative lesions found amongst the joints of postcontact individuals when compared to a precontact sample.

Not all native communities were exposed to the same intensity of labor. This seems quite clear from the analysis of the samples from Mórrope and Eten and how their degenerative expression and severity differ from one another. Ramírez (1996) discusses some of these labor differences between highlands and coastal environments of Peru. In the city of Cajamarca, located in Peru's northern highlands, laborers were assigned to shepherd large herds of alpacas and llamas as well as guard crops such as wheat. In addition, they were expected to come up with some sort of material good to turn into their masters. In the case of the highlands, laborers provided enough wool clothing and tapestry to their master to appease him. In the case of this highland area, gold and silver were not available to be mined, so tribute had to be paid by different means – one that local ecology and geology could provide.

The coastal areas of Peru experienced Spanish contact earlier than those in the highlands. The coast also had more constant and direct Spanish interaction with its native peoples. In such a setting, the *encomenderos* of Jayanca (located in the mid-La Leche valley), for example, received a greater diversity of tribute when compared to the highland *encomenderos*. Rather than just wool products and the occasional bundle of wheat, *encomenderos* of Jayanca received loads of corn, fowl, sheep, bedding, blankets, ponchos, loads of beans, fish, salt, and chili peppers. In addition to this list of items, the two encomenderos of Jayanca also received differing amounts of gold and silver (Ramírez, 1996). *Encomendero* Francisco de Lobo received fourteen small plates of gold and small silver bars once every two months, while Diego Gutierrez received nine small bars of silver and four to five plates of gold every three months (Ramírez, 1996). Not only did coastal encomenderos receive a greater quantity of agricultural and pastoral goods than those in the highlands, but this amount of gold and silver was also something that those in the highlands did not generate. However, this supply of gold and silver was not common in the coastal plains. In fact, there were no known gold or silver mines found anywhere on the coastal plains. This means that these metals were not mined by the laborers under the coastal encomenderos, but were gathered through a forced bartering system between indigenous groups as a way to satisfy the demands of their Spanish masters (Ramírez, 1996). This extensive trade system would have required at least some native individuals to travel greater distances than they had before to obtain the metals that their *encomenderos* demanded of them.

Not only were individuals traveling to trade for the minerals, but also in many instances, laborers had to travel to the mines themselves to procure the tribute demanded of them. In short, it appears that the Spanish *encomenderos* were able to use their newfound power over the indigenous peoples to abuse their labor (Ramírez, 1996). This means that such laborers were not only traveling greater distances than they had before, but they were also being exposed to more intense labor conditions in the mines than they would be experiencing in the agricultural fields. But it was not as though those individuals whom were now traveling and were only exposed to these new activities, they were also still expected to continue producing and working in areas they were previously assigned to be working, such as farming or herding. Mineral procurement was an additional step to the tribute system never before encountered, an increase in physical labor that workers in the precontact tribute system would not have endured. This, too, would explain the increased frequency of DJD that Klaus et al. found in their pre- and postcontact Mórrope comparison, since the people at Mórrope would have encountered these elevated working conditions found in coastal Peru (2009). This being said, that there was an increase in the prevalence in DJD in the Mórrope sample population immediately following European contact in the Early/Middle Colonial period.

However, it must be remembered that most of the statistically significant differences between the Mórrope and Eten samples involved that superior appendicular skeleton and the cervical vertebrae in the axial skeleton. What is seen in the Mórrope sample is an increase in physical activity involving joint systems that would be affected in their newly assigned task: mining. It is worth considering some of the specific repetitive movements and motions involved in swinging a pickaxe – a miner would bring the head of the pickaxe directly over their head, they would proceed in swinging the head of the pickaxe downward toward the object while keeping a firm grasp on the handle as to not let it slip, the whole time keeping their eyes on the object that they are aiming for. From this description, the joint systems being mainly affected by these movements match with the joint systems significantly affected in the Mórrope sample: the shoulder, the cervical vertebrae, and the hands. The same motion would be true for sowing seeds. This suggests that Mórrope endured a greater intensity of labor. Figure 11 shows the affects of DJD on the shoulder joint system on an individual from the Mórrope sample. In the photo, there is clear osteophytosis affecting both the humeral head and the glenoid fossa of the scapula. On the other hand, Figure 12 shows the same joint system, but from individuals among the Eten sample. Figures 11 and 12 show just how different the joint systems are affected by DJD between each sample. Figures 13 and 14 depict images of the elbow joint system (the inferior epiphysis of the humerus) of individuals from the Mórrope and Eten samples respectively. These images also show the complete obliteration of the joint in Mórrope compared to the joint in the Eten sample.

Figure 6.2 – Osteophytosis and porosity of the Glenoid Fossa of the Scapula (left) and Humeral Head from an Individual in the Mórrope Sample. Photo by and courtesy of Haagen Klaus.

Figure 6.3 - Glenoid Fossa of the Scapula and Humeral Head from Individuals in the Eten Sample. Photo by and courtesy of Haagen Klaus.

Figure 6.4 – Distal joint surfaces of the radius (left) and ulna (right) demonstrating significant lipping, minor porous foci, and modification of the joint surface contours themselves in an Individual from the Mórrope Sample. Photo by and courtesy of Haagen Klaus.

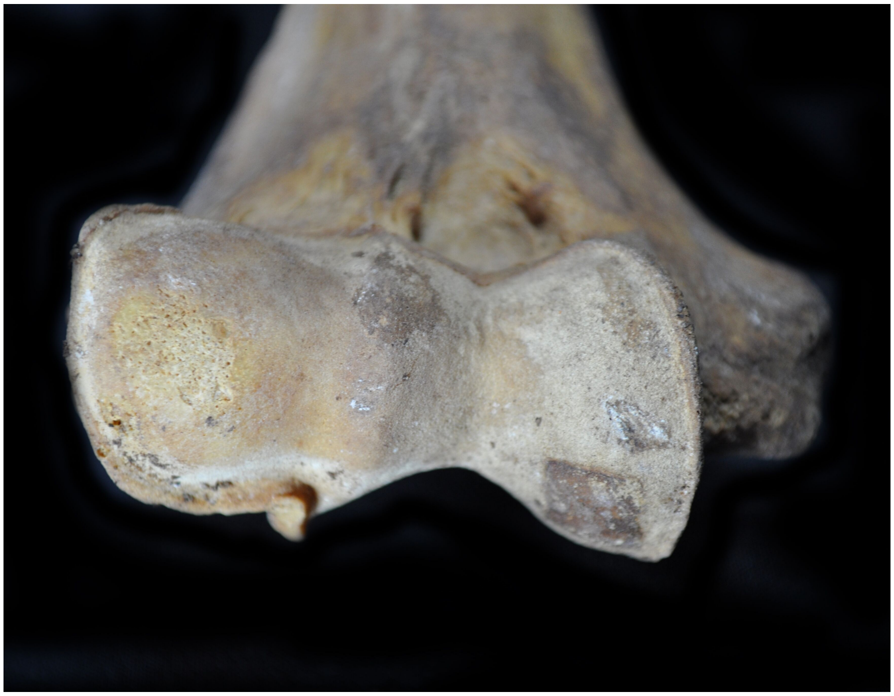

Figure 6.5 - Distal Epiphysis of the Humerus from an Individual from the Eten Sample demonstrating minor but quite abnormal osteophytic development. Photo by and courtesy of Haagen Klaus.

A 2014 study conducted by Pollard and colleagues examined incident reports from the United States Mine Safety and Health Administration between 2002 and 2011 involving worker injuries. Some of Pollard et al.'s (2014) data are not applicable to the Muchik (e.g., injuries related to power tools). Yet, some strains on miners' bodies certainly seem to be more common and relatable by analogy. Injuries that were associated with the most lost days from work were back and shoulder strains attributed to repetitive handling of heavy materials. In addition, frequent awkward and restricted postures, forceful exertions, and manual material handling also were frequent causes of documented injuries (Pollard et al., 2014).

Here, even in recent times, posture, forceful exertion, and manual handling frequently cause injury to the back and shoulders, which align well with the expressions of DJD found in the Mórrope sample. In the Pollard et al. study, the effect of non-powered hand tools on work injury was carefully examined. In this, 21% of lost workday incidents were associated with the use of axes and hammers, 15% with crow and pry bars, 14% with wrenches, and 7% with knives (Pollard et al., 2014). In addition, another third of the lost workday incidents were due to the employees overexerting themselves while using non-powered hand tools, most of which were the result of back and shoulder strains from the use of axes, hammers, and other non-powered hand tools. When the injuries were focused around the hands and fingers of the workers, it was commonly caused by a number of factors, including a worker having a lower experience level, workplace conditions, working practices such as being in a hurry, and the capabilities of the workers (Pollard et al., 2014). This suggests that a worker who was less experienced and in a hurry to obtain the ores from the mines were often those who injured themselves.

The Mórrope sample could be reflecting a similar physical environment with similar physical strains. The extensive gypsum, salt, and phosphate deposits just to the north of Mórrope was seen by the Iberian colonists as something they could profit from. The Muchik people of Mórrope were manipulated to extract such resources. In particular, ethnohistoric documents show the Church may have been behind much of this – demanding ever-increasing amounts of gypsum in particular as payment for the native's "ecclesiastical rent" (Klaus and Alvarez- Calderón, 2017). The proximity to some resources (minerals) and distance to others (alluvial soils) narrowed the specific economic possibilities in the colonial order that were set by local geology. Along with this, Muchik laborers began working harder than they ever had to before as a result of the broad-spectrum economic intensification due to the implementation of this early form of capitalism brought about by the Spanish leaders.

Eten, on the other hand, appears to have not been as negatively affected by the economic intensification. Unlike Mórrope, Eten was far from geological deposits that could be mined for profit. This may explain why the superior joint system of the Eten sample reveals less long-term habitual loading and stress in terms of DJD prevalence, expression, and severity, when compared to their Mórrope neighbors. Being that Eten was located on a more fruitful area of land encompassing many different microenvironments that provided a larger array of goods for the Spanish leaders, it was, perhaps, not as physically strenuous for the Eten Muchik to obtain the tribute that their Spanish leaders demanded of them.

6.4 – Conclusion

It appears that many people on the Colonial Peruvian town of Mórrope had an exceedingly tougher life to live in the wake of European contact than the Muchik had ever experienced before. This work provides an interesting and valuable regionally-based case study, as European contact did not leave the same embodied effects on each and every Peruvian settlement. Rather than being a uniform phenomenon, the biocultural effects of Spanish hegemony in the Lambayeque River Valley Complex shows contact can produce significantly differing effects on native peoples even in virtually neighboring settings. As it has been shown, DJD prevalence, type of expression, and severity are meaningfully different the Mórrope and Eten samples, showing how different the social realities and lived experiences of these sample populations were from one another.

This examination of DJD in the Lambayeque region shows that the lived experience of the colonized shows how humans are both biological organisms affected by their environments as well as social beings affected by the cultural constructs of nutritional stressors and physically intense labor conditions that can all mold the human body and be expressed in many different ways. Perhaps DJD is giving us some insight into the Muchik lives. The dry bones found in both Mórrope and Eten give insight into not only the health of the individuals involved but also tells about the condition in which they lived and corroborate accounts recorded by many Spanish and native witnesses to colonization (Ramírez, 1996). Yet, the physical suffering documented here was not recorded in the Spanish chronicles or any other source. The examination of DJD also explores the way these Muchik individuals were habitually employed and used in this new economy brought onto them by the Spanish leaders. Samples examined with both pre-Hispanic and postcontact skeletal remains have shown that there was an increase in DJD prevalence after colonization, showing the transition from a reciprocal exchange economy to one that sought economic reward and material gain for only its most powerful members.

Not only is the increased prevalence of DJD among the Muchik in Mórrope depicting the strenuous labor conditions as they were habitually employed in economic gain for their leaders, but it also give insight into the structural violence of the times. The Mórrope sample is the good example of skeletal remains exhibiting signs of structural violence. The Mórrope sample shows how the political and economic construction of the new social order under Spanish control affected the Muchik in several biocultural dimensions. As Spanish control and socioeconomic inequality became a normalized part of the Muchik life, the invisible and subtle form of violence and suffering enacted on the natives did as well. When comparing the late pre-Hispanic Lambayeque Valley Muchik skeletons with the colonial era series from Mórrope, the skeletal samples showed a statistically significant increase in systemic stress among those in the Colonial era sample including porotic hyperostosis, femoral growth velocity, and periosteal infection (Klaus and Tam, 2009; Klaus 2012). What we could be seeing with the increased DJD prevalence seems to go along with this. Structural violence in the form of compulsory labor extraction affected the native population, specifically in the upper limb joint systems. Again, manipulation and control over native labor forces was something of a trademark of the colonial agenda, as slave labor, *de facto* slave labor, and exploitation were integral parts of the political economy (Stern, 1982). As the lifeways of the Mórrope Muchik grew more and more stressful and strenuous, evidence of an increase in biomechanical loading, wear and tear, and injury to the joint systems of the natives became clear, which is consistent with many different written sources describing economic intensification (Klaus, 2012).

Though there are many different factors that produce pathological DJD, as it is a complicated multifactorial condition of which all the causes remains incompletely understood. Nutritional stress, environmental factors, and physical activity all seemed to have been playing an interwoven role in the expression of degenerative joint disease in both Mórrope and Eten. This complex intertwining of factors can be attributed to the elevated expression and severity of DJD in the Mórrope sample. However, further research into other phenomenon, such as cross-sectional geometry, application of DOHaD-style analyses, and isotopic studies of diet can hopefully produce a better understanding of these interconnected factors among the Muchik of Mórrope and Eten.

CHAPTER SEVEN:

CONCLUSION

Bioarchaeological study of the Colonial Muchik skeletons from Mórrope and Eten shows that, among other observations, DJD patterning and manifestation reflect larger-scale biological and cultural factors coming into play to create such a difference in DJD prevalence, expression, and severity. This allows for the lifeways of both the Mórrope and Eten samples to be examined and compared to one another to gain insight into their colonization and how European contact affected them in a multi-scalar sense – in biological, social, economic, regional, and even hemispheric dimensions.

In Chapter 2, an exploration of the biological aspects of joint pathology and the manifestations of DJD on dry bone established elements of the biological and bioarchaeological contexts of DJD, showing DJD is a biologically elaborate multifactorial and pathological process and disease. Chapter 2 also examined previous literature to show that there has been limited study of DJD in South American bioarchaeology. Chapter 3 gave a background on the archaeological and historical context of both the Mórrope and Eten samples by exploring previous literature and primary written records. Chapter 4 discussed the archaeological contest of each sample and described the different methods used in this examination. Chapter 5 offers the results of these statistical tests, which showed that there was a higher prevalence of DJD, each expression type, and severity among the Mórrope sample when compared to the sample taken from Eten. Finally, Chapter 6 discussed possible conditions (nutritional, ecological, and labor polities) that could explain the increased prevalence in one sample over the other. While each different factor could have contributed to the manifestations of DJD, the local variations in labor policies put into effect after European contact is suggested to have been a key influence on Mórrope.

The results of the statistical tests show that Mórrope's people lived a physically more strenuous life than those in Eten. Mórrope was previously found to have experienced elevated porotic hyperostosis and periosteal infections in previous literature, and the same is true for DJD prevalence as well as the type of manifestation (porosity, eburnation, and osteophytosis) expressed on the joint surfaces as well as the severity of those manifestations. When each individual joint system was used to compare Mórrope and Eten, there is a stark difference and elevation of DJD manifestation and severity in the superior articular joint systems of the Mórrope Muchik. While several different factors could be used to explain this, there is no definitively known single cause of DJD. However, using this evidence in tandem with written records, we can make informed inferences and interpretations about why there is a great elevation of DJD in the postcontact Mórrope sample. Examinations of diet and nutritional factors, ecological factors, and physical activity have all been closely examined as possible causes of this increase.

While no one cause can be (or *should* be) to blame for the increased DJD in the Mórrope postcontact sample, a culmination of all three factors can give some insight into the Mórrope lifeway. Mórrope was created as a *reducciones* towards the beginning of Spanish control. As a community established as a hyper-dense forced resettlement in the 1530s, Mórrope was populated by a relatively large number of people packed into a small place and in a marginal ecological setting. Water, diverse crops, meat, and other food sources were scarce. While ecological and nutritional strain play a substantial role in the degeneration in the overall health of the Muchik in Mórrope, the increased demands in physical labor probably had the biggest impact on the population.

When the Spanish realized the unique economic potential of the Lambayeque Valley Complex, the exploited area's resources and its indigenous peoples as a sort of "cash cow" for their own material and economic gain. Their imposed idea of economy was vastly different than Andean socioeconomic practices. While the standard European model of the economy used labor sources to gain economic and material power, the natives were use to a tribute system that involved the reciprocity of goods and services. Usually, indigenous peoples understood that the service of the job (i.e., farming, pastoralism, and mining) was the most important part of their economic system, not the goods that those services yielded. Hence, when the Spanish leaders began to demand goods over service, the physical constraint on the Mórrope Muchik bodies increased as the demands from their new leaders increased. This is a textbook example of structural violence.

This examination of DJD between the Eten and Mórrope Muchik shows that physical activity in Eten was not affected by colonization in the same way. Eten was located several fertile microenvironments, so water and food sources were not as scarce.

In addition, the Eten population would have had an easier time growing food sources to harvest to give to their Spanish leaders. Unlike Mórrope, Eten was far from geological deposits that could be mined for profit.

This examination of DJD expression and severity provides a clear example of how bioarchaeological science can be used to show that we, as humans, are more than biological creatures. We are biocultural organisms constantly being molded and shaped by the complex interplay between elaborate innate biological mechanisms and external social, ecological, and even historical processes affecting us everyday. The increased prevalence of DJD among the Muchik in Mórrope reveal the strenuous labor conditions of the time as their population was being habitually employed in economic gain for their Spanish leaders in an area with highly marginal ecological factors causing stressful nutritional stress events in the lives of the Muchik peoples.

Future research can seek to correlated evidence of early life stress with the presence, absence, and severity of DJD lesions using Kaplan-Meyer survivorship curves and interpreted in terms of the DOHaD hypothesis. Differences between males and females can be further studied, though further sub-division of subsample sizes makes that a somewhat risky proposition. Given the diversity of postcontact DJD outcomes between Mórrope and Eten, excavation of additional postcontact sites in Lambayeque and beyond are also needed to deepen the regional reconstruction of life and labor on the coast of Peru following the conquest.

Bodies, dead or alive, can tell the story of an individual's social life; this is the whole idea of embodiment. Indeed, the Muchik samples examined here show a life full of suffering in the form of lack of a reliable food and water source, as well as increased labor demands. By understanding the affects of physical labor due to colonization, archaeologists can better understand what it meant to be controlled by a demanding governmental force, and how the human body reacts to such barriers. We as humans are more than just social beings we are biological organisms molded by our surroundings.

REFERENCES

Aho, O. M., Finnilä, M., Thevenot, J., Saarakkala, S., & Lehenkari, P. 2017. Subchondral Bone Histology and Grading in Osteoarthritis. PloS one, 12(3), e0173726. doi:10.1371/journal.pone.0173726

Attur, M.J., Dave, M., Akamatsu, M., Katoh, M., and Amin, A.R. 2002. Osteoarthritis or osteoarthrosis: the Definition of Inflammation Becomes a Sematic Issue in the Genomic Era of Molecular Medicine. J. of the OsteoArthr. Res. Society Int. 10: 1-4.

Aufderheide, A.C., Rodriguez-Marin, C. 1998. The Cambridge Encyclopedia of Human Paleopathology. Cambridge: Cambridge University Press.

Austin, A.E. 2017. The Cost of a Commute: A Multidisciplinary Approach to Osteoarthritis in New Kingdom Egypt. Int. J. of Osteoarchaeol. 27: 537-550.

Ball, S.J., and Klaus, H.D. 2017. Osteometric Reconstruction of Body Mass in the Lambayeque Valley Complex, Peru: Pre-Hispanic Variability and the Impact of Spanish Conquest. Am. J. of Phys. Anthropol. 162: 109.

Barker, D.J.P., Eriksson, J.G., Forsén, T., and Osmond, C. 2002. Fetal Origins of Adult Disease: Strength of Effects and Biological Basis. Int. J. of Epidemiology 31:

1235-1239.

Bass, S.L, Saxon, L., Daly, R.M., Turner, C.H., Robling, A.G., Seeman, E., and Stuckey, S.. 2002. The Effect of Mechanical Loading on the Size and Shape in Pre-, Peri-, and Postpubetal Girls: A Study in Tennis Players. J. of Bone and Mineral Res. 17: 2274-2280.

Bridges, P.S. 1989. Changes in Activities with the Shift to Agriculture in the Southeastern United States. Current Antrhopol. 30: 385-394.

Bridges, P.S. 1992. Prehistoric Arthritis in the Americas. Annu. Rev. Anthropol. 21: 67-91.

Buikstra, J., Ubelaker, D. 1994. Standards for Data Collection from Human Skeletal Remains. Fayetteville: Arkansas Archaeological Survey.

Burger, Richard L.1995. Chavín and the Origins of Andean Civilization. London: Thames and Hudson.

Cameron, N., and Demerath, E.W. 2002. Critical Periods in Human Growth and Their Relationship to Diseases of Aging. Yearbook of Phys. Anthropol. 45: 159-184.

Cook, D.C., Buikstra, J.E., DeRoussea, C.J., and Johanson, D.C. 1983. Vertebral

Pathology in the Afar Australopithecines. Am. J. of Phys. Anthropol. 60 (1): 83-101.

Cook, N.D. 2004. Demographic Collapes: Indian Peru, 1520-1620. Cambridge: Cambridge University Press.

Craig, O.E., Biazzo, M., O'Connell, T.C., Garnesy, P., Martinez-Labarga, C., Lelli, R., Salvadej, L., Tartaglia, G., Nava, A., Renò, L., Fiammenghi, A., Rickards, O., Bondioli, L. 1995. Stable Isotopic Evidence for Diet at the Imperial Roman Coastal Site of Velia (1st and 2nd Centuries AD) in Southern Italy. Am. J. of Phys. Anthropol. 139: 572-583.

De Bont, L.G.M. 1995. Degenerative and Inflammatory Temporomandibular Joint Disorders. In: Sessle. B.J., Bryant, P.S., and Dionne, R.A., ed. Temporomandibular Disorders and Related Pain Conditions. IASP Press: Seattle. 133-140.

Farmer, P. 2003. Pathologies of Power: Health, Human Rights, and the New War on the Poor. Berkley: University of California Press.

Felson, D.T., Anderson, J.J., Naimark, A., Walker, A.M., and Meenan, R.F. 1988. Obesity and Knee Osteoarthritis: The Framingham Study. Annals of Internal Medicine 109: 18-24.

Goodman , A.H., Lallo, J., Armelagos, G.J., Rose, J.C.1984. Health Changes at Dickson Mounds, Illlinois (A.D. 950-1300). In: Cohen, M.N. and Armelagos, G.J. ed.

Paleopathology at the Origins of Agriculture. University of Florida Press: Gainsville. 271-305.

Gluckman, P.D., and Hanson M.A. 2006. Adult Disease: Echoes of the Past. Eur. J. of Endocrinol. 155: S47-S50.

Gosman, J.H. 2012, The Molecular Biological Approach to Paleopathology. In: Grauer, A.L. ed. A Companion to Paleopathology. Hoboken: John Wiley & Sons. 76-96.

Hemphill, B.E., 1999. Wear and Tear: Osteoarthritis as an Indicator of Mobility among Great Basin Hunter-Gatherers. In: Hemphill, B.E. and Larsen, C.S., editors. Prehistoric Lifeways in the Great Basin Wetlands: Bioarchaeological Reconstruction and Interpretation. Salt Lake City: The University of Utah Press.

Hough, A.J. 2001. Pathology of Osteoarthritis. In: Moskowitz, R.W., Altman, R.D., Hochberg, M.C., Buckwalter, J.A., and Goldberg, V.M. editors. Osteoarthritis: Diagnosis and Medical/Surgical Management Philadelphia: Lippincott Williams & Wilkins. 51-72.

Johnson, V.J. and Hunter, D.J. 2014. The Epidemiology of Osteoarthritis. Best Pract. And Res. Clin. Rheumatology 28: 5-15.

Jordan, K.M., Syddall, H., Dennison, E.M., Cooper, C., and Arden, N.K. 2005. Birthweight, vitamin D receptor gene polymorphism, and risk of lumbar spine osteoarthritis. The J. of Rheumatology 32 (4): 678-683.

Kennedy, K.A.R. 1989. Skeletal Markers of Occupational Stress. In: Iscan MY, Kennedy KAR, editors. Reconstruction of Life from the Skeleton. Liss Inc.:New York. 129-160.

Klaus, H.D. 2008. Out Of Light Came Darkness: Bioarchaeology Of Mortuary Ritual, Health, And Ethnogenesis in the Lambayeque Valley Complex, North Coast Of Peru (Ad 900-1750). PhD Dissertation. Ohio State University, https://search.proquest.com/docview/1923883741?pq-origsite=primo.

Klaus, H.D. 2012. The Bioarchaeology of Structural Violence: A Theoretical Model and a Case Study. In: Martin, D.L., Harrod, R.P., and Pérez V.R. ed. The Bioarchaeology of Violence. Gainsville: University Press of Florida. 29-62.

Klaus, H.D. 2013. Frontiers in the Bioarchaeology of Stress and Disease: Cross‐Disciplinary Perspectives from Pathophysiology, Human Biology, and Epidemiology. Am. J. of Phys. Anthropol. 155 (2): 294-308.

Klaus, H.D and Alvarez-Calderon, R. 2017. Escaping Concquest?: A First Look at Regional Cultural and Biological Variation in Postcontact Eten, Peru. In: Murphy M.S. and Klaus, H.D., editors. Colonized Bodies, Worlds Transformed: Toward a Global Bioarchaeology of Contact and Colonialism. University Press of Florida: University Press of Florida: Gainesville. 95-128.

Klaus, H.D., Larsen, C.S., Tam, M.E., 2009. Economic Intensification and Degenerative Joint Disease: Life and Labor on the Postcontact North Coast of Peru. Am. J. of Phys. Anthropol. 139, 204–221.

Klaus, H.D. and Tam, M.E. 2009. Contact in the Andes: Bioarchaeology of systemic stress in colonial Mórrope, Peru. Am. J. of Phys. Anthropol. 138 (3): 358-368.

Klaus, H.D. and Tam, M.E. 2010. Oral Health and the Postcontact Adaptive Transition: A Contextual Reconstruction of Diet in Mórrope, Peru. Am. J. of Phys. Anthropol. 141 (4): 594-609.

Kosok, Paul. 1965. Life, Land and Water in Ancient Peru. New York: Long Island University Press.

Krieger, N. 2004. Embodiment: a Conceptual Glossary for Epidemiology. J. Epidemiol. Community Health 59: 350-355.

Larsen, C.S. 1981. Functional Implications of Postcranial Size Reduction of the Prehistoric Georgia Coast, U.S.A. J. of Hum. Evolution 10: 489-502.

Larsen, C. S. 1995. Biological Changes in Human Populations with Agriculture. Annu. Rev. of Phys. Anthropol. 37: 109-154.

Larsen, C.S., Griffin, M.C., Hutchinson, D.L., Noble, V.E., Norr, L., Pastor, R.F., Ruff, C.B., Russell, K.F., Schoeninger, M.J., Schultz, M., Simpson, S.W., and Teaford, M.F. 2001. Frontiers of Contact: Bioarchaeology of Spanish Florida. J. of World Prehist. 15 (1): 69-123.

Larsen, C. S. 2015. Bioarchaeology: Interpreting Behavior from the Human Skeleton, second edition. Cambridge: Cambridge University Press.

Lieverse, A.R., Weber, A.W., Bazaliiskiy, V.I, Goriunova, O.I., Savel'ev, N.A. 2007. Osteoarthritis in Siberia's Cis-Baikal: Skeletal Indicators of Hunter-Gatherer Adaptation and Cultural Change. Am. J. of Phys. Antrhopol. 132: 1-16.

Lovejoy, C.O., Meindl, R.S., Mensforth, R.P., Barton, T.J. 1985. Multi-Factorial Determination Of Skeletal Age At Death: A Method And Blind Tests Of Its Accuracy. Am J Phys Anthropol 68:1–14.

Mackey, Carol J. 2006. "Elite Residences at Farfán: A Comparison of the Chimú and I Inka Occupations." In: Christie, J.J and Sarr, P.J. ed. Palaces and Power in the Americas: From Peru to the Northwest Coast. Austin: University of Texas Press. 313- 352.

Mankin, H.J., and Brandt, K.D. 1992. Biochemistry and Metabolism of Cartilage in Osteoarthritis. In: Moskowitz, R. ed. Osteoarthritis Diagnosis and Surgical Management. Saunders: Philadelphia. 109-154.

Merbs, C.F. 1983. Patterns of Activity-Induced Pathology in a Canadian Inuit Population. Ottawa: National Museum of Man Mercury Series, Archaeological Survey of Canada No. 119.

Netherly, P.J. and Dillehay, T.D. 2017. The Environmental Setting, Past and Present. In: Dillehay, T.D. Where the Land Meets the Sea: Fourteen Millennia of Human History and Huaca Prieta, Peru. Austin :University of Texas Press.

Ortner, D.J. 1968. Description and Classification of Degenerative Bone Changes in the

Distal Joint surface of the Humerus. Am. J. Phys. Anthropol. 28: 139-156.

Ortner, D.J. 2003. Osteoarthritis and Diffuse Idiopathic Skeletal Hyperostosis. In: Ortner, D.J. ed. Identification of Pathological Conditions in Human Skeletal Remains. Cambridge: Academic Press. 545-560.

Ortner, D.J. 2012. Differential Diagnosis and Issues in Disease Classification. In: Grauer, A.L. ed. A Companion to Paleopathology. Hoboken: John Wiley & Sons. 250-267.

Peterson, R.O. 1977. Wolf Ecology and Prey Relationships on Isle Royal. Scient. Monogr. Ser. No. 11, U.S. Nat'l Park Serv, Washington DC.

Peterson, R.O. 1988. Increased Osteoarthritis in Moose from Isle Royale. J. of Wildlife Diseases 24(3): 461-466.

Peterson, R.O., Vucetich, J.A., Fenton, G., Drummer, T.D., Larsen, C.S. 2010. Ecology of Arthritis. Ecol. Lett. 13: 1124-1128.

Pickering, R.B. 1984. Patterns of Degenerative Joint Disease in Middle Woodland, Late Woodland, and Mississippian Skeletal Series from the Lower Illinois Valley. PHD Dissertation, Northwestern University, Evanston, IL.

Pollard, J., Heberger, J., and Dempsey, P.G. 2014. Maintenance and Repair Injuries in US Mining. J. Qual. Maint. Eng. 20 (1): 20-31.

Poole, A.R., Guilak, F., and Abramson, S.B. 2007. Etiopathologenesis of Osteoarthritis. In: Moskowitz, R.W., Altman, R.D., Hochberg, M.C., Buckwalter, J.A., and Goldberg, V.M. Osteoarthritis: Diagnosis and Medical/Surgical Management Philadelphia: Lippincott Williams & Wilkins. 27-49.

Putschar, W.G.J. 1960. General Pathology of the Musculoskeletal system. In: Büchner F, Letterer E., Roulte, F. editors. *Handbuch der Algemeinen Pathology, vol 3(2).* Berlin: Springer. 363-488.

Ramírez, S.E. 1996. The World Upside Down: Cross-Cultural Contact and Conflict in Sixteenth-Century Peru. Stanford: Stanford University Press.

Robbins, S.L., Kumar, V., and Cotran, R.S. 2010. Robbins and Cotran Pathologic Basis of Disease. Amsterdam: Elsevier Health Sciences.

Rogers, J., Waldron, T., Dieppe, P., Watt, I., 1987. Arthropathies in Paleopathology: The Basis of Classification According to Most Probably Cause. J. of Archaeol. Science 14, 179-193.

Rojas-Sepu´lveda C, Ardagna Y, Dutour R. 2008. Paleoepidemiology of Vertebral Degenerative Disease in a Pre-Columbian Muisca Series from Colombia. Am. J. Phys. Anthropol. 135:416– 430.

Rossen, J., and Dillehay T.D. 2001. Bone Cutting, Placement, and Cannibalism? Middle Preceramic Mortuary Patterns of Nanchoc, Northern Peru. Chungará 33 (1): 63-72.

Ruff, C.B. 2008 . Biomechanical Analyses of Archaeological Human Skeletons. In: Katzenberg, M.A., Saunders, S.R., editors. *Biological Anthropology of the Human Skeleton, Second Edition.* Hoboken: Wiley-Liss. 183-206.

Sharma, L, and Kapoor, D. 2007. Epidemiology of Osteoarthritis. In: Moskowitz, R.W., Altman, R.D., Hochberg, M.C., Buckwalter, J.A., and Goldberg, V.M. Osteoarthritis: Diagnosis and Medical/Surgical Management. Philadelphia: Lippincott Williams & Wilkins. 3-26.

Shimada, Izumi. 2000. "The Late Prehispanic Costal Societies." In: Minelli, L.L. ed. The Inca World: The Development of Pre-Columbian Peru, AD 1000-1534. Norman: University of Oklahoma Press. 49-110

Stern, S.J. 1982. Peru's Indian Peoples and the Challenge of Spanish Conquest: *Huamanga* to 1640. Madison: University of Wisconsin Press.

Straus, W.L. and Cave, A.J.E. 1957. Pathology and the Posture of Neanderthal Man. The Q. Rev. of Biol. 32 (4): 348-363

Temple, D.H. 2019 Bioarchaeological Evidence for Adaptive Plasticity and Constraint: Exploring Life-History Trade-Offs in the Human Past. Evol. Anthropol. 28: 34-46

Verano, J.W. 1997 Physical Characteristics and Skeletal Biology of the Moche Population at Pacatnamu. In: Donnan, C.B. and Cock, G.A ed. The Pacatnamu Papers Vol. 2: the Moche occupation. Los Angeles: University of California. 189-214.

Waldron, T. 1994. Changes in the Distribution of Osteoarthritis over Historical Time. Int. J. of Osteoarchaeol. 5 (4): 385-389.

Wiess, E., and Jurman, R. 2006 Osteoarthritis Revisited: A Contemporary Review of Aetiology. Int. J. of Osteoarchaeol. 17: 437-450.

Woo, E.J., and Pak, S. 2013. Degenerative joint diseases and enthesopathies in a Joseon Dynasty population from Korea. Homo 64 (2): 104-119.

Woo, E.J., and Pak, S. 2014. The Relationship between the Two Types of Vertebral Degenerative Joint Disease in a Joseon Dynasty Population, Korea. Int. J. of Osteoarchaeol. 24 (6): 675-687.

BIOGRAPHY

Michelle L. Yockey received her Bachelor of Arts in Anthropology and History from Ball State University in 2016. After completing her B.A., she went on to receive her Master of Arts at George Mason University as of 2019.