EARLY-LIFE STRESSORS IN PRE- AND POSTCONTACT PERU: EVIDENCE FROM INCREMENTAL ENAMEL MICROSTRUCTURES

by

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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

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Date: __________________________________ Spring Semester 2020
George Mason University
Fairfax, VA

Early-life Stressors in Pre- and Postcontact Peru: Evidence from Incremental Enamel Microstructures

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DEDICATION

This thesis is dedicated to the people from Huaca Chornancap, Huaca de los Sacrificios, and Colonial Eten. I hope this study respects their memories and their descendants.

ACKNOWLEDGEMENTS

Thank you so much to my advisor, Dr. Dan Temple, for teaching and helping me along. I've learned more from you in the last two years than I have in my entire prior education, and am all the better for it. Your patience and willingness to help has been very much appreciated. You are an incredible inspiration to me, and I could not have had a better advisor.

Thank you as well to Dr. Haagen Klaus for letting me use his material for this study and for being an inexhaustible resource of knowledge about Peru. You've been an incredible source of support and inspiration.

Thank you to Dr. Cortney Hughes Rinker, for being such a fantastic professor and helping me to keep the cultural aspect in mind. Your perspective reminded me to be holistic and thoughtful in my interpretations.

Thank you to my cohort for being my friends through this whole thing- I could never have done any of this without your support, especially during this last semester.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Capilla del Niño Serranito	CNS
Cemento-Enamel Junction	CEJ
Chotuna-Chornancap Archaeological Complex	CCAC
Degenerative Joint Disorder	DJD
El Niño Southern Oscillation	ENSO
Linear Enamel Hypoplasia	LEH
Millions of Years Ago	MYA
Proyecto Archaeologico de Eten Colonial	PAEC
Sea Surface Temperature	SST

ABSTRACT

EARLY-LIFE STRESSORS IN PRE- AND POSTCONTACT PERU: EVIDENCE FROM INCREMENTAL ENAMEL MICROSTRUCTURES

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George Mason University, 2020

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This study seeks to understand how populations in the Lambayeque Valley Complex on the north coast of Peru, were affected by Spanish colonialism through the study of linear enamel hypoplasia (LEH). Here, stress chronologies are compared between two late precontact samples from Huaca Chornancap (1375-1470) and Huaca de los Sacrificios (AD 1470-1532) with a sample from Eten dating to the Early/Middle Colonial era (AD 1535-1620). The three samples represent indigenous Muchik peoples from two distinct contexts (sacrifice victims and postcontact church cemetery). To characterize the timing of early-life stress, high resolution impressions were used to produce tooth crown replicas and studied under an engineer's measuring microscope. Perikymata were measured from the most occlusal region of the imbricational enamel along the length of each tooth to the cemento-enamel junction. Accentuated perikymata

were used as indicators for LEH and identified using z-scores and a moving average. Employing constants for crown initiation and cuspal enamel formation for each tooth and an eight-day periodicity for each perikymata, age-at-defect-formation was calculated. Age-at-defect formation ranged from 1.1 to 4.4 years across the sample. Although there were no statistically significant differences in age-at-defect-formation across the study, the sample from Eten had the widest range of ages and a slightly lower median age-at-defect-formation. This is hypothesized to represent a change in the timing or prevalence of stress during the Colonial era, whether through shifts in weaning patterns or nutrient access.

CHAPTER ONE

Early Life Stress and Impacts: LEH as Early Life Stress

The study of stress is foundational in bioarchaeology, and is vital to understand and reconstruct past events and societies. This study uses early life stress markers in the form of linear enamel hypoplasia (LEH) to understand how lived conditions early in development impact morbidity and mortality at future stages of the life cycle.

Early Life Stress

Bioarchaeology seeks to illuminate the past using human remains and archaeological context, and through this course, to understand the lived experiences of human populations. Many things can be revealed about ancient societies through these studies- diet, social structure, subsistence methods, and activities. Over the years, many techniques have been developed to glean information from the remains left behind. One of the most commonly studied experiences has been stress in the early life environment. The goal of stress studies is to understand interactions between human behavior and diet, environment, and social structures, and how these interactions disrupt biological functioning in specific and empirically observable ways.

The concept of stress is reliant on a basic tenet, although it is complex in reality and function. The genetic instructions that drive an organism's development unfold and ultimately manifest according to environmental conditions, using the physiology, energy, and adaptive potential that have been afforded by evolution. Human physiology is greatly influenced by the environment, and this reality is displayed in every part of the skeleton. The ways in which the body reacts to stress are highly evolved strategies meant to keep the individual alive to reproduce in times of prolonged harsh conditions.

The early life environment is possibly the most important time for stress to be recorded, as there are so many ways for the phenomenon to impact the body, due to this being the period of growth and development when the body is both expending the most energy and more vulnerable to changes in social environmental conditions (Henry and Ulijazsek, 1996; Barker et al., 1989; Hales and Barker, 2001; Goodman and Armelagos, 1988). There are two major periods of intense physical growth in humans- the first is from birth to two years, and the second is adolescence, during the early to mid teenage years. These phases are a manifestation of the differential growth of the brain and body, with the space in between marking a phase where the energy is devoted to growth of the brain rather than the body (Aiello and Wheeler, 1995). The human body conserves a finite amount of energy, and needs to utilize this energy in the most efficient way possible. In practice, this means that certain processes are prioritized.

Thus, when energy flow is interrupted, such as by nutrient deficiencies, some growth processes can be halted to keep the body alive (Mahoney et al., 2017; Kuzawa and Quinn, 2009). When an individual experiences stress, such as nutritional deficiency, the body becomes more conservative with resources, redirecting energy from non-essential processes to keep the body alive in a sort of physiological rationing (Flatt and Heyland, 2011).

Stress is never localized, unlike many diseases or conditions that may attack only certain parts of the body. Stress is a systemic response across the body that manifests in various ways in different places depending on the processes that take place (Klaus, 2014). Stress may be invisible in some parts of the body because those parts were either vital enough to not be rationed, or did not contain processes or organs that would see great effects from energy rationing. Also, biological stressors are not indiscriminate- physiological disruption occurs for a reason. These reasons may not be specifically available for interpretation in the skeleton, but there are greater forces- evolutionary, climatic, social, and otherwise- that are at work during the lifespan.

As a general rule, stress elicits energetic trade-offs. The body can only consume and maintain a finite amount of energy, so energy must be distributed with regards to the most vital functions of the body. In times of stress when the body is not receiving optimal nutrition, it aims to protect the continued function of the body as a whole, preserving life in the short term at the expense of future growth and development (Flatt and Heyland, 2011).

Throughout the course of evolution, life strategies that promote survival to reproductive age with the most consistency become more numerous in future generations. Every organism has a typical trajectory of growth and development, and certain influences can alter this development towards different outcomes. This process is commonly referred to as 'canalization', because the body during early development is looking out for signals to prepare and set systematic precedents for the later environment the organism will face (Stearns and Kawecki, 1994; Kuzawa and Quinn, 2009).

This is seen in the prenatal-postnatal nutrition imbalance, where poor nutrition in the womb has been linked with metabolic disorders during life (Barker et al., 1989; Silveira et al., 2007; Sellen, 2007; Gluckman, et al., 2007). One of the first stress studies to incorporate lifespan perspectives focused on birth weight of infants and compared this data to metabolic disorders later in life (Barker et al., 1989). The Barker Hypothesis holds that a decreased birth weight, here taken to reflect poor nutrition during early development, caused individuals to be more susceptible to metabolic disorders later on.

Because the environment the body prepared for in the womb was poor, the body was primed for an environment of dearth, and metabolic systems effectively went into overdrive, causing problems when the external environment was associated with calorically dense foods and sedentism. This mismatch between pre-natal and post-natal environments can cause a highly canalized relationship between nutrition and stress, which creates a feedback loop of increased stress inhibiting the body's ability to absorb nutrients. In turn, the nutrient deficiencies result in stress. These processes result in various preconceived outcomes for the body, both during growth and in adulthood (Barker et al.,1989; Henry and Ulijazsek, 1996).

Both in ancient and modern studies, stature can be used as a nonspecific proxy for economic conditions, as it is controlled consistently by the dietary and stress factors that make up much of the differences in status. Stunting of growth is one of the most common physiological reactions to stress (Bogin et al., 2002). Stature is commonly used in modern studies to understand the nutritional environment during development. One of the more compelling examples of the relationships between stature and environment explores variance between Maya children in Guatemala and Maya American children- the results display a significant change in stature, with Maya children that grew up in America having a much greater height on average than those in Guatemala (Bogin et al., 2002). The authors interpret this difference as indicative of variation in environmental and dietary quality (Bogin et al., 2002). These findings were consistent with earlier studies that demonstrate plasticity in response to the early life environment, including convergence of cranial form following development in a shared environment (Boas, 1912). Although not specifically a stress study, this is a good representation of how the environment impacts later-life outcomes. In adults, chronic infection is a common result of physiological stress. Non-specific infections such as periostosis are manifestations of stress in skeletal samples (Klaus, 2014).

Changes in fertility rate can also be observed through the lens of stress. Pregnancy is considered a large allostatic load, one that must be sustained for nine months in humans, and thus the body is careful in regulating the proceedings (Dunsworth et al., 2012). Ovulation as a process is controlled by the same rules that prioritize life over growth, and the frequency of ovulation can be reduced or stopped entirely in times of nutritional stress, when the body is too compromised to support fertility. This has been studied in both ancient and modern populations, to understand how population growth is affected by stressors in the population (Buikstra et al., 1986; Larsen et al., 2002; Klaus et al., 2014).

Recent studies find variation in the ages at which first menstruation occurs varying along with socioeconomic status (Rogers et al., 2019). This is based on the function of leptin as a stress regulator, and menarche has been found to be related to estrogen levels, which are based on workload (Klaus, 2014).

Two ideas that are vital to the study of stress and the genetic factors that regulate bodily response to it are the thrifty phenotype hypothesis (Barker et al, 1989; Hales and Barker, 2001) and the expensive tissue hypothesis (Aiello and Wheeler, 1995). Both explain the trade-offs that the body has to make in energetics. The thrifty phenotype hypothesis, an expansion of the Barker hypothesis, is a generalization of the observations that reduced fetal growth is correlated to chronic conditions during adulthood and later life, a representation of the body preparing for the external environment while in utero in a cost-saving maneuver to maximize resources during life (Hales and Barker, 2001).

The expensive tissue hypothesis is vital because it provides an example of the body rationing energy to certain processes and adapting to those circumstances. The human gut is unique compared to that of other primates- much smaller relative to body mass. The human brain becoming so expensive (1/5 of total caloric intake) forced the gut to become smaller and less complex, in the way of 'something's got to give,' as well as the increase in calorically rich foods from practices like hunting and cooking allowing the small gut to extract more energy from the food, which further released an energetic constraint on brain growth (Aiello and Wheeler, 1995; Kuzawa et al, 2014). This, in turn, helped drive other fascinating evolutionary shifts in the human species, such as diet and technology.

The Developmental Origins of Health and Disease hypothesis, or DOHaD, is a concept that encompasses much of this thinking, centering on the idea that much of later life stress and conditions are primed or caused during early life (Silveira et al., 2007). Commonly, this is used in clinical studies to understand how early life stressors such as the fetal environment and early diet can have long-term effects on the individual and in populations as a whole (Mandy and Nyirenda, 2018; Worthman and Kuzara, 2005). DOHaD has been a very useful perspective for scholars, both in clinical and archaeological fields, for understanding the effects of early life environment on the development and maintenance of the body during the lifespan.

In the early years of growth and development, the body is highly adaptable and can alter certain functions in order to accommodate conditions that are abnormal. This is part of the plasticity of the body, in that it can work around certain circumstances in order to keep the individual alive. In biology, plasticity operates solely through growth and development, and any changes made by the body are not heritable, because they are strictly the body's reaction to external stressors.

However, there exist limits on adaptability. Physiological constraints exist as energetic investment in survival must be carefully allocated to essential tissue function. The body adapts to environmental conditions, mostly influenced by nutrition, and canalization is a result of evolutionary constraints on the body's capability for adaptation.

Stress in Bioarchaeology

Bioarchaeology is vital to the reconstruction of lived experience in the past because of the strong reliance on contextual lines of evidence. The body illuminates experiences that would otherwise be neglected in historical records or other forms of archaeological evidence. The human body is not a finished product from birth, but the embodiment of what the individual experiences during life- the crossroads of evolution and culture. Taken as a whole, the body can be viewed as a manifestation of the social experience, and can reveal things that are not written or that people and institutions would otherwise hide, as a sort of autobiography. In bioarchaeology, stress studies can be very useful for understanding the lives of ancient populations, and contributing to other lines of evidence such as socioeconomic inequality, social stratification, diet, and the impacts of historical events on the lives of individuals.

However, all of this depends on the skill of scholars to interpret these findings, and do so correctly. Stress is an incredibly useful concept for the bioarchaeologist when studying samples, but scholars must exercise caution in offering well supported conclusions. The study of stress, and especially of enamel defects, must amount to more than simply a counting and measuring of lesions, more than simply impact and consequence. The human skeleton is a complex interwoven system composed of nearly infinite variables, and stress markers in the skeleton have many etiologies. Other context, from archaeological sites and historical records, must be taken into account to have a thorough understanding of what these stressors mean and how the experiences affected the individuals that lived with them.

The meaning and importance of stress in bioarchaeology has been difficult to consistently operationalize because skeletal evidence cannot be treated like clinical cases, and many authors use stress interchangeably with the concept of health (Temple and Goodman, 2014). This makes it difficult to actually understand what stress markers can reveal about the skeletal sample, because of the misuse of the term "health" that has been rampant in publications for decades (Temple and Goodman, 2014; Reitsema and McIlvaine, 2014).

Health as a concept is not directly applicable to the skeletal record, because it relies on cultural factors that are subjectively defined and not always visible in the skeleton (Canguilhem, 1978). Stress is a much more useful term, as it can be identified and quantified in the skeleton. Every individual experiences stressors during life differently, with different standards for how much can be withstood and what manifests in the skeleton. There are consistent manners in which it is recorded in the body, but the range of individual variation and population resilience must be taken into account in these studies.

The understanding of the normal functioning of the human body and how it reacts to stressors has changed much over the lifetime of bioarchaeology as well. What scholars consider stress- the state that is abnormal- by necessity must rely on what is considered normal, and this has not always been static. In previous years, homeostasis was the dominant theory of normal physiological function. Homeostasis relies on there being a specific point at which optimal physiological function is achieved- a single, static, non-changing point that operates along a one-dimensional line (Selye, 1936; Selye, 1950).

One of the best examples of this perspective is the 'normal' body temperature of 98.6 degrees Fahrenheit. Although considered the 'optimal' body temperature, the human body is perfectly capable of functioning normally throughout a range of body temperatures.

Today, the concept of allostasis is becoming more widely used to describe the intricate balancing act of the body (Edes and Crews, 2017). This idea holds that the body is an active participant and adjusts to the environment and stressors, maintaining stability through changes that will best support life. Importantly, allostasis uses a range of what can be considered 'normal' for the body, which better accounts for individual variation and evolution than the homeostasis paradigm. Allostasis keeps in mind that the human body is a complex construct controlled by a vast amount of variables, and that balance is achieved through the juggling of many different factors in a constant, dynamic fashion.

The reference for what is out of the natural range has changed as well, due to this new understanding. Physiological stressors can be considered in terms of the allostatic load, which refers to the cost that the body accrues by maintaining allostasis. Allostatic overload is when this load becomes too much for allostasis to be consistently achieved, and this is the point at which physiological disruptions begin to occur.

Another change in the thinking surrounding the field and how studies are undertaken is the Osteological Paradox (Wood et al., 1992). The osteological paradox revealed some important gaps in the understanding of bioarchaeology- namely that the skeletal sample does not and cannot exist as a snapshot of that population as it existed in life. Diseases and stressors are not indiscriminate, so neither can be the deaths that occur as a result (DeWitte and Wood, 2007). The major components of the Osteological Paradox assert that no skeletal sample can be representative of mortality as it actually occurred in the population, because of factors such as hidden heterogeneity and selective mortality (Wood et al., 1992). Hidden heterogeneity refers to the concept that individuals have different mortality risks due to variable immunity and history, causing a heterogeneous response within the population. These risks occur independently of skeletal lesions, and therefore mortality risk cannot be assumed as the same across a population. Selective mortality refers to the conditions under which individual risk of death increases, such as frailty and pathological conditions.

The Osteological Paradox was an important theoretical moment in that it forced introspection and a closer look into how samples are viewed. The work provided the capability to carefully understand relationships between skeletal and dental indicators of disease within the context of survival. This approach allows bioarchaeologists to focus more on context than on consequences.

However, the paradox alone cannot provide a complete explanation of bioarchaeological context, and has certain limitations in practice. For example, many infections do not have direct relations to mortality, and that there are many lesions and conditions that can result from independent sources that are invisible in the skeleton. There are many hidden effects of physiological stress and how it relates to morbidity, and the paradox cannot take population resilience into account (DeWitte and Stojanowski, 2015).

The Osteological Paradox is still vital to bioarchaeology, reminding scholars to be cautious and conservative with interpretations, and to consider the variables that cannot be viewed. The major importance of the Osteological Paradox today is that it forced bioarchaeologists to think critically and reexamine their relationships to samples and those of the samples to the populations they belong to. This helped bring about a greater focus on context and the methods that occur at the beginning of study, with excavation and sampling design (Wright and Yoder, 2003). Keeping context at the forefront is one of the most important parts of studying early life stress, because scholars must remember that early life stress has a relationship with mortality and that conclusions must be made with this fact in mind.

As much as the field has grown theoretically, the problem still remains that the sample can never be fully complete as a representation of life. The intent of the field of bioarchaeology is to reconstruct, to the best of scholarly ability, life as it was in the past. However, when trying to reconstruct an entire history and society from the remains of individuals, the sample cannot represent the entire population as it was *in situ*.

Another important factor is that stress as an indicator of biological disruption cannot be directly measured. Most skeletal and dental indicators of stress are non-specific, resulting from experiences that cannot be attributed to one particular stressor. Most diseases do not directly target bone, and manifestation of such in the skeleton is only incidental, a side effect of the disease targeting soft tissue. There are many etiologies contributing to stress, many of which can be co-occurring, such as nutritional deficiencies and psychosocial stress. For example, periostosis is one of the most common skeletal lesions that is associated with stress. Periostosis is a non-specific stress result, generally caused by chronic inflammation from an infection. While the condition is caused by bacterial infection in many cases, the specific cause of periostosis just from the bone is impossible to ascertain (Klaus, 2014). To this end, the cause is not necessarily what is important, but that stress is observed manifesting in the skeleton. What scholars are looking at are sequellae, or 'scars' in skeletal tissue that are the results of stress. The approaches of life history theory and DOHaD are vital to bioarchaeological studies of stress, due to the way that these theories emphasize the embodiment of lived experience in the early life into the grown skeleton. Because taking the life history of an individual into account necessitates understanding the early life environment and the circumstances within the population, this is an important approach to studying stress and has opened up new avenues to a more complete view of stress in the archaeological record.

Stress as Manifested in Teeth

Tooth enamel is the hardest known organic material, and the most mineralized material in the human body, as enamel is made of approximately 97% hydroxyapatite. Enamel is formed through a process called amelogenesis, where ameloblasts, enamel forming cells, secrete enamel proteins. The ameloblasts then lay down the enamel proteins on the tooth surface, before altering function and proceeding to reabsorb the protein and water from the sites. What is left after this is approximately 97% calcified salt, and the final product of enamel (Antoine and Hillson, 2016; Kinaston et al, 2019).

Tooth enamel is one of the most information-dense structures in the human body. Teeth in general provide age estimates and insight into the activity an individual undergoes, as seen through dental wear, and the chemical composition of teeth can be analyzed for data on geography and diet through stable isotopes- as well as DNA (Turner et al., 2013; Shimada 2005). Enamel also preserves a very precise record of development, through the perikymata along the surface of the tooth.

Perikymata are manifestations of the striae of Retzius on the tooth crown, grown incrementally much like the rings of a tree. When viewed through a microscope, perikymata appear as vaguely even lines spanning the labial surface of the tooth, widest at the tip of the crown and growing narrow nearing the cemento-enamel junction (CEJ). Enamel is secreted at a constant rate throughout growth, with one band being completed every six to eleven days (Reid and Dean, 2006; Mahoney et al., 2016). This rate differs across various population groups, but is constant within individuals (Reid and Dean, 2000, 2006).

Ameloblasts are delicate and easily disrupted by acute stress, so perikymata become accentuated as the energy in the process is stretched thin (Hillson and Antoine, 2011; Antoine and Hillson, 2016). Thus, disruptions in enamel growth are visible and quantifiable based on accentuated perikymata spacing. Hypoplasia events typically represent acute stress events, lasting for days to weeks (Hillson and Antoine, 2011).

One factor that makes enamel such an important study material is the unchanging nature of the material. Tooth enamel only grows during one period of life, from gestation to around puberty, and does not remodel- the material is unchanged after formation. This quality makes enamel a particularly useful tool for uncovering the early life history of individuals (Humphrey et al., 2008). Also of note is that the process never completely stops as long as the enamel is laid down- only death can prevent the growth of enamel entirely, until the material is fully laid down as the teeth are fully erupted. The process is complete by mid-adolescence with the eruption of the last permanent tooth, but until then, enamel secretion cannot be entirely ceased, barring death. This means that the time record in teeth is never altered or disturbed, and there cannot be bands that are simply missing, thus providing a full record from gestation to the completion of tooth growth (Reid and Dean, 2006).

Because the process of enamel development is so easily disrupted, LEH is considered a nonspecific marker of stress, as it has many different etiologies, many of which can exist comorbidly. In early life, LEH represents episodic stressors such as poor nutrition, weanling diarrhea, and acute or chronic infection (Armelagos et al., 2009; Cook and Buikstra, 1979). Birth is considered one of, if not the, most stressful events of the early life, given the drastic change in environment, physical strain, and diet. This event is marked on the teeth as the neonatal line, which can be used in histological studies to understand timing of stress events during growth and development (Garland, 2020; Dirks et al., 2010; Smith et al., in press).

LEH are typically used in bioarchaeology either macroscopically or microscopically. Macroscopic studies of LEH serve to count the prevalence of individuals with LEH, which are usually marked as either present or absent or measured with calipers to gauge where along the tooth the LEH lie. However, there are problems with this method. Not all

LEH are macroscopically visible and so many markers can be missed, and measurements along the tooth can be inaccurate because teeth are not standard in size and thus age cannot be accurately discovered.

LEH can be quantitatively studied through microscopic means, by measuring the perikymata across the length of the tooth and finding areas of accentuated perikymata. By tracking back the perikymata at which the enamel defect occurs and using the age constant at which enamel begins forming for each individual tooth type, the age at which the defect formed can be revealed (Reid and Dean, 2006; Ritzman et al., 2008). This method is more accurate, because definitive counts of LEH are collected, as well as accurate ages at which the stress events occurred. This can provide useful data on the stress and subsequent survival of individuals. Context is vital to these studies because a variety of sociocultural and ecological factors may explain differential manifestation within the sample (Armelagos et al., 2009; Temple, 2019). Many studies have been done using this method that elucidate previously unknown and uncontextualized variables of the life experience of populations (Temple, 2014, 2019; Garland, 2020; King et al., 2002, 2005).

One of the issues in measuring and quantifying enamel hypoplasia is that the rate of enamel secretion is not constant across the entire human species, but regionally controlled in some cases. For example, in the Americas and Europe, the rate has been observed as eight days per perikymata, but the anterior dentition from African samples had modal enamel formation rates of approximately nine days (Reid and Dean, 2006).

This measure is one of the most vital parts of enamel studies, as the timing of LEH gives important information about the early life environment. The age-at-first-defect-formation matters greatly in terms of later life outcomes. An early age-at-first-defect-formation has been correlated with an early age-at-death, and this is believed to be because of ties to related physiological problems, such as immune-system failure and metabolic disorders (Temple, 2014; King et al., 2005; Armelagos et al., 2009; Goodman and Rose, 1990). Individuals who experience earlier age-at-first-defect-formation are at an increased risk of mortality, quite possibly in association with damage to the development of vital physiological systems.

The presence of LEH on the dentition represents survival, as enamel continues growing following the formation of the defect. Numerous studies have been done on what this survival means in the face of physiological stress, and the roles of adaptive plasticity and constraint in the survival of individuals following the events (Temple, 2019).

This Study

This study's purpose is to analyze LEH chronology in several samples from the north coast of Peru, to understand early life conditions between samples associated with pre- and post-contact environments. Understanding the normal patterns of development is vital to knowing when something deviates from those patterns, and what those deviations mean for the lives of the people that survived these conditions. LEH studies are one of the best ways to view the early life history and development of individuals during this crucial period, and so are a very useful window into the sociocultural conditions of life.

In comparing the timing of LEH between the three samples, this study will illuminate the similarities and differences between the early lives and stress of the different populations.

Conclusion

Understanding the fundamentals of how the human body accumulates and processes physiological stress can affect many aspects of both modern life and interpretations of ancient life. Many studies analyze skeletal samples from past populations to understand the lives that these peoples lived, and sometimes this evidence contradicts historical narrative. For example, written history is biased by the perceptions and worldviews of authors, but skeletal and dental tissue provide an objective service to understand lived experience. Colonial narratives have been particularly harmful by introducing narratives that the biocultural changes associated with colonialism were beneficial or "civilizing". However, human skeletal and dental remains challenge these narratives by providing evidence for detrimental impacts of these practices and agency by local communities. This study will use LEH chronology to understand differences and similarities in the early life environment of pre- and postcontact samples in Peru, focusing on individuals who were ritually sacrificed and those from varied Colonial-era environments.

CHAPTER TWO

Life on the North Coast of Peru

"…the context within which human remains are discovered is as important as the bones themselves" (Martin et al., 2013: 60).

Peru has a very long and complex history, being host to several of the world's most complex premodern civilizations. Each and every community left a unique and lasting imprint on the land, rich in history, culture, and technology. In order to fully understand the entwined relationships between biology and culture, the cultural history of the region must first be established, as many factors of these cultural traditions represent the contexts in which stress was experienced.

Environment of the North Coast

The history of a place has enormous impacts on the modern reality of that place, making context the most important factor for understanding early life experiences. The geology of an area shapes soil and weather patterns, effectively laying down barriers or providing opportunities for all organisms that might live there. In reference to dental studies, the geology of an area influences the climate, and therefore the diet and all developmental patterns that follow. Therefore, geological history must be first taken into account to understand modern environments and the barriers that shape the course of civilizations.

Geologically speaking, Peru experienced a volatile history. The Andes Mountains are relatively young, with the currently ongoing Andean Orogeny having begun in the Cretaceous Period, driven by the widening of the South Atlantic. This is considered one of the most significant geological occurrences that took place during the Cenozoic era. The Andes maintained growth via crustal thickening through the entire Cenozoic, and are achieved the current height approximately 14 million years ago (Evenstar et al., 2015).

The continued breakup of supercontinents Gondwana and Laurasia drove both a major rise in sea level and a rise in sea surface temperatures, leading to a peak in greenhouse activity. During the late Cretaceous era, South America was divided in two by an epeiric sea that effectively put the northwestern part of the continent underwater, with the Andes forming a sort of large peninsula connecting to what would later become Central America. Therefore, from approximately 100 MYA until approximately 20 MYA, Peru was mainly oceanic floor, with a peninsula of exposed mountain ranges. Most fossils found in coastal Peru are accordingly marine in origin, including many species of ammonite and other mollusks. Later Cenozoic materials are dominated a plethora of cetacean and pinniped species, as well as crocodilians and various large mammals, such as ground sloths and glyptodons. (Bianucci et al., 2018; Pujos and Salas, 2004).

The Maastrichtian regression at the end of the Cretaceous (72-66 MYA) drove a major process of sea level drop, draining most epeiric seas and leading to a more continental-driven climate pattern. This caused the inland sea that separated the Andes from the rest of the continent to gradually disappear, and the sea was gone completely by 20 MYA (Jaillard et al., 2005). Figures below display the transgression and regression of this inland sea (Blakey, 2020).

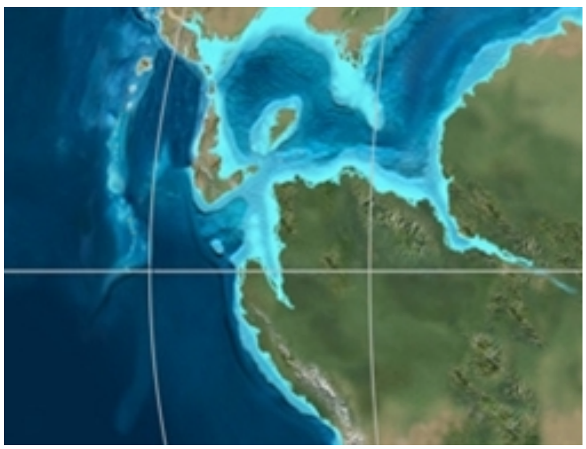

Figure 1. 120 MYA.

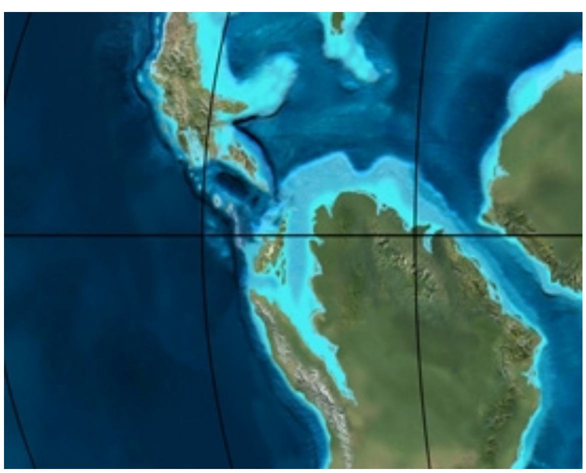

Figure 2. 105 MYA.

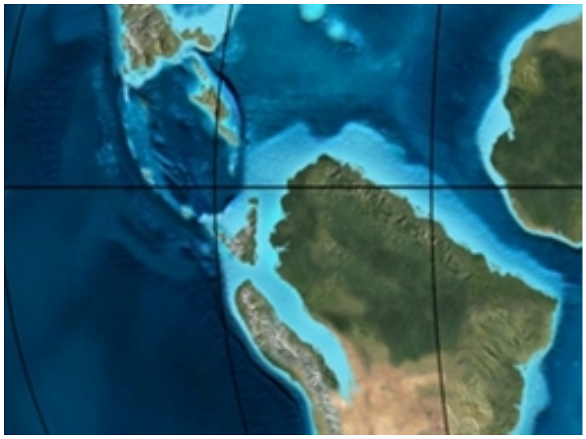

Figure 3. 90 MYA.

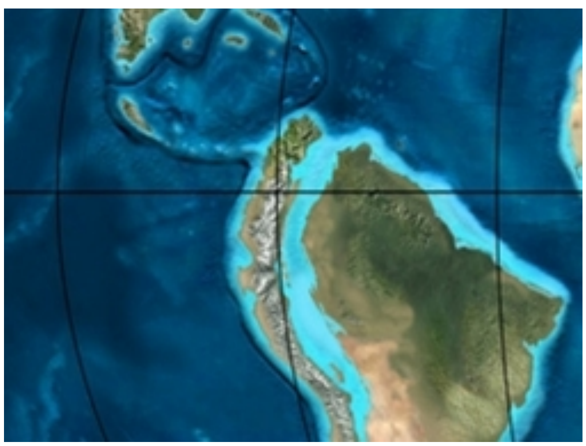

Figure 4. 65 MYA.

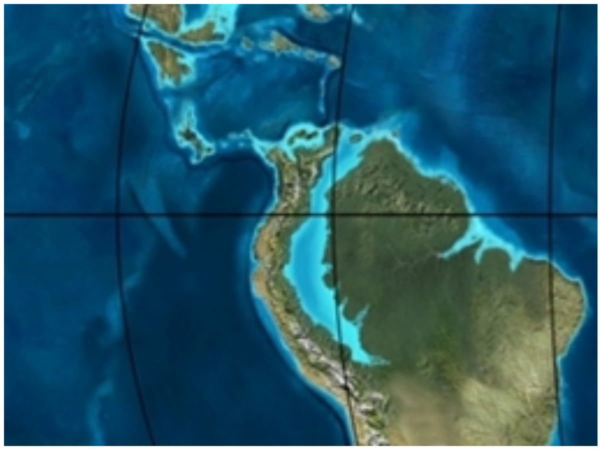

Figure 5. 50 MYA.

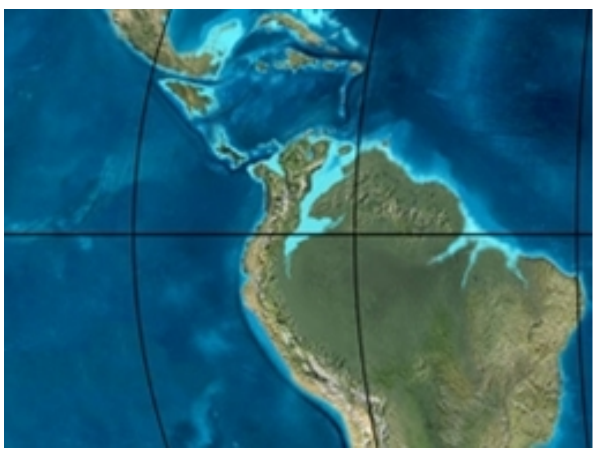

Figure 6. 35 MYA.

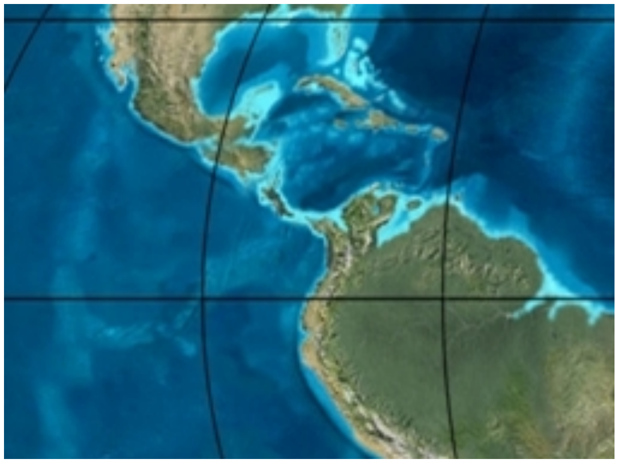

Figure 7. 20 MYA.

All maps by Ron Blakey of Deep Time Maps.

There are three main branches of the Andes marked by where the mountain range lies relative to the center of the Andes. The Cordillera Central is in the middle, the Cordillera Oriental on the eastern side facing the wider portion of the landmass, and the Cordillera Occidental defines the coast of Peru on the western side (Pfiffner and Gonzalez, 2013). The Cordillera Occidental is a primary reason the coast of Peru has become the dry but fertile area it is today, due to the mountains blocking rain clouds from passing over, thus creating rivers on the windward side of the mountains. The environment of the coast is mainly coastal desert and scrubland, and human existence in coastal Peru relies heavily on the presence of these rivers.

The coastal environment of Peru is controlled largely by the currents of the Pacific, which rely on the trade winds to function. The trade winds typically blow straight across the Pacific from East to West, creating a gyre of warm water at the surface by the eastern coast of Australia. The warm water in turn forces the cold deep water off of South America's coast to the surface, bringing with it nutrients from the lower levels of the water column. This cycle is why the western coast of South America, most notably Peru, has such productive fishing economies, as the upwelling of colder, nutrient-rich water creates an ideal environment for large populations of marine life.

The trade winds drive the Humboldt Current, which is a northward-bound current flowing along the coast of Peru, bringing with it the cold, nutrient-rich water that marine life thrives in. The Humboldt Current accounts for nearly a fifth of the global marine catch (Penven et al., 2005). The trade winds are usually a self-sustaining cycle, due to the circulation of water and air across the ocean. El Niño and La Niña are both the extremes of this naturally occurring El Niño Southern Oscillation (ENSO), which relies on the temperature of water to drive currents, due to the natural circulation of water and air.

When the trade winds weaken, the gyre becomes unstable. The warm water is no longer pushed steadily westward, instead spreading out across the Pacific, causing a general increase in sea surface temperatures (SST). This means that the upwelling of cold water does not occur as it should in the East, causing the entire circulatory system of the Pacific to be thrown off. The fish populations of coastal South America experience exceptional die-offs due to the rapid incursion of warm water and disruption of the Humboldt Current, and other devastating effects can be felt worldwide, such as flooding, increases in storm severity, and droughts. In general, El Niño, with its epicenter in the waters off of coastal Peru, can have destabilizing effects on weather patterns across the globe, because the increase in warm water at the surface around the Equator can drive global temperatures up.

ENSO is a continuous cycle that varies in temperature with a certain amount of predictability, meaning that the El Niño and La Niña events can usually be periodic in nature. El Nino events typically occur every two to seven years under normal conditions, beginning around December and lasting for the greater part of the following year (NOAA, 2020). El Niño events have been common in this region for at least 10,000 years (Carré et al., 2005).

The economy of coastal Peru relies heavily on the fishing industry, from ancient times to today, which means that El Niño events can be devastating to the economic state of Peru. Archaeologists have studied this in the past, correlating certain instances of economic declines, political instability, and human sacrifice events with dates of past El Niño events (Bourget, 2016; Klaus and Shimada, 2016; Prieto et al., 2019).

People and Civilizations: A Regional Cultural History

The nation-state of Peru is seen as one of the seven centers of ancient autogenous human civilization where large scale societies emerged. The peopling of Peru began at least 14,500 years ago with Paleoindian groups that travelled south from North America, and there is evidence of consistent occupation ever since. Within the Andes, there were been two major centers of populations in Peru: the highlands and the coast.

The north coast is the area of study here, and one of the most fascinating in terms of population history. The north coast of Peru is typically defined as extending from the

Piura valley in the north to either the Nepeña valley or Huarmey valley in the south. The north coast is made up of 14 river valleys, the largest of which is Lambayeque. The river valleys that make up the north coast of Peru are as follows, from northernmost down: Chira, Piura, Lambayeque, Reque, Zaña, Jequetepeque, Chicama, Moche, Virú, Chao, Santa, Nepeña, Casma, and Huarmey (Shimada 1994).

The Lambayeque River Valley Complex is made up of the Motupe, La Leche, Lambayeque, Reque, and Zaña rivers. Around 1000 AD, the five rivers were connected into one complete system by canals, making this the largest hydrological engineering project accomplished in Native America (Shimada 1994).

The Lambayeque River Valley Complex at first glance appears as a barren, resource-poor setting. In fact, it is a particularly rich constellation of microenvironments, especially when compared to the rest of coastal Peru (Shimada, 1994). As a coastal area, many marine proteins were available for consumption, such as fish, sharks, seals, and gastropods, but the diet also included terrestrial sources such as camelids, deer, and cuy, as well as domesticated crops (Shimada 1994). This river valley complex comprises approximately one third of all arable land on the Peruvian coastline, which is a large part of why the area was so desirable to control by the states and empires of late prehistory as it was a very fertile area for large-scale agriculture.

Because of the distribution of resources on the north coast, this area has been occupied for quite a long time by many different civilizations. Some of the first major complex societies of South America arose here, and occupation has not stopped since. Many groups either leveraged control or sought influence over the Lambayeque region and all the resources it holds. Before the Spanish colonization, it is estimated that Lambayeque was home to approximately one third of the entire population of the Peruvian coast (Kosok, 1965).

Approximately 10,000 years ago, the preceramic era in Peru began, and it theoretically marked the transition from Paleoindian era. While this era predates the use of ceramic media, there has been some archaeological work done to understand the peopling of Peru at this time. The earliest known canals built in South America date to the mid-Preceramic era, approximately 6,000 to 7,000 years ago (Haas et al., 2008; Dillehay, 2011).

The site of Caral, a northern extension of the Norte Chico culture, is one of the first known monumental population centers on the north coast of Peru. The site dates to approximately 2600-2000 BCE, and is considered one of the earliest complexes in the Americas. The architectural complex spanned around 2.5 square miles and included a main temple complex, as well as communal plazas and a small number of residential houses. Stone beads and musical instruments made of animal bones have been unearthed in the temple complex, and the discovery of textiles suggests that the site was used mainly for trade- a commercial economy that for the first time articulated the coast with the highlands. As such, Caral seems to have been a hub of sorts for nineteen other complexes in the Supe Valley, which are estimated to have held a total of 20,000 people at their peak (Shady et al., 2001).

Cupisnique

The Cupisnique period opened the Formative era on the north coast, and they persisted approximately 1500 BCE to ~600 BCE. These people were known for their adobe structures and the use of ceramics as an artistic medium and vehicle for the communication of a complex ideological system. They appear to be the first to have introduced the symbolic decapitator entities – the mythical beings that were at least symbolic of human sacrifice and the regeneration of life (Elera, 1993).

The Cupisnique were originally believed to have been a part of the Chavin culture in the highlands, but more recent excavations show that these communities formed an independent culture, although with some characteristics in common. The Cupisnique are known from archaeological sites such as the temples of Puemape, Moro de Eten, Collud, and Ventarrón. The latter is considered one of the oldest temples in the Americas, at approximately 4,500 years old (Alva Meneses, 2008, 2012). The temple included mural designs painted in red and white coloring and others that depicting hunting activity (Alva Meneses, 2008).

Cupisnique period is the first time gold appears in the record of the north coast, at the sites of Chongoyape in Lambayeque and Kuntur Wasi in the highlands (Onuki, 1989, Onuki, 2000). Human sacrifice in Peru as well first appears in the Cupisnique civilization, as artistic representations of throat slitting on ceramics (Cordy-Collins, 2001).

The Cupisnique declined around 600 BCE. It is hypothesized that this dissolution is due to multiple factors, from ideological fatigue to ENSO activities and a tsunami that struck the coast. (Elera, 1993).

Salinar

The Salinar culture rose around 200 BCE and is usually considered representative of a transitional period between the Cupisnique and Moche periods (Hoyle, 1944). The Salinar saw an increase in population size and consolidation, displaying a level of urbanism not previously seen in the archaeological record of the north coast, with the population mainly consolidated into dense settlements. One of the major traits of this period is the fortification of these settlements. The people here lived in a settlement pattern that was new to the area, with a focus on defensible locations and valley flanks.

Ceramic art of the Salinar culture displays more diversity compared to Cupisnique styles, but there is visible continuation from the earlier type- archaeologists have noted that ceramics are more carefully prepared and of finer quality in the Salinar culture (Hoyle, 1944). Molds were used, and handles and spouts were mainly positioned at the back. Art was mainly representative, either anthropomorphic or zoomorphic, with animals and human figures taking central focus in ceramics.

The first sign of the Salinar culture was noted in a cemetery in the Chicama Valley by Rafael Larco Hoyle, where there were burials seen to be below Moche burials and intrusive into Cupisnique burials, and yet distinct from both (Hoyle, 1944). The burial style of the Salinar was uniform, bodies laid out on the right side with legs extended and slightly crossed and arms laid on the sides.

Most people were buried with small amounts of grave goods, typically found with one to three ceramic vessels placed around the body. The individuals were covered at least partially with cloth and adorned with jewelry, and some were buried with oval or circular sheets of gold on their mouths. Also found in among the burials are shells of marine animals such as mussels and clams, and organic material like pumpkin seeds and corn cobs. Some of these burials displayed a sort of early precursor to a stone-lined tomb, with large flat pieces of stone laid over the body, called 'tumba de lajas.' Larco Hoyle noted that several of the objects found with the burials were similar to Cupisnique style, such as spatulas carved from llama bone that displayed distinct incised designs (Hoyle, 1944).

One of the major sites known to the Salinar people is Cerro Arena, near the Moche River. Cerro Arena is considered the largest residential site dated to the Salinar phase. Most structures were constructed from locally quarried granite, and the layout appeared well-planned prior to building (Brennan, 1980). The Salinar phase declined around 200 CE, for reasons that are largely unknown, but threads and influence of the Salinar culture are seen in various societies that emerged later.

Gallinazo

The Gallinazo culture was named after the site where evidence for this occupation was first detected in the Virú valley (Bennett, 1950). Accordingly, Virú is an earlier, alternate name for this culture. The Gallinazo society was probably a loose confederation of many chiefdoms throughout the coast. Settlement patterns mostly reflected the pre-Salinar trend of spread-out living across the valley floors and large amount of land was cultivated. The Gallinazo period saw an increase in overall population, as well as consolidation of economic and political power in the hands of some kind of elite sector of society (Millaire and Morlion, 2009; Lambert, et al., 2012).

The Gallinazo had a strong, tiered administrative structure, which can be interpreted as having laid the foundation for that of the Moche (Butters, 2009; Strong and Evans, 1952; Millaire and Morlion, 2009). Early Gallinazo ceramics are notable for a technique called 'negative painting.' Through this process, a substance such as wax was spread over designated areas on the pot prior to baking it. After baking, the wax melted off and the area it covered would be lighter in color than the rest of the vessel, creating patterns on the surface (Strong and Evans, 1952).

Although the Gallinazo may have co-existed with the Moche for a time, it is likely that the Gallinazo were the cultural springboard, so to speak, that the Moche developed out of, the main influence of the fundaments which helped form Moche culture (Millaire and Morlion, 2009).

Moche

The Moche were the dominant cultural development of the first millennium CE, and the influence of this culture was felt throughout the entire north coast of Peru. The civilization emerged during the first century CE. The origins of the Moche are currently poorly understood, but the current hypothesis is that at least some preexisting Gallinazo polities undertook a radical change in religious-political leadership, forming what is now known as the Moche civilization (Benson, 2012). Moche society was highly stratified, with well-defined classes ranging from the lower classes of workers and agriculturalists to the rich elites, with a middle class of craftspeople and merchants. The Moche relied greatly on domesticated cultivars, such as maize, squash, and beans, as well as marine protein. This period also saw a drastic increase in the consumption of terrestrial protein from herds of llamas that were kept by the people, which were also used for trade and wool (Benson, 2012).

One of the notable characteristics of Moche ceramic style is reproducibility- the Moche used molds to mass produce pottery, enabling scale of production at a level not seen before in this area. Molds were not new, but the sheer level of ceramic production was unprecedented. Another aspect is the narrative tradition that can be viewed through ceramic artwork during this time. The Moche had an artistic tradition with a complexity probably second only to that of the ancient Greeks (Shimada, 2010), developing fine line pottery painting techniques that told complex narrative stories often relatable to some element of sacrifice, sex, and death. Moche art is typically representational, but also holds a supernatural aspect, depicting mythical creatures and ancestral figures. The Moche 'portrait head' vessels were notable for realistic and life-sized representations of humans, oftentimes specific individuals (Donnan, 2010).

Much of Moche religion is depicted through artwork, with individuals or entities possessing agnathic fangs. This convention was an artistic marker denoting a supernatural figure. It has been argued whether or not the Moche had deities that were worshiped (Benson, 2012), but there is no question that the people did venerate ancestral entities. The most well-known of these is the Snake Belt god, or Ai-apaec, considered the most highly revered of the ancestors (Benson, 2012). Moche religion has been viewed as having a similar basic concept to that found in many other places in the Andes, being concerned with the flow of energy across the ecosystem, representing blood as both life energy and rainwater. This may be a manifestation of the vitality of water and rain to both cultures (Golte, 2009). Most sacrifices dating to the Moche seem to reflect this belief, with blood being the primary motivator- sacrifice methods such as throat slitting were used.

The first physical evidence of throat-slitting appears in individuals from the later Moche (Bourget, 2016; Verano, 2001b). The first archaeological evidence of chest-opening in sacrifice also dates to the Moche, with an example from Huaca de la Luna Platform III (Verano, 2008, Verano et al., 2008). Huaca de la Luna is half of one of the most famous and archaeologically rich sites depicting the Moche civilization, the Huacas de Moche in the lower Moche river valley. The site contains the remnants of the southern Moche capital, sometimes alternately named Cerro Blanco after the nearby mountain. Two major *huacas* are of interest at this site- Huaca del Sol and Huaca de la Luna. Both of these *huacas* were used as burial mounds, although Huaca del Sol was looted by the Spanish and thus of less archaeological interest. Huaca de la Luna is known to have been a site for human sacrifice rituals, with the individuals being sacrificed through blunt force trauma to the cranium and their bodies tossed off the steep *huaca*, where they would lay exposed (Bourget, 2016; Benson and Cook, 2001; Verano, 1998).

Moche lords were typically warrior-rulers or warrior-priests, and depicted as such in iconography, often garbed in elaborate headdresses and carrying ceremonial weapons. At the same time, these accoutrements communicated absolute and uncontestable secular and religious authority (Verano, 2001a).

Most Moche sacrifices were men- young to old, usually associated with battle (whether ritual or real combat), because of pathological conditions noted on the skeleton. The current evidence suggests that the Moche sacrifices were Moche in origin (Shimada, 2005; Toyne et al., 2014), leading to the hypothesis that sacrifice in this case was a more internal affair, possibly consisting of ceremonial sacrifice related to power structure.

Sacrifice in the Moche society seems to have been tied more to ceremony and religious and political authority, as many burials of elite individuals who are sacrificed seem to reflect scenes displayed in a famous Moche iconography that has come to be called the Sacrifice Ceremony, with the sacrifices portraying different figures represented (Bourget, 2016). Many Moche sacrifices seem to be related to ceremonies depicted in iconography, or otherwise serve as offerings to new huacas constructed or the burials of high-ranking elites (Bourget, 2016).

Moche burials took a specific form or style that in fact persisted long after the demise of the Moche society itself. This long-lived burial pattern involved individuals laid flat on their back in an extended position with their legs pointing towards the north and heads to the south. Ethnically Muchik people still buried their dead in this tradition well into the Colonial period (Klaus, 2008, 2013; Klaus and Alvarez-Calderón, 2017). As noted later, Sicán and Chimú lords practiced very distinctive burial rituals to communicate different power relations, identities, and their authority (Shimada et al., 2004).

The richest tomb ever found in the Americas is the Lord of Sipán, who was a Moche lord (Verano, 1997). Along with the lord, the tomb at Huaca Rajada was filled with enormous amounts of gold, masterful works including many pieces of jewelry (Alva and Donnan, 1993; Ingo et al., 2013). Since this discovery, 15 other tombs have been found at Huaca Rajada, most related in some way to the Lord of Sipán (Klaus et al., 2018).

Moche pyramids were not made in the chamber-and-fill style, rather having been built with millions of adobe bricks (Bourget and Jones, 2008). This is one of the reasons why so many are still well-preserved, despite being older than the more recently built Sicán pyramids. Older pyramids were also co-opted by later cultures and sometimes covered or expanded upon by new adobe constructions and decorated with murals.

During the unfolding of Moche history, the civilization was mainly separated into two distinct halves- northern and southern. The northern Moche were typically made up of multiple centers acting separately from one another, whereas the southern Moche was under the control of one main center that rested in the Moche valley (Benson, 2012).

In the terminal Moche phase, the power and influence of the civilization began declining. The southern Moche collapsed during the sixth century due to an increase in environmental hardships, such as major droughts that marked the latter half of the century. From here, the capitol was abandoned and the population moved north, where a new capitol, Pampa Grande, was formed in the Lambayeque river valley (Shimada, 1994). Characteristics of other cultural groups entered into the Moche territory, showing a growing influence from other societies. The Wari people in the south began expand economically and militarily, and artistic styles known to this culture have been observed in several Moche sites (Butters et al., 2012).

The Moche experienced a political collapse around 800 CE, with the centralized governing body dissolving due to a majority of factors, including natural disasters and external influence (Shimada, 1994). The civilizations that rose following the Moche, including the Sicán and Chimú, are both believed to have grown out of remnants of the Moche state (Shimada, 1994).

Sicán

The Sicán civilization was the next major state-level entity to control the north coast of Peru. The Lambayeque Valley Complex was the center of political activity in the northern Moche state, and after the Moche state fell, many elements of the Sicán culture arose from the literal ashes of the Late Moche collapse and abandonment of the city of Pampa Grande (Shimada, 1994). The Sicán civilization's main focus remained in Lambayeque region in the La Leche drainage, with many secondary hubs forming sites such as Túcume, Illimo, Santa Rosa, Batán Grande, La Pava, and elsewhere (Shimada, 2000).

The population of Lambayeque is estimated at approximately 1.5 million people at its Sicán-era peak (Klaus and Shimada, 2016). The majority of the Sicán population was the local Muchik ethnic group who were the direct biocultural descendants of the previous Moche population, but the ruling class have been found to be foreign to the area, possibly tied to Southern Ecuador (Shimada et al., 2004).

The Sicán society is chronologically divided into three eras- the Early Sicán (AD 750–900 CE), the Middle Sicán (900–1100 CE), and the Late Sicán (1100–1375 CE) (Shimada, 2000). The Middle Sicán era is when the civilization truly reached its apogee. The Sicán civilization was an economic powerhouse, a highly technological state-level society, and is considered the most resplendent culture that existed in Peru at that time, only surpassed by the later Chimú and, in a few ways, the Inka.

The Sicán people were metal smiths, inventing bronze through the alloying of arsenical copper, which required much experimentation and skill. The Sicán brought gold-smithing to the highest level of technological and artistic proficiency seen in the Americas before the introduction of modern technology (Shimada, 2000; Shimada et al., 1999).

The Sicán built pyramids in a chamber-and-fill style, making outlines of structural forms with adobe bricks and then filling the interior with dirt, sand, and refuse including vast quantities of broken ceramics to fill up the space (Shimada, 2000). This approach functioned perfectly well for the time, but has resulted in significant destructive erosion to these structures by modern times. Once the adobe bricks on the exterior have been eroded by rains, the interior literally pours out and collapses.

The religion of the Sicán are currently understood as a state-run ancestor cult centered around the ancestors of the Sicán lords, although the lack of overtly religious iconography in the graves of many of the common Muchik peoples seems to display that this ancestor cult was not fully accepted. Burials of gold and ceramic craftspeople at Huaca Sialupe dating to around 1000 CE are done in the Moche style, without any symbols of the Sicán ancestor cult at all, even when the Sicán lords are buried surrounded by such symbols, likely made by metal craftworkers like those buried at Huaca Sialupe (Klaus, 2003).

The Sicán continued the tradition of human sacrifice, commonly using the method of throat slitting first seen in Moche sacrifices (Klaus and Shimada, 2011; Klaus, 2009). The Middle Sicán site of Cerro Cerrillos also displays chest opening for the purpose of removing the heart (Klaus et al., 2010b). At least 84 individuals were interred here after being sacrificed. Most of the individuals were juveniles, along with some male adults, and all were considered to be both local and of non-elite social status (Klaus et al., 2010b). However, the demographics seemed to change- the Middle Sicán sacrifice seemed to focus more on children than the Moche sacrifice, which displays a possible change in perspective and tradition.

Both these styles of sacrifice remain in practice until the end of the pre-Hispanic era, as well as the burial methods that went along with them, that originated with the Moche tradition and continued with the ethnically Muchik population (Klaus, 2013). The body was viewed as a seed, in a way that is seemingly more than simply metaphorical. The dualistic, reciprocal perspective that these people held about life and death extended to the body in such a way that the dead were viewed as being the producers or catalyst for new life. Life and death were considered a cycle that repeated and brought about each other. In the same way that seeds planted for crops are dry, desiccated, and appear lifeless, the bodies of the dead would be left exposed for a time, both to allow the soul to escape through insect activity and to dry out the flesh of the body, letting it take on the desiccated appearance of a seed. After this, the bodies would be buried to promote growth and new life. This process was most likely related to vegetal fertility (Klaus and Tam, 2015; also see Shimada et al., 2015).

This particular style of prolonged primary burial was used in several sacrificial contexts- notably Huaca de los Sacrificios at Huaca Chotuna (an Inka occupation of an originally Sicán-era site), where the body was left open to the air for the express purpose of allowing flies to colonize the dead bodies (Klaus et al., 2010a; Klaus et al., 2016). The people believed that the soul exited the body in the form of flies, little by little, so this process was necessary to give the victim a good death and probably also rendered the body into another, additional offering medium.

Burial practices reveal the way individuals were killed, due to the display of social factors in the burial. Burials are manifestations of a society's views and ideologies surrounding life and death, identity, and hierarchy. Burials are reflections of social organization, and displays of relationships that the society has with the dead (Moore 2004; Shimada et al., 2004).

The transition from Middle to Late Sicán was marked by multiple disasters that caused deep cultural changes, some natural and others cultural. Around 1100 CE, two major events happened at approximately the same time- the *huacas* at Sicán's grand plaza in the La Leche drainage were deliberately destroyed, set on fire in an event that was the culmination of years of internal conflict (Shimada, 1990). Not long after, a massive flood passed through the area, caused by one of the worst El Niño events in the history of the country (Shimada, 2000). The extent of the burning of these huacas displays a deliberate effort to destroy signs of the leadership that had been in charge of the site, and the change in capital and obvious alterations in iconography from this point forward also point to an abrupt change in ideology and leadership (Shimada, 2000). Everyday life for the common people seemed to continue without many changes, but the overarching culture of the Middle Sicán was lost.

The Late Sicán continued on for a few more centuries at a new capital called Túcume, located where the La Leche and Lambayeque river valleys meet. However, the Late Sicán were conquered by the Chimú around 1375 CE, as the latter civilization quested for further territory in the northern reaches of the coast (Shimada, 2000).

Chimú

The Chimú empire is believed to have originally formed from vestiges of the Moche civilization between 700-800 AD, specifically from the more southern part of the Moche. The Chimú culture reached their peak during the 1200s, with an empire that reached from Lima in the south to the modern-day border with Ecuador in the north (Moseley and Cordy-Collins, 1990). Today, the Chimú are remembered as one of the most influential societies to ever exist in Peru.

The Chimú capital was Chan Chan, north of the Moche River. Chan Chan was established approximately 900-1000 CE, and is considered one of the largest, most populated urban centers in the Americas prior to colonization (Moseley and Mackey, 1973, 1974; Moseley and Day, 1982). Archaeological studies reveal evidence of a rich civilization, with a large gap of wealth and power between the elite rulers and the common people (Moore,1996, 2004). The Chimú are known for works of large-scale architecture and blackware ceramics, which were created through a process called reduction firing. By starving the fires in the kiln of oxygen, this causes the fire to interact with the oxygen in the clay, changing both the chemical makeup and the color of the finished ceramic (Moseley and Day, 1982).

The Chimú occupied the north coast of Peru beginning in approximately 900 AD, and began expanding to both the north and south during the 1300s, as far as Manchan in the central coast and Túcume and the Ecuadorian frontier to the north. On the road north, the Chimú took control of Farfán from the Sicán lords, gaining control over the Jequetepeque River Valley and the coastal routes that ran through Farfán. Soon after, they expanded into the La Leche River Valley, conquering the Sicán site of Túcume (Shimada, 2000). The site of Túcume had previously been a center of the Late Sicán civilization and a ritual area made up of 24 *huacas*, the largest concentration of these pyramids produced by the Late Sicán civilization. The Chimú used Túcume as a sort of secondary capital and regional administrative center (Mackey, 1987). There, they expanded upon the area greatly- the enormous walls and ramps of Chimú construction can still be observed today at the site, as well as many Chimú style ceramics. As the

Chimú were intent on harnessing only the economic power in the region through resources and industry, the culture was left alone for the most part.

The demise of the Chimú came sometime around 1470 CE, when communities fell to the Inca territorial expansion into the north coast. The Chimú resisted for a time, but the emperor, Minçhancaman, was defeated and the empire taken under control of the Inka, where the polity began to gradually disintegrate and was restructured (Ramírez, 1990). The civilization was completely under Inka rule by 1493, with Chimú puppet lord descendants from the last emperor ruling on behalf of the Inka until Spanish colonization.

Inka

The Inka Empire is largely considered the most influential and powerful civilization to have ever arisen in the pre-Hispanic Americas. Through Colonial-era documents, it is known that the people called this civilization *Tahuantinsuyu*, a Quechua term meaning 'the four regions' or 'the land of the four quarters.'

The Inka originally developed in the highlands of the Andes, likely with very strong roots in elements of the Wari tradition (Shimada, 2016), and quickly expanded influence throughout the entirety of Peru, as well as parts of Ecuador, Colombia, Bolivia, Argentina, and Chile. This gave the Inka empire control over nearly the entire western coast of South America, necessitating construction of the Qhapac Ñan, a series of roads that ran for approximately 25,000 miles (D'Altroy, 2002). At its peak, the empire was made up of around 12 million people, making it the largest empire in South America at the time. The state religion of the Inca was sun-worship, revering the sun god, Inti, and

Inka presence is seen in various places such as Túcume, where platforms for sun worship were built.

The Inka were widely known as conquerors, sometimes taking over other polities via military force, but most of the time through diplomatic overture and alliance building. Territories were absorbed under the Inka mantle and ruled by lower lords that submitted to the power of the Inka. The Inka derived significant power through systems of socioeconomic reciprocity, labor tribute or labor tax, and redistribution of goods. The Inka conquered and absorbed many previously used sites of the north coast- however, as the goal was economic and political power, the Inka mainly ruled indirectly, without oppressing a client population if it could be avoided (Ramirez, 1990). The Inka controlled the entirety of Peru until the Spanish came to the area in 1531, and destroyed the empire.

The Colonial Era

Peru was one of the main hubs of Spanish colonization in the Americas, and this process changed life in the area forever. The economy, social organization, religion, and most other factors of lifeways were radically altered by colonialism. Spanish colonization across South America was marked by drastic changes in the core of civilizations (Ubelaker, 1994; Ubelaker and Newson, 2002).

The Spanish had several main goals in colonization: extraction of natural and human capital, establishment of military bases to keep out other imperial powers, and the creation of a new population of tax-paying subjects of the Spanish crown out of the native population. The establishment of Catholicism in colonies was vital to the Spanish goal of expansion, as converting the population would grant the crown more power over the native people, and the ability to extract more capital in tributes and taxes (Farriss, 1984).

Pizarro first reached the north coast of Peru in 1532 after continuously sweeping south from the northern Andes. In 1534, Trujillo was founded as a center for colonial administration, one of the first cities founded by the Spanish colonists. From here, the Lambayeque Valley was apportioned for colonial purposes, and the local people taken under control of colonial governance.

When the north coast was conquered by the Spanish, society was at first only slightly disrupted. Eventually, it would be entirely restructured. The native economy was dismantled and taken over by Spanish administrators, and entire communities were uprooted and forced into colonial towns, called *reducciónes* (Ramírez, 1996). The land was transformed from indigenous farmland and natural floodplains into plantations for sugar cane and alfalfa, and the native people placed instead into areas that did not produce well (Ramírez, 1996; Klaus and Alvarez-Calderon, 2017). The large herds of coastal camelids that local populations relied on for food, wool, and trade for centuries were regionally exterminated by the Spanish to make space for imported cattle and pigs.

The changes and limitations imposed upon native lifeways effectively pressed communities into poverty and famine via a intentionally designed mechanism that aimed to generate multiple forms of institutionalized oppression (Burkholder and Johnson, 1998). The colonial system prioritized the raising of crops and livestock for sale and tribute over subsistence, and the indigenous peoples suffered (Figueroa and Idrogo, 2004). Marginalization was not a failure of the economic system the Spanish set up, but a built-in mechanism of the economy. This is the case in most situations of societal inequality.

As well as the colonial governance and forced shifting of lifeways, the population would have faced an increased disease load that their immune systems were unfamiliar with. There is evidence for drastically heightened infection rates of diseases such as smallpox, measles, mumps, rubella, scarlet fever, and influenza. Generally speaking, the north coast experienced a large amount of social buffering through large population and fertile land, meaning that the area underwent less intense population loss and mortality than other areas under colonialism. The depopulation of the area was still severe, however, with the *encomienda* of Jayanca facing a depletion of 81% in 25 years (Cook, 1981). The lives of indigenous peoples in Colonial era Peru were very different to those before the Spanish colonization, in many variable ways.

A thorough understanding of the social conditions experienced over the history of north coast Peru is important because of the impacts of lived experience on biological conditions such as stress. This study will examine the differences in LEH chronology and how these differences relate to changing social conditions across the pre- and post-contact timeline.

CHAPTER THREE

Incremental Microstructures Up Close

Materials and Methods

Materials

This section will include a description and brief history of each site where the samples studied are sourced, in order to give exposition and context on the importance of the cultural variation. There are three sites included- Proyecto Chotuna and Huaca de los Sacrificios, both from the Chotuna-Chornancap Archaeological Complex, and PAEC (Proyecto Arqueológico de Eten Colonial) from the colonial town of Eten.

Sites

Chotuna

The Chotuna-Chornancap Archaeological Complex is a monumental and multicomponent archaeological site in lower Lambayeque river drainage, today in the San Jose district. It is made up of a series of truncated adobe pyramids and structures, with two main centers: the pyramids of Chotuna and Chornancap. The complex is one of the largest monumental sites in the Lambayeque Valley Complex, including temples, plazas, and workshops along with the platform mounds. The site was surrounded by residential area, and the residents of the site and surrounding environs are believed to be mainly Muchik people (Klaus et al., 2016).

The pyramid Chotuna is named after Chot, a location mentioned in the legend of Naymlap, which chronicles the founding of the Sicán culture. Chot was the shrine of the idol Yampallec, next to which the figure Naymlap intended to be buried. Although Hans Heinrich Brüning, who originally studied the site and named it such, later changed his mind on its mythical status, local opinion holds that Naymlap is buried there (Klaus and Toyne, 2016).

The Chotuna-Chornancap site spanned four different occupations. It was originally constructed by the local Sicán as a ceremonial locus, and was used as a ritual center of the Sicán culture from approximately 900/1000- 1375 CE (through the Middle and Late Sicán eras). After this, it was occupied by the Chimú from 1300- 1470 CE, when it was co-opted and held by the Inca until 1532, after whose fall to the Spanish invasion, the site was abandoned, though some locals still buried the dead here into the Early Colonial era (Donnan, 2012).

During the rule of both foreign empires, Chotuna-Chornancap functioned as a sort of satellite center of Túcume to control the area. The Chimú made many additions to the complex after taking over the area, and continued using the whole site for its original purpose. During the Inka occupation, Huaca Chotuna was at the center of all activity including human sacrifice that will be discussed later. Huaca Chornancap appears to have been abandoned and not used by the Inka (Donnan, 2012).

Two samples from this study were taken from the Chotuna-Chornancap Archaeological Complex, labeled ‘Proyecto Chotuna’ and ‘Huaca de los Sacrificios.’ Both were groups of sacrificed individuals, but because the individuals lived under different regimes at different times- the first from Chimú occupation dating from 1375-1470 CE and the second from Inka occupation dating from 1470-1532 CE- the groups are archaeologically, culturally, and temporally distinct. However, multiple lines of bioarchaeological evidence indicates the individuals were members of the local Muchik population (Klaus et al., 2016).

Proyecto Chotuna

The samples labeled 'Proyecto Chotuna' originate from Huaca Chornancap. Huaca Chornancap consists of a T-shaped truncated pyramid platform constructed from three broad tiers of adobe bricks. The pyramid was approximately 25m in height, and around it lay many lower plazas, with the pyramid in a sort of central position. The sample consists of the preserved dentition from 24 individuals that were buried in Huaca Chornancap's North Platform. These burials date to the Chimú occupation of the site (1375-1470 CE). The individuals were found in 18 separate burials of similar time period, all in extended position and all but one placed facing the sea to the west. There were only a few grave goods found, including a single ceramic vessel, camelid bones, and *Spondylus* shells. These burials appear to have been interred rapidly after death and were undisturbed, except for three that were later opened and ritualistically altered (Klaus et al., 2016).

The age and sex distribution of these sacrifice victims was composed of ten subadults under the age of 21, and at least nine adults, six adult males, and three adult females. The individuals exhibited no active pathological conditions and are believed to have been in good health at the time of death, but approximately half (8/15 or 53%) of those that included dentition displayed LEH, showing a relatively high crude prevalence of early life stress. However, this pattern was consistent with typical dental conditions of the late pre-Hispanic (Klaus et al., 2016).

Nine individuals of this site exhibited cut marks consistent with throat slitting, seven with chest opening, and five exhibited both types of mutilation. The method of sacrifice was uneven across the demographics, as well- the individuals with signs of chest-opening all appeared to be adult males, and the subadults showed cut marks consistent with throat slitting, exhibiting that different methods were perhaps used with different groups. (Klaus et al., 2016).

Huaca de los Sacrificios

The other sample from the Chotuna-Chornancap Archaeological Complex was excavated from a structure near Huaca Chotuna: a small ceremonial adobe platform mound called Huaca de los Sacrificios (previously known as Huaca Norte by Donnan, 1990). The individuals from this site date to the terminal Inka occupation of Chotuna, from 1470-1532 CE.

Huaca de los Sacrificios is a small mound within the Chotuna-Chornancap Complex, approximately 28m tall, 24m East-West, and 26m North-South. This structure was evidently used as a locus for human sacrifice only. Thirty-three individuals were found buried inside the pyramid, inside the architecture itself and under floors in three separate alcoves made of adobe brick. The sacrifices in Huaca de los Sacrificios appear to have occurred at different time periods within the relatively short Inka phase (Klaus et al., 2011).

Chronologically speaking, Chamber Three represented was the first event. Chamber Three itself was made up of three levels, representing two separate and closely timed events of sacrifice. Level 3 of this chamber is the oldest interment in the *huaca*, involving seven individuals. Levels Two and One were formed in a single event, located above this layer followed afterwards, with 18 individuals sacrificed. Chamber Two appears to have been made at approximately the same time as these later levels, with a shaft containing five individuals buried in separate levels inside. Chamber One was located at the top of the pyramid, where three individuals were found buried (Klaus et al., 2016; Wester, 2010).

The interments were unusual as far as north coast burials are concerned. There were clusters of people that had been buried at same time, and individuals appeared 'stuffed in' with their arms in a position that suggested they had been tied behind their backs. There were few grave goods associated with this site- juvenile camelids, likely also sacrificed, a single ceramic vessel, as well as a few seeds and a bracelet. The most notable grave good found in the interments with the individuals was a copper figurine of Inka make. Most of the individuals interred at Huaca de los Sacrificios were subadults, with ages ranging from approximately 4 to 15, although there were a few adult female skeletons also identified. The individuals appeared to be of low socioeconomic status, due to the state of their skeletons and dentition (Klaus et al., 2016).

These individuals did not show signs of active pathological conditions on the skeleton, but prior studies on the dentition exhibit relatively high levels of stress occurring at a young age. Another interesting observation from this assemblage involves the demographic variation of the sacrificed individuals (Klaus et al., 2016). Typically, sacrifices in the local region were men, usually adult or older. This site breaks from that pattern, with a sacrificed group made up mainly of subadults and females (Klaus et al., 2016).

The pattern that this demographic follows more closely is the Inka style, where sacrifices consisted mostly of subadults and young females. Thus, the makeup of the sacrificed individuals appears to be a mix of both local and Inka tradition. In the Inka tradition, individuals to be sacrificed were taken from the polity to the highlands, where the individual lived for months (and up to a year in some cases) before the sacrifice was performed. This tradition does not appear to hold with the site of Huaca de los Sacrificios.

At Huaca de los Sacrificios, the individuals who were sacrificed displayed a largely local dietary pattern, consistent with the subsistence economy in the area, whereas Inka sacrifices from the highlands, such as the Llulliallaco Maiden, typically display a change in diet over the last month towards a more high-status diet before sacrifice (Wilson et al., 2007; Fernández, et al., 1999). The sacrifices at Huaca de los Sacrificios did not show any such ritual dietary change (Turner et al., 2013).

As well, the sacrifice victims in this instance appear to have been local, rather than taken from separate polities across the coast or highlands, which had been more common among Inka sacrifices that leveraged socioeconomic power and ties using human sacrifice.

In this case, it appears that the sacrifice was done by local people, using local people and local ceremonial history and burial styles- however, the presence of the Inka *conopa* figurine displays that there was some Inka influence worked into the ritual. The Inka are believed to have ruled indirectly in the area, for the most part- as they wanted control over the economy and resources of the north coast, tribute sufficed and attempting to institute major cultural change or subjugate the people fully was unnecessary for the Inka's goals (Ramirez, 1990; Hayashida, 2006).

Understanding who was sacrificed can lend clarity as to what sacrifice meant to the population, and what kind of intent was behind the action of sacrifice and what motivated the people to perform this ritual- knowing the cultural background behind the sacrifice is a large part of understanding the purpose of sacrifice. This site is important to scholars of the area because it is a fascinating case study on the impact of Inka rule on local ritual and ceremony, and this can lend perspective into the lives and deaths of the people that lived in the area.

The burials at Huaca de los Sacrificios were very well preserved, with many burials including textiles as well as mummified soft tissue. Entierro 2 was observed to include fingernails and hair of the individual, and Entierro 3 was described in the report as "excellent state of preservation- quantities of soft tissue (mummified) still adhering to bone" (Klaus et al., 2016). This preservation state was very important for developing multiple lines of evidence discovered in the excavation process regarding the method of sacrifice.

The individuals sacrificed at Huaca de los Sacrificios were mutilated as part of the sacrifice, with their throats slit and chests opened. The sacrificial technique seemed to vary without clear patterns, however, with individuals displaying varying cut marks on the cervical vertebrae, clavicles, and ribs. Most common were cut marks on the cervical vertebrae, with the marks seeming to cluster around the anterior cervical bodies and proceeding from side to side reflecting ritualized mutilation of the throat (Klaus et al., 2016; Perez et al., 2010).

The method of sacrifice is consistent with the throat being slit horizontally across the front. This motion is visible in the cervical vertebrae, where series of cut marks can be observed on the anterior surface of the vertebral bodies. In order to create marks on the vertebrae, the blade would have to pass through the trachea, esophagus, and the arteries and veins of the anterior neck, and the tough and fibrous anterior longitudinal ligament.

In Entierro 9, an interesting observation was made. Klaus et al. (2016) described a possible exposed and bisected left pulmonary trunk, suggesting that the heart was removed (Klaus et al., 2016). The excellent preservation of the contents of the thoracic cavity (such as lung tissue) suggests that the chest was opened during the perimortem interval, which caused the structures inside to desiccate more quickly than other structures in the body, such as the abdomen, which was not preserved as well. This burial suggests a different form of sacrifice involving heart removal.

The process of heart removal necessitated that the ribs be cut through- probably around the costal cartilage- and the left side of the thoracic rib cage swung open to expose the interior. The cut marks on the left medial clavicle, anterior manubrium, and several of the left ribs support serve as evidence of this process, as well as perimortem fractures on the ribs that are believed to have resulted from the rib cage being pulled open. From there, the heart would have been removed.

As example, several individuals, including Entierros 2, 3, 10, and 18, exhibit cut marks along the left ribs, specifically the superior ribs 2 through 5. Approximately a third of the individuals displayed cut marks on the left clavicle. Entierro 24 displays incomplete fractures on the posterior sections of the left rib cage, also suggesting that the rib cage was manually pulled open. In the case of Entierro 16, the manubrium had been cut so deeply as to bisect the thick bone (Klaus et al., 2016).

However, the methods of sacrifice do not look the same across both samples. Huaca de los Sacrificios displays a preference for chest opening over throat slitting, possibly showing a change in sacrificial tradition (Klaus and Toyne, 2016). There was significant insect activity among the bodies, with puparia preserved in the interments in both sites. It is likely that the bodies were left exposed for probably a month of more, which fits in with the Muchik burial patterns of prolonged primary burial. From a theoretical point of view, this seems to suggest that the sacrificed individuals were viewed well in death, because of the attention required in prolonged primary burials. The individuals were given a good death, the bodies cared for after the sacrifice. This along with the organic matter left as grave goods is a possible extension of the comparison of dead bodies with seeds, and sacrifices as offerings for vegetal fertility.

Eten

The Proyecto Arqueológico de Eten Colonial, or PAEC, excavated the Colonial period samples (Klaus and Alvarez-Calderón, 2017). Per the name, the site featured the ruins of the postcontact or Colonial-era settlement of Eten, which was a focus of study concerning the bioarchaeology of Spanish colonialism (Klaus and Alvarez-Calderón, 2017; Klaus and Tam, 2009).

The original spelling of Eten is the Muchik word *Ätim,* translated as 'the place where the sun was born'- an interesting naming convention given that the town is on the furthest southwest portion of the region, nearest the sunset.

The colonial town of Eten was a port town. Archaeological excavation unearthed ceramics from places as far as Panama and Indonesia, and even from the Ming dynasty of China (Torres, 2012). Although Colonial Eten no longer exists, Ciudad Eten and Puerto Eten today exist on either side of Colonial Eten. Both were formed after Colonial Eten was abandoned in the 1750s, when the two main economic foci of the town (agriculture and fishing) diverged into separate villages.

Previous studies have been done about the town of Eten, most commonly in conjunction with a nearby town of Mórrope. Eten and Mórrope were both Muchik Colonial-era towns, relatively close geographically, but the towns were surrounded by very different microenvironments. Colonial Eten had access to water, being located near multiple rich bodies of water, and floodplain soil that was fertile for crops (Castillo, 2011), whereas Mórrope was located near the border of the Sechura desert and had soils consistent with this, high in salt and low in nutrients, that did not bear crops as easily (or at all). The town also did not have the access to water that Eten did (Klaus and Tam, 2009, 2010). Historical records from Morrope in the 18th century record the economy of the area as mainly relying on agriculture and mining (Modesto Rubiños y Andrade, 1936). The evaporites in the area, such as gypsum, would have been mined mainly by the native people, and the church set mining quotas in place of taxes.

Bioarchaeological studies of skeletal samples from both populations reveal a drastic difference in how the people lived and experienced the Colonial period in ways that can be tied to resource access and governance patterns. Individuals from Mórrope exhibited much higher rates of pathological conditions such as infectious disease, degenerative joint disorders (DJD), dental caries, and antemortem tooth loss that point to a low quality of diet and life for Mórrope peoples (Klaus and Tam, 2009; 2010; Klaus et al., 2009). Mórrope's skeletal samples displayed highly elevated rates of DJD associated with increased loading consistent with hard labor, and it is hypothesized that this population endured much harsher social, political, and ecological conditions. Younger individuals in this sample also displayed higher rates of DJD, showing that the people were made to undergo more strenuous conditions earlier in life, possibly being put to work earlier and harder (Klaus et al., 2009).

The skeletal samples from Eten displayed much lower rates of these pathological conditions, although the people lived around the same time and under the same Colonial government, less than an hour away. The hypothesized explanation for this is cultural buffering, because Eten had natural resources that Mórrope lacked, such as resources and socioeconomic capital. Eten is believed to have been buffered from the effects that Mórrope experienced by means of their stronger economy and the microenvironment that was available to them (Murphy and Klaus 2017a, 2017b). Middens dating to the early Colonial era show that diets in Eten remained fairly diverse, with access to marine sources of protein from the nearby Pacific Ocean (Del Alcazar, 2011).

The burials in Eten are derived from three church ruins. The original mission church, where the individuals in this study were interred, was used during the Early Colonial era roughly from the 1530s until the 1620s or so. A second church was constructed about 400 m to the east and used between roughly 1620 and 1750. Then the town was abandoned and a third church was built at the site in 1776 related to the town's religious mythology involving apparitions of the Christ Child.

This third structure, the Capilla del Niño Serranito (CNS), was built directly above and atop the ruins of the first mission church in 1776. The mission church and its mortuary samples are entirely underground at the present day. During the construction episode in the late 18^{th} century, the builder preserved the original church by covering the ruins with a clay cap, using that as a foundation, and building on top (Klaus and Alvarez-Calderón, 2017). The church itself lies within sight of the Pacific Ocean, only separated by approximately 400m of sand dunes. The floor of the later church is brick, covered by mounds of blown-in desert sand, and also the abode brick of the walls that have fallen into the church in the decades since.

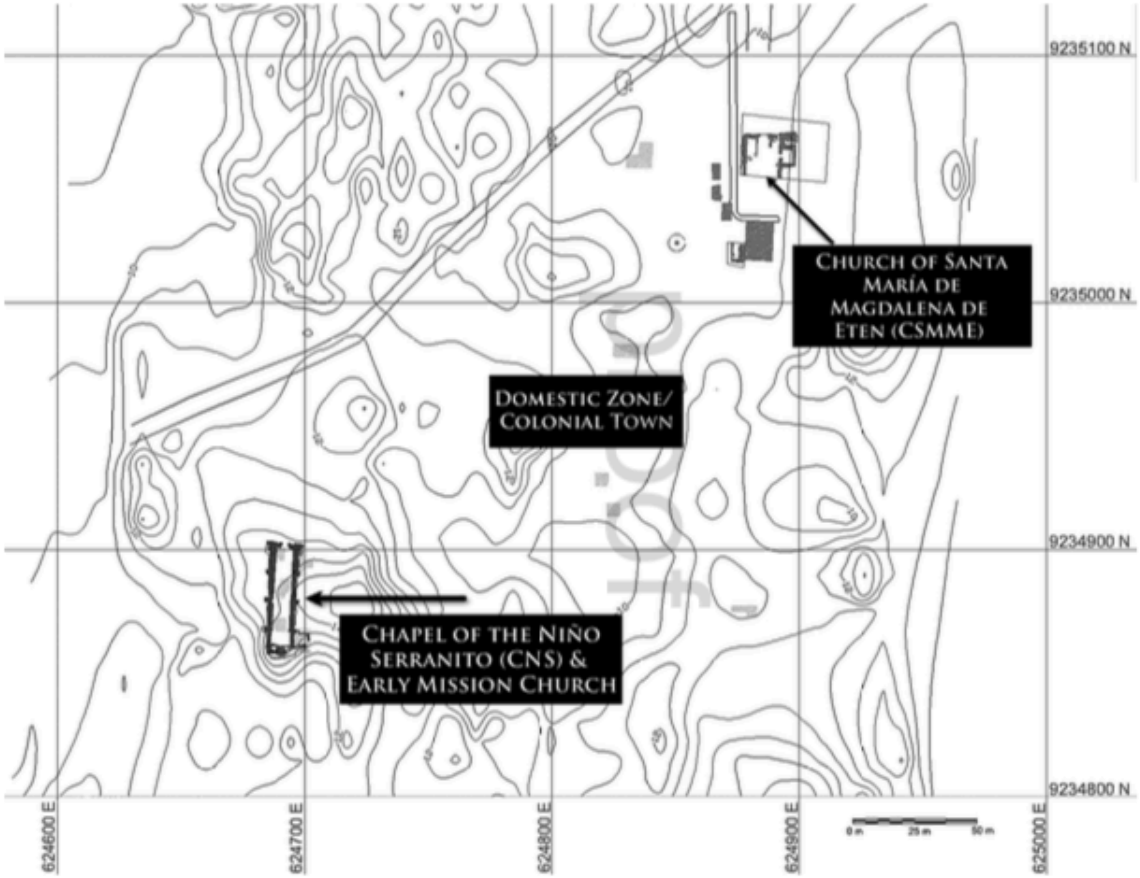

Figure 8. The site of Eten, showing the location of all three churches. Map from Klaus and Alvarez-Calderón, 2017.

Today, the church of Eten consists of approximately half of a brick building, with the roof and most of all four walls having collapsed. The walls making up the front and back of the church are most intact, being about 10m tall. The wall where the entrance doors are still has the alcove for the bell on its interior. The exterior of the front is better preserved than the interior as it was a late 19th century addition in the Neoclassical style with decoration and painted walls superimposed on the original 18th century church front.

Figure 9. The church as seen facing the back wall, where the altar stood. Unit 3 is approximately in this area. Photo by Genevieve Brown.

Figure 10. The interior of the church as facing the front wall, displaying the side walls crumbling inside. Unit 4 is approximately in this area. Photo by Genevieve Brown.

Figure 11. The exterior front of the church, displaying the remains of the paint. Photo by Genevieve Brown.

There are a few 19th century interments in the area of the CNS, but the interments in the mission church (Early Colonial Era) are laid out in what is referred to as 'cookiecutter Catholic' fashion- the bodies were laid out facing the altar of the church, wrapped in shrouds rather than in coffins, with their hands in a praying position. One burial was noted in Unit 3 where the individual was interred in a wooden coffin- this individual has been hypothesized by the excavators to have been a priest in life. The skeletons are mostly complete but often fragmented, owing to proximity to the ocean, with groundwater intrusion and salt erosion, producing fragmentation and cracking.

The burials from Eten are split up into different zones, based on where within the mission church they are located. It is believed that relative distance to the altar of the chapel served as an indicator of social status, with the individuals buried closer being considered more important than those further away. Interments in the mission church were documented in three units- Units, 2, 3, and 4. Unit 2 is situated nearest the main doors of the church, Unit 3 by the back wall nearest the altar, and Unit 4 in the middle of the church between the two.

In Unit 4 in the middle section of the church, there were 22 individuals (U4-68 through U4-82) that make up a single mass burial. The current hypothesis is that these individuals were victims of an epidemic, and future studies are planned to further understand this specific instance of burial. Besides this, however, all other interments in the church are either single or double burials. The individuals in the units are buried approximately five to six people deep (Klaus and Alvarez-Calderón, 2017).

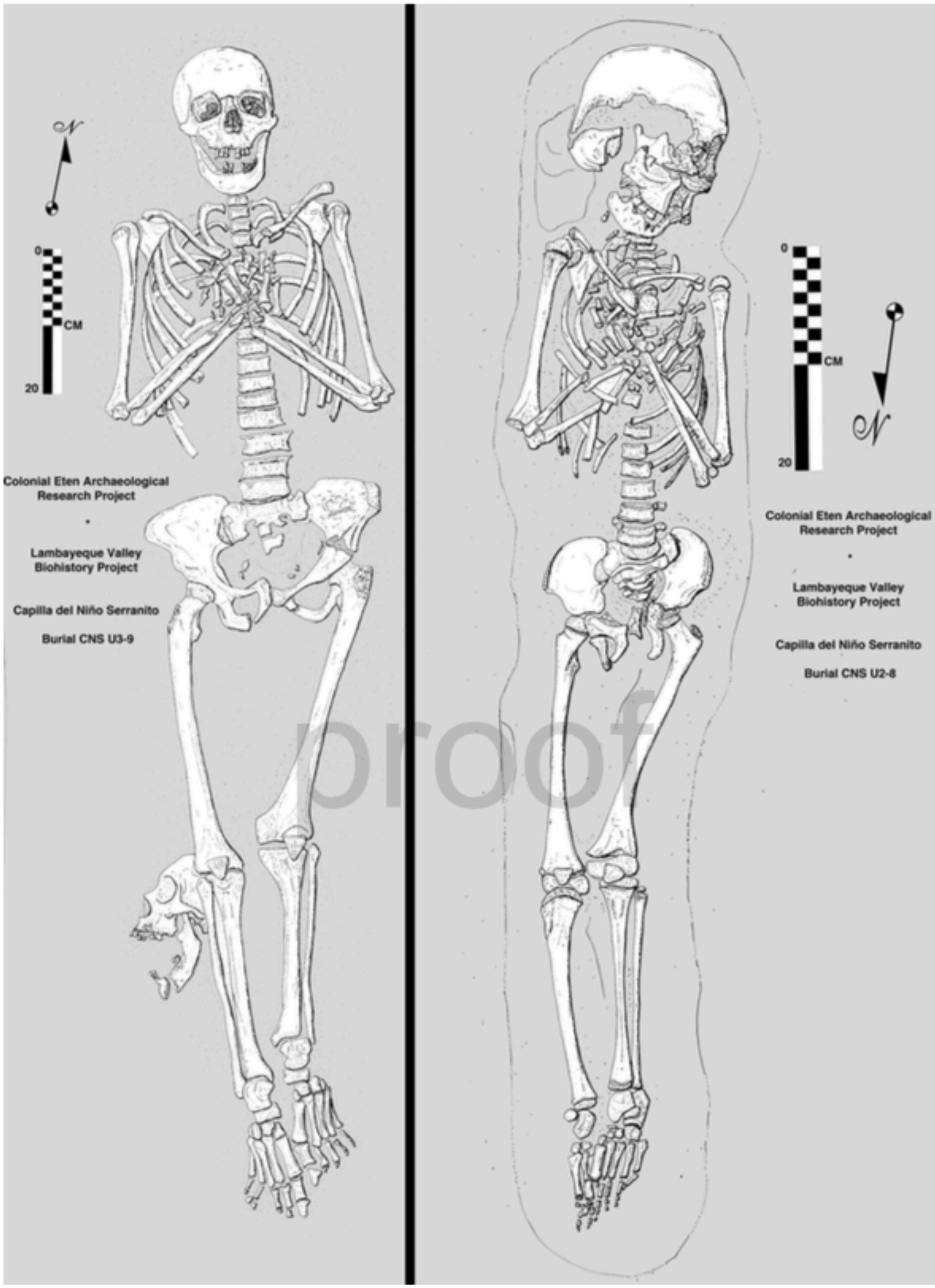

Figure 12. Example of burial pattern at Eten, drawn by Haagen Klaus.

Many burials have pre-Hispanic accoutrements, such as jewelry and clothing from Chimú-Inka tradition. Among the material excavated was a Chimú-style pendant in the shape of a fish, and several drilled beads in very late pre-Hispanic style. However, others have Spanish jewelry (glass earrings) produced between the 1530s to 1570s that frames the dates as Early Colonial (Klaus and Alvarez-Calderón, 2017).

This site is truly interesting in how it displays the resilience of native culture under the rule of Spanish colonialism, and how the culture manifested and held on in everyday life and burial practices. The Muchik culture survived into the Colonial era, and survives today in the descendants, and it is vital to studies of culture to understand how the practices were preserved under changes in institution and broader culture, and how these changes affected the individuals in terms of stress.

Methods

Data Collection

The methods used for this study begin with dental impressions. Coltene President Regular Body Impression Material Plus had been used to create molds of the teeth during the process of excavation and skeletal analysis. This process is easily and quickly done, and allows dental analysis for many features without needing the teeth to be physically present at a lab. The impression material allows for high-resolution molds to be made, displaying the whole surface of the tooth.

The molds were surrounded by forming Coltene Coltoflax Dental Putty into small 'boats' to allow for the creation of resin casts. The resin used was EpoFix Resin and Hardener. The resin was mixed together at a 15:2 ratio of resin to hardener for two minutes, along with one drop of red dye to make for better visibility. The mixture was then put into the centrifuge for 2 minutes at 3000 rpm, balanced by a tube filled to the same volume with water- this process has been used to reduce the amount of bubbles in the resin, that could otherwise obscure the fine detail of the cast. Then the resin was left to rest for two minutes before being poured into the molds, again to reduce bubble formation. Once the resin fully set, the casts were removed from the molds and viewed with an engineer's measuring microscope. These casts are high resolution with a stated reproducibility of 0.2 micrometers, and if the tooth surface was well preserved, every perikymata is visible.

In this study, the microscope was connected to the computer, allowing for the view screen of the microscope to be relayed on the computer screen. The VisionGauge software was used to view and measure the surface of the tooth. VisionGauge has settings that allow measuring of items on screen, and this function was used to measure the perikymata along the entire vertical surface of the tooth, from crown to cemento-enamel junction (CEJ). This is required to give a record following the bands, making the final set of measurements directly follow the growth of perikymata from crown eruption to the cessation of enamel growth.

Perikymata form over a range of six to eleven days- eight days is the modal periodicity, and this study assumed an eight-day periodicity for each perikymata. A lower magnification was used (5x). The calibration in VisionGauge was set to measure in micrometers, using the calibration slide at 0.1 micrometers.

As LEH are non-specific stress markers, with over a hundred possible etiologies, the enamel defect cannot be used to determine any specific causes of physiological stress on the body. However, LEH do make timely proxies for acute events of physiological stress in general, and can record such timing.

The most applicable use of LEH studies is in analyzing populations- using the state of the enamel to understand the widespread nature of stress defects on the group. Taken with bioarchaeological evidence, this can reveal the ages, social statuses, and sexes that were most affected, and illuminate much about the society these people lived in.

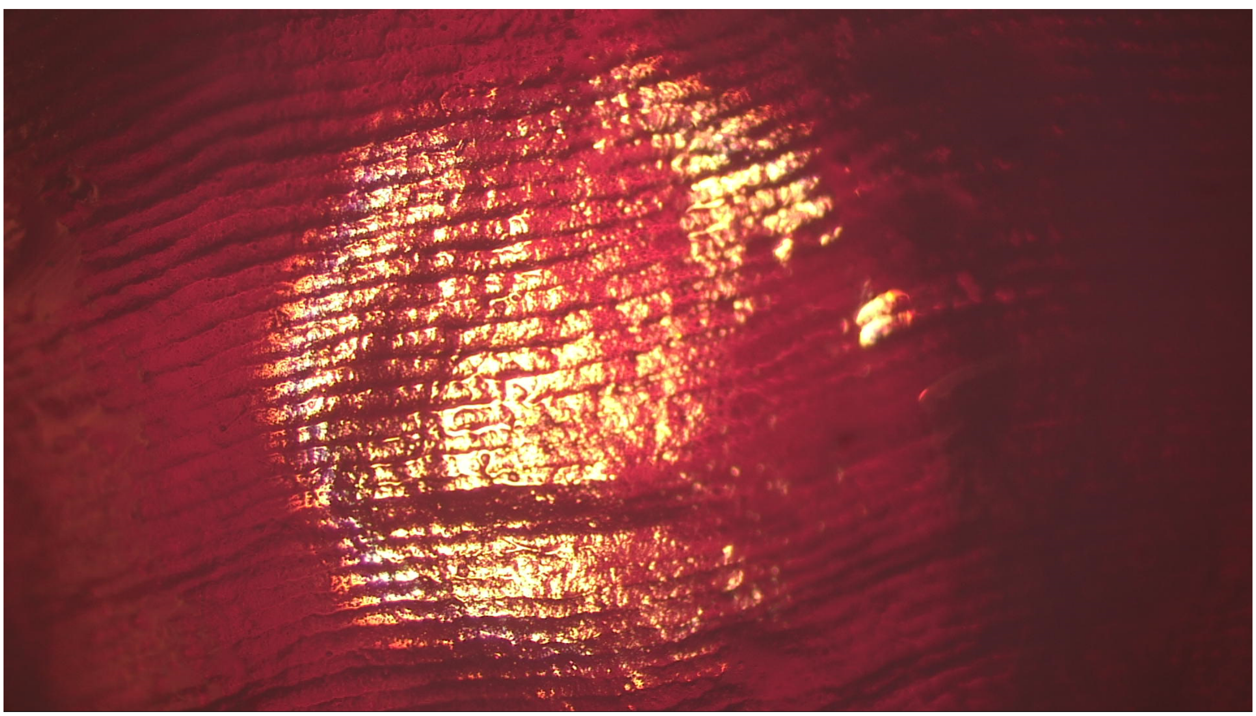

Figure 13. Image of perikymata taken using VisionGauge. Lower left second incisor from Huaca Chornancap (Proyecto Chotuna), Entierro 15. Photo by Genevieve

Brown.

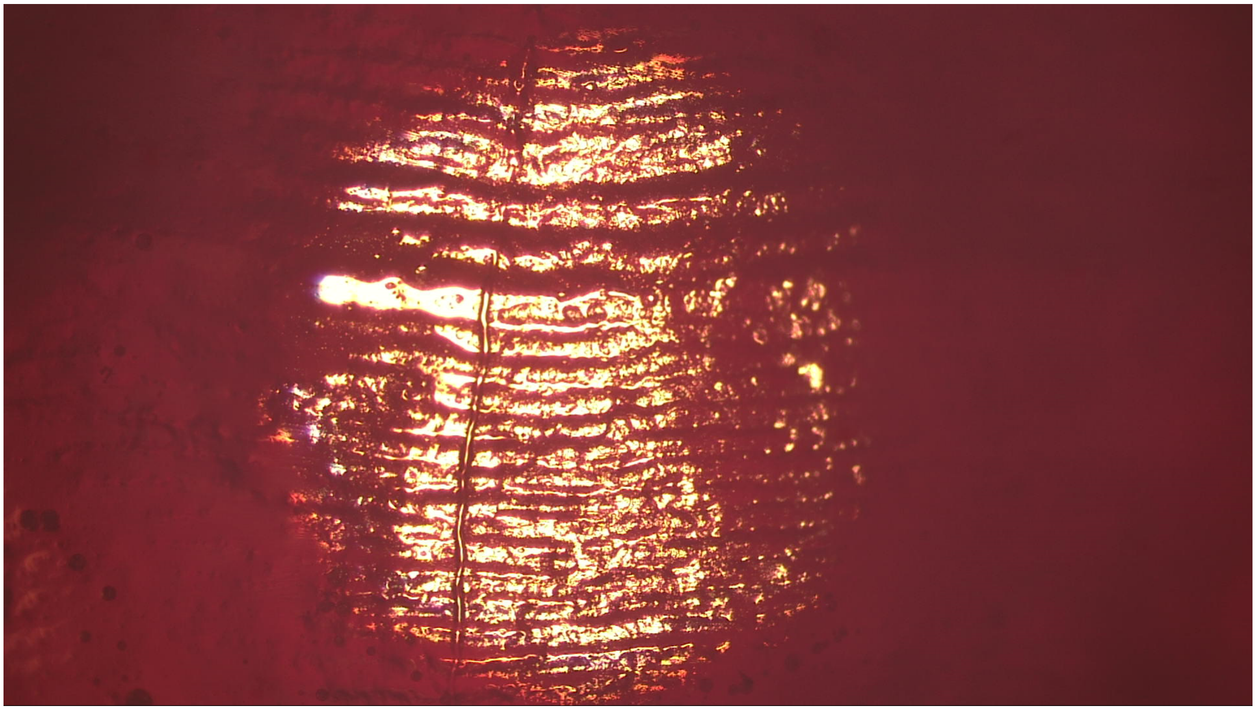

Figure 14. Image of perikymata, including accentuated perikymata near top, taken using VisionGauge. Upper left second incisor from Huaca Chornancap (Proyecto Chotuna), Entierro 16. Photo by Genevieve Brown.

Statistics

The measurement record for each tooth was put into an Excel spreadsheet, along with the site, burial number, and tooth of each measurement. From there, an equation was used across the measurement record, to understand each value's relationship to the mean. This was done by taking the average of the surrounding perikymata, divided by the standard deviation of the same surrounding perikymata (Hassett, 2012).

In order to acquire an accurate understanding of the accentuation of a single perikymata relative to the perikymata around it, the statistics take the five perikymata on either side of the one in question. This keeps the standard deviation relevant only to the specific distance down the tooth where the perikymata is located rather than taking it across the entire tooth, which would skew the data.

The five perikymata above and below, in this case from two to twelve, are averaged together, subtracted from the original starting point perikymata, at seven, and then divided by the standard deviation of two to twelve. This results in a z-score applied all the way down the measurement record of the tooth, displaying how accentuated each perikymata is in relation to the surrounding ones. If a z score is above 1.85, the perikymata is considered accentuated, representing an LEH. These perikymata were marked and placed into a new excel spreadsheet together, representing all of the LEH across all of the teeth sampled.

From there, the age-at-defect-formation was calculated by beginning with the crown initiation and cuspal enamel formation time constant, taken in days (Reid and Dean, 2006). Then the number at which the accentuated perikymata occurs was multiplied by 8, to get the number of days that had occurred since the enamel began forming. This number was then added to the previous age of cuspal enamel formation, and then the whole number was divided by 365 in order to take the number in years.

$$(\text{Age in days} + (\text{N perikymata to accentuated} \times 8)) / 365$$

For example, an accentuated perikymata is visible at location number 35, on a mandibular canine. The age for enamel formation for the mandibular canine is estimated as 1.5 years, which, when taken in days, comes out to 547.5 days. When calculated, this comes out to 2.3 years. This score is interpreted as the enamel defect having formed when the individual was 2.3 years of age.

After calculating all of the ages of LEH in the separate document, this data was input to SPSS. The values were analyzed using boxplots, to understand the range of ages at which the enamel defects occurred for each separate site. This was run both between the different sites all together, and between the different excavation units at Eten. The results of these data are displayed in Chapter 4.

Ethical Considerations

It is important for non-destructive methods to be used whenever possible, and when not possible, that the researcher first take steps to record as much of the material as possible before destroying it. The method used in this study was non-destructive, as it used casts of the dentition, and as it produces copies of the exterior surface of the dentition this makes it so that the dentition can be studied in multiple institutions at the same time. This also makes it possible to conduct analyses using destructive methods later on without losing any information about the external surface of the tooth.

Limitations

The importance of this method is that both the microscopic viewing and statistical quantification allow for an incredibly precise view of the LEH present on a tooth, as the markers may not all be macroscopically visible. This gives researchers a more accurate picture of the stress events individuals experienced during early life, and a better, more thorough understanding of how these events influenced and were influenced by other variables in the sociocultural and biological environment.

Although this method is accurate for identifying LEH that may not be visible on the macro scale, there are several limitations. Using this method requires the entire tooth to be measured, so teeth that have major amounts of wear on the occlusal and labial surfaces cannot be reliably analyzed, because so many of the perikymata on the surface are lost, and therefore the record of earliest formation as well. Several teeth in the sample displayed visible LEH on the surface, but the preservation of the tooth surface was not good enough to measure the perikymata, limiting how many teeth could be used in the study. In situations where the external surface of the tooth is not well preserved, it might be a good option to examine the dental histology as well (Goodman and Rose 1990; Smith et al., in press).

The method relies on the assumptions that the crown initiation and cuspal enamel formation times are constant, and that the periodicity of perikymata formation is constant. These assumptions are made because they have been tested and found to be as accurate as possible in many studies (Antoine et al., 2009; Guatelli-Steinberg et al., 2004; Reid and Dean, 2006; Temple 2016, 2019).

In the future, it may be useful to combine this method with macroscopic studies of LEH, as preservation levels may have an effect on the overall rate of LEH in a sample and possibly on demographics within. It is entirely possible that, due to burial locations and circumstances in some locations, individuals of lower social class may not preserve as well, potentially making some data on social status and physiological stress incomplete. Sex was not a factor in this study, as only the dentition was analyzed, and sex has thus far not exhibited any correlation with physiological stress.

CHAPTER FOUR

Results

Across Cultural Sites

Every individual that was observed in all three samples had at least one LEH, making the percentage of affected individuals in this study 100%. The box plot in Figure 12 displays a comparison of LEH chronology between the three sites: Huaca de los Sacrificios (labeled 'HS'), Huaca Chornancap (labeled 'PC' for 'Proyecto Chotuna'), and Eten (labeled 'PAEC'). The interquartile ranges all show substantial overlap, with the medians close together as well. Huaca de los Sacrificios and Huaca Chornancap have medians that are almost exactly the same, resting at around 3 years of age, with that of Eten being slightly lower. This means that the ages of defect formation are similar in each case, and there is no statistically significant difference between the three. There was no difference in the average age-at-defect-formation between Huaca de los Sacrificios and Eten ($p = 0.991$), Huaca de los Sacrificios and Chotuna ($p = 0.971$), or between Eten and Chotuna (0.931).

The ages of defect formation are most restricted at Huaca Chornancap ('PC'), with the youngest age being 1.5 years and the oldest being 3.7 years. At Huaca de los Sacrificios, the youngest age at defect formation is 1.3 years and the oldest age is 3.9 years. At Eten, the youngest age is 1.1 years, and the oldest age is 4.4 years. Eten displays the widest range of ages at defect formation, with both the youngest and oldest ages. This means that LEH formed for a longer time, beginning earlier and ending later, in this grouping.

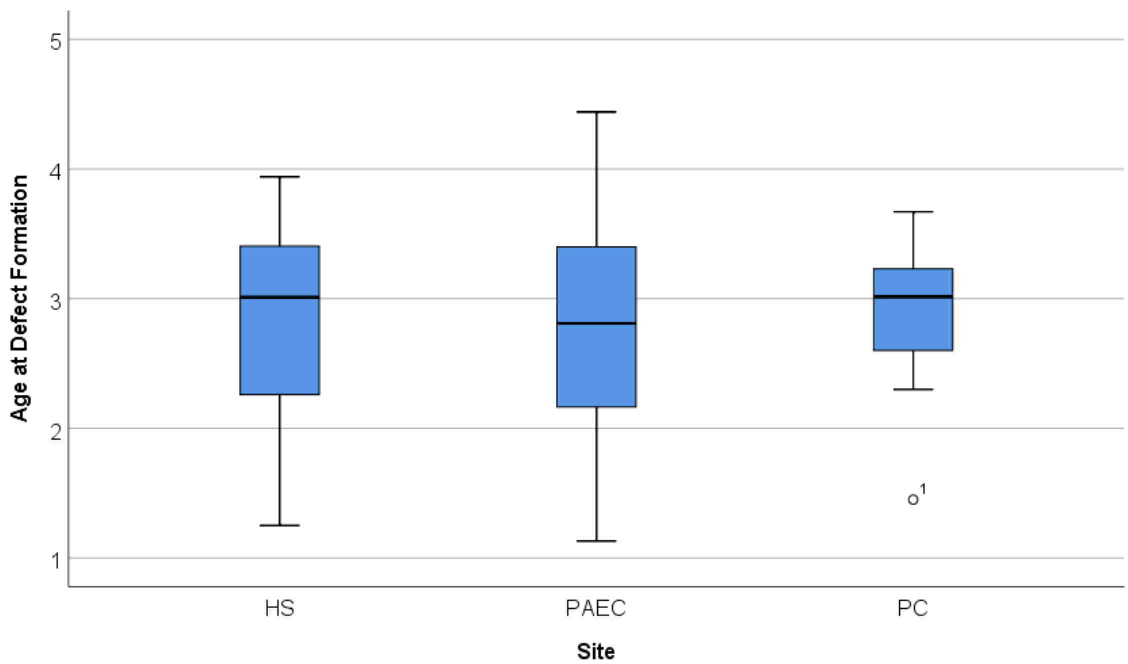

Figure 15. Box plot of data between the three sites.

Table 1. Percentiles.

Statistics

Age

N	Valid	169
	Missing	0
Mean		2.8050
Std. Deviation		.79181
Variance		.627
Percentiles	25	2.2400
	50	2.8500

	75	3.3900

Univariate Analysis of Variance

Table 2. Between- Subjects Factors.

Between-Subjects Factors

		N
Site	HS	28
	PAEC	127
	PC	14

Table 3. Tests of Between-Subjects Effects.

Tests of Between-Subjects Effects

Dependent Variable: Age

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.095[a]	2	.048	.075	.928
Intercept	626.645	1	626.645	988.497	.000
Site	.095	2	.048	.075	.928
Error	105.234	166	.634		
Total	1434.997	169			
Corrected Total	105.329	168			

a. R Squared = .001 (Adjusted R Squared = -.011)

Post Hoc Tests

Table 4. Multiple Comparisons.

Multiple Comparisons

Dependent Variable: Age

Scheffe

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
HS	PAEC	.0217	.16623	.991	-.3888	.4323
	PC	-.0632	.26062	.971	-.7069	.5805
PAEC	HS	-.0217	.16623	.991	-.4323	.3888
	PC	-.0850	.22422	.931	-.6388	.4689
PC	HS	.0632	.26062	.971	-.5805	.7069
	PAEC	.0850	.22422	.931	-.4689	.6388

Based on observed means.
The error term is Mean Square(Error) = .634.

Homogeneous Subsets

Table 5. Scheffe Test of Age.

Age

Scheffe[a,b,c]

Site	N	Subset 1
PAEC	127	2.7943
HS	28	2.8161
PC	14	2.8793
Sig.		.928

Within Site Comparisons at Eten

The box plot in Figure 13 displays a comparison between two of the excavation units inside the church of colonial Eten- Unit Two, which was situated nearest the front doors of the church and Unit Four, in the center of the church. The context of the burials, with social status typically being related to where inside the church individuals were interred- specifically with higher-status individuals typically interred closer to the alter-, relayed the possibility of differential age-at-formation times that would be relevant to differences in social status. Unit Three, which was placed nearest the altar of the church and potentially represented the highest social status in the sample, was not included because the usable data from the unit came from a single individual.

Unit Four displays the youngest average age-at-defect formation, though no significant differences in average age-at-defect-formation was found between the two (p= 0.993). Unit Four also displays the youngest age at defect formation, at 1.1 years, but the oldest age was nearly identical between the two units, at 4.4 years. Neither of the units displays significant departures from the other, meaning that there was no substantial difference between the age-at-defect formation in the grouping. This means that the ages of defect formation were very similar in the groups, with no statistically significant difference between the ages at which stress occurred.

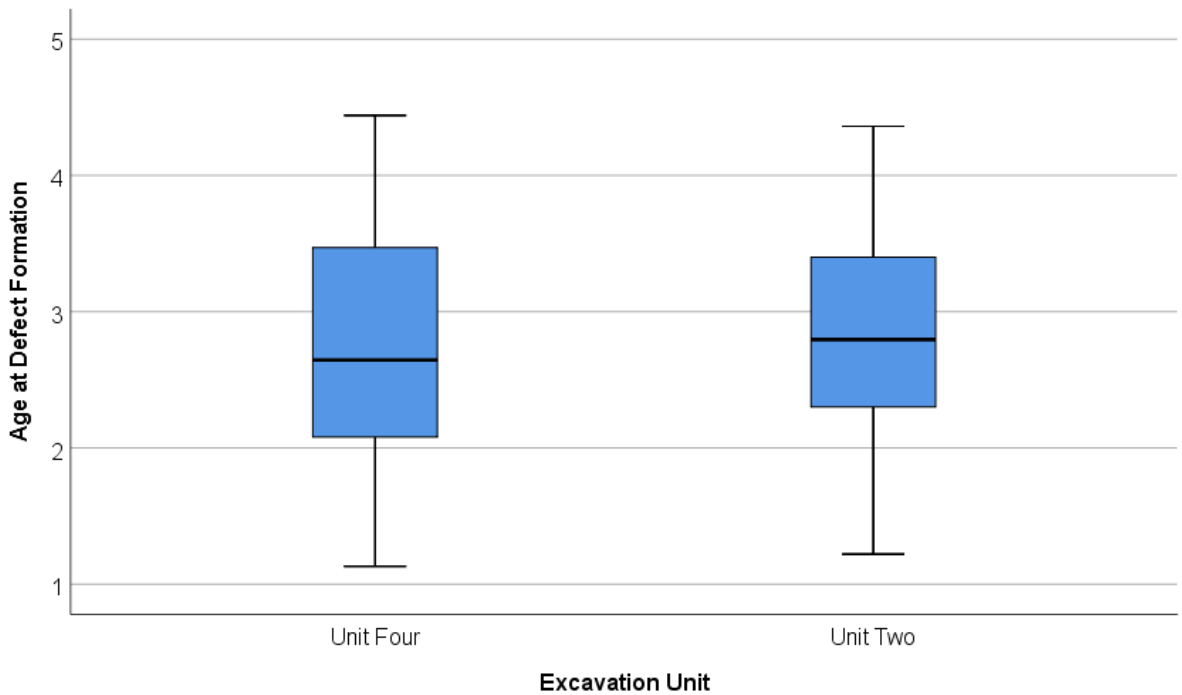

Figure 16. Box plot of data between two units at Eten site.

Frequencies

Table 6. Percentiles.

Statistics

Age

N	Valid	112
	Missing	0
Mean		2.7802
Std. Deviation		.85158
Variance		.725
Percentiles	25	2.1450
	50	2.7150
	75	3.4225

Univariate Analysis of Variance

Table 7. Between-Subjects Factors.

Between-Subjects Factors

		N
VAR00001	Unit Four	82
	Unit Three	15
	Unit Two	29

Table 8. Tests of Between-Subjects Effects.

Tests of Between-Subjects Effects

Dependent Variable: Age

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.464E-5[a]	1	5.464E-5	.000	.993
Intercept	679.261	1	679.261	928.234	.000
Unit	5.464E-5	1	5.464E-5	.000	.993
Error	80.496	110	.732		
Total	946.188	112			
Corrected Total	80.496	111			

a. R Squared = .000 (Adjusted R Squared = -.009)

CHAPTER FIVE

Discussion

Linear Enamel Hypoplasia Prevalence and Chronologies in Colonial Context

Each individual from all three samples had LEH (Klaus and Alvarez-Calderón, 2017). Previous studies (i.e., Klaus and Alvarez-Calderon, 2017) relied on macroscopic identification of LEH. Macroscopic identification of LEH under-enumerates the prevalence of this condition when compared with macroscopic approaches (Guatelli-Steinberg et al., 2004; King et al., 2005; Hassett, 2012, 2014; Temple et al., 2012; Temple, 2016). One reason for this under-enumeration relates to striae of Retzius geometry. Striae of Retzius are less acute in the occlusal region of the tooth, resulting in shallow, poorly defined LEH, while striae of Retzius in the intermediate and cervical thirds are more acute and produce deeper, more well defined defects (Hillson and Bond, 1997; Guatelli-Steinberg et al., 2012). As a result, LEH in early forming enamel may not be included in prevalence counts. Because the microscopic approach relies on an objective identification of LEH that does not take into account enamel depth, LEH forming in early enamel are possible to identify.

No significant differences were found between the ages of defect formation across the three samples. This means that in all three samples, the ages at which the defects formed did not vary widely, with none occurring at drastically younger ages. Typically, the most important factor in studying LEH is the age at which the defects first occur, as this typically means that the individual was experiencing greater stress events at an earlier age. The age at first defect also correlates with higher mortality rates at a younger age, which can have major effects on the lifeways and patterns of population demographics.

The majority of LEH in all three populations occurred between two and three and a half years of age, with the median resting at three years. When Spain colonized the north coast of Peru, the lives and practices of the native people were uprooted and transformed. As the goals of colonization were economic and political, Spain intended to extract the maximum amount of human and resource capital possible. To do this, Spain forced resettlement into colonial towns and an entire overhaul of the socioeconomic structure. Floodplains and native agriculture land were transformed into plantations and pasture for imported cattle and pigs, and the native people were forced to adapt to a new diet far from what had nourished the population for centuries, as well as working the plantations. In many ways, this has been shown to have disrupted the lives and bodies of the people (Klaus et al., 2009; Garland et al., 2015; Klaus and Tam, 2010). Skeletal samples from Colonial-era towns in the area have shown that the native people were used for arduous labor such as mining and working sugarcane plantations, as shown by drastically elevated rates of DJD and markers of physiological stress (Klaus et al., 2009, Klaus and Tam, 2009).

The individuals from Huaca Chornancap and Huaca de los Sacrificios were sacrificed and therefore normal mortality patterns do not apply in this case, so any conclusions must be cautiously applied. Any perceived randomness seen in a typical cemetery is not applicable, as these individuals were deliberately chosen for sacrifice by the Chimú and Inka peoples, potentially skewing sample demographics. However, they do appear to have lived lives typical to low-status Muchik common people, so the early life stress patterns can be considered fairly typical. As well, the town of Eten was relatively better off than other known Colonial-era towns. As discussed earlier, Eten was culturally buffered from many deleterious effects of colonial rule by a rich microenvironment and stable economy (Klaus and Alvarez-Calderon, 2017; Thomas et al., 2019).

Previous research has evaluated the rates of crypt fenestration enamel defects (CFED) between Eten and another colonial town nearby called Mórrope, to understand differences in survivorship between the two samples. This study found that Eten showed greater survivorship than Mórrope, in individuals both with and without CFEDs (Thomas et al., 2019). These findings suggest that the experience of colonialism was relatively uneven, with some communities experiencing greater hardship in association with local environment due to lessened access to resources or forced move into less arable land.

Previous research into enamel defect rates in pre- and postcontact Peru shows fascinating results. In these studies, the pre-Hispanic samples showed greater quantities of LEH, paired with a smaller prevalence of other lesions and skeletal pathological conditions (Klaus and Tam, 2009; Klaus and Alvarez-Calderón, 2017). As LEH is a marker of stress, the individual must survive the stress event for the defect to form. Therefore, non-expression of the stressor does not necessarily mean less stress was leveraged on an individual or a population. Rather, non-expression can also mean that the individual did not survive the stressor. In the studies referenced here, the postcontact samples showed lower rates of LEH, even as all other lesions and pathological conditions measured increased (Klaus and Tam, 2009).

Together, this evidence points to a conclusion that the postcontact individuals likely experienced greater frailty. This matches with other data and studies showing that the disease rate in post-contact populations drastically increased, suggesting that the populations experienced greater stress in terms of age-specific disease prevalence (Klaus and Tam, 2009, 2010; Klaus et al., 2009). The economic and social restructuring that came along with colonization also implies greater stress. Skeletal data reveals very little difference between the late pre-Hispanic and early postcontact. Ball (2017) studied body mass in samples from both pre- and postcontact, finding that body mass saw a slight increase of between 5 and 7% in the postcontact samples, which was hypothesized to relate to the changing diet in Colonial-era populations that brought increasing levels of carbohydrate intake (Ball, 2017). Because of the large percentage of growth that takes place during early life and the impact that the dietary transition to complementary foods has on the body's ability to complete that growth, this is a factor that can be used to understand early life stress as well.

The early life period is a vital part of the body's development, and nutrient deficiencies during this time have a large impact on the later lives of individuals, so this transition from breast milk to a solid diet is necessary to understand the full circumstances of the population. Historic and skeletal data from the area relate that the populations of north coast Peru underwent many changes during Spanish colonialism, and although there is no solid data as of yet, it can be hypothesized that these changes extended to the early life environment and weaning patterns as well. This study sought to discover any such patterns between the pre-Hispanic and Colonial-era samples, as well as what the LEH could possibly be related to.

Eten did display the lowest ages-at-defect-formation in the sample, with the youngest age at 1.1 years, but this was not significant in changing the distribution of LEH chronology. The wider range of ages-at-defect-formation in the Eten sample could represent an increase in stress, with events occurring outside of the usual range that marks the weanling transition to solid food. In this case, the stress markers could result from resource restriction, shifts in events or timing of stress, or a cultural change in weaning patterns due to colonial governance, among other possibilities. Further research into the lives of this population will be needed to understand if this wider range and greater prevalence of older ages in the sample is a result of stress events occurring later during life, with greater frequency, or if this is possibly a sign of the drastic sociopolitical changes wrought by Spanish colonization.

Also taken into account were the within-sample differences of the church at Eten. Given that there were multiple excavation units at different areas in the church- areas which typically correlate with differing social status- the possibility of varying age-at-first-defect existed, due to variance of stress events with diet and social status. No significant difference was found- the average age-of-defect formation was similar between the two samples. The oldest ages-at-defect-formation were nearly identical in both samples as well. In this case, these results display that stratification within the population buried at Eten was not wide enough to produce drastic changes in the ages of enamel defect formation. However, there are still interments in the church that have not been excavated or studied in this way, and the unit that was most likely to represent individuals of higher status (Unit 3) was unable to supply data that was useful to this study. As more excavations are done in this site, estimation of LEH chronologies should be continued to provide a more complete understanding of these patterns and whether this may change once all burials are examined.

Linear Enamel Hypoplasia and Infant Feeding Behavior

It is possible that the chronology of LEH observed at these sites reflects weaning stress. There have been many studies of this type done on archaeological samples, due to the importance of understanding weaning patterns in context of population life histories. One of the major stress events related to LEH is the introduction of complementary foods and cessation of breastfeeding (Gowland, 2015, 2018). Cessation of breastfeeding increases psycho-social and physiological stress burdens, due in part to the unraveling of the mother-infant nexus (a deeply embodied relationship reflecting combinations of social and physiological dependence)- a shift in diet from breast milk to solid food, and a sudden influx of foreign bacteria can cause problems with the infant's still developing immune system (Gowland, 2015, 2018; King et al., 2018a; Veile and Kramer, 2018). This early period of life is an incredibly dynamic one, responsible for setting the stage for later growth and development, and gives great insight into the mechanisms that make up the vital processes of development (Kuzawa and Quinn, 2009; Lupton, 2013; Marmot, 2010, Norris and Cameron, 2013; Chinique de Armas et al., 2013)).

Humans breastfeed exclusively for the first six months of life due to physiological constraints on body weight and capability that must be met, and the process of weaning is initiated with the introduction of complementary foods after that point (Sellen, 2007). Cessation of breastfeeding occurs between the ages of two and three years, with breastfeeding rarely seen past four years (Dettwyler, 1995; Wright and Schwarcz, 1999; Tsutaya et al., 2016). The ages at which weaning is begun and breastfeeding stops entirely are culturally and ecologically determined and vary across the world, but these practices can rely to an extent on the available resources that regulate the composition and type of complementary foods (Halcrow and Gowland, 2020; Lee et al., 1991; King et al., 2018a, 2018b; Konner, 2005).

The average age at which a population ceases breastfeeding can reflect on the subsistence strategies and available resources of the population, as well as on the stressors faced during lived circumstances. Populations that practice agriculture tend to wean earlier than non-agricultural populations, due to an abundance of calorie-dense foods such as grains that can be used to complement breast milk (Sellen and Smay, 2001; Fogel et al., 1989). In many cases, LEH is associated with the process of weaning due to the stress of the dietary shift resulting in weanling diarrhea, and these enamel defects can represent the ages at which the process is taking place (Hillson and Antoine, 2011; Dirks et al., 2010). Many studies have tethered the formation of LEH to the process of weaning, due to the change in diet and introduction of foreign bacteria to a yet untested immune system (Katzenberg et al., 1996; Schurr, 1998). Because breast milk acts as a sort of buffer, as the nutritional quality is not adversely affected much even if the mother's body is in a famine state, very early life stressors that are seen before the beginning of weaning may be representative of a poor state of the mother, rather than stressors in the infant's life.

There are issues with estimating the chronology of LEH from macroscopic identification alone, as not all LEH are macroscopically visible and the lack of quantified scale means that an age-at-defect-formation cannot be properly estimated. As well, these earlier studies lack the necessary context of isotopic evidence to correlate the shift in diet caused by weaning behavior (Humphrey, 2008). As LEH are nonspecific stress markers, the defect cannot be tied to any specific stressor unless correlated in timing.

Later studies on weaning patterns correct this, using evidence from stable isotopes to properly identify the process of weaning in archaeological samples (Tsutaya et al, 2016; Katzenberg and Pfeiffer, 1995; Schurr, 1997; Pearson et al., 2010; Reynard and Tuross, 2015). Stable isotopes such as those of nitrogen and carbon can indicate where along the tooth the diet of the individual shifted from breast milk to solid foods, relating the age at which the infant ceased breastfeeding. These studies have been instrumental in identifying the weaning patterns of various civilizations, which give insight into the early life environment of the populations and context to the stress markers represented in the skeleton.

Tsutaya et al. (2016) analyzed weaning patterns from the Yoshigo site of Japan, home to people of the Late/Final Jomon period (4000-2300 BP). This study found that cessation of breastfeeding in this sample occurred at approximately 3.5 years of age, which was concurrent with other archaeological hunter-gatherer populations (Tsutaya et al., 2016). Another study focused on the Maya site of Kaminaljuyú in Guatemala, using nitrogen and carbon stable isotopes to track the introduction of solid foods into the diet. At this site, complementary foods appear to have been offered around 2 years of age, with full cessation of breastfeeding estimated at approximately 4 years (Wright and Schwarcz, 1999).

Two approaches to correlations between LEH and weaning are found in the bioarchaeological and primatological literature. These approaches include intra-tooth identification of stress and weaning and inter-population identification of stress and weaning. Intra-tooth identification of stress and weaning relies on isotopes and developmental defects derived from the same tooth of the same individual (Humphrey, 2008). Here, it is found that the period leading up to and following the cessation of breastfeeding is associated with the formation of LEH, and thus, represents periods of greater psycho-social and ecological stress burdens (Dirks et al., 2010; Sandberg et al., 2014). Differing stress patterns are also observed in association with dietary quality in the weaning environment (Garland, 2019). In addition, LEH chronology is identified using microscopic methods, and tethered to the weaning environment based on broad generalizations of age-at-breast-feeding cessation across a sample. This work also finds significant associations between the time period leading up to and following breast feeding cessation (Temple, 2016, 2018, 2020).

Studies on the weaning patterns of archaeological populations are useful for understanding the early life environment and stressors, and can be used in conjunction with stress studies and skeletal evidence to gain new insight into biological and cultural realities of archaeological populations. However, there has been very little research done on the weaning practices in the north coast, and there is no hard tissue evidence as of yet telling the ages at which weaning began and ended, either before or after contact. Despite a lack of isotopic data available from the north coast, there is a study that analyzed weaning ages from two sites in the southern Peruvian Andes dating to 500-1100 CE using nitrogen and carbon stable isotopes (Greenwald et al., 2019). The work found that cessation of breastfeeding in this area occurred at approximately 2.6 to 2.8 years of age. These ages are consistent with the interquartile ranges for LEH formation in all three samples of 2.2-3.3 years, with an average age of LEH formation at 2.8 years. While these weaning ages were derived from populations located in more distant regions, these results suggest that the majority of LEH among samples from the north coast appear in the six months prior to and following breastfeeding cessation. In this sense, it is possible that the intense psycho-social and ecological changes experienced in this environment are associated with LEH formation. Because of the difference in cultural and environmental context, the ages of cessation of breastfeeding cannot be assumed to have been the same among the north coast peoples, though the close correspondence of results provides compelling evidence for indirect associations between breastfeeding cessation and stress in the north coast samples.

This kind of data would be useful in this situation to understand the changes that native people underwent and how these changes began affecting even the youngest individuals. An interesting topic of future study is to analyze using stable isotope evidence whether the ages of breastfeeding cessation differed between pre-Hispanic and Colonial eras in the same place- this would further understanding into the early life environment of the population. Using these studies in conjunction with LEH could also serve to analyze the ties between weaning ages in the area and stress events, to understand the nature of the process within the population.

CHAPTER SIX

Conclusion

In this study, the time-at-defect-formation of LEH was analyzed between three separate groups on the north coast of Peru in order to understand the timing of stress events in the lives of the populations. Huaca de los Sacrificios and Huaca Chornancap are both sacrificial sites dating to the late pre-Hispanic, and Eten is a town dating to the early Colonial era. Stress markers like LEH have long been one of the most commonly studied traits in bioarchaeological context, as studies of stress are one of the most important ways to grasp the underlying environment that regulates growth and development.

The impact that the early life environment has on later life and mortality rates make characteristics of this environment vital to population studies. Understanding the circumstances under which individuals developed gives great insight into the cultural and biological lives, relating such facts such as weaning patterns, subsistence methods, social status and hierarchy, and hardships the populations faced. LEH is an important mechanism of these studies because of the precise quantified timeline these defects relay of stress events during the individual's lifetime.

Because of the sensitivity of the human body to stress and the tightly genetically controlled timing of enamel formation, studies of LEH provide a unique understanding of early life stress. Through the addition of bioarchaeological and historical context, this can be a great way to understand social hierarchies and makeup, general functioning of population groups, and resource allocation.

This study focuses on the expression of stress through linear enamel hypoplasia defects, aiming to understand more thoroughly the realities of stress both across pre- and postcontact Peru, as well as in different cultural categories such as sacrifice and socioeconomic class. Previous studies have shown that Colonial-era populations in north coast Peru experienced many negative effects to the skeletal and dental development, likely due to colonial governance and changing conditions (Klaus and Tam 2009, 2010). It was hypothesized that there would be differences between the groups, to a point where factors like status and economic makeup would explain the variability in stress levels.

For this study, casts of the dentition were analyzed microscopically to create a record of the enamel growth, and a z-score was applied to the results to reveal which of the perikymata were accentuated and considered LEH. From there, box plots were used to display the variance between the groupings and understand what the age-at-formation meant for life in each group.

No statistically significant differences were seen between age-at-formation across any of the three populations, nor between the excavation units at Eten. This shows that all individuals in the samples experienced stressors that caused the enamel defects at approximately similar ages and that there was no drastic change across the shift from precontact to colonial era, or across perceived social status in the church. This result could be due to the lower social status of the human sacrifices at Huaca Chornancap and Huaca de los Sacrificios than in normative burials, or because of the cultural buffering and resilience of the town of Eten to deleterious effects of colonization, or any number of reasons therein and besides. Eten did display a relatively wider range of ages-at-defect-formation, which relates a longer period of time that stress events were occurring, but this difference was also not significant. However, the results add interesting context to studies of contact and colonial-era social environments. This wider range may relate to increased stress in the population, or changes in weaning patterns and diet- hypotheses which can be tested by further research.

Recent studies have made apparent that contact led to a new reality in the cultural and biological space, affecting the formation and maintenance of identity and socioeconomic structures. Colonization did not result in immediate and complete collapse of the colonized groups, but rather a transformation of sorts to adapt to the new circumstances. This perspective of complexity must be kept in mind during studies of contact and conquest- there are multitudes of factors at play that influence the outcome of these circumstances and how individuals and populations react to contact.

In summary, these data fits with other studies that have been completed concerning the town of Eten, and adds to the idea that the impacts of colonialism and the reaction of native people, both biologically and culturally, are more complicated and dynamic than previously known.

Future studies analyzing the stress markers and pathological conditions in the area should be done in order to have a larger sample size, from more varied walks of life and mortality patterns. There are many more studies to be done in this area, on other samples and social categories, to better understand the overall social environment. This study may have been limited by the specific traits of the sites, as none of the three are particularly typical burial representations of the respective time periods, but outliers should not be ignored simply because of that character. Contact is an incredibly varied phenomenon, with different impacts everywhere, and every sort of impact is relevant to the study, because it reflects the lengths to which the human body can go in cases of stress.

Studies should always strive to achieve the most complete understanding possible, with as many lines of evidence as possible. This study is submitted not as anything groundbreaking or revelatory, but as another line of evidence to strengthen the understanding of the area and time period given. As more studies are done and more samples studied, academic understanding of pre-Hispanic and Colonial-era Peru, and the transition period between the two states, will be elucidated to form a more cohesive comprehension of history.

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