CRIBRA ORBITALIA AND POROTIC HYPEROSTOSIS IN MIDDLE HORIZON PERU: AN OSTEOLOGICAL ANALYSIS OF COLLOTA AND TENAHAHA

A thesis submitted to the faculty of
San Francisco State University
In partial fulfillment of
The Requirements for
The degree

Master of Arts
In
Anthropology

by

Guadalupe Ochoa

San Francisco, California

May 2013

CERTIFICATION OF APPROVAL

I certify that I have read *Cribra Orbitalia and Porotic Hyperostosis in Middle Horizon Peru: An Osteological Analysis of Collota and Tenahaha* by Guadalupe Ochoa, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requests for the degree: Master of Arts in Anthropology at San Francisco State University.

Mark C. Griffin
Professor of Anthropology

Cynthia A. Wilczak
Professor of Anthropology

CRIBRA ORBITALIA AND POROTIC HYPEROSTOSIS IN MIDDLE HORIZON PERU: AN OSTEOLOGICAL ANALYSIS OF COLLOTA AND TENAHAHA

Guadalupe Ochoa
San Francisco, California
2013

The primary focus of this thesis is to determine the frequency rates of cribra orbitalia and porotic hyperostosis brought on by nutritional deficiencies and other causes in the Collota and Tenahaha sites in Cotahuasi Valley during the Middle Horizon in Peru. Environmental factors, such as parasites, chronic disease, and nutritional deficiency anemia due to a lack of nutrient-rich foods in early childhood are all elements that have the potential to impact the cranial surface Using a comparative population from Huaca del Loro and Chakipampa in the Nasca Valley disease rates within and around the establishment of the Wari political state helps highlight the statistical significance, if any, of Collota and Tenahaha. There were differing percentage rates between the comparative population and this sample; the Wari controlled populations of Huaca del Loro and Chakipampa had a higher frequency of orbital and vault lesions than the skeletal material of this thesis. However, Fischer's exact test did not demonstrate that these frequencies were statistically significant. While the differences in percentages suggest different rates of cribra orbitalia and porotic hyperostosis, the results were not sufficient to state that a Wari-controlled population was more biologically stressed and nutritionally deficient than a population that was just outside imperial rule.

I certify that the Abstract is a correct representation of the content of this thesis.

Chair, Thesis Committee

16 Dec 13
Date

ACKNOWLEDGMENTS

This thesis could not have been completed without the advice and support of my committee members Mark C. Griffin and Cynthia A. Wilczak. Their steadfast encouragement and solid guidance gave me motivation when I needed it the most. I would also like to thank Justin Jennings, Corina Kellner, and Willy Yepez Alvarez for allowing me to be an active participant in their project. Their assistance on and knowledge of the Wari culture was informative and inspiring. My wonderful and supportive group of friends that have inspired me to be better every day, especially Priscilla Mollard, whose continuous support and friendship helped motivate this project's completion. Finally, I would like to thank my family; my awesome brothers Jose and Art, my wonderful mother Herlinda, and finally my father Arturo, who has been a constant pillar of support and reminds me every day I can finish everything I start. I hope I made you proud, Dad.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 – INTRODUCTION

The primary aim of this thesis is to determine the rates of cribra orbitalia and porotic hyperostosis within a sample skeletal population. Through osteological analysis, the sites of Collota and Tenahaha in the Cotahuasi Valley in Southern Peru were observed. These sites were excavated during a period of five annual summer excavations beginning in 2000 and ending in 2005. The goal of these excavations was to better understand the complex societies within the Cotahuasi Valley during the Middle Horizon period, which lasted from A.D. 500 to 1000 (Bauer 2004). Excavation was specifically aimed at evaluating the influence of the Wari empire which began in the Middle Horizon and spread out from the Ayacucho Basin, northward into the Cotahuasi Valley, and through much of Peru (Jennings 2001).

The sites of Collota and Tenahaha were occupied during a period of Wari cultural and imperial florescence. Cultural and archaeological data from these two sites contributed valuable information to the bioarchaeological analysis carried out in this thesis. Collota and Tenahaha were originally believed to have been under Wari imperial control (Chavez Chavez 1982; Jennings and Craig 2001; Smith and Montiel 2002; Trawick 1994), but this was not exactly the case. Sites in the Cotahuasi Valley, such as Collota and Tenahaha, appear to have merely imitated imperial infrastructures in order to emulate Wari control without being subjugated by it (Jennings and Yepez Alvarez 2002). Jennings (2006) suggests that appearing Wari during this time benefitted the imperial state by giving the impression that their influence was far-reaching. Wari architectural and ceramic styles throughout the Cotahuasi Valley would have created the impression that Wari imperialism was widespread and that Collota and Tenahaha were within Wari borders (Jennings 2002).

Although adopting Wari architectural and ceramic styles granted the Cotahuasi Valley a degree of autonomy, emulating Wari infrastructure may have proved less advantageous in the long run. The Wari developed agricultural terracing systems that were incredibly effective in producing larger amounts of food, but this increase of agricultural production led to increased population growth (Schreiber 1992), which is one of several factors potentially responsible for increased rates of disease (Turner and Armelagos 2012).

Human health is very likely to be negatively impacted by environmental stressors such as parasites and iron-deficiency anemia due to a lack of nutrient-rich foods in early childhood. In addition to these environmental stressors, the increase in population that tends to coincide with technological advancement (Roberts and Manchester 2007; Turner and Armelagos 2012), such as Wari-style agricultural terracing (Jennings et al. in press), also tends to lead to an increase in disease rates in populations, due to improper waste disposal and inadequate hygiene (Wright and Chew 1999). These factors all potentially contribute to the development of chronic disease, which can manifest in the skeleton over the course of a human lifetime (Roberts and Manchester 2007; Stuart Macadam 1985; Turner and Armelagos 2012).

Cribra orbitalia and porotic hyperostosis are skeletal lesions that were once thought to develop in response to iron deficiency in the diet (El-Najjar 1976; Mensforth et al. 1978; Moseley 1965; Stuart-Macadam 1985). More recent research (Brecher 2005; Rothschild 2000) suggests that other possible causes include parasitism, B12/folate deficiencies, and genetic anemias. The various conditions thought to lead to the development of cribra orbitalia and porotic hyperostosis are described in this thesis to better understand the process or processes by which individuals come to acquire them. The expressions of both cribra orbitalia and porotic hyperostosis, their similarities and differences, and their possible causes are discussed in detail in the Literature Review chapter, as are the scoring methods that were developed to describe their range of expression (Nathan and Haas 1966; Stuart-Macadam 1982, 1991). These are discussed in the order in which they were developed, and in the order of their applicability to the sample from Collota and Tenahaha in the Methods chapter.

Cribra orbitalia and porotic hyperostosis are quite common in skeletal remains from Latin American populations. Both pathologies are directly influenced by environmental stressors impacting human health and would likely have been experienced by a population emulating Wari-style agricultural technology. The primary hypothesis of this thesis is that a high frequency of both of these skeletal lesions would be observable in the skeletal sample from Collota and Tenahaha. The Methods chapter builds upon the scoring methods described in the Literature Review chapter (Nathan and Haas 1966; Stuart-Macadam 1982, 1991), and explains how these methods can be used to interpret heath in the populations from Collota and Tenahaha. Data collection, skeletal material retrieval, and processes of analysis are also discussed in this chapter, as well as ontological variation, and sex identification. Finally, the statistical formula Fischer's exact test (Thomas 1986) is discussed, as well as its implications for understanding the significance of the data collected for this study.

In order to evaluate the hypothesis that cribra orbitalia and porotic hyperostosis would be present in high frequencies in the study population, the osteological and pathological profiles of Collota and Tenahaha were compared to those of a contemporaneous neighboring population. This would lead to a better interpretion of the occurrence of pathological conditions within the sample population as compared to others in the same region. For this study, the author found it appropriate to use a sample from the Middle Horizon Nasca Valley sites of Huaca del Loro and Chakipampa. While both the study population and the comparative population date to the same time period, Collota and Tenahaha are believed to have been just on the outskirts of Wari control (Jennings and Yepez Alvarez 2002), while Huaca del Loro and Chakipampa were well within official Wari borders (Kellner 2002; Schreiber 1992). This study attempted to confirm that, due to the more peripheral location of Collota and Tenahaha, the skeletal sample would have been less affected by nutritional deficiencies and disease when compared to the population from Huaca del Loro and Chakipampa.

The Results, Conclusion, and Discussion chapters discuss the scoring methods and statistical tests applied to the cases of cribra orbitalia and porotic hyperostosis observed in the sample population as well as the rates of the porotic expressions in the comparative population of Nasca. These chapters will ultimately shed light on the importance of statistical comparisons and the impact of nutritional deficiencies, anemia, and a host of other influences on the health of individuals from Collota and Tenahaha. Pathological skeletal conditions, such as cribra orbitalia and porotic hyperostosis, are therefore vital streams of data that have the potential to illuminate dietary, social, and environmental stressors in Middle Horizon Peru.

CHAPTER 2 – LITERATURE REVIEW

A review of the various works pertaining to cribra orbitalia and porotic hyperostosis is necessary in order to understand the historical contexts and various shortcomings that exist in the analysis of these pathologies. The range of expression for each skeletal effect is reviewed here as well as the similarities and differences. Possible causes of cribra orbitalia and porotic hyperostosis are also discussed, and the bioarchaeological context provides a larger cultural and historical perspective in which we can evaluate the appearance of these pathological lesions. Methodological approaches in scoring and interpreting cribra orbitalia and porotic hyperostosis are also described, as an evaluation of these methods is important in order to understand possible fluctuations in data within populations, potential drawbacks of the methods, and the caution that must be taken in interpreting the causes of cribra orbitalia and porotic hyperostosis in sample populations.

Human Paleopathology

The aim of paleopathology can be defined as understanding the courses of diseases and how they affected and changed human life in ancient civilizations (Aufderheide 1998; Buikstra 2006; Ortner and Putschar 1981). Disease has a long history in human civilization and its effects on human populations can be catastrophic and devastating.

The pathological conditions created by disease have fascinated humans so intensely that their study has developed into a thriving subfield in biological anthropology. "Human paleopathology can be defined as the study of disease in ancient populations by the examination of human remains. So defined, it has been practiced to some degree for more than a century" (Aufderheide and Rodriguez-Martin 1998:xv). Paleopathology is a means by which we are able to look at diseases and acquire insight into what was ailing human populations throughout several time periods, generating and testing hypotheses as to both the causes of these ailments and their effects on the populace.

Aufderheide and Rodriguez-Martin (1998) describe the genesis of paleopathology as beginning with isolated and descriptive observations, mostly carried out with little adherence to the scientific method. Between the Renaissance and the nineteenth century this was exactly the case: unofficial and coincidental discoveries of basic interest with little to no scientific interpretation. The birth of paleopathology coincided with the German naturalist Johann Friederich Esper's identification of osteosarcoma on a bear's femur in 1774 (Aufderheide and Rodriguez-Martin 1998).

Marc Armond Ruffer's 1910 publication furthered the study of paleopathology through the growing trend of Egyptian studies (Aufderheide and Rodriguez-Martin 1998). Because he was medically trained and studied bacteriology, he was quick to recognize the importance of examining the exhumed mummified human remains and properly documenting and observing the different kinds of diseases suffered by these populations. "He developed a method of rehydrating mummy soft tissues and preparing histological slides that expanded substantially the range of diagnosable diseases" (Aufderheide and Rodriguez-Martin 1998:6), but died before he was able to accomplish much research. The momentum of soft tissue pathology from the archaeological context slowed in consequence.

Another important figure in paleopathological studies was Roy Lee Moodie, a paleontologist who helped publish the last works of Ruffer after his death (Aufderheide and Rodriguez-Martin 1998). Moodie was trained in anatomy and focused his studies on lesions in human remains. Studying disease in ancient plants and animals, he later published a radiological study of the large collection of Egyptian and Peruvian mummies that were stored at the Field Museum in Chicago. Ales Hrdlicka was also an important contributor from this early time period. Having been on the anthropological staff at both the National Museum of Natural History and the Smithsonian Institution, he had access to large collections of specimens from both North and South America. Many of his publications concerned the analysis of cranial features, including lesions, indications of violence, and trepanation.

Earnest Albert Hooton (1930) continued in the path of Hrdlicka and introduced methods and aspects of data collection that hadn't yet been used extensively. Hooton introduced the importance of demographics and adopted a more holistic approach to paleopathology by observing statistical, ecological, and cultural components that could possibly affect the individuals under observation. He also demonstrated chronological changes in disease frequency (Ortner & Putschar 1985).

Scientific advancements in paleopathology did not come without a few difficulties in accurate diagnoses of dry bone and other issues contributing to the biased data problem. Post-mortem damage, and the recovery of only fragmentary or poorly preserved remains, was and is a common hurdle. Observations of the distribution pattern of abnormal changes in bone are not always possible, and often the minimum number of individuals is too small to determine whether a particular disease was prevalent in the larger population (Roberts and Manchester 2007).

Cribra Orbitalia and Porotic Hyperostosis

Cribra orbitalia and porotic hyperostosis are distinctive effects on the skeletal tissue of the cranium and are characterized by an increase in both the diploic surface and general porosity of the cranium (Stuart-Macadam 1982). The most unique characteristic of cribra orbitalia and porotic hyperostosis, also known as usura orbitae/hyperostosis spongiosa orbitae and symmetrical hyperostosis/hyperostosis cranii/spongy hyperostosis respectively, is the kind of porous surfaces they create on the superior region of the orbit, the posterior region of the parietals, and, on occasion, the anterior region of the occipital bone.

Cribra orbitalia and porotic hyperostosis have been interpreted, both separately and together, as indicators of health, diet, disease, and environment. Their close proximities suggest that these pathologies are not only directly associated with each other, but that they also have similar causes; these lesions do have similar patterns of manifestation and are the result of similar changes in the bone in different areas of the skull. These changes typically consist of the "thinning of the outer table of the skull, due to vertically orientated trabeculae in the diploe causing pressure on the table, and thickening of the diploe between the two skulls tables…apart from skull lesions, particularly seen on the parietal and occipital bones (porotic hyperostosis), the orbital roofs are affected in the form of 'holes' in the bone surface (cribra orbitalia)" (Roberts and Manchester 2007:132).

Cribra orbitalia and porotic hyperostosis share a few key similarities in development and porotic expression. Cribra orbitalia is more commonly seen in its active form in infants and children from populations with high rates of malnutrition and anemia. Both lesions can also be observed in healed forms in adults who had at one time suffered nutritional deficiencies and anemia during childhood.

It had long been assumed, because the two conditions feature the same characteristics of hair-on-end structures and the breakdown of surface bone structure (Ortner 1998), that there was a direct relationship between cribra orbitalia and porotic hyperostosis. Cribra orbitalia appears on the internal surface of both the left and right orbits. Porotic hyperostosis is seen primarily on the external surfaces of the left and right parietal bones and frontal bones, although it also occurs to a lesser extent on the occipital bone, and to an even lesser extent on the temporal bones. When an individual skull features both types of lesions it is tempting to assume that these skeletal processes are one and the same. The same porous surfaces and the same deterioration of the external table resulting in web-like structures of lacunae contributed to the assumptions that both were caused by the same underlying pathological process.

Expression of Cribra Orbitalia.

Cribra orbitalia begins when "the hypertrophy of the underlying diploic bone produces pressure atrophy of the thin cortical bone layer composing the orbital roof; this increase in spongy bone results in increased thickness of the orbital plate, often several times its normal thickness" (Steinbock 1976:239). Orbital lesions can form bilaterally, and are more often observed to be symmetrical than asymmetrical (Stuart-Macadam 1989). Stuart-Macadam (1987) describes several phenomena that occur during the process of skeletal changes she associated with anemia, including: trabeculation, or the thinning of the outer table of compact bone, the development of granular patterns of bone texture, diploic thickening of vault and orbital roof bones, sinus heights, and changes in the orbital rim (Stuart-Macadam 1987). The condition exists along a range of expression encompassing "1. Light: scattered foramina, 2. Medium: large and small isolated foramina and foramina that have linked to form a trabecular structure [and] 3. Severe: outgrowth in the trabecular structure from the normal contour of the outer bone table"

(Stuart-Macadam 1985:392). Figure 1 below is a good example of what these lesions look like.

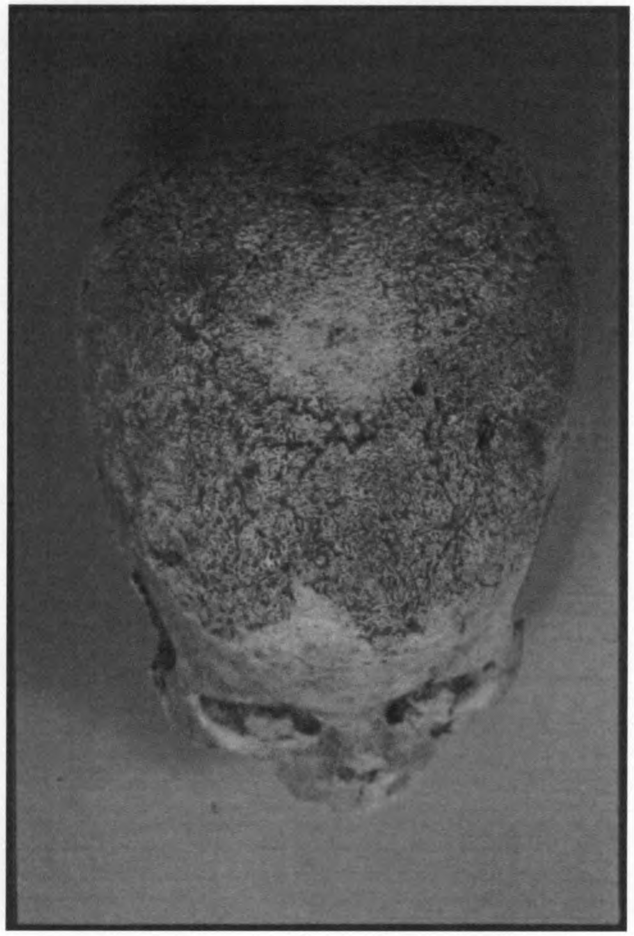
Figure 1. Cribra orbitalia: inferior view of left and right orbits.

Images of specimen from Amelia Island, Florida (Larsen 1998)

***Expression of Porotic Hyperostosis*.**

Porotic hyperostosis is similarly described as “skeletal effects [that] reflect the marrow’s effort to increase [red blood cell] production by hyperplasia. . . the skull’s frontal and parietal bones show thickening due to widened diploe that demonstrate fewer but thicker, spike-like trabeculae lying perpendicular to the inner and outer tables, generating a ‘hair-on-end’ radiological appearance, and a resorbed overlying outer table” (Aufderheide 1998:346). The vault bones become thicker and develop a sponge-like appearance, while the outer table thins and deteriorates: “porotic hyperostosis of the skull has a macroscopic appearance which varies from small porosities on the outer table to large inter-connecting trabeculae which project above the normal contour” (Stuart-Macadam 1987:522). The resorption of the outer table in response to diploic expansion, which creates the porosities and contributes to the overall spongy appearance of the cranium, is readily seen in radiographs (Walker et al. 2009). Figure 2 is an example of how the lesions appear on the vault.

Figure 2. Porotic hyperostosis: proximal view of the cranial vault.



Images of specimen from Amelia Island, Florida (Larsen 1998)

Similarities and Differences.

One of the most likely reasons that cribra orbitalia and porotic hyperostosis manifest on skeletal tissue is nutritional deficiency. Historically, these two conditions were believed to be associated with each other since the disease process appeared to be so similar. Because cribra orbitalia appears to manifest in the orbital region before porotic hyperostosis begins to develop on the vault bones, the relationship between the two was thought to be chronological, with porosities simply appearing in one region before the other (Angel 1966; Mensforth 1978). However, despite their similar appearances, others (Ortner and Putchar 1981) were not so convinced of the relationship between the two conditions, as the exact causes of these skeletal lesions were still unclear.

In Mensforth's (1978) study, which analyzed 241 juveniles from an Ohio ossuary, all of the skulls with cranial vault lesions were found to feature orbital lesions as well. This supported the idea that both orbital lesions and vault lesions have a higher likelihood to appear during infancy and early childhood. Stuart-Macadam (1985) observed this pattern in the Poundbury Camp study, 88% of skulls that possessed vault lesions also possessed orbital lesions (Stuart-Macadam 1985). This observation indicates that both pathologies are seemingly correlated. All ranges of severity in bone change were observed to feature this apparent correlation, from mild bone change with scattered minute foramina, to large interconnected trabeculae.

Walker et al. (2009) describe the different etiologies of cribra orbitalia and porotic hyperostosis and the direct association that has been suggested between the two pathological conditions. Walker states "in paleopathological studies, cribra orbitalia has generally been considered a result of the same pathophysiological process that produces porotic hyperostosis. This conclusion is supported by radiographic and histological studies showing that porosities in the orbital roof are often associated with hypertrophy of the underlying marrow space [even though both pathologies] are sometimes present in the same individual, this [supports] the theory that they are responses to the same systemic problem" (Walker 2009:115). The authors (Walker et al. 2009) recognition of a direct association between cribra orbitalia and porotic hyperostosis continue by stating that "cribra orbitalia is an earlier, less severe manifestation of the pathological process producing porotic hyperostosis, this might explain the greater prevalence of cribra orbitalia" (2009:115).

If cribra orbitalia is a pathological condition that manifests as a result of nutritional abnormalities during very early childhood, (Caffey 1938; Mensforth 1978; Middlemiss 1961; Stuart-Macadam 1982) depending on population frequencies and skeletal sample, there could be fluctuations as to the statistical representation of health within a population. There is also a small probability that even the most anemic individual in a population does not demonstrate the skeletal effects of that pathological condition. In other words, the skeleton of an individual who suffers from anemia does not necessarily display the physical evidence of this condition. Therefore, the debate that these skeletal lesions are chronological, with cribra orbitalia occurring in childhood and leading to the development of porotic hyperostosis in adulthood, is still open for debate (Walker 2009). Current theory still suggests the underlying causes are similar for cribra orbitalia and porotic hyperostosis despite the non-coincidence reported in some skeletal samples.

Clinical Pathology

Clinical studies, primarily those focusing on anemia, are important to highlight briefly in this research. The processes of skeletal change due to anemia, including orbital roof thickening, is a feature characteristic of cribra orbitalia; the presence of cribra orbitalia in the skeleton could suggest that the individual had lived with anemia. These clinical observations served as the basis for further study in the bioarchaeological context (Angel 1966; Stuart-Macadam 1987; Platt 1994).

To better explain the physical manifestations of anemia in the skeleton, it is helpful to review the work of other researchers in the medical field (Caffey 1937; Middlemiss 1961; Vanier 1967) who have also focused on anemia. Middlemiss's (1961) clinical study focused on the skeletal, specifically the orbital, effects of sickle cell anemia. Sickle cell disease is a genetic blood disorder that warps red blood cells into rigid sickle shapes and decreases their flexibility, resulting in a much higher risk factor for various complications such as stroke and osteomyelitis. Sickle cell disease results in anemia and, therefore, can possibly disrupt the process of bone growth. Middlemiss (1961) observed thickening of the orbital roofs in radiographs of patients with sickle cell anemia and found this was very similar to those of patients with other genetic, non-sickle cell anemias, such as thalassemia, (Platt 1994; Caffey 1937). This again suggests a correlation between cribra orbitalia and anemia. Hershkovitz et al. (1997) also observed the osteological changes associated with sickle cell anemia in children, specifically the "calvarial 'ballooning'" that occurs in the bone table (Hershkovitz 1997:213). Radiographic data suggests the severe forms of hereditary hemolytic anemia can produce porotic hyperostosis, but sickle cell anemia produces the least amount of this change in comparison to other genetic anemias (Hershkovitz 1997).

Clinical studies provide a better understanding of the connection between diseases and their manifestation in individual skeletons throughout life. However, hematological research is still inconsistent in proving iron-deficiency anemia alone could be a primary reason for cribra orbitalia and porotic hyperostosis as it is more commonly found to be coupled with other causes like parasitic infection (Walker 2009). When the results of these clinical studies are viewed in light of the data deriving from comparative analysis of skeletal samples, common ground can be found to create a more comprehensive picture of skeletal changes due to anemia. This comparative insight is necessary in order to link clinical outcomes to anthropological material.

Possible Causes

The conditions of cribra orbitalia and porotic hyperostosis are attributed to dietary iron inhibitors or otherwise poor diets that fail to replenish iron loss due to injury, destruction of red blood cells, or other physiological factors (Kent 1992). Walker (2009) states that "several lines of evidence suggest that the accelerated loss and compensatory over-production of red blood cells seen in hemolytic and megaloblastic anemias is the most likely proximate cause" (105). The following sections will describe the different causes that may lead to the development of the skeletal porosities characterizing cribra orbitalia and porotic hyperostosis, beginning with the various types of anemia and parasitic infections, and ending with lead poisoning and population density.

Dietary Anemia.

Anemia is defined as a condition that results from a subnormal number of red blood cells per cubic millimeter (Stuart-Macadam and Kent 1992); iron-deficiency anemia is one of the most common of the many types of anemia in the world (Brecher et al. 2005; Nathan 1991; Stuart-Macadam 1989; Walker et al. 2009). The probability of developing iron-deficiency anemia increases when the diet is severely deficient in iron for long periods of time. This observation has led to the common practice of attributing most occurrences of anemia to low iron levels due to diet. However, a number of scientists studying the precise amount of iron lost through sweat, urine, stools, and other secretions (Stuart-Macadam and Kent 1992) have concluded that it is unusual for iron deficiency to occur as a result of dietary deficiency alone (Kent 1993). "This iron deficiency anemia hypothesis is inconsistent with recent hematological research that shows iron deficiency per se cannot sustain the massive red blood cell production that causes the marrow expansion responsible for these lesions. Several lines of evidence suggest that the accelerated loss and compensatory over-production of red blood cells seen in hemolytic and megaloblastic anemias is the most likely proximate cause of porotic hyperostosis" (Walker et al. 2009). The more probable cause of anemia is therefore not a lack of iron, but rather a chronic disease or inflammation in the body that would hinder its absorption (Grauer 2011).

Aufderheide and Rodriguez-Martin (1998) suggest that the diets of some past populations, such as the southwestern Native Americans, may have contained too little iron to restore normal body iron content as children progressed into adulthood (El-Najjar et al. 1975). Some representations of this can be seen in other populations, like the Maya, and other groups from ancient Mexico and Central America. "A tropical climate increasing iron loss; protozoal, helminthic, and bacterial infections of the intestine preventing adequate iron absorption and indeed, causing chronic loss of blood; cooking methods which destroy folic acid and vitamin B12 in the food; and dietary insufficiencies of iron, ascorbic acid, and protein -- all contribute to produce the high frequency of iron-deficiency anemia in modern-day Maya and presumably in the ancient Maya as well" (Steinbock 1976:238). In these populations, anemia could have persisted long enough to induce skeletal changes such as cribra orbitalia and porotic hyperostosis.

Subadults, specifically infants, may be predisposed to developing cribra orbitalia through breast milk from mothers who are suffering from nutritional deficiency. Breast milk that does not contain enough supplementary iron for the first few months of life can make the baby vulnerable to a number of diseases. In addition, parasitic infections, which will be discussed in the following section, could hinder absorption of iron, causing anemia and disrupting normal bone growth in infants. Factors contributing to the development of anemia in Classic Maya populations seem to have been both dietary and parasitic (Wright and Chew 1999). "The inhibition of intestinal absorption of iron by phytates [cereals and beans which were important to the primary diet in the poorer classes]…cannot be excluded" (Facchini 2004:133). Wright and Chew (1999) therefore theorized that cribra orbitalia and porotic hyperostosis in the New World were more likely the results of childhood anemia caused by diet during the early stages of life, rather than genetic causes; this is discussed further in this section of the current chapter that deals with populations studies.

Finally, there are specific regional diet deficiencies that could cause iron-deficiency anemia in Latin America that do not coincide with European populations directly. Unlike Angel (1966) who attributed Mediterranean populations' porotic hyperostosis with thalessemia, diet and environment were the more common factors found in the populations of North and South America. Porotic hyperostosis occurred more frequently in maize agriculturalists as opposed to nomadic peoples (Cohen and Armelagos 1984; El.Najjar et al. 1976). However, Rothschild (2012) debates that the dietary shift and iron deficiency is not a plausible primary candidate in causing cribra orbitalia and porotic hyperostosis. "Iron deficiency is the result, not the cause of the marrow hyperplasia that produces the porotic hyperostosis. This contrasts with primary iron deficiency, which causes hypo-regenerative (atrophic) marrow and no skull alterations…" (Rothschild 2012: 157). The initial study lead by Lanzkowski (1968) only resulted in 15 out of the thousands of cases having skeletal lesions relating to iron deficiency making it extremely rare and does not support the correlation between the cause and effect. He continues that analysis further reveals maize consumption did not become "a significant part of North American human diets until the past 1000 years, long after notation of high frequency porotic hyperostosis" (Rothschild (2012:157). This further contradicts the maize-induced iron deficiency claim that many, in the beginning, adopted (Angel 1978; El-Najjar et al. 1975; Hill and Armelagos 1990; Ortner 1982).

Parasitic Infection.

Another possible cause of iron deficiency contributing to the formation of both cribra orbitalia and porotic hyperostosis is parasitic infestation, which can lead to disruption of healthy skeletal growth rates. Steinbock discusses this phenomenon by stating that "the high incidence of iron-deficiency anemia in the tropics is chiefly caused by parasitic infestation such as by *Entamoeba histolytica, Balantidium coli, Strongyloides, Ascaris lumbricoides, Giardia intestinalis, Trichuris trichuris,* and particularly hookworms (*Ancylostoma duodenale* and *Necator americanus*)" (1976:246). In a broader sense, parasitic infestation weakens the body's defenses against other more chronic diseases. Hookworm is a good example of this as infestation with hookworm significantly increases the probability that the human host will develop anemia. "Hookworm's single, significant clinical effect is iron-deficiency anemia. This is because the adult worm derives its nutrition by sucking blood from a mucosal capillary . . . when the collective total blood loss from the intestinal worm burdens exceeds the marrow's maximum output, anemia will result" (Aufderheide 1998:239). In tropical environments, this accelerates the process of iron deficiency within a population that already has a low level of iron intake to begin with. In a growing child, even a normal marrow is barely able to meet the rapidly increasing oxygen demands of the expanding body mass (Aufderheide 1998). Any impairment of red blood cell production can be manifested as anemia. This is of course paired with increased infection rate and generally aggravated malnutrition among populations.

Djuric et al. (2008) analyzed porotic lesions in immature skeletons in Serbia and questioned whether the children were in fact iron deficient. Even though it may seem a logical supposition that iron deficiency due to insufficient dietary intake of iron could induce anemia, this (Djuric et al. 2008) study suggests that this is not the case. During the Medieval period in this region there was ample opportunity to graze protein rich cattle, and foods like fish, and rue. Oats were also a major component of the diet. Because of this, it is unlikely that porotic lesions developed due to a lack of dietary iron. "Various details support the hypothesis that infectious diseases were mainly responsible for the anemic condition which would eventually result in the formation of cribra …" (Djuric et al. 2008:8). So, in this sample, it is likely that parasitic infections made them susceptible in developing anemia, which in turn resulted in porotic lesions such as cribra orbitalia and porotic hyperostosis.

Not only were factors such as food availability and dietary intake possible causes of anemia, but also the exposure to parasitic infection as was the case in Djuric et al.'s (2008) study. The conditions in which many populations lived during this time (de Vizia et al. 1985; Stoltzfus et al. 1997) lent support to the idea that parasites were the likely cause of much of the anemia that has been observed. It was quite ordinary for humans to share living quarters with farm animals, often during cold weather, which would have made the transmission of microorganisms from livestock to humans very easy. The authors (Djuric et al. 2008) note that the historical data pertaining to infectious disease in the area make frequent reference to "dysentery, ergotism, jaundice, smallpox, and scabies, while malaria, skin rash, plague, and leprosy are mentioned occasionally" (2008:5). The close lodgings that humans and animals shared in this population (Djuric et al. 2008) would have made human exposure to numerous pathogens, such as bacteria and viruses which are passed on by direct or indirect contact, inhalation, and ingestion very likely. In other words, crowded living conditions, particularly those placing humans in close contact with livestock, create higher chances of contracting parasites that could potentially weaken individuals enough to put them in an anemic state and increases the chances of developing cribra orbitalia and/or porotic hyperostosis.

Poor sanitation practices would have been particularly problematic and would have exposed early populations to sickness and chronic states of disease (Djuric et al. 2008).

The lack of clean water, sewers, and effective waste disposal systems would have allowed germs and parasites to infect the population; this would have been especially prevalent in populations living in close quarters, particularly in crowded towns. In addition, poor standards of personal hygiene and the lack of antibiotics would have made an individual especially vulnerable to disease transmission.

Disease and infection usually affect the intestinal tract and typically cause secondary symptoms such as diarrhea; intestinal malabsorption due to diarrhea can lead to iron and magnesium deficiency, and possible blood loss due to dysentery. Both chronic diarrhea and dysentery can contribute to the development of anemia and, in turn, cribrous lesions (Djuric et al. 2008).

Hemolytic Anemia.

In hemolytic anemia, red blood cell plasma membranes rupture prematurely, releasing hemoglobin into the plasma and possibly damaging the glomeruli in the kidneys (Grabowski and Tortora 2003). It is a "condition [that] may result from inherited defects such as abnormal red blood cell enzymes, or from outside agents such as parasites, toxins, or antibodies…" (Grabowski and Tortora 2003:654).

Two of the most common of the hemolytic anemias are thalassemia and sickle-cell anemia.

> "Thalessemia and sickle cell disease are inherited syndromes characterized by deficient or abnormal hemoglobin structures and anemia. Thalessemia is caused by a deficiency in alpha or beta chain production that ranges from mild to severe. Total absence of synthesis of one of the alpha chains is lethal in utero; absence of beta chain synthesis (thalassemia major) results in a progressive anemia in the newborn period. In an attempt to compensate for significant degrees of anemia, hematopoietic tissue expands, causing characteristic bone abnormalities and enlargement of the liver and spleen" (Brecher et al. 2005:508).

Both of these examples of hemolytic anemia have been found to cause the disintegration of blood cells that could eventually lead to porotic skeletal changes. "Sickle cell disease results from a single base substitution in the gene for the beta chain of hemoglobin. The hemoglobin of individuals homozygous for this abnormality can irreversibly polymerize and cause red cells to deform or 'sickle'" (Brecher et al. 2005:208). The thalassemias are slightly different, as they are "inherited disorders of hemoglobin synthesis characterized by absence of diminished synthesis of one or the other of the globin chains of hemoglobin A" (Nathan 1991:205). Both thalassemia and sickle cell disease have the potential to lead to skeletal change in the cranium if they progress to the point of causing marrow hyperplasia. "Deficient or absent synthesis of a specific globin chain leads to unbalanced chain synthesis [having two] effects: inadequate hemoglobinization of developing erythroid cells, and an unbalanced globin chain synthesis…chains present in relative excess…precipitate in the developing erythroid cell. This damages surface membranes in both developing and mature cells. Cells this handicapped either die in the bone marrow…or…are promptly removed…causing hemolysis." (Nathan 1991:207). Both occurrences combine to cause marrow hyperplasia and, according to Nathan, "This in turn leads to a hypermetabolic state, skeletal changes, and increased intestinal absorption of iron and iron overload" (1991:207).

It has been shown that severe and chronic anemias can cause very distinct changes in bone (Brecher 2005; Caffey 1937; Nathan 1991; Stuart-Macadam 1985), however, thalassemia and sickle-cell disease does not necessarily guarantee a bony display of altered surfaces since only a proportion of people that possess it actually demonstrate it. The likelihood of either thalassemia or sickle-cell disease influencing the cranial morphology of this thesis' study population is very unlikely as they are uncommon in this part of the world. Due to the fact the geographic location of the sample population for this study does not have the genetic predisposition of hemolytic anemia during this time period, the possibility of it being a cause of cribra orbitalia and porotic hyperostosis does not make it a possibility for this thesis. "Although the thalassemias are found all over the world, specific forms occur with high frequency in certain populations – notably in Mediterranean populations (i.e., from southern Italy and Greece) and [Asian] populations (i.e., from Thailand, China, and the Philippines)" (Nathan 1991:205).

B12, Folic Acid Deficiencies, and Other Causes.

Walker et al. (2009) provide evidence that hemolytic and megaloblastic anemias are the disorders that cause porotic hyperostosis. While hemolytic processes are more applicable in Old World countries, parasitic infections are more plausible in the New World in relation to porotic hyperostosis (Rothschild 2000). "In addition to simple blood loss [from parasitic infection]…consumption of vitamin B12 results in 'ineffective erythropoiesis'…the marrow keeps producing cells, but they are not very effective in transporting oxygen" stimulating hyperplasia (Rothschild 2000:3). Vitamin B12 deficiency, a coenzyme necessary for red blood cell formation, could lead to anemia and impaired activity of osteoblasts if it is coupled with parasitic infections (Tortora and Grabowski 2003) which could further lead to pathological lesions. Rothschild (2000) continues that along with parasitic infections, nutritional causes are a more plausible hypothesis than iron deficiency.

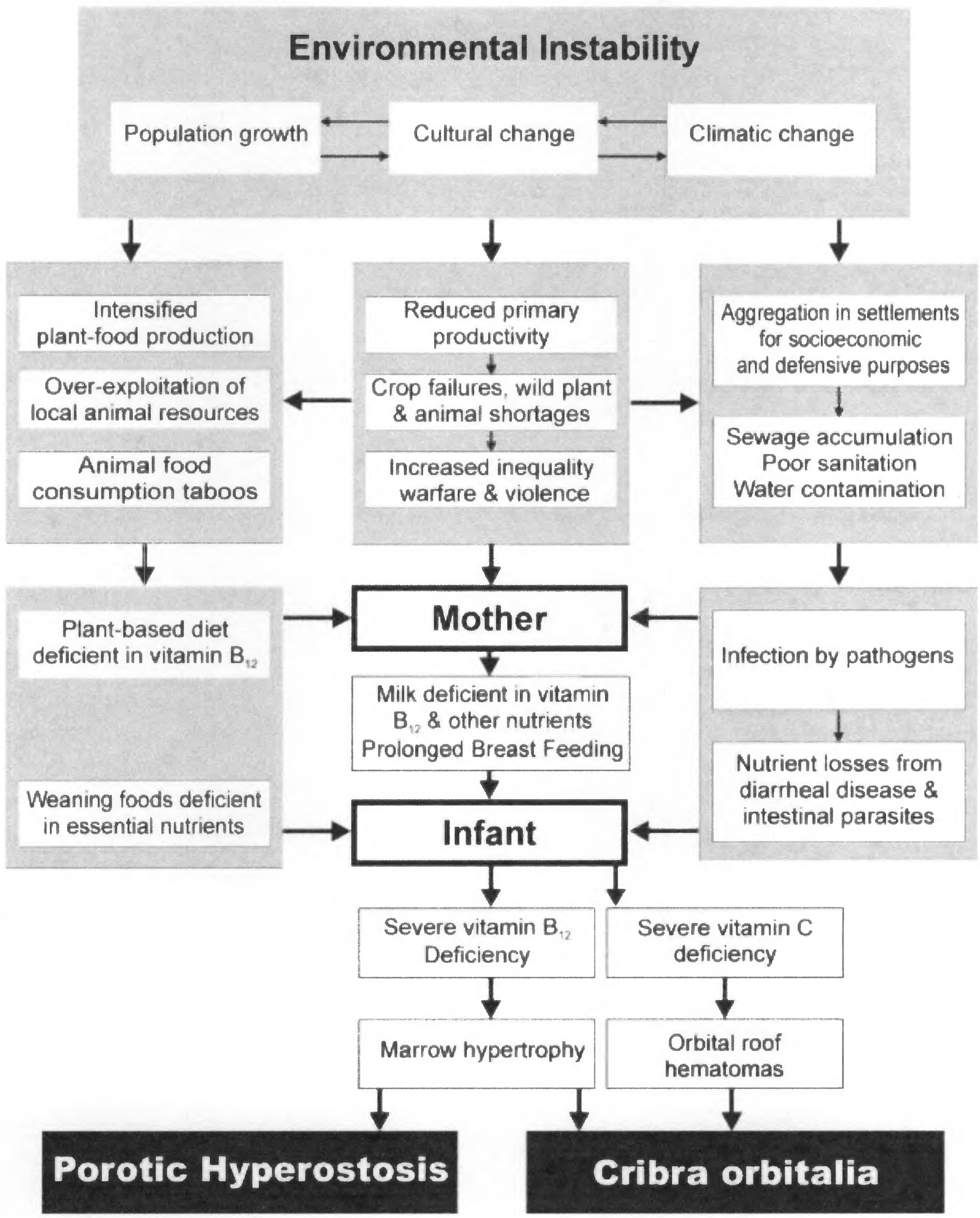
Folic acid, also known as B9 or folate, is another essential vitamin that is required to produce healthy red blood cells and reduce the risk of anemia (Tortoro and Grabawski 2003). Acquired megablastic anemia, inhibiting DNA synthesis in red blood cell production (Tortoro and Grabawski 2003), is due to B12 and folic acid deficiencies and is one of the underlying causes of porotic hyperostosis. The differences in anemia of chronic disease and iron-deficency anemia are highlighted as well. Oxenham and Cavill (2010) agree with Walker et al.'s (2009) study on this point but argue that, "the former erythropoietic activity is suppressed while in the latter it is increased…the only form of anemia unlikely to lead to porotic hyperostosis and cribra orbitalia, due to a characteristic suppression of erythropoietic activity, is [anemia of chronic disease]" (Oxenham and Cavill 2010).

Facchini (2004) observed that the elemental causes of cribra orbitalia and porotic hyperostosis, in addition to hemolytic anemia and dietary deficiencies, were in large part environmental factors. In individuals from this Roman population (Facchini 2004) it was hypothesized that the observed skeletal changes in the cranium were most likely the result of differential diet in response to economic factors, gastrointestinal infections, and parasitic infections. In addition, lead poisoning was suggested as a possible factor, likely due to the styles of food receptacles that were being used. “Lead poisoning inhibits some enzymes necessary for the formation of hemoglobin [to occur]” (Facchini et al. 2004:127). This additional possibility highlights the fact that multiple factors within a population could potentially contribute to the process of disease that produces porous lesions in the skull.

The development of cribra orbitalia and porotic hyperostosis relies on multiple factors throughout the lifetime of an individual. “The pathogenesis of the synergistic interactions between constitutional factors, diet, and infectious disease” (Mensforth 1978:2) shows that multiple variables are involved when inadequate nutrition, infectious diseases, and parasitic infestation are combined in one environment. For example, the frequencies of orbital lesions have been observed to increase when there is a high population density, inadequate sanitation practices, and high pathogen rates or chronic health problems (Blom et al. 2005; Buzon 2006; Hengen 197; Kent 1986; Palkovich 1987; Walker 1986).

Walker et al. (2009) created a flow chart representing some of the possible external elements that could lead to pathological conditions that cause cribra orbitalia and porotic hyperostosis. This chart (Figure 3) represents disease development, nutritional anemia, parasites, and other environmental factors. As the authors (Walker et al. 2009) summarize, “the synergistic effects of nutritionally inadequate diets, poor sanitation, infectious disease, and cultural practices related to pregnancy and breastfeeding provide a plausible explanation for the high rates of porotic hyperostosis found in many prehistoric populations” (2009:331). Even though not all skeletal remains exhibit conclusive traits of environmental stress, it is possible to observe skeletal pathologies and hypothesize the different aspects of life that were acting upon them.

Figure 3. Environtmental instability: the process of acquiring anemia.



(Walker et. al. 2009)

Analyzing skeletal material could lead to any number of these environmental elements as a cause. In the case of this thesis, nearly all elements of this diagram (Fig. 3) are relevant to the data that were recovered from the sample site. Population change, climatic change, and cultural change are all factors that acted upon the sample population during the historical time period in question.

Bioarchaeological Context

Population comparisons are essential to assess whether certain rates of disease within a population and rates of pathological expression on human remains are significant or not. The following sections discuss the different approaches past studies have taken to understand the health and success of past populations. Also discussed are the differences in expression of cribra orbitalia and porotic hyperostosis between subadults and adults within populations.

Population Studies.

Cribra orbitalia and porotic hyperostosis can be observed in skeletal materials from a wide variety of populations (Bothwell 1995; Walker 1986; Blom et.al. 2005; Stodder 2006). Due to the associations between these conditions and anemia, their presence or absence can create a better picture of what different peoples have endured in terms of health and nutrition. Piontek and Kozlowski (2002) observed the frequency of cribra orbitalia in 92 subadult individuals from the mortuary site of Gruzcno in Poland. According to the authors, this frequency reflects the population's poor environmental conditions. "The factors influencing the health and the quality of life in the medieval population…were particularly unfavorable for the growth and development of children and adolescents" (Piontek and Kozlowski, 2002:206). Orbital porotic lesions were found in 28% of the subadult population at Gruzcno, and though adult samples were not taken for this study (Piontek and Kozlowski 2002), the authors did provide an overview of data from adult samples from surrounding areas. The occurrence of orbital porotic lesions in these neighboring adult samples were in the same range of 20-30%, indicating that these lesions were common skeletal attributes within medieval Poland.

In another study (Facchini et al. 2004), the authors examined a large population of 180 individuals from two Roman necropolises and found that cribra orbitalia appeared quite frequently in the sample, occurring at a rate of 56% in one site and 40% in the other. Separating individuals by age groups, the authors observed that there were considerably more subadult individuals with cribra orbitalia than there were adults with the condition suggesting that younger individuals are more susceptible to causes that lead to the development of porotic lesions.

Analyses of cribra orbitalia and porotic hyperostosis in the New World have provided a more comprehensive picture of the prehistoric populations therein and have raised a number of questions regarding the causes of the skeletal effects within this region. The disease to which these conditions are typically attributed in the Old World "do not explain the high prevalence of cribra orbitalia…in past populations that lived in places where there have been neither human malaria nor hemolytic anemia" (Facchini 2004:127) as is believed to have been the case in the pre-Columbian New World.

Wright and Chew (1999) hypothesized that cribra orbitalia and porotic hyperostosis in the New World was more likely symptomatic of childhood anemia caused by poor nutritional periods during the early stages of life, rather than genetic causes. In Wright and Chew's study (1999), they compared the health of living populations with prehistoric populations to provide a correlation between fluctuating degrees of lesion abundance; the authors explored "the use of ethnographic data as a tool to evaluate the broader implications of poor health on an archaeological culture" (Wright and Chew 1999:924). Although Wright and Chew's (1999) approach created a larger outlook of the ways in which the rates of cribra orbitalia and porotic hyperostosis have changed over time in the New World, their study received some degree of criticism for potentially over representing rural areas (Robin 2001; Whitaker 2011). This was more prevalent in the modern sample, which could have resulted from slightly skewed data, since rural communities in modern-day Guatemala show that 23-30% of children have low hemoglobin counts due to modern dietary trends and nutritional deficiency-related anemia. This information, acquired from a country-wide nutritional survey, is revealing when compared to the pre-Columbian sample in Wright and Chew's (1999) data. They found that during the Classic period, "a greater proportion of children survived their childhood than they do today" (934), and concluded that…" the rarity of porotic hyperostosis on the skulls of modern forensic skeletons may be due to a heavier burden of infectious disease, earlier weaning, and thus higher childhood mortality when compared to the prehistoric condition" (Wright and Chew 1999:934). Although the minor changes in diet and infection may have been a factor, it is concluded that a higher mortality rate in childhood leads to fewer anemic lesions in modern adult crania (Wright and Chew 1999).

Subadults versus Adults.

According to Stuart-Macadam (1985), the age at which the bones of the skull stop changing in response to anemia is unknown. However, other studies (El-Najjar 1975; Lewis and Roberts 1997) suggest that it is mainly during early childhood that traces of anemia are more plainly observable in the skeletal record, with most orbital lesion porosity manifesting mainly in the subadult stages of bone growth. Irregularities in porosity, grade, and thickness of the parietal or occipital bones, as well as the orbital surfaces, have commonly been interpreted as evidence that the individual suffered through a period of poor health during his or her childhood. According to Stuart-Macadam "there is no evidence to suggest that skull changes occur in adults who have only recently acquired anemia" (1985:394); this suggests that skeletal remains displaying signs of anemia in the cranial bones, such as cribra orbitalia and porotic hyperostosis, are specifically displaying signs of childhood anemia. Skeletal remains who had only acquired the condition in adulthood would therefore be underrepresented as they would most likely not display any cranial bone porosities.

The most accepted conclusion indicates that cribra orbitalia and porotic hyperostosis occur more frequently in juveniles than adults within the same populations (Djuric et al. 2008; El-Najjar et al. 1975; Stuart Macadam 1985). When porotic hyperostosis is observable in adults, most cases indicate that these adults had experienced childhood anemia due to nutritional deficiencies or parasites. "Bone change induced by iron deficiency anemia may occur in early infancy due to inadequate diet or gastrointestinal diseases…such changes may also occur in adulthood as a result of diet or chronic blood loss through parasitic infection" (Steinbock 1976:231). This suggests that bone changes in both juveniles and adults appear to have a common origin of disease or infection; while an individual can be afflicted with this bone porosity at any point during his or her life, changes occur at a higher degree of severity during childhood than they do during adulthood.

Further evidence can be seen in Stuart-Macadam's (1985) analysis of fourth century A.D. skeletal remains from the Romano British site of Poundbury Camp. Porotic hyperostosis is observed in both juvenile and adult remains, but juveniles display more severe lesions in both the orbits and cranial vaults (Stuart-Macadam 1985). This indicates that the factors contributing to the development of iron-deficiency anemia were affecting children to a much greater degree than they were affecting adults in the Poundbury Camp population.

The different patterns of formation of cribra orbitalia and porotic hyperostosis between adults and juveniles are interesting points that El-Najjar et al. (1975) observed among prehistoric and historic remains of Anasazi Indians from the Southwestern region of the United States. In this study (El Najjar et al. 1975) the authors conclude that skeletal changes are more likely to develop in infants and children because the skull bones are simply thinner and are not fully mineralized. In contrast, adult bones are "minerally rich in texture are mechanically resistant and less likely to [deform]" (El-Najjar et al. 1975:484).

Ribot and Roberts's study (1996) added to these observations by analyzing the impact of stress on the youngest members of populations and the effects of stress on their overall skeletal structures. This study (Ribot and Roberts 1966) involved two comparative populations from the cemeteries of Raunds and Chichester in England. These populations were analyzed for traces of possible evidence of environmental stress and their skeletal indicators. The purpose was to highlight the effects of different conditions related to stress and nutrition on subadults (Ribot and Roberts 1996). The increases in skeletal size and shape that occur during growth can be altered if disturbed by external factors, especially those related to nutrition. The purpose of Ribot and Roberts' (1996) study was to explore several pathological conditions and analyze porosities on the external surface of the skull, specifically orbital and vault lesions. Ultimately however, they (Ribot and Roberts 1996) determined that skeletal growth is so varied, and the etiology of stress indicators are so hypothetical, that their analyses did not lead to solid interpretations of the health status of past populations.

The studies previously described highlight the importance of certain points that will be discussed in subsequent chapters of this thesis. The skeletal porosities that stem from nutritional deficiencies and other causes must be reviewed to better understand the elements of environmental stress that the study population endured. Because the samples discussed in this thesis are mostly adults, with very few confirmed juveniles, it is crucial to recognize the skewed rates of pathological lesions in the population. Adults in this population represent survivors of childhood malnutrition, anemia, disease, and environmental factors creating ill health. In some cases only fragments were available for scoring cranial and orbital lesions, and only then in healed forms. To understand the methods and techniques used in the past is to understand the kind of information that will be yielded in future studies; recognizing errors and shortcomings in past data collection can also shed light on these studies' possible inconsistencies.

Paleopathology in Peru.

Paleopathological studies of the Peruvian Valleys, from which this thesis' study population is derived, became mainstream interest in 1923. This was the year in which George Grant MacCurdy published his study of human skeletal tissue from the Urubamba Valley (MacCurdy 1923), applying osteological methodology in his study. Prior to this landmark work a more well-known archaeologist, Julio Tello, professor at Lima's Universidad Mayor de San Marcos and director of the National Museum of Anthropology, had studied artificial mummification of the head, trepanation, and medical practices in Peru. He later published a book in 1909 on the antiquity of syphilis, alleging its pre-Columbian existence in that country (Aufderheide and Rodriguez-Martin 1998).

Although Peruvian paleopathology has been ongoing for approximately a century (MacCurdy 1923; Tello 1909), analyses of human remains from Peru have occurred with increasing frequency during the last few decades and have made significant contributions to the understanding of health and disease in Latin American populations. Recently, Turner and Armelagos (2012) discussed the existence of pathologies in Peruvian remains from Machu Picchu. They found that of the 73% of the population that still had intact cranial remains, 7% displayed porotic hyperostosis lesions, all of which were in advanced stages of healing at the time of death. Of the 65% that featured adequate preservation of the orbital vaults, 23% displayed cribra orbitalia, which was also in advanced stages of healing. Due to the correlations between both of these conditions and anemia, the authors (Turner and Armelagos 2012) concluded that the population most likely experienced high rates of childhood anemia. This study highlighted the variability of exposure to pathogens and diet that could contribute to the development of cribra orbitalia and porotic hyperostosis within a population. The authors (Turner and Armelagos 2012) concluded that, "the wide variation in isotopic proxies of early-life diet and residence, coupled with variation in the frequencies and severities of common pathological conditions, suggest variation in early-life experiences that impacted individuals' health" (80). This draws attention to the variability of pathological afflictions within a single population.

Grace (2011) ran an osteological analysis of a relatively small sample size of eleven individuals from the highland region of Cuzco in Peru. Grace (2011) found that every individual displayed some form of either cribra orbitalia and/or porotic hyperostosis and suggests that the differences of cribra orbitalia frequencies between coastal and inland/highland people in her study was due to local diet availability in both regions. Nevertheless, the populations on the coast had the potential to be just as much at risk; coastal people would have had better access to fish, which could possibly have carried marine parasites. In contrast, seafood would not have been readily accessible in the highland areas without a relatively long journey to acquire it. Populations that relied on both marine and agricultural resources may have therefore had a greater prevalence of diet-related anemia because of the high phosphoric content of marine foods, which could potentially reduce iron uptake in the diet (Blom et al. 2005).

Blom et al. (2005) also discuss coastal populations in Peru, and emphasize the effects of the rich aquatic diet that they likely consumed; most of the available dietary material would have included marine resources such as fish, algae, shellfish, sea animals, shore birds, and salt, all of which are high in phosphorous (Blom et al. 2005). There was a correlation found in this study (Blom et al. 2005) to suggest that cribra orbitalia lesions appeared in childhood prior to the development of porotic hyperostosis. The data showed that children consuming a more marine-based diet were either more likely to survive with childhood anemia, or died very early, before any bony evidence could form. Finally, Blom et al.'s (2005) study showed that environmental stressors, such as parasites and disease, were more likely the primary cause of childhood anemia in Andean populations, rather than the dietary practices of the coastal samples.

Kellner (2002) wrote her doctoral dissertation on the environmental and social challenges facing populations in prehistoric Peru, specifically those within and around the Nasca territories. Her bioarchaeological analysis encompassed many populations through different time periods ranging from the Preceramic/Archaic period (8000-2500 B. C.) to the Late Horizon period (A.D. 1476-1534). A portion of the populations observed in this study consisted of two Wari-influenced Nasca populations, Huaca del Horo and Chakipampa. These populations will be discussed further in the methods section as they will be used to compare the rates of cribra orbitalia and porotic hyperostosis to this sample population of Collota and Tenahaha.

Overview of Scoring

Historically, various methods of data collection have been utilized to interpret presence, absence, and expression of cribra orbitalia and porotic hyperostosis. Scoring systems have been modified and built upon to better represent the range of pathological expression. However, not all scoring systems are reliable; there are inconsistencies in the scoring method that, if misapplied, have the potential to skew results.

Scoring Method.

Even though a variety of techniques have been established to determine the varying degrees of cribra orbitalia and porotic hyperostosis in the skull, these methods remain problematic. Anthropologists have worked to refine this system in order to represent accurate frequencies and degrees of expression for these conditions. As Steinbock (1976) states, "pathological conditions create an imbalance in the normal equilibrium of bone resorption and formation. Therefore bone reacts to abnormal conditions by an increase or decrease in the normal processes of bone formation... it is composed of living cells in a hard matrix which are quite sensitive to such influences as... infection" (Steinbock 1976:15). Differing patterns of bone formation or resorption can therefore help identify and differentiate exposure to disease and illness when compared to healthy bone. The techniques used to observe these pathologies can make the most out of the information generated from their expression.

As these pathologies have the potential to be confused with healthy or healed bone, especially when their expression is only minimal, several authors have attempted to develop accurate scoring methods. Welcker (1888) developed the first scoring method, with three options to describe the different levels of change in porosity and thickness on cranial surface areas: weak, strong, and strongest (Welcker 1888). Nathan and Haas (1966) also discussed three different degrees of expression, of porotic hyperostosis and cribra orbitalia: the porotic type which features only fine openings on the roof of the orbit; the cribrotic type, in which the openings are larger and more numerous, forming larger apertures; and the trabecular type, which is no longer considered to feature fine openings but rather "large, irregular apertures often arranged in radiating patterns from one or more centers in the orbital roof" (Steinbock 1976:239).

Another scoring system (Stuart-Macadam 1982), which is used extensively in this thesis, consists of categorization of bone surfaces, ranging from normal, to scattered foramina, to severe outgrowth in trabecular structure from the normal contour of the outer bone table (Stuart-Macadam 1982). This method built upon the earlier method (Nathan and Haas 1966) and specified four distinct types of porosity. These were: 1) Type 1, fine scattered porosity; 2) Type 2, mixture of large and small pores; 3) Type 3, trabecular porosity; 4) Type 4, extreme trabecular porosity that extends beyond the normal contour of the bone (Stuart-Macadam 1982).

The author (Stuart-Macadam 1982) later redefined the parameters of each of these types and added a fifth type, Type 5, so as to better represent the full range of expression. The revised method (Stuart-Macadam 1991) included the following types: 1) Type 1, fine impressions, but no full porosities, on the bone; 2) Type 2, fine, scattered porosity; 3)

Type 3, a mixture of large and small porosities; 4) Type 4, trabecular porosity; and 5) Type 5, extreme trabecular porosity beyond the outer bone table.

As will be explained in the methods section, the scoring system used in this project was Stuart-Macadam's earlier method (1982). The least degree of pathological skeletal change observed in the Collota and Tenahaha samples would be categorized as fine, scattered porosities, rather than impressions.

Problems in the Scoring Method.

Cribra orbitalia and porotic hyperostosis are two of the most commonly evaluated pathological conditions in skeletal analysis, yet data collection can be problematic if the methods are not executed correctly. Jacobi and Danforth (2002) conveyed the importance of standardizing methods for identifying cribra orbitalia and porotic hyperostosis by setting up tests of interobserver variability. Standardizing methods that are used in all sites would make collecting data more consistent and accurate for those comparisons between sites and studies.

In Jacobi and Danforth's (2002) study, 20 scorers with varying experience and five others with no experience evaluated 21 partial skulls and reported their findings. The presence of pathology, appearance of porosities, the degree of healing, and the confidence in which they felt their decisions were made were gathered and recorded. According to the authors (Jacobi and Danforth 2002), around 80% of the participants agreed as to whether a lesion was indeed present. However, there was disagreement in evaluating the size and degree of expression of that lesion and in identifying when specimens were free of pathology.   Potentially more confusing is diseased bone, in healed or mildly affected states, were confused with healthy bone during initial observation; the possibility of information being lost increases when there are varying degrees of opinions among analysts. Inconsistencies in data collecting are ever present in the field without standardization.   This highlights the need to refine the scoring standards for these two skeletal pathologies, and suggests future reform of these standards is necessary.

CHAPTER 3 – MATERIALS

The analysis of cribra orbitalia and porotic hyperostosis from Collota and Tenahaha contributes to the overall picture of human health on the periphery of Wari imperial influence in the Cotahuasi Valley during the Middle Horizon Period. To better understand this study's sample population, cultural, archaeological, and bioarchaeological contexts of Collota and Tenahaha are observed and analyzed to understand the influence of Wari people accordingly. Although cultural remains from these sites resemble Wari-style wares, the sites of Collota and Tenahaha are not hypothesized to have been directly under Wari imperial rule. This concept was mentioned in the Introduction chapter, and will be expanded upon in the cultural context section to follow. Reviewing preceding archaeological framework is essential, so as to describe what is known of this area archaeologically and to illustrate those details that are still unknown. Finally, discussing the bioarchaeological context will emphasize past studies regarding health, diet, and pathology within and beyond Wari territory.

The Area of Study: Collota and Tenahaha

The sites of Collota and Tenahaha are located near the Cotahuasi River and have long been associated with one another (Benavides 1991; Isbell 1988; Jennings 2002; Lumbreras 1960). Because research has not been extensive in this area of the Cotahuasi Valley, the literature available is comparatively much less than what is available for other Wari sites like Pikillacta or Cerro Baul, two administrative centers that were directly associated with the Wari polity (Schreiber 1992). The territorial boundaries that defined Collota and Tenahaha were so hazy when research first began in the 1980's, the names of the sites were still undetermined. According to Yepez Alvarez (in press) the place name "Collota," first used by Chavez Chavez (1982), was not officially designated until 2004. The following year the second site, which was originally named "Netahaha," was changed to "Tenahaha" (Alvarez in press). Finally, although these two sites had long been associated with each other as a singular area, recent literature (Jennings 2010, 2011; Jennings and Yepez Alvarez 2009) has begun to refer to Collota and Tenahaha as two different sites.

The site of Collota spans one hectare and is located fewer than 800 meters from the neighboring site of Tenahaha. Tenahaha extends four hectares along the Cotahuasi River, located adjacent to the site (Jennings and Yepez Alvarez 2005), and is divided into two sections. "The first is a ceremonial/domestic component that is concentrated into a two hectare area that has been partially destroyed by modern agriculture and the erosion of the riverbank. The second component is [a] cluster of tombs located on the hillocks surrounding the ceremonial/domestic area" (Yepez Alvarez in press). The sites of Collota and Tenahaha revealed cultural material, archaeological remnants, and human remains; the significance of this material will be discussed further in the sections that follow.

Cultural Context

The Wari civilization was a large and commanding polity. By influencing many adjoining cultures in ceramic styles and architectural design, this "empire expand[ed] beyond their core and…control[led] regions and peoples far beyond their boundaries…manipulating the political structure of those other societies in such a way as to exercise sovereign control over them" (Schreiber 1992:3). Within a few hundred years, the Wari dominated a territory that stretched along the Pacific Coast and into the western highlands from modern day Cajamarca to Cuzco; "they were one of the first ancient Peruvian civilizations to cast a wide political net that folded in many distinct ethnic groups... [they were also] believed to be among the first to establish walled cities built of stone rather than the traditional adobe bricks" (Hunefeldt 2004:231). Smaller localized populations throughout this area were enveloped into the more prominent political power that would eventually be known as the Wari Empire (Isbell and McGowan 1991; Jennings and Craig 2001; Lumbreras 1974; Schreiber 1992).

Cultural aspects began to change around A.D. 600 as regional influences that were much smaller in scale and localized began to give way to uniformity. The rapid expansions in political boundaries, and increases in agricultural production, artistic expression, and political administrative centers that accompanied the spread of Wari influence, make the Wari a captivating culture to examine.

The Wari People and the Middle Horizon Period.

The Wari civilization flourished during the Middle Horizon period from A.D. 500 until its decline in A.D. 1000 (Bauer 2004). Wari control expanded through nearly the entire territory of modern day Peru, from the northern territories of Chan Chan to the southern tip of modern Ayacucho (Blom et.al. 2005; Jennings 2006; Jennings and Alvarez 2001; Schreiber 1992). The Wari changed the face of ancient states in this region. From architecture and cultural practices, to art and ceramic styles, the identifying markers of Wari authority were apparent.

The strength of imperial control and influence throughout the Wari territory was directly correlated with the proximity of Wari administrative centers. Sites like Pikillacta, considered a strong administrative center (Schreiber 1992), divulged consistent material evidence of Wari presence whereas Collota and Tenahaha, further away from any such center, contained less distinct material. Wari imperialism is highlighted in

Schreiber's (1992) work, in which the author states that "Wari imperial investment was largely determined by a region's distance from the center, political organization, wealth potential, and tolerance to outside rule…the level of imperial presence and its method of control could differ radically from region to region" (Schreiber 1992:5). Following this logic, the evidence of authority was seemingly associated with either the direct relationship or distance between the elites and the subjects that resided in their communities.

Wari imperial structure shares many attributes with similar patrimonial empires akin to Babylon and ancient Egypt (Schreiber 1992). Firstly, expansion occurs quickly through military means, and secondly, the Wari did not impose rule directly in all regions "but rather manipulated local political systems to serve imperial needs…thirdly, these polities turned their attention very quickly to economic interests…controlling the production and distribution of all necessary resources" (Shreiber 1992:4). Also, these imperial power structures only continued through a few generations, making it more common to refer to this kind of polity as a political "state" (Service 1975; Wright and Johnson 1975).

The political power of the Wari is a controversial issue, as many scholars do not necessarily agree as to whether they were an "empire" or were simply exuding imperial control through a loose economic network of Wari-run administrative centers. Katharina Schreiber (1992) coined the term "mosaic of control" (267) in her description of Wari political force and suggested that Wari imperial investment was largely determined not only by a region's distance from the center, but also its political organization, wealth potential, and tolerance to outside rule. Schreiber (1992) suggested that the level of imperial presence and its method of control could therefore differ radically from region to region. In other words, the distance from some of these centers, along with other factors, is directly correlated with the amount of power and influence the Wari had over that area.

There was much to gain politically through connections to the Wari polity. Recognition through association had advantages for local merchants and market commerce in that it provided strength and protection; in turn, imperial connections became advantageous to subordinate classes that wished to convey authority within their own communities. The sites of Collota and Tenahaha took advantage of these connections, and conveyed power through symbolically mimicking Wari architecture in order to promote imperial status as built by local elites and not directly by Wari command (Jennings and Yepez 2001).

Local governing systems may have been left intact (Schreiber 1992), however, in sites like Collota and Tenahaha, settlements that were removed from larger, more populated areas may have been dealt with by infiltrating their upper echelons. "Three general strategies involve replacing the local ruler with an imperial one, leaving the local ruler in place, but adding an imperial overseer, or leaving the local ruler autonomous" (Schreiber 1992:21). The advantages that would have been conveyed to local elites adopting Wari culture are too considerable to reject, as valley resources would have been exchanged for imperial protection (Jennings and Yepez Alvarez 2005). In addition, as regions grew additional surplus, they created the means to support growing state bureaucracies, so these resources would not necessarily have represented a great cost to the valley populations. "Just as the political hierarchy is modified to fit into the imperial administrative, so is the local prestige economy, and to a degree the domestic economy, restructured to provide the economic support required by the empire" (Schreiber 1992:28).

Increases in agricultural production and the development of a more sophisticated system of political hierarchy in the Cotahuasi Valley was evident (Chavez Chavez 1982; Trawick 1994). Settlement patterns and city structures also changed throughout the beginning of Wari influence and scholars have found territories on opposite ends of Peru featuring similar central instillations (Lumbreras 1974; Menzel 1964; Rowe 1963). This argues that architectural similarities thoughout the territories of the Wari state would "promote a model of… hierarchy [that would be] supported by evidence [of] Wari manipulations" (Isbell and Schreiber 1978; Rowe 1963; Shaedel 1978).

Once the Wari had a determined political hold, standardized architectural and ceramic styles would have visually unified its territories while simultaneously downplaying various features of the previous local cultures (Blacker 2001; Glowacki 1996; Isbell 1991; Knobloch 1991; Schreiber 1978, 1992; Smith and Montiel 2001). Though Collota and Tenahaha were positioned in the periphery of Wari influence, and were not large posts for either trade or commerce, Wari-style material and cultural remains were found within these sites (Jennings and Yepez 2001). Direct evidence of Wari influence and authority, however, was less obviously apparent (Smith and Montiel 2001).

As Jennings summarizes, "Like many regions of Peru, the evidence for Wari influence on the Cotahuasi Valley is unmistakable, but evidence for Wari control is ambiguous. The relationship that Wari had with Cotahuasinos was clearly different than the relationships that the state maintained with the larger Wari provincial centers of Pikillacta and Cerro Baul" (Jennings 2001:149). Larger stone structures, walled enclosures representing the transition from adobe to stone building materials, and extensive residential districts represented a period of urbanism or a trend towards larger settlements (Lenning 1967). These cities were representative of one of two things: 1) urbanism, or "extensive expression," (Jennings 2001:142; Schreiber 1992) that represented organization through isolated nodes of state authority scattered among local populations (Moseley 2001); or 2) Wari architecture that was being showcased through "nodes" of administrative control symbolized by large centers of commerce, expanding culture, and architectural technologies (Schreiber 1992).

These changes coincided with the beginning of the Middle Horizon period in ancient Peru. "Before the Middle Horizon, the people of the upper Cotahuasi Valley lived in eleven small villages that clung to the steep flanks of the canyon. The villagers subsisted on a mixed economy of agriculture and animal herding and there is no evidence for political centralization above the village level" (Jennings 2001:145). After this period of localized control, a number of changes began to occur that would alter cultural development in this upper valley. "The population increased, with five new sites founded and several older sites increased in size... data from both ceramic assemblages found at cemeteries and architectural forms at habitation sites suggested the development of social stratification by at least this period... [and] the political organization of the area changed as the upper valley may have been brought under the control of the site of Collota" (Jennings 2001:152). This population increase, and the development of different art forms and architecture, symbolizes the societal change this population was undergoing; change that may have resulted in the skeletal implications of nutritional deficiencies and biological stress which were previously discussed in the Literature Review chapter.

Wari-Influenced Populations.

> "At least 20 sites in the Wari periphery have been found that contain buildings that follow aspects of rigid architectural canon that appears to have derived from the state... These sites are often interpreted as part of a network of Wari administrative centers that directly controlled local populations, organized the extraction, storage, and redistribution of local resources, and ruled through an idiom of generalized reciprocity" (Jennings 2006:270).

Only a handful of sites are suggested (Schreiber 1992) to have been true administrative centers of the Wari, however there are still those who would disagree as to what constitutes an administrative center and which characteristics make that area a distinct representative of the Wari (Jennings and Craig 2001; Schreiber 1992). Jennings and Craig (2001) explain that there have been other models of Middle Horizon Peru, including one of actively trading regional polities, loosely tied, oracle-dominated federations, and multi-lineage confederations that dominated the region. In the sites of Collota and Tenahaha for example, ceramics appear to have originally reflected local styles, but began to emulate Wari styles during the Middle Horizon. These emulations were apparent in not only ceramics, but also textiles and other material culture dating from this period, and were construed as an effort to demonstrate dominance in cultural representation (Isbell 1998; McEwan 2005; Schreiber 1992). However, the process of determining whether these Wari styles were enforced by an overpowering state infrastructure or were a mark of only slight cultural contact and influence is quite difficult. "The stylistic variability in architecture and ceramics can perhaps be conceived of as the state adapting to local environments... however, [it can be counter-argued] these sites were built and occupied by local inhabitants" (Jennings 2006:270). In other words, territories within the Wari state could have simply been copying the example and culture of the dominant state, as opposed to having been actively forced to do so by the Wari. Collota and Tenahaha are two of a few areas that are not so easily interpreted as the much larger Wari states due to precisely this uncertainty (Jennings and Yepez 2005).

Confirmed Wari-affiliated sites have been determined by examining the aforementioned characteristics of ceramics, styles of architecture, and textiles. For example, Jincamocco, Cerro Baul, and Pikillacta all have these Wari characteristics and have been confirmed as these such affiliated sites. Pikillacta, as an administrative center, demonstrated all the characteristics of a Wari state; traditional architectural layouts and signature cultural artifacts that emphasized control all support this claim. "This power [whichever the source] took material form in the construction of Collota and Tenahaha – sites that broke with regional traditions not just in their architectural form but also in their centralized, trade-oriented site location. The twin sites can perhaps best be seen as administrative centers built by local elites in order to organize production in a region" (Jennings 2001:155). Jennings and Yepez Alvarez explain further that these two sites were a direct product of the expansion of Wari rule; even though the Wari-esque structures were not built by the Wari themselves, their imperial influence was present visually through their structures, artwork, and politics (Jennings and Yepez Alvarez 2005). The sites of Collota and Tenahaha have a mutual, geographical advantage in that they are in close proximity, and through this relationship one can observe, within archaeological data, the shifts in command from a regional state of tradition and local power to an elite imperial one (Smith and Montiel 2009).

Archaeological Context

Food preparation, social constructs, and cultural identity can all be defined from the archaeological record. The archaeological sites of Collota and Tenahaha provided these material goods and human remains that can emphasize life during the Middle Horizon. As many as 12 areas in Peru have experienced identifiable shifts in ceramic styles, political organization, and settlement structures that have been "perceived as pockets of direct Wari control in the imperial mosaic" (Jennings and Yepez Alvarez 2005). The sites of Collota and Tenahaha are thought to have had a mutual and geographical advantage as they are in close proximity. Through this relationship one can observe, within the archaeological data, the shifts in command from a regional state of local power, to an elite imperial power (Smith and Montiel 2009).

Because the Wari state was so vast, it was rather difficult to differentiate the genuine Wari state and those that created the illusion of the Wari state through archaeological means. However, this very argument of genuine state versus emulated influence of the state was applied to the sites of Collota and Tenahaha:

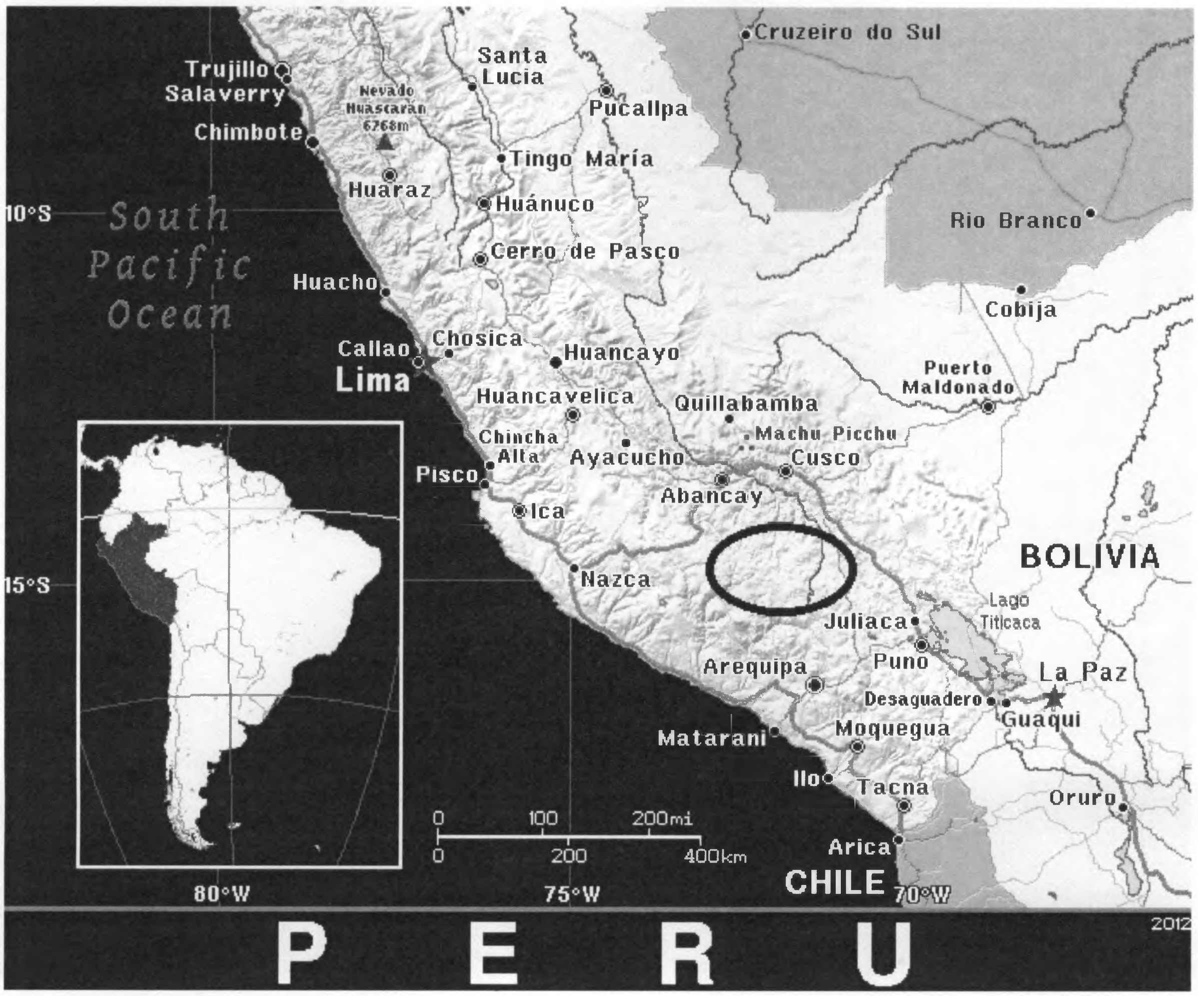
> "Wari influence was profound and led to the creation of new sites, the intensification of agriculture, and an increase in political hierarchy. These changes are correlated to the contruction of two closely associated sites, Collota and Netahaha[Tenahaha], that emulated Wari architectural forms. The combination of significant changes in an area with the introduction of two sites with intrusive imperial architecture would suggest that direct control was imposed by a state or empire…We argue, however, that the Cotahuasi data suggest that Wari control was never direct in this region…we offer an alternative model of indirect control or influence, in which these elites elevated their status by association with the empire" (Jennings and Yepez 2001:144).

The efforts of centralizing a region through the image of imperial influence can become beneficial for that particular territory and for the empire itself. Schreiber (1992:25) suggests that the local elite can essentially create a strong political structure by creating the impression of Wari control; in doing so, the flow of imperial ideas and goods into a region can significantly alter patterns of production, exchange, and political structure without any intervention or intent by an imperial power. The sites of Collota and Tenahaha positioned themselves in creating a centralized center giving the impression they were ruled by the Wari state. Because Collota and Tenahaha were not under direct Wari control (Jennings and Yepez Alvarez 2005), there has been debate as to the relationship between the sample sites and the Wari since there are inconsistencies in artistic artifacts.

The Cotahuasi Valley.

With the valley edges, rising over 3,500 meters from the valley floor in certain parts, Cotahuasi is one of the deepest canyons in the world. The location of this area is found in the circle highlighted in Figure 4 below.

Figure 4. Southern Peru: Cotahuasi Valley



(Public Domain)

Although it is hypothesized that the Cotahuasi Valley was heavily forested during the Middle Horizon period (Guillet 1992), it is now "the driest sub-tropical desert to the equivalent of [an] arctic tundra" (Trawick 1994:32); this confirms the idea that Andean communities positioned themselves in a wide array of environments (Trawick 1994; Schreiber 1992). The valley lies along the northern edge of the volcanic plateau of Arequipa in the Central Andes, and the Cotahuasi-Ocoña river drainage is one of several rivers that cut deep into this plateau as they flow collectively into the Pacific Ocean.

There have only been three brief archaeological investigations that have occurred in the Cotahuasi Valley that have shed light on the people of this region. Hiram Bingham, during his 1911 expedition to Peru, made astute observations referring to the people of the valley and the environment. However, no real archaeological excavation investigating the prehistory of this area was ever conducted since most of his accounts are of his personal travels. Decades later, archaeologist Jose Antonio Chavez Chavez (1982) surveyed this area extensively, and researched its prehistory, leading the investigation of archaeological sites around the Cotahuasi Valley (Chavez Chavez 1982). And recently, Paul Trawick (1994) conducted his dissertation research on the impact of the local economy on land tenure, social organization, and irrigation methods in the valley. An understanding of this area is essential in order to firmly grasp the impact of the Wari polity.

A handful of additional investigations into the archaeology of the valley have been conducted in recent years (Perry et.al. 2006; Sandweiss et al. 2004; Tripcevich 2008) which have depicted the resources that were available to the people that settled in this location. Throughout the history of the valley settlement production, food consumption, travel, and trading methods do not appear to have fluctuated dramatically before the Middle Horizon. Jennings and Yepez Alvarez's (2001) work emphasized the ceramics of neighboring regions, particularly ceramic manufacturing and decorative detail, land resources, and cultural identity during the Middle Horizon (Jennings 2002; Jennings and Yepez Alvarez 2001). Substantial amounts of academic literature are scarce since academic interest in this area is barely starting to peak, however, what is available can still generate an important view of the people who lived in the Cotahuasi Valley.

The Cotahuasi Valley was occupied by at least 2000 B.C. (Jennings and Yepez 2002) and was settled by small groups of agropastoralists. These small groups didn't maintain their residency as settling in more suitable regions for long-term occupancy was more appealing. The Cotahuasi Valley was difficult to get to and was possibly too mountainous to make it an appealing location for permanent residence. This changed during the second half of the Middle Horizon period. "During the Middle Horizon, population rapidly increased, new sites were founded, agricultural production expanded, the exploitation of the valley's obsidian, precious metals, and rock salt intensified, and social stratification increased" (Jennings in press). Jennings (in press) argues that, although the reason behind this influx of prosperity and change in this location is unclear, there was indeed a period of rapid transformation and growth (Jennings in press).

Pastoral people manipulated the land for agricultural endeavors since its occupation. Maintaining larger, growing communities modified the land's infrastructure to its maximum potential. During this increase in terrace-building to modify and improve agricultural methods, the potential of maintaining a larger population within the area became more feasible. To this day the same agricultural food sources are being harvested, such as maize and various kinds of tubers. The potential of the valley, during the beginning stages of permanent settlement, became more appealing due to the various resources that could be gained.

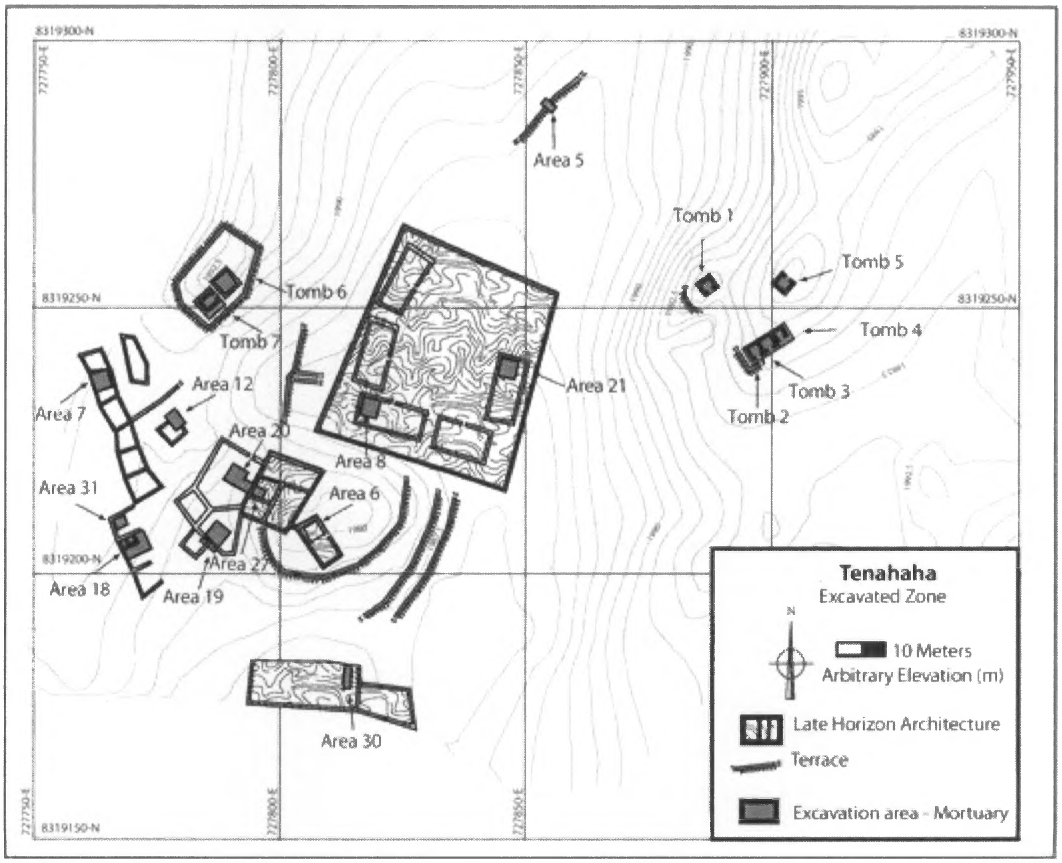
Additional attraction to this area, other than successful food production, was responsible for population growth; the land was rich in valuable minerals that were potentially a good stepping stone towards economic gain. Pre-Columbian shafts documented in the valley attest to a tradition of small-scale mining that may date to as early as the Middle Horizon creating a potentially affluent market of natural minerals (Chavez Chavez 1982). Natural sources of obsidian, gold, silver, copper, and rock salt were featured prominently in the makeup of the valley and were valuable commodities to neighboring communities and Wari political structures. These could be considered advantageous features to a population seeking political gain. If the people in Collota were not taken over by the Wari, as Jennings suggests (2001), these valuable resources helped this area to stand out as a resourceful post in addition to emulating Wari structures. In other words, these resources positioned the inhabitants of Cotahuasi Valley to benefit from and create a political relationship with the Wari without imperial imposition.

Despite its isolation, these few, very specific aspects made this territory very appealing for its settlers. It was located within a natural passageway from Pikillacta, the modern day Cuzco region, to the Pacific Ocean making it a natural position to become a trading route from the highlands to the coastal settlements. Its natural resources also positioned the area to possibly become a valuable outpost within the Wari state, preserving its communities and perhaps lending itself to imperial influence and political acquisition.

Bioarchaeological Context

The human skeletal remains found within the Collota and Tenahaha sites had been analyzed for demographic, pathological, and cultural data. The burial site contained several tombs that were situated between the two areas. Seven of the areas, labeled “tombs” (Figure 5), were the locations from which all skeletal and cultural materials were retrieved. Since burial chambers are reentered after interment, which is common in Andean tradition (Kellner 2002), it was difficult to decipher complete individuals in some cases. Because of partial flood damage in some locations, there was some skeletal material that were too fragmented to verify the age, sex, and other categorizing criteria that could enrich the overall view of Collota and Tenahaha's human population. The detailed site map (Figure 5) from the excavation process locates the different sections within both sites where human remains were found and exhumed. Besides tombs six and seven, all other areas were much closer together. There was no evidence at the time this study was being conducted that there was any correlation or significant association between each tomb.

Figure 5. Collota and Tenahaha: the archaeological site.



(Jennings et.al. in press)

Comparative Sample: The Nasca.

For this thesis, population comparisons between rates of pathological conditions are beneficial to better understand the health in the sample sites of Collota and Tenahaha.

Dr. Corina Kellner's dissertation (2002) analyzed similar populations that were considered comparable for this work. In Kellner's research (2002) populations from three prehistoric Nasca cemeteries from the Las Trancas Valley were analyzed in full. The purpose of her project was to gain a better understanding of environmental and social changes represented in these populations. Ultimately, she concluded that drought, population aggregation, and Wari imperialism had a significant impact on health in the Nasca populations (Kellner 2002). Within Kellner's (2002) study, there were several chapters explaining the details of this impact discussing trophy skulls, trauma, height differentiation, and pathology. Only a fraction of her study, however, will be analyzed here. Other descriptors, such as cranial modification, are not needed for this analysis.

The sites of Huaca del Loro and Chakipampa were of particular interest as good comparative material as they were both from the Middle Horizon period. The Nasca also had a period of change, development, and environmental stress during the beginning of Wari control, similar to the environment of the Cotahuasi Valley. Kellner had confirmed in her research that the Nasca were conquered by the Wari (2002), whereas Collota and Tenahaha were not (Jennings and Yepez Alvarez 2005). The differences between a population under direct Wari rule and a population that was on the outskirts of it were tested between the sample population and the population of the Nasca to better understand the environmental factors that potentially affected dietary deficiencies and infection. Highlighting the significance between this study's sample population and the comparative sample population can evaluate biological implications that occur under a structured political state.

CHAPTER 4 – METHODS

This chapter will expand upon the techniques introduced in the Literature Review and will describe the methods of data collection and processes of analysis employed in this study in greater detail. This analysis incorporated ontological variation, sex identification, and techniques identifying the pathological conditions of cribra orbitalia and porotic hyperostosis. The scoring methods that were utilized to interpret the state of health in the sample populations are specified in order of development (Nathan and Haas 1966), revision and clarification (Stuart-Macadam 1982), and lastly in the most detailed descriptors of porosities of the bone surface (Stuart-Macadam 1991). Finally, the statistical formula Fischer's exact test will be discussed, as this test will be employed in the successive Results chapter, to indicate the significance of the data collected.

Osteological Methods

As this is an osteological analysis of a sample from the populations of Collota and Tenahaha, it was important to first define the sample in terms of age and sex. Paleopathological data could then be interpreted in the context of these parameters. Of the 171 individuals that were recovered from Collota and Tenahaha, 106 met the criteria of preserving 25% or more of their ecto-cranial surfaces and/or their orbital surfaces. Macroscopic analysis of these 106 individuals focused on recording all retrievable information pertaining to the population as a whole.

Subadult vs. Adult.

The total observable sample available for analysis is shown in Table 1.

Table 1. Total of individuals in sample.

Pathology	**Subadult**	**Adult**
Cribra Orbitalia	7	42
Porotic Hyperostosis	6	51

Age-at-death was determined for all remains, according to Buikstra and Ubelaker's (1994) Standards, and was noted during skeletal inventory by the archaeological staff. Each individual was taken manually out of field bags by the author and was examined individually. Because the purpose of this study was to determine rates of cribra orbitalia and porotic hyperostosis rather than the age at which these effects occurred, assigning each individual to broad categories of subadult versus adult was of top priority rather than determining more precise ages. The distinction between subadult and adult was determined through several different means depending on the material that was available for each individual. Totals numbers of subadults and adults examined for cribra orbitalia and porotic hyperostosis are summarized in Table 1.

Dental eruption and attrition patterns were utilized, when the relevant skeletal material was present (Skelton 1996; Smith 1984; Ubelaker 1989), and different stages of dental growth were analyzed in order to determine whether the individual in question was an infant, a child, or was nearing adulthood. Cranial vault thickness (Krogman and Iscan 1986) and suture closure (Perizonius 1987) were also observed and noted, although these methods are not as reliable in age-determination as are methods utilizing the dentition (Hillson 1996; Skelton 1996; Ubelaker 1989).

Sex.

When possible, sex was determined based on the sexually dimorphic traits of the skull (Ascadi and Nemeskeri 1970; Krogman and Iscan 1986; Wolfe et.al. 1994). Only 51% of the adults featured enough cranial material to determine whether they were male or female. As the cranial vaults were rarely intact, robust or gracile muscle attachment landmarks were relied upon for sex determination as male or female respectively (Krogman and Iscan 1986; Skelton 1996; Wolfe 1994). These landmarks were primarily the nuchal crest, mastoid processes, supraorbital margins, and temporal lines.

Scoring Cribra Orbitalia and Porotic Hyperostosis

Cribra orbitalia and porotic hyperostosis were observed and noted within the skeletal inventory. Because there were many fragmentary pieces, only those featuring diagnostic landmark areas, where proper estimation of age and observation of pathologies could be made, were considered for the statistical report. As discussed earlier in the Literature Review chapter, certain scoring methods were more appropriate than others for this particular study.

This thesis employed two main scoring systems: 1) the method developed by Nathan and Haas (1966) to evaluate the severity of porotic hyperostosis lesions, including cribra orbitalia; and 2) Stuart-Macadam's (1982) original scoring method, which defined four types of porosity to describe the range of expression. Both orbital and other cranial porosities were analyzed, and scored accordingly.

Nathan and Haas's (1966) scoring method is based on more simplistic observation than is the method by Stuart-Macadam (1982). According to this method (Nathan and Haas 1966), porotic lesions fall into the category of porotic, cribrotic, or trabecular types. Samples from Collata and Tenahaha were first evaluated according to this method (Nathan and Haas 1966) and were placed within each type accordingly.

Stuart-Macadam's (1982) scoring method described the range of expression in skeletal porosity as falling within four types: 1) Type 1, fine scattered porosity; 2) Type 2, a mixture of large and small pores; 3) Type 3, trabecular porosity; and 4) Type 4, extreme trabecular porosity that extends beyond the normal contour of the bone (Stuart-Macadam 1982). The samples from Collota and Tenahaha were evaluated according to this method and, as with the earlier method (Nathan and Haas 1966), each individual was allocated to a particular type (Stuart-Macadam 1982). Due to the low frequencies of this study's sample population, however, the data was noted as present or absent for the statistical analysis.

Archaeological Excavation at Collota and Tenahaha

The study area is comprised of two sites: Collota and Tenahaha. Collota features two rectangular enclosures measuring 120 by 30 meters, and 30 by 20 meters; both enclosures open up into patios. There is archaeological evidence to suggest that these enclosures were formed when passageways were blocked off and new buildings were constructed over them (Jennings 2001). Tenahaha is located about 800 meters west of Collota, and is also divided into two sections; the first is an enclosure made up of six rooms, and the second is a group of rectangular buildings and patios. "A cemetery is located between the two residential sectors of the site. Looted tombs in the cemetery are circular, stonelined pits that generally hold 2-4 individuals. All of the ceramics from these tombs date from the Middle Horizon period" (Jennings 2001:211).

Excavation areas within each site were determined according to permits allowed by the Peruvian government. Between the two sites, a total of 218.5 square meters were excavated, 60 square meters in Collota and 158.5 square meters in Tenahaha. There were a total of 32 excavation areas, and each area was subdivided into one by one meter excavation units (Yepez Alvarez, in press).

Skeletal remains were distributed throughout the two sites of Collota and Tenahaha. There were a total of seven funerary structures, each measuring two to three meters in length, with a depth of between one-and-a-half and two meters. All structures had single openings on the southeastern side that were originally covered with stone, and all structures had been disturbed to some degree. Each area featured human remains and associated artifacts that ranged from complete articulated skeletons with adjacent ceremonial goods, to completely scattered and severely fragmented skeletal remains with looted cultural material that could not be associated with one another. There was also one area with severe water damage due to a flood, which had damaged skeletal and cultural materials, and had minimized the potential for pathological examination.

Because the author was only involved in the laboratory analysis portion of the excavation, the remains herein described were neither observed nor photographed *in situ.* Remains were bagged in the field, and were separated by area and lot number. Each area represented a different plot, or tomb, and each held multiple interments; these interments had been added to throughout the years, as is typical in the Andean tradition (Kellner 2002). Since the addition of individual interments was an active process, older remains and their accompanying funerary objects were, in some cases, destroyed. Due to the multiple interment tradition, and the movement of looters over the years, many of these areas were found to be highly disturbed on excavation.

Even when skeletal material was found in adequate condition to be removed, there were slight setbacks in regards to collecting certain osteological information. Many of the remains had been fragmented to the point where the author, on finding skeletal material with porous surfaces, was unable to clearly decipher the sex of the individual. In addition, the subadult remains that were still intact were extremely fragile, and severely fragmented. Despite these issues, the skeletal material recovered from Collota and Tenahaha provided enough evidence as to whether the individual had once had, or was actively, suffering with cribra orbitalia or porotic hyperostosis at death. Also, because the author could not observe remains that featured both cribra orbitalia and porotic hyperostosis together due to the highly fragmentary nature of the remains, the assumption that cribra orbitalia was present before porotic hyperostosis manifested, as other researchers have suggested in past studies (Hengen 1971; Stuart-Macadam 1989), could not be evaluated for this particular population.

Archaeological and osteological material that was found within the study area was subsequently bagged, labeled, and removed to laboratories within the city of Arequipa, 1,075 kilometers from the site. In this laboratory process, two teams were available for analysis: the ceramics and cultural materials team, and the bioarchaeology and human osteology team. The latter was responsible for the complete skeletal inventory of all human remains found on both sites and was tasked with taking a full skeletal inventory and noting all cultural modifications and pathologies, including age, sex, and physiological differences.

Comparative Population: the Nasca

Kellner's (2002) dissertation featured an analysis of Middle Horizon Nasca Valley populations from the sites of Huaca del Loro and Chakipampa. This thesis combines these populations into a single, comparative population, which was used to provide a broader regional context for the rates of cribra orbitalia and porotic hyperostosis observed in the skeletal remains from Collota and Tenahaha. The combined sample population for Huaca del Loro and Chakipampa totaled 151 individuals; there were 57 males and 68 females in total, 25 subadults and 126 adults. Both of these sites had been conquered by the Wari, which meant that Wari administrative centers would have been located at or near both sites.

Given the fact that the bioarchaeology of the valleys surrounding Collota and Tenahaha remains understudied, there are not many available populations to compare skeletal disease rates within that geographic area. Therefore, it was necessary to include a comparative population in this study, in order to compare and contrast the skeletal findings spanning both sites and to ascertain whether any skeletal attributes were specific to the Cotahuasi Valley. In addition, rates of disease representation in Collota and Tenahaha could be concluded to have been very high, or very low, if comparing them to a population which derived from the same time period and was also likely to have been under imperial influence.

Kellner (2002) applied the same observational methods to skeletal remains from Huaca del Loro and Chakipampa as were applied to the populations from Collota and Tenahaha (Nathan and Haas 1966; Stuart-Macadam 1982), but she also used an additional method by Buikstra and Ubelaker (1994). This method defined observed skeletal lesions as falling into one of four categories, which can be thought of as: 1) indistinct porosity; 2) porosity; 3) widely scattered foramina; and 4) widely scattered foramina associated with broad change in the bone (Buikstra and Ubelaker 1994). Kellner (2002) also employed a chi-squared statistical analysis to her total population, as is appropriate when dealing with very large numbers of individuals. This method was also not appropriate for the population from Collota and Tenahaha, as the total population was too small.

Statistical Analysis

Fischer's exact test was used to determine whether the differences in percentages and totals between Collota and Tenahaha and the comparative population were significant. "Fischer's test is designed to answer one question: what are the chances of obtaining observed results as extreme (or more extreme) as those obtained in the experiment" (Thomas 1986:293). The population sample from Collota and Tenahaha, and the comparative Nasca population from Huaca del Loro and Chakipampa were, in theory, equally likely to be exposed to dietary anemia, parasites, and other causes that contribute to the development of cribra orbitalia and porotic hyperostosis. The purpose of applying Fischer's exact test to these populations is therefore to assess whether there was a significant difference between the health of the populations from Collota and Tenahaha and the neighboring populations of the Nasca who had similar environmental stressors. As discussed, chi-squared was more appropriate for Kellner's (2002) study, as this test relies on very large numbers. Because there were far fewer individuals in the study population from Collota and Tenahaha, as compared to Kellner's (2002) total population, Fisher's exact was more fitting (Cochran 1954; Grizzle 1967; Thomas 1986).

Statistical analyses, such as Fischer's exact, can shed light on the significance of pathological observations within a particular population, as compared to those of surrounding populations; i.e., whether the study population experienced fewer social and biological stressors than did their neighbors. In the Results chapter to follow, the rates of cribra orbitalia and porotic hyperostosis will be compared between subadults and adults, and again between male adults and female adults, in Collota and Tenahaha. These rates will then be compared to subadults and adults, and between male adults and female adults in the comparative population. This will highlight the differences between each subgroup and each pathological condition and will test whether these associations are statistically significant.

CHAPTER 5 – RESULTS

Due to the fragmentary nature of the skeletal material, only a small number of the 171 individuals recovered from Collota and Tenahaha were deemed observable. The fragments that exhibited orbital and vault lesions in various degrees of severity and activity were compared to the population from Huaca del Loro and Chakipampa. According to the site report (Jennings et al. in press), 73 of these individuals were subadults (from birth to the ages of 15 to 18), while the remaining 98 were adults. Further examination determined that 25 of these individuals could be confidently identified as male, while an additional 25 could be identified as female; sex identification was not possible for the remaining individuals due to the lack of identifiable landmarks on skeletal structures (Jennings et al. in press).

From the totals listed above only seven subadults and 42 adults could be evaluated for cribra orbitalia, as only these individuals featured sufficient surface area preservation. Only 13 males and 17 females from the adult sample featured enough of the orbital surface to observe possible evidence of pathology. The same situation was in place for porotic hyperostosis; a total of only 51 adult individuals featured enough surface area preservation to evaluate this effect, along with only six individual subadults. The distribution of orbital and vault lesions between males and females, and subadults versus adults, could illuminate the rates in which cribra orbitalia and porotic hyperostosis were expressed within the sample population.

The population from Collota and Tenahaha would have encountered varying degrees of environmental stressors that could have made them more susceptible to nutritional anemia, parasitic infection, and other detrimental health conditions. The following findings will suggest whether these elements had a considerable impact on the sample population, or whether their impact was not significant enough to reject the null hypothesis in which no statistical significance is apparent. As the results will show, in the case of Cotahuasi Valley, neither dietary anemia nor parasitic infection seem to have had a great effect to form cribra orbitalia or porotic hyperostosis lesions. The percentages of adults and children with either or both porosities were too low to make the case for an environment with endemic disease or other factors that could potentially affect the population.

Cribra Orbitalia

This thesis evaluates cribra orbitalia and porotic hyperostosis separately in order to gain a clear understanding of whether there were higher frequencies of the former versus the latter in the sample population. Statistically, the frequencies of both skeletal lesions were relatively low in the individuals from Collota and Tenahaha, however, there are some disparities between subadults and adults, as well as females and males, within the population.

Subadults versus Adults.

In regards to the occurrence of cribra orbitalia in this study's sample, one subadult out of seven exhibited active lesions with visible porosities; this means that only 14.3% of the subadult population had active porosities on the orbital surfaces. A single female from the adult population, identified through cranial sex variation methods (Bass 1995; Krogman and Iscan 1986; White and Folkens 1991; Wolfe 1994), exhibited active coalescing porosities in the orbital vault. This individual was the only adult, out of a total of 42, who demonstrated any degree of orbital porosity which placed the expression of cribra orbitalia in adults at 2.4%. When comparing subadults to the adult population, the difference in percentages of individuals displaying porosities is therefore relatively minimal (Table 2).

Cribra orbitalia expression in the subadult population was 11.9% higher than in the adult population; this suggests that the subadult population had slightly more exposure to environmental stress factors than did the adult population. While this aligns with other studies (i.e. Blom 2005) in their discussions of the higher likelihood of developing orbital lesions during early childhood, Fischer's exact test shows that there is no statistical significance in the different rates of expression of cribra orbitalia between these two groups. These results are summarized in Table 2.

Table 2. Fischer's exact test: cribra orbitalia between subadults and adults.

Cribra Orbitalia	Subadults	Adults	Total	P-Value
Present	N=1 (14.9%)	N=1 (2.4%)	2	P=0.2769
Absent	N=6 (85.7%)	N=41 (97.6%)	47	
Total	7	42	49	

Males versus Females.

None of the 13 adult males from Collota and Tenahaha exhibited orbital lesions. In comparison, one out of the 17 females, or 5.9% of females exhibited orbital lesions, as shown in Table 3. Only one female exhibited cribra orbitalia, which were scored as coalescing porosities that were active at the time of death. Though this sample size is admittedly small, these results could suggest that further investigation into the frequencies of cribra orbitalia in females versus males may reveal a pattern of pathology that has yet to be recognized.

Table 3. Fischer's exact test: cribra orbitalia between males and females.

Cribra Orbitalia	Males	Females	Total	P-Value
Present	N=0 (0%)	N=1 (5.9%)	1	*P*=1.00
Absent	N=13 (100%)	N=16 (94.1%)	29	
Total	13	17	30	

Because the P-value is higher than 0.05, there is no statistical significance between males and females within the sample population.

Porotic Hyperostosis

During osteological analysis, the skeletal material from Collota and Tenahaha revealed slightly higher numbers of individuals with porotic hyperostosis than cribra orbitalia in the adult population. Because parietal and occipital cranial vault bones, where porosities and lesions tend to occur, are more robust than the orbital surfaces, the likelihood of bone preservation in these areas when compared to the fragile orbital surfaces is higher. Although the rate of porotic hyperostosis is higher than that of cribra orbitalia in individuals from Collota and Tenahaha, the skeletal material from these sites did not feature many examples of either condition.

***Subadults versus Adults*.**

Due to the lack of observable skeletal material, rates of porotic hyperostosis lesions could not properly be evaluated for subadults versus adults in the study sample. Only six subadults from Collota and Tenahaha possessed enough cranial material to be included in the study and none of them exhibited cranial vault porosities. The adult population, however, featured several individuals with observable degrees of cranial vault porosity.

Eight individual adults, or 15.7% of the total 51 individuals, exhibited cranial vault lesions; these were mostly located on the parietal bones or, less frequently, on the occipitals. The relatively small degree of porotic hyperostosis lesions, observed in both subadults and adults from Collota and Tenahaha, could suggest either a low survival rate from childhood anemia or a relatively healthy population with lower possibilities of developing diseases that would manifest in porotic hyperostosis. The rates for subadults and adults are summarized in Table 4.

Even though it seems as though there is a significant difference between subadults and adults, Fisher's exact test indicates this as not significant so we cannot accept the null hypothesis; there is no direct association between the two variables (Table 4).

Table 4. Fischer's exact test: porotic hyperostosis between subadults and adults.

Porotic Hyperostosis	**Subadults**	**Adults**	**Total**	**P-Value**
Present	N=0 (0%)	N=8 (15.7%)	0	
Absent	N=6 (100%)	N=43 (84.3%)	49	*P*=0.5796
Total	6	51	57	

***Males versus Females*.**

Rates of porotic hyperostosis could not be compared between males and females as most skeletal materials displaying these lesions were too fragmentary to determine sex. The vault fragments were not intact and did not reveal any available landmarks that could lead to sex estimation.

Comparative Sample: Cotahuasi versus Nasca Valleys

A comparative population was used during this study to determine whether there were fewer environmental stress factors affecting the sample from the Cotahuasi Valley just outside of Wari imperial boundaries (Jennings and Yepez Alvarez 2001) than there were the Nasca Valley populations that were under Wari control. Three Fischer's exact tests were used to compare the available population data. The first test aimed to determine whether there was a significant difference between the rates of cribra orbitalia lesions in the subadult populations from both valleys (Table 5).

Table 5. Fischer's exact test: comparing cribra orbitalia between subadults.

Cribra Orbitalia	Cotahuasi	Nasca	Total	P-Value
Present	N=1 (14.3%)	N=4 (28.6%)	5	*P*=0.6244
Absent	N=6 (85.7%)	N=10 (71.4%)	16	
Total	7	14	21	

Because the P-value is high the null hypothesis cannot be rejected. This means that even though it appears the Nasca may have experienced a higher frequency of cribra orbitalia lesions, the statistical data does not support it. Table 6 displays the rates of cribra orbitalia between the adult populations from both valleys, and reveals a similar situation.

Table 6. Fischer's exact test: comparing cribra orbitalia between adults.

Cribra Orbitalia	Cotahuasi	Nasca	Total	P-Value
Present	N=1 (2.4%)	N=4 (5.2%)	5	*P*=0.6552
Absent	N=41 (97.6%)	N=73 (94.8%)	114	
Total	42	77	119	

Again, there is no statistical evidence that the rates of cribra orbitalia lesions differed significantly between adults from the two valleys as the P-value here is greater than 0.05. The final Fischer's exact test compares rates of porotic hyperostosis lesions in adults between the Cotahuasi and Nasca Valley populations as seen in Table 7.

Table 7. Fisher's exact test: comparing porotic hyperostosis between adults.

Porotic Hyperostosis	Cotahuasi	Nasca	Total	P-Value
Present	N=8 (15.7%)	N=5 (6.2%)	13	*P*=0.1311
Absent	N=43 (84.3%)	N=75 (93.8%)	118	
Total	51	80	131	

These contingency tables add insight to the analysis of the sample population from Collota and Tenahaha and draw attention to the similar environmental circumstances shared between the populations of the Cotahuasi and Nasca Valleys.

CHAPTER 6 – DISCUSSION

The statistical results described in the previous chapter help highlight the overall health of individuals in the Cotahuasi Valley and reflect the rates of possible nutritional deficiencies, parasitic infections, and other conditions resulting in anemia in the sample population from Collota and Tenahaha. This was compared to a neighboring population with similar environmental circumstances. The only differing variable was Collota and Tenahaha were situated on the outskirts of Wari control while the population from the Nasca Valley was fully incorporated within the Wari polity.

Overall results show a relatively low presence and expression of cribra orbitalia and porotic hyperostosis in both populations. It is possible that the sample population represents a larger population that experienced only slight health deficiencies; however, there are some who argue that this assumption should not be made so hastily. "The Osteological Paradox" (Wood et al. 1992) contests the long adopted assumption that a high frequency of pathological lesions in a skeletal sample represents a population that was unhealthy while an increase in pathology represents an increase in disease. In this paper Wood et al. (1992) suggest that the presence of pathological lesions alone actually reveals little about overall population health. In any population an individuals' susceptibility to disease varies. "Because frail individuals are prone to an early death, a low level of pathology may actually indicate high mortality in a relatively frail population. Conversely, a high level of pathology may indicate high survivorship in a population of low frailty. In short, better health makes for worse skeletons" (Wood et al. 1992:456).

According to Wood's (1992) theory, the skeletal samples of the Cotahuasi and Nasca Valleys actually suffered from extremely poor health, since there is very little presence of pathological lesions in either group, rather than representing extremely healthy populations. Wood (1992) stipulates that a large number of adults with healed lesions would indicate that these individuals had survived past ailments. Given the scarcity of observable lesions in the adult skeletal material from Collota and Tenahaha, the population may have actually suffered relatively poor health. In other words, the small amount of skeletal material exhibiting pathological lesions may represent the relatively small amount of individuals who had survived illness, parasitic infection, and disease, rather than individuals who had succumbed to it.

In the skeletal sample from Collota and Tenahaha, the number of individuals exhibiting clear signs of cribra orbitalia and porotic hyperostosis was not significant enough to statistically determine whether there were prominent health issues that distressed the population. Comparing the total percentage of skeletal lesions from the sample study to the comparative study of Huaca del Loro and Chakipampa, there is a slight difference in percentages of individuals exhibiting these lesions. Even though the Huaca del Loro and Chakipampa sample population contained more individuals expressing orbital lesions, this difference is not significant enough to suggest the Nasca

Valley population was under more rigorous environmental stressors due to the presence of the Wari polity.

Cribra orbitalia lesions occurred at different rates in the Cotahuasi and Nasca Valleys; the Nasca featured a higher percentage at 28.6%, compared to a 14.3% expression rate in the Cotahuasi Valley. One third of the subadults from the Nasca population exhibited cribra orbitalia lesions in either active or healed states. The adult populations, when compared, were modest as Nasca's population had 5.2% showing orbital lesions to the 2.4% of the Cotahuasi Valley. Although the statistical evidence is not significant partially due to the sample size available for examination, further studies with larger samples are warranted.

The distribution of cribra orbitalia between the sexes was also interesting to examine. The population of Nasca were noticeably higher among females than males, the same occurred in the Cotahuasi Valley with a somewhat lower percentage. In Huaca del Loro and Chakipampa the females exhibiting orbital lesions were 6.8% of the population where the males were a mere 3%. In Cotahuasi Valley none of the males that were identifiable had orbital lesions where one female was affected (5.9% of the females). Blom et al. (2005) maintained "osteological data [that] could not be informative in situations where girls were more commonly afflicted with anemia and were more likely to die in childhood. Likewise, the presence of higher frequencies of lesions in adult males could indicate either that boys were more at risk for anemia or that they were more likely to survive than girls were" (2005:163). It is possible females were more vulnerable, especially in early childhood, but this is not well supported in this sample. Even though female totals were higher than males, the sample is too small to state there is a significant difference in the occurrence.

Porotic hyperostosis also has dissimilar rates in the Huaca del Loro and Chakipampa populations when compared to the Collota and Tenahaha populations. In the Nasca populations 6.25% of the adult population had some form of cranial vault lesions with varying degrees of porosities as opposed to the 15.7% of the sample Cotahuasi population. This indicates a difference in the adults with lesions of porotic hyperostosis; this differentiation suggests that the people living in Huaca del Loro and Chakipampa had fewer or less severe environmental factors that made them more susceptible to developing anemia. The initial hypothesis stated the possibility that Wari-controlled areas contained more environmental stress than outer lying territories. Knowing that Collota and Tenahaha were located outside of the political boundaries of the Wari (Jennings 2002) this 15.7% of Cotahuasi compared to the 6.25% of the Nasca reveals this is not actually the case.

Cribra orbitalia and porotic hyperostosis are both present in these four territories and within these two valleys; both populations were under similar hardships, nutritional deficiencies, possible parasites, and disease. However, the indicator that stands out is the Nasca population usually had the higher percentage when compared to the sample population of the Cotahuasi Valley. The subadult group from the Huaca del Loro and Chakipampa populations had almost twice the amount of cribra orbitalia than the Collota and Tenahaha populations. The adult samples also were slightly higher in Nasca with just a 2.8% difference. Only when analyzing the expression of porotic hyperostosis did the Cotahuasi sample population lead with a 15.7% percentage to the Nasca's 6.25%. Even though the differences are seemingly evident during the comparative analysis, the numbers of samples from each population are too small to state one population was exposed to a more stressful environment. Therefore, further comparative studies are necessary to understand, in this case, the relationship between an upheaval of local tradition to a streamlined, uniform political state and its biological influence in the expression of pathological lesions.

Access to iron rich foods, more sanitary living standards, and/or exposure to fewer environmental factors that could cause cribra orbitalia and porotic hyperostosis could explain the slightly healthier population of the Cotahuasi Valley. In Blom et al.'s (2005) study, the different regions of pre-Columbian Peru highlight that vault and orbital lesions can vary depending on the geographic locations and time periods. The beginning of the Middle Horizon was a time when the impact of social change could have shaped the health of local people (Schreiber 1992). Also geographic location and differential access to certain foods, such as a higher quantity of maize or a higher quantity of marine and shore resources, could also affect the ability to process certain nutrients that would result in anemia and its skeletal outcomes. Ubelaker (1992) also determined that there was a higher frequency of porotic hyperostosis in coastal Peruvian populations compared to highland populations and suggested that parasitic infection may have been a contributing factor to this condition. Parasites, such as hookworms, require warm and damp environments like those found on the coast. Armas (1979) conducted research which demonstrated the abundance of aquatic parasites on the north coast of Peru and found a diet high in fish increases the risk of acquiring these parasites. This demonstrates the ways in which a population can be effected by the different dietary resources they have access to; the lower frequencies of cribra orbitalia and porotic hyperostosis in highland communities can support the current skeletal analysis of the frequencies of cribra orbitalia and porotic hyperostosis in Collota and Tenahaha.

These studies represent a small corner of South America, but the frequency of cribra orbitalia and porotic hyperostosis is comparatively lower than earlier European (Stuart-Macadam 1989) and North American studies (El-Najjar 1975; Walker 1986). Genetic anemias and dietary deficiencies affected those sample populations to a greater degree than this study's sample population. The statistical comparisons between The Nasca and Cotahuasi Valleys were not significant enough to state one population suffered from more environmental factors than the other. Further investigation is encouraged in Wari-influenced populations during the Middle Horizon; doing so would create a larger scope in understanding health, diet, and stress among Wari influenced cultures.

CHAPTER 7 – CONCLUSIONS

The original hypothesis intended to highlight the rates of pathological effects on the skeletal surface due to stressful political environments and compare the findings with neighboring populations. However, statistical analysis did not reveal that there was a significant difference between the Cotahuasi and the Nasca populations. This is largely due to the fact that the sample size was small and could not conclude to a more significant outcome. Within this study's sample comparing the frequencies of cribra orbitalia and porotic hyperostosis between subadults and adults, the P-value was not significant enough to state that there was a substantial difference. Subadults were not significantly affected more than the adult population with cribra orbitalia, even though it is typical to find higher rates in children than adults (Hengen 1971; Mensforth 1978; Stuart-Macadam 1985). The same can be said of porotic hyperostosis; even though none exhibited this in this study's subadult sample.

When comparing percentage rates between the Cotahuasi and Nasca Valleys, the latter shows its population had slightly higher frequency rates, with the exception of porotic hyperostosis, among adults. However, when using the Fischer's exact test, there is no statistical significance. The purpose of this osteological analysis was to decipher the rates of cribra orbitalia and porotic hyperostosis within the sample populations of Collota and Tenahaha and compare the results against the similar sample populations of Huaca del

Loro and Chakipampa. Exploring these percentage rates had the potential to shed light on the cultural and political change in the society and culture Collota and Tenahaha during the Middle Horizon. The assumption that environmental stress created within the Wari empire was more considerable as opposed to outside the Wari empire is not supported by this data.

The expression of cribra orbitalia and porotic hyperostosis was not prominent in this study's population. Even though the adults from this sample had lesions, only one adult demonstrated active porosities at the time of their death. This small trace of mostly healed porosities on the cranial vault observed in a few adults, and a smaller amount of active lesions in one subadult, demonstrated the presence of skeletal lesions, but was not significant. This infliction on the bone reveals a temporary state of malnutrition or environmental stress; however, comparatively looking at the rates of these pathologies in peripheral populations, the percentage is lower. This was possibly due to other causes of porosities in the skull in the Andean highlands such as high-altitude hypoxia, retaining low oxygen saturations (Sanzano and Callegari-Jacques 1988), or marrow hyperplasia due to iron-deficiency anemia. Since it has been found that any dietary staple that interferes with the absorbtion of iron can cause more hyperplastic marrow response (Brecher 2004), it may have also affected the population as well. We find this to be true in indigenous Southwestern populations in the United States where maize was a staple (El-Najjar 1975). This is not the case in the Cotahuasi Valley. "Agriculture terracing in the valley dates to at least the Middle Horizon…since maize and other agricultural products figure prominently in [ancient tributary customs], it seems likely that the valley's agricultural potential has long been one of its major attractions" (Jennings in press). The difference may be due to higher prevalence rates from other causes. "Environmental stressors, such as parasites and disease, rather than specific dietary practices were found to be more likely associated with childhood anemia…in Andean samples" (Blom et.al. 2005).

Because there are still active archaeological sites in this part of the world, there is an active effort for future analyses of these pathological lesions and their connecting causes within Andean populations. This is indeed an important endeavor that will bring to light further information on disease and its manifestations on the skeletal record.

LITERATURE CITED

Angel, J. L. 1966. Porotic hyperostosis: Anemias, malarias, and the marshes in the prehistoric eastern Mediterranean. *Science* 153:760-763.

Aufderheide, Arthur C., and Conrado Rodriguez-Martin, editors. 1998. *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge University Press.

Bass, W. M. 1995. *Human Osteology: A Laboratory Field Manual, Fourth Edition.* Special Publication No.2 of the Missouri Archaeological Society.

Bauer, Brian S. 2004. *Ancient Cuzco: Heartland of the Inca.* University of Texas Press, Austin.

Benavides C., Mario. 1991. Cheqo Wasi, Wari. *Huari Administrative Structure: Prehistoric Monumental Architecture and State Government.* Eds. William H. Isbell and Gordon F. McEwan pages 55-69. Washington, D.C.: Dumbarton Oaks.

Bingham, Hiram. 2003. *Inca Land: Explorations in the Highlands of Peru.* National Geographic Adventure Classics. Washington D.C.

Blom D. E., Buikstra J. E., Keng L., Tomczak P. D., Shoreman E., Stevens-Tuttle D. 2005. Anemia and childhood mortality: latitudinal patterning along the coast of Pre-Columbian Peru. *American Journal of Physical Anthropology* 127:152-169.

Bothwell, T.H. 1995. Overview and mechanisms of iron regulation. *Nutrition Reviews* 53:237-245.

Brecher, Mark E., Regina M. Leger, Jeanne V. Linden, Susan D. Roseff. 2005. *American Association of Blood Banks Technical Manual 15th Edition.* Bethesda, Maryland, United States.

Buikstra, J. E., and D. H. Ubelaker, editors. 1994. *Standards for Data Collection from Human Skeletal Remains.* Proceedings of a seminar at The Field Museum of Natural History, Organized by Jonathan Haas. Arkansas Archaeological

Survey Research Series Number 44. Fayetteville: Arkansas Archaeological Survey.

Buzon M. R. 2006. Health of the non-elites at Tombos: nutritional and disease stress in New Kingdom Nubia. *American Journal of Physical Anthropology* 130:26-37

Caffey, J. 1937. The skeletal changes in the chronic hemolytic anemias. *American Journal of Roentgenology, Radium Therapy and Nuclear Medicine*. 37(3):293-324.

Chavez Chavez, Jose Antonio. 1982. Evidencias arqueologicas en la Cuenca del Rio Cotahuasi-Ocona, Unpublished thesis presented for the license of archaeology. Universidad Nacional de San Agustin, Arequipa (Peru).

Cochran, William G., 1947. Some Consequences When the Assumptions for the Analysis of Variance Are Not Satisfied. *Biometrics* 3:22-38.

Concha Contreras, Juan de Dios. 1975. Relacion entre pastores y agricultores. *Allpanchis* 8:67-101. Cusco (Peru).

De Vizia, B., V. Poggi, P.Vajro, S. Cucchiara, and A. Acampora. 1985. Iron Malabsorption in Giardiasis. *Journal of Pediatrics* 107:75-78.

Djuric, M. P., A. Milovanovic, M. Janovic, K. Draskovic, and P. Milekovic. 2008. Porotic Lesions in Immature Skeletons from Stara Torina, Late Medieval Serbia. *International Journal of Osteoarchaeology*. Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/oa.955.

El-Najjar, Mahmoud Y., Betsy Lozoff, and Dennis J. Ryan. 1975. The Paleoepidemiology of Porotic Hyperostosis in the American Southwest: Radiological and Ecological Considerations. *The American Journal of Roentgenology, Radium Therapy, and Nuclear Medicine*. 125(4): 918-924.

Facchini, F., E. Rastelli, and P. Brasili. 2004. Cribra orbitalia and cribra cranii in Roman Skeletal Remains from the Ravenna Area and Rimini I-IV Century AD. *Internation Journal of Osteoarchaeology* 14: 126-136.

Glowacki, Mary. 1996. "The Wari Occupation of the Southern Highlands of Peru: A Ceramic Perspective from the Site of Pikillacta," unpublished Ph. D. dissertation, Brandeis University, Waltham, Massachusetts.

Grace, Emily. 2011. Demography, Paleopathology, and Health Status of the Moche Remains in Huambacho, Peru: A Comprehensive Osteological Analysis. Unpublished thesis, Lousiana State University.

Grauer, Anne L. 2011. *A Companion toPaleopathology: First Edition.* Wiley-Blackwell Press. Maldon, MA.

Grizzle, J.E., 1967. Continuity Correction in the Chi-Squared test for 2x2 Tables. *American Statistician.* 1967:28-32.

Guillet, David W. 1992. *Covering Ground: Communal water Management and the State in the Peruvian Highlands.* University of Michigan Press, Ann Arbor.

Hengen, O.P., 1971. Cribra orbitalia: pathogenesis and probable etiology. *Homo* 22:57-75.

Hooton, E. 1930. *The Indians of Pecos Pueblo: A Study of their Skeletal Remains.* New Haven: Yale University Press.

Hrdlika, Ales. 1909. "Health and Disease," in *Handbook of American Indians North of Mexico. Bulletin of the Smithsonian Institution, Bureau of Ethnology,* Vol. 30. Edited by F. Hodge, pp. 540-541. Washington D.C.: Government Printing Office.

-------. 1914. Anthropological work in Peru in 1913, with notes on the pathology of the ancient Peruvians. *Smithsonian Miscellaneous Collections* 61(18):1-69.

Hunefeldt, Christine. 2004. *A Brief History of Peru.* University of California, San Diego. Facts On File, Inc.

Isbell, William H. 1988. City and state in Middle Horizon Wari. In: Peruvian Prehistory, edited by Richard W. Heatinge, pp. 164-89. Cambridge: Cambridge University Press.

-------. 1989. Honco Pampa: was it a Huari administrative centre? In: The Nature of Wari: A Reappraisal of the Middle Horizon Period in Peru, edited by R. M. Czwarno, F. M. Meddens and A. Morgan, pp. 98-114. BAR International Series 525.

-------. 1997. *Mummies and Mortuary Monuments: A Postprocessual Prehistory of Central Andean Social Organization.* University of Texas Press, Austin.

Isbell, William H. and Gordon F. McEwan. 1991. *Huari Administrative Structure: Prehistoric Monumental Architecture and State Government.* Dumbarton Oaks Research Library and Collection Washington, D.C.

Jacobi, Keith P. and Marie Elaine Danforth. 2002. Analysis of Interoserver Scoring Patterns in Porotic Hyperostosis and Cribra Orbitalia. *International Journal of Osteoarchaeology. 12: 248-258.*

Jennings, Justin. 2002. "Prehistoric Imperialism and Cultural Development in the Cotahuasi Valley, Peru." Unpublished Ph.D. dissertation. Department of Anthropology, University of California, Santa Barbara.

--------, 2006. Understanding Middle Horizon Peru: Hermeneutic Spirals, Interpretive Traditions, and Wari Administrative Centers. *Latin American Antiquity*, 17(3), pp. 265-285.

Jennings, Justin and Willy Yepez Alvarez. 2001. Architecture, Local Elites. And Imperial Entanglements: The Wari Empire and the Cotahuasi Valley of Peru. *Journal of Field Archaeology,* Vol. 28, No. ½ (Spring – Summer, 2001), 143-159.

Jennings, Justin and Nathan Craig. 2001. "Polity Wide Analysis and Imperial Political Economy: The Relationship between Valley Political Complexity and Administrative Centers in the Wari Empire of the Central Andes," *Journal of Anthropological Archaeology* 20(4): 479-502.

Jones, Joseph. 1876. *Explorations of the Aboriginal Remains of Tennessee.* Smithsonian Contributions to Knowledge; 259:117.

Kaushansky, Kenneth. M. Lichtman, E. Beutler, T. Kipps, J. Prchal, U. Seligsohn. *Williams Hematology, Eighth Edition.* Mcgraw – Hill Professional. 2010.

Kellner, Corina. 2002. Coping with Environmental and Social Challenges in Prehistoric Peru: Bioarchaeological Analyses of Nasca Populations. Unpublished Ph.D. Dissertation. University of California Santa Barbara.

Kent, Susan. 1986. The influence of sedentism and aggregation on porotic hyperostosis and anaemia: A case study. *Man* 21:605-636.

Kent, Susan. 1992. Iron deficiency and other acquired anemias. In *The Cambridge Historical, Geographical, and Cultural Encyclopedia of Human Nutrition:* edited by K.Kipple, ed. Cambridge: Cambridge University Press.

Kent S., Weinberg E.D., Stuart-Macadam P. 1994. The etiology of the anemia of chronic disease and infection. *Journal of Clinical Epidemiology* 47:23-33.

Krogman, Wilton Marion and Mehmet Yasar Iscan. 1986. *The Human Skeleton in Forensic Medicine.* Springfield, Illinois: Charles S. Thomas.

Lanning, Edward P. 1967. *Peru Before the Incas.* Englewood Cliffs, New Jersey. Prentice Hall.

Larsen, Clark Spencer. 1998. Post-Pleistocene Human Evolution: Bioarchaeology of the Agricultural Transition. *14th International Congress of Anthropological and Ethnological Sciences Williamsburg, VIginia, July 26-August 1.*

Lewis, Mary and Charlotte Roberts. 1997. Growing Pains: The Interpretation of Stress Indicators. *International Journal of Osteoarchaeology, Vol. 7: 581-586.*

Lumbreras, Luis. 1974. *The Peoples and Culture of South American.* Betty Meggars, trans. Washington, D. C.: Smithsonian Institution.

-------. 1999. *XII Congreso Peruano del Hombre y La Cultura Andina: Tomo II Arqueología.* Universidad Nacional de San Cristóbal de Huamanga. Impreso en el Peru, Peru Llaqtapi quellqasqa.

Maccurdy, George Grant. 1923. "Certain Specimens From the Riviere Collection." In *American Anthropologist* 25(1) 72-89. American Anthropological Association.

McEwan, Gordon. 2005. *Pikillacta: The Wari Empire in Cuzco.* University of Iowa, Iowa City.

Mensforth R. P., Lovejoy C. O., Lallo J. W., Armelagos G. J. 1978. The role of constitutional factors, diet, and infectious disease in the etiology of porotic hyperostosis and periosteal reactions in prehistoric infants and children. *Medical Anthropology* 2:1-59.

Menzel, Dorothy. 1964. Style and time in the Middle Horizon. *Nawpa Pacha* (6): 1-105.

Middlemiss, H. 1961. *Tropical Radiology*. London: William Heinemann Medical Books.

Moodie, R. 1923. *Paleopathology: An Introduction to the Study of Ancient Evidences of Disease.* Urbana: University of Illinois Press.

Moore, S. 1929. Bone changes in sickle cell anemia with note on similar changes observed in skulls of ancient Mayan Indians. *Journal of Missouri State Medical Association* 26:561-564.

Moseley, Michael E. 2001. *The Incas and Their Ancestors: The Archaeology of Peru.* Thames and Hudson, Ltd. London.

Nathan, David G. 1991. "The Thalassemias" In *Hematology 5th Edition.* MIT Press Cambridge Massachusetts.

Nathan, H., and N. Haas. 1966. 'Cribra Orbitalia' A bone condition of the orbit of unknown nature. *Israel Journal of Medical Sciences* 2:171-191.

Obertova, Z., and M, Thurzo. 2008. Relationship between Cribra Orbitalia and Enamel Hypoplasia in the Early Medieval Slavic Population at Borovce, Slovakia. *International Journal of Osteoarchaeology.* 18: 280-292.

Ortner, D. 1991. "Theoretical and methodological issues in paleopathology," in *Human paleopathology: current synthesis and future options.* Edited by D. Ortner and A.C. Aufderheide, pp. 5-11. Washington: Smithsonian Institution Press.

-------. 1998. "Male-female immune reactivity and its implications or interpreting evidence in human skeletal paleopathology," *Sex and Gender in a Paleopathological Perspective.* Edited by A. Grauer and P. Stuart-Macadam, pp. 79-92. Cambridge: Cambridge University Press.

Ortner, D. and W. Putschar 1985. Identification of Pathological Conditions in Human Skeletal Remains. *Smithsonian Contributions to Anthropology.* Number 28. Smithsonian Institution Press Washington and London.

Owen, R. 1859. Report on a series of skulls of various tribes of mankind inhabiting Nepal, collected and presented to the museum by B.H. Hodgson. Report British Association, London.

Oxenham, Marc Frederick and Ivor Cavill. 2010. Porotic hyperostosis and cribra orbitalia: the erythropoietic response to iron-deficiency anaemia. *Anthropological Science.* 118(3):199-200.

Palkovich A.M. 1987. Endemic disease patterns in paleopathology: porotic hyperostosis. *American Journal of Physical Anthropology* 74:527-537.

Perry, Linda, Daniel H. Sandweiss, Dolores R. Piperno, Kurt Rademaker, Michael A. Malpass, Adan Umire, and Pablo de la Vera. 2006. Early Maize Agriculture and Interzonal Interaction in Southern Peru. *Nature* 440(2): 76-79.

Piontek, J., and T. Kozlowski. 2002. Frequency of Cribra Orbitalia in the Subadult Medieval Population from Gruczno, Poland. *International Journal of Osteoarchaeology* 12: 202-208.

Platt O. S., Brambilla D. J., Rosse W. F. 1994. "Mortality in sickle cell disease: life expectancy and risk factors for early death". *New England Journal of Medicine* 330(23):1939-44.

Ribot, Isabelle and Charlotte Roberts. 1996. A Studey of Non-specific Stress Indicators and Skeletal Growth in Two Mediaeval Subadult Populations. *Journal of Archaeological Sciences* 23: 67-69.

Roberts, Charlotte, and Keith Manchester. 2005. *The Archaeology of Disease Third Edition.* Cornell University Press Ithaca, New York.

Robin, Cynthia. 2001. Peopling the Past: New Perspectives on the Ancient Maya. *Proceedings of the National Academy of Sciences of the United States of America.* 98(1):18-21.

Rothschild, Bruce. 2000. Porotic hyperostosis as a manifestation of iron deficiency? *Chungara: Revista de Antropologia Chilena*. 32(1) 85-87.

--------. 2012. Exterpolation of the mythology that porotic hyperostosis is caused by iron deficiency secondary to dietary shift to maize. *Advances in Anthropology* 2(3): 157-160.

Rowe, John H. 1963. "Urban Settlements in Ancient Peru," *Nawpa Pacha* 1: 1-27.

Ruffer, M. 1910. Remarks on the histological and pathological anatomy of Egyptian mummies. *Cairo Scientific Journal.* 4:1-5.

Salzano, F.M. and S.M. Callegari-Jacques. 1988. South American Indians: a case study in evolution. Research monographs on human population biology, no. 6. Oxford: Claredon Press.

Schreiber, Katherina J. 1978. Planned Architecture of Middle Horizon Peru: Implications for Social and Political Organization. Ph. D. Dissertation, SUNY Binghamton.

-------. 1992. *Wari Imperialism in Middle Horizon Peru.* Anthropological Papers Museum of Anthropology, University of Michigan. No. 87.

Silverman, Helaine. 2006. *Archaeological Site Museums in Latin America.* University Press of Florida. Gainesville, FL.

Smith, Michael E., and Lisa Montiel. 2001. "The Archaeological Study of Empires and Imperialism in Pre-Hispanic Central Mexico," *Journal of Anthropological Archaeology* 20: 245-284.

Steinbock, R.T. 1976. *Paleopathological Diagnosis and Interpretation: Bone Disease in Ancient Human Populations.* Springfield, IL: Charles C. Thomas.

Stodder, A.L.W. 2006. Skeletal biology: Southwest Indians: Sturtevant WC, editor. Handbook of North American Indians. Washington: Smithsonian Institution. P 557-580.

Stoltzfus, Rebecca J., Michele L. Dreyfuss, Hababuu M. Chwaya, and Marco Albonico. 1997. Hookworm Control as a Strategy to Prevent Iron Deficiency Anemia. *Nutrition Reviews* 55(6): 223-232.

Stuart-Macadam, Patricia. 1985. Porotic Hyperostosis: Representative of a Childhood Condition. *American Journal of Physical Anthropology* 66: 291-398.

-------. 1987. Porotic Hyperostosis: New Evidence to Support the Anemia Theory. *American Journal of Physical Anthropology* 74:521-526.

-------. 1989. Porotic Hyperostosis: Relationship Between Orbital and Vault Lesions. *American Journal of Physical Anthropology* 80:187-193.

-------. 1991. Anemia in Roman Britain: Poundbury Camp. *Health in Past Societies: Biocultural interpretations of human skeletal remains in archaeological contexts.* Eds. H. Bush and M. Zvelebil. Oxford: Temvs Reparatvm 101-103.

Stuart-Macadam, Patricia and Susan Kent. 1992. *Diet, Demography, and Disease: Changing Perspectives on Anemia.* Aldine De Gruyter. New York.

Thomas, David Hurst. 1986. Refiguring Anthropology: First Principles of Probablility and Statistics. Waveland Press. Prospect Heights, Illinois.

Trawick, Paul. 1994. The struggle for water in the Andes: a study of technological change and social decline in the Cotahuasi Valley of Peru. Unpublished Ph.D. dissertation, Department of Anthropology, Yale University, New Haven.

Tripcevich, Nicholas. 2008. Llama Caravan Transport: A study of mobility with a contemporary Andean salt caravan. Paper presented at the 73rd Annual Meeting of the Society for American Archaeology. Vancouver, Canada.

Turner, Bethany L. and George J. Armelagos. 2012. Diet, Residential Origin, and Pathology at Machu Picchu, Peru. *American Journal of Physical Anthropology* 149:71-83.

Ublaker, D.H. 1999. *Human Skeletal Remains: Excavation Analysis, Interpretation. 2nd Edition.* Washington, D.C.: Taraxacum.

White, Tim. 2000. *Human Osteology 2nd Edition.* San Diego: Academic Press.

Walker, Philip L. 1986. Porotic Hyperostosis in a Marine-Dependent California Indian Population. *American Journal of Physical Anthropology* 69:345-354.

Walker, Philip L., Rhonda R. Bathurst, Rebecca Richman, Thor Gjerdum, and Valerie A. Andrushko. 2009. The Causes of Porotic Hyperostosis and Cribra Orbitalia: A Reappraisal of the Iron-Deficiency-Anemia Hypothesis. *American Journal of Physical Anthropology* 139:105-125.

Wapler, Ulrike, Eric Crubezy, and Michael Schultz. 2004. Is Cribra Orbitalia Synonymous With Anemia? Analysis and Interpretation of Cranial Pathology in Sudan. *American Journal of Physical Anthropology* 123:333-339.

Warren, J. 1922. A Comparative View of the Sensorial and Nervous Systems in Man and Animals. Boston: Ingraham.

Welcker, H. 1888. Cribra orbitalia, ein ethologischdiagnostisches merkmal am schadel mehrerer menschrassen. *Archiv Anthropologie* 17.

White, Tim D. and Peter A. Folkens. 1991. *Human Osteology*. San Diego: Academy Press.

Whitaker, Katie. 2011. Anemia Among Past Maya Populations: When Will We Have the Answer? *Totem: The University of Western Ontario Journal of Anthropology* 13(1): 1-8.

Williams, H. 1929. Human Paleopathology. *Archiv Anthropologie* 17:839.

Wood, James W., George R. Milner, Henry C. Harpending, and Kenneth M. Weiss. 1992. The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples. *Current Anthropology* 33(4):343-370.

Wood-Jones, F. 1910. The pathological report. *Bulletin of the Archaeological Survey Nubia* 2.

Woodruff, C. 1958. Multiple causes of iron deficiency in infants. *Journal of American Medical Association* 167(6):715-720.

Wright, Lori E. and Francisco Chew. 1999. Porotic Hyperostosis and Paleoepidemiology: A Forensic Perspective on Anemia among the Ancient Maya. *American Anthropologist* 100(4):924-939.