LIFE IN THE LATE INTERMEDIATE PERIOD AT ARMATAMBO, PERÚ

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Doctor of Philosophy

by

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The undersigned, appointed by the Dean of the Graduate School, have examined the dissertation entitled:

LIFE IN THE LATE INTERMEDIATE PERIOD
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Presented by Keith Chan

A candidate for the degree of Doctor of Philosophy of Anthropology

And hereby certify that in their opinion it is worthy of acceptance

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ABSTRACT

The ability of the ruling class to provide for the health of their subjects through labor is an exchange that resonates throughout much of human existence. The central Andean coast permits study of a variety of social systems since there was a long sequence of pristine cultural development. This dissertation looks at one Late Intermediate Period cemetery site of Armatambo, a city belonging to the Ychsma state. Based on contributions from world systems theory and parental investment theory, the thesis of this dissertation is that the development of complex urban states in the central Andean coast was made possible by depleting the health and increasing the physical activity of the adult

laborers while using the fruits of their labor to support the health of the subadults.

I use bioarchaeology to test the hypothesis. A diverse field of indicators will be used to evaluate both chronic stress and acute stress episodes. Stress that occurred in childhood will be distinguished from that which occurred as an adult. Arthritic changes, signs of trauma, and age at death will measure adult responses to state demands. The prevalence of these indicators will be compared to sites on the central Andean coast representing several cultural periods.

The results show that the interred population at Armatambo shared a homogenous lifeway. Males showed more vertebral pathology than females, but were otherwise similar in stress indicator prevalence. Most indicators also showed no difference between those with or without cranial deformation, an indicator of social affiliation. These results do not support the hypotheses derived from world systems theory, but mirror patterns seen in prehistoric Central American states.

Comparisons between Armatambo and earlier sites found evidence supporting the main hypothesis. Results found that subadult health at Armatambo reversed a trend of worsening health seen in less complex sites through time. In contrast, adults in the Late Intermediate showed more indicators of high activity levels. However, health at Armatambo compares less favorably to health at a Huari empire site: subadult health at Armatambo was generally worse, and adult physical activity was higher. These results support the predictions based on the combination of world systems theory and parental investment theory.

Additional analysis compared Armatambo with the data from the Inca Empire collected by Murphy (2004) and Andrushko (2007). As with the comparison with the Huari Empire site, Armatambo showed more degenerative joint disease than at Inca Empire sites. Differences in stress prevalence between individuals interred at Armatambo and nearby Puruchuco-Huaquerones open up possibilities for future research on health changes between the Late Intermediate Period and the following Inca Period (Late Horizon).

The results of this study shows how bioarchaeology can be used to address anthropological theories such as word systems theory, life history theory, and parental investment theory. Future work can expand our knowledge of the Armatambo skeletal population, especially the dichotomy between the cranially deformed and undeformed.

CHAPTER 1: INTRODUCTION

This dissertation analyzes a complex urban Andean state from a bioarchaeological perspective. First-generation cultures in the Andean region grew in complexity through thousands of years of prehistory before the arrival of the Spanish. Theories about the cause of the successful development of Andean states have focused on factors such as variation in the environment, competition among elite, and the intertwining of elite rule and traditional beliefs. All of these factors may have played a role, but one avenue that is just starting to be explored is the state's use of the health of the people themselves as a metaphorical currency to pay for the upkeep of the state society: a social contract. If a society grows in complexity, it requires more efficient use of its physical landscape to provide subsistence for the elites and increasing population. This study proposes that the elite in complex societies manage the health of their people primarily for their own benefit. Specifically, the existence of the state may be possible by demanding more labor from the populace, increasing physical activity to the point of worsening health in the adult labor class. But, if the result of the high amount of labor is improved nutritional health, affecting both subadults and adults, a larger future labor pool will result. Bioarchaeology is an appropriate tool to investigate this hypothesis, since it focuses on the indicators of health and activity from the skeletons of the individual laborers of the state.

Ethnohistory and archaeology, common approaches to the study of past empires, can only indirectly access the health of a population. Several issues complicate the use of written historical records in ethnohistory. The context of the sources has to be considered. Historical documents were not written to document a culture on its own terms, but served other goals. Documents were made for mundane tasks such as court proceedings, military reports, accounting, public entertainment, and funding requests (Schreiber, 1993; Foucault, 2002). Past writers did not always share the need to be impartial and objective that we place in our own scientific work (Kelly, 1997). Groups such as minorities and common laborers are commonly misrepresented in the written record as the knowledge of writing typically belongs to the elite, who do not know the life of the lower classes (Block, 1992; Little, 1994; Kelly, 1997; Burke, 2001; Groover, 2003). Scholars have to be careful that a written source is applicable to the subject of interest, and not too far removed temporally or spatially (Kolb, 1997). There is also the cultural divide between the modern researcher and the scribe of the past. Meaning can be lost in translation and interpretation (Lustick, 1996; Munslow, 1997; McCullagh, 2000; Ramírez, 2006).

Archaeology also has biases towards the elite by being drawn to the spectacular and monumental. For example, there has been a disproportionate amount of study on religious and political centers (surveyed by Smith and Schreiber, 2006). While important, the focus on the powerful detracts from the study of the commoners, the majority of the culture by population and the builders of the monumental.

Models of Health and the Urban State

This dissertation will examine the biological consequences of living in a complex urban state society. The hypotheses are based on research from a wide breadth of disciplines. In particular, the hypotheses tested in this study are informed by world systems theory from sociology (e.g. Wallerstein, 1974), and life history theory and parental investment theory from biology (e.g. Trivers, 2006[1971]). At a basic level, world systems theory postulates an interaction between social complexity and health, while life history theory and parental investment theory suggests that the interaction between social complexity and health is directed towards maximizing investment in offspring. The roles of these theories on the background of this dissertation are described in Chapter 4. Also extremely important to the theoretical aspect of this dissertation are previous work on the bioarchaeology of states (e.g. Larsen, 2001; Tung and del Castillo, 2005), as well as the archaeology, bioarchaeology, and ethnohistory of the Andes in particular (e.g. Malpass, 1993; Covey, 2006; Andrushko, 2007), Research in these fields set the stage for studying urban states, particularly in the Andean region. The bioarchaeological and archaeological underpinnings of this study are elaborated upon in Chapters two, three, and five.

This study proposes that the health of the subjugated in a state-level society will differ from health in less-complex societies. Several comparisons can be made among different social formations to compare the use of labor in a state society versus non-state societies. Furthermore, differences in health between sexes, among individuals of different social affiliations, and among individuals of varying ages at death within a complex state are expected. Bioarchaeology provides the means of effectively examining past health among groups.

Bioarchaeology is the study of human remains, especially bones and teeth, in an archaeological context. Environmental processes such as certain diseases and physical forces affect bones and teeth, leaving indicators that can be measured and studied across populations (Larsen, 1997). These processes are called "physiological stressors," or in this study, simply "stressors."

Age is an important factor in determining whether stressors leave an imprint on bones. Bones are most susceptible to stressors during subadulthood, when an individual undergoes growth and development. For example, chronic anemia from parasitic infection can cause a phenomenon called porotic hyperostosis to form on the crania of subadults. By adulthood, however, fewer processes have the ability to alter bone. Porotic hyperostosis visible in adult skeletons is actually a remnant of chronic anemia experienced in subadulthood, not adulthood. The distinction between indicators of adult stressors, and indicators of subadult stressors visible in adult remains is important and elaborated upon below.

Buffering, the processes by which an individual resists disease, also affects the manifestation of stress indicators on bone (Goodman and Armelagos, 1989; Larsen, 1997:6). Buffering can be provided through either through cultural practices or the individual's physiology (although Goodman and Armelagos [1989:226] uses the term "host resistance factors" for physiological buffering). For example, if nutrition is adequate, an individual is more likely to resist a disease, reducing the chance that bone is affected. Also, good nutrition makes an individual less likely to die from a disease, meaning that there will be fewer subadults in the skeletal population bearing markers of the disease if nutrition is generally good for the whole group.

Bioarchaeology enhances understanding of complex societies in two ways. The first is that bioarchaeological studies contribute lines of evidence not available to archaeology or history (McCullagh, 2000; Perry, 2007). Data from human skeletons avoid some of the biases of historical record and material culture (with different biases of their own, as described in Chapter 4) (see Cohen, 1989; Grauer, 1995; Walker, 2001a; Perry, 2007). Second, and more importantly, bioarchaeology can generate and answer new questions unapproachable by other means (Joyce, 2005; Krieger, 2005). These new questions and answers can then feed back and generate more research in all fields. Accounting for the strengths and weaknesses of different lines of evidence helps to give us the most accurate reconstructions (Braudel, 1980; Bauer, 1992a; Knapp, 1992; Thurston, 1997; Bauer and Covey, 2002; Knudson and Stojanowski, 2008). Where lines of evidence converge on a hypothesis, there is greater confidence in that explanation. Where lines of evidence conflict, new research is needed to resolve the contradictions.

The following section describes the four models proposed in this study and their hypotheses. Then, the bioarchaeological stress indicators used to gauge health in skeletal remains are introduced. The last section of the introduction describes the proveniences of the skeletal collections examined in this dissertation. Table 1.1 summarizes these sections.

MODEL A: SEXUAL DIVISION OF LABOR IN AN URBAN STATE

HYPOTHESIS

State organization of labor of individuals is expected to differentiate tasks by sex, assigning more extremely physically demanding work to males as a move towards increasing efficiency in resource production. Following parental investment theory, males are less likely to provide directly for their offspring than females (Bird, 1999), a trend that would be heightened in a state system where there are more extraneous tasks demanded of the laborers. Since females have the important role of producing offspring, a successful elite authority would not be likely to assign them hard labor (e.g. mining, travel, warfare) that would conflict with or impede this activity to the detriment to the growth of the society (White et al., 1977; Beneria and Sen, 1981). For example, while Perry and colleagues (2009:437) found that the elite in the Byzantine Empire had specialized roles for women and children in mining it was still the fit males who undertook the most physically demanding labor. The women were tasked with operating ore mills, and children worked in small tunnels.

Table 1.1: Summary of Sites, Stress Indicators, and Hypotheses

		Comparisons Within Armatambo (Imperial Periphery)						
Comparison	**Hypothesis Tested**	**General Expectations**	**Chronic Anemia**	**Chronic Bacterial Infection**	**General Growth and Development**	**Degenerative Joint Disease**	**Trauma**	**General Adult Health Quality**
Within Armatambo (urban state)								
Males vs. Females	Model A: Sexual Division of Labor	Males, as physical laborers, are expected to have worse adult health outcomes and show more arthritis from physical exertion.	More prevalent in males	More prevalent in males	Worse in males	More prevalent in males	More prevalent in males	Worse in males
Cranial Deformed vs Undeformed	Model B: Social Division of Labor	Levels of health and physical activity will differ between individuals with different ethnic markers.	A difference should be present between groups.					
Among Armatambo and Other Sites								
Paloma (fishing village)	Model C: Urban State vs. Less Complex Societies	Subadult health should be slightly worse, adult health better, and physical activity less extreme, than at Armatambo	More prevalent compared to Armatambo	More prevalent compared to Armatambo	Worse compared to Armatambo	--	--	Better than at Armatambo
Cardal (non-coercive society)	Model C: Urban State vs. Less Complex Societies	Subadult health should be worse, and adult health better, than at Armatambo				Less than at Armatambo	Less than at Armatambo	
Villa el Salvador and Tablada de Lurín (city during social flux)	Model C: Urban State vs. Less Complex Societies	Subadult health should be worse, and adult health better, than at Armatambo						
Huaca Malena (early Andean empire periphery)	Model D: Urban State vs. an Empire	Subadult health should be better, and adult health worse, than at Armatambo	Less prevalent compared to Armatambo	Less prevalent compared to Armatambo	Better compared to Armatambo	More than at Armatambo	More non-violent trauma, less violent trauma than at Armatambo	Worse than at Armatambo

ALTERNATIVE HYPOTHESES

Even if males have more physically demanding tasks, if they have access to more high quality food, their health could be equivalent or better than that of females (though nutrition will have no effect on markers like trauma). Or, sexual differentiation of labor could be reduced in complex societies as traditional roles are reorganized by the state, resulting in little or no difference in health states between the sexes.

MODEL B: SOCIAL DIVISION OF LABOR IN AN URBAN STATE

HYPOTHESIS

State organization is expected to be rigidly hierarchical. One of the assumptions of world systems theory, a prevailing paradigm in empirical study of states and empires, is that ethnicity and social class are always related to the division of labor in a state society. Wallerstein, 1974; Kuznar, 1999:226). In this dissertation, cranial deformation will be used as a marker of social affiliation, which may include ethnicity. Cranial deformation is the manipulation of the crania of infants to form a shape that is culturally desirable (Allison et al., 1981; Gerszten and Gerszten, 1995). The practice is permanent and possibly lethal (de Souza et al., 2008), suggesting that crania are deformed with a strong cultural purpose. As a precedent, Pechenkina and Delgado (2006) used the presence or absence of cranial deformation in an Andean skeletal population as a marker of social affiliation in their bioarchaeological study and found significant differences in health between the two groups. Cranial deformation in the Americas has also been linked with social affiliation by Tiesler (1998), Torres-Rouff (2002), and Blom (2005).

Individuals with cranial deformation should exhibit differing levels of stress indicator prevalence than those lacking cranial modification, reflecting differential social roles along possibly ethnic lines. The meaning of cranial deformation in the Andes is under debate (reviewed in Andrushko, 2007). Therefore, the hypothesis states that a difference will be found in health and activity between the cranially deformed and undeformed in an urban state's skeletal population, but no prediction will be made on which social group will exhibit better health or less activity.

ALTERNATE HYPOTHESES

Alternatively, the movement of peoples from isolated towns to urban settlements, allowing for tighter state control, may also cause a homogenization of labor between people of different ethnic origins. Thus, traditional specialties and occupations may be abandoned in favor of production clustered in specialized state settlements (e.g. the creation of a town of weavers dependent on other towns for ceramics and other goods). Textile production in the Vijanayagara Empire in India exhibited this shift towards clustering specialists in urban centers (Sinopoli, 1988, 1995). There, researchers concluded that weaving underwent changes following the creation of the empire: stylistic standardization towards the state standard, intensification of production, and the creation of master weaver and merchant classes as regulatory bodies.

Model C: Urban State versus Non-State Societies

HYPOTHESIS

The main hypothesis of this model is that an urban state society is expected to produce better subadult health and worse adult health than non-state societies, based on world systems theory and parental investment theory. Here, an urban state is defined as a sovereign society with a hierarchical institutionalized authority that controls one or more cities, settlements with high population density and an important role in politics, religion, and economy (Wright, 1977; Cowgill, 2004). Non-states lack an institutionalized hierarchy of control. Further exploration of definitions of the urban state is in Chapter 2.

World systems theory contributes the idea that the state interacts with its population, perhaps including the health of its members. At first glance urban state rule may be expected to cause worse health overall for its subjects (see the alternative hypotheses listed below). However, while the distribution of goods to the elites seems wholly detrimental to the subservient laborers, a state can offer certain advantages to its subjects not possible in less-hierarchically organized societies. A state can provide resistance against famine, conflict, and disease with the effect of improving overall health (Benfer, 1984; D'Altroy, 1992; Covey, 2006). Following parental investment theory, which states that parents invest resources in their offspring to increase future returns, improvement in health state should be most visible in the remains of subadults, though, barring other factors, people of all ages would benefit. However, such advantages, which lead to the general prosperity of the state, may require a more intense extraction of adult labor to produce surpluses, possibly increasing physical labor beyond a level the skeleton could withstand without pathological outcomes such as degenerative joint disease. The thesis of this model is that the demands of the state elite were extreme and adversely affected the health of the adult subjects, though health against malnutrition was buffered.

ALTERNATIVE HYPOTHESES

The effect of state control on health could be the opposite of the above: subadult health is worsened while adult health is improved. This could occur if adult diet improved in total calories, but the nutritional quality of the diet diminished, impacting children more strongly and negatively than adults.

Another alternate hypothesis is that both subadult and adult health worsened. Two factors associated with statehood could reduce health. One is urbanization, the clustering of peoples in dense settlements. Urbanization can lead to poor sanitation, which then promotes the spread of infectious disease (McNeill, 1976; Storey, 1985; Lawrence, 1999). The other factor is the dependence on a carbohydrate-rich monodiet, a low variety of crops, with the onset of intensive agriculture. A monodiet can reduce nutrition, also promoting the spread of disease (Cohen and Armelagos, 1984). This decline in health with social complexity may be especially evident in the laboring classes as a widening gap in health quality between elites and non elites in state-level societies has been found compared to less complex societies (Danforth, 1999).

Lastly, benevolent state rule could improve health in all age groups, due to the benefits of a safer, more orderly environment in which surpluses can be produced and stored against emergencies. Still, if increased population density worsened sanitation, health could still be negatively impacted.

Model D: Urban State versus an Empire

HYPOTHESIS

In contrast to Model C, Model D proposes that an urban state will have weaker control of the labor output of it subjects, and thus worse subadult health and generally better adult health, than an empire. Here, an empire is defined as a state that has expanded to subsume heterogeneous cultures and territory under its rule, increasing the complexity of its social stratification (Conrad and Demarest, 1984). In an urban state, the dependence on local production may cause health to suffer more as resources are less varied and the chance is higher that a localized famine could affect access to food. The impact of famine and malnutrition on health would then be visible in subadult remains and remnants of subadult health visible in adults. In an empire, by definition a larger society, greater access to more variable resources would provide better buffering against famine, though the tighter control of labor to obtain these resources would place more pressure on the health of adults.

ALTERNATIVE HYPOTHESIS

Health may be better for everyone living in an empire relative to an urban state because of the greater amount and variety of resources available to the subjects. The diversity of labor and resources available to an empire may reduce the amount of work per individual such that people in an empire may not have to work as hard to achieve the same results as in an urban state.

Health for the laborers may be worse in an empire if people are relocated from diverse locations to dense urban centers with poor sanitation, an ideal environment for infectious disease. Another alternative to the hypothesis of this model is that there is no link between the size of an urban state (whether it has expanded to an empire or not) and the health of its subjects.

Testing the Hypotheses

This section details the changes in health and physical activity that are expected to appear in the skeletal record and the specific indicators used to evaluate health and activity. The Central Andean sites used for this comparative study are also described.

Indicators of Physiological Stress Used in this Study

Bioarchaeological indicators of physiological stress will be used to gauge the health of skeletal populations representing societies of varying levels of complexity. This section describes the measures of health used in this study, and the skeletal indicators used to evaluate them.

The issue of the osteological paradox (Wood et al., 1992) has to be considered when interpreting the prevalence, or frequency, of stress indicators in a skeletal population. If there is a relation between the indicator and age at death, called "differential mortality," it is possible that a paradoxical explanation might be made. That is, one group with very low frequency of a trait associated with early death, such as porotic hyperostosis, might actually have had high mortality and worse health, while another population with a high prevalence of porotic hyperostosis actually had better survivability and better health. A further exploration of the osteological paradox and a test for a paradoxical effect on the data in this study are in Chapter 4.

INDICATORS OF SUBADULT STRESS

The indicators described in this section will be used to test the hypothesis that subadult health in an urban state is better than in non-state societies but worse than in an empire. More detailed descriptions of these stress indicators and their uses in bioarchaeology can be found in Chapter 6.

General Growth and Development

<u>Harris Lines:</u> Stress events that disrupt the normal growth of bone in subadulthood can leave distinctive markings visible in radiographs (Harris, 1926, 1931; Park, 1964; Wells, 1964). Stressors that can cause the formation of a Harris line include nutritional stress and infectious disease. In the remains of subadults, Harris line counts reflect health in individuals who have died in childhood. If there is greater investment in children in an urban state, then Harris lines should be fewer in subadult remains compared to non-state societies. For individuals who died as adults, for whom Harris lines reflect stress in adolescence that has been overcome, the number of lines should be higher at the urban state than at

the non-states to reflect the adolescent entrance into the physically demanding labor force.

Between an urban state and an empire, subadults in the urban state should have more Harris lines to reflect the lesser variety of resources available to support the subadult's growth and development. The difference in adult Harris lines is less clear. Adults in the empire may show more Harris lines than adults in an urban state as a result of a more intensive extraction of labor from workers as they entered adulthood, or the imperial (i.e. living in an empire) adults could show fewer Harris lines than the urban state adults as a result of better buffering against nutritional stress.

<u>Corrected Subadult Age Estimation (CSAE):</u> The CSAE is a measure of missed growth potential calculated from the difference between two subadult age estimations: age estimated from limb bone length and age estimated dental eruption state (following Demirjian et al., 1985; Demirjian, 1986; Saunders et al., 1993 Pechenkina et al, 2007). The environment, including nutrition and disease, affects whether a subadult achieves his or her genetically-determined growth potential. Environmental factors affect the growth of subadult limbs more than sequence of dental eruption. In other words, a subadult with poor nutrition will look "younger" than one with good nutrition based on limb bone length, but would appear the same age based on dental eruption. Thus, a wider gap between age estimated from limb length and dental eruption suggests worse health. The prediction in this study is that the CSAE, the difference between age estimation

bases on limb bone length and dental age, should be lower at the urban state than at non-states. From a different perspective, urban state subadults should be taller given their age compared to the other sites.

Individuals in an urban state would have relatively higher CSAE than an empire since nutrition should be more adequately supported in an empire.

Tibia Length: The maximum tibia length in an adult reflects whether full genetic growth potential had been met during the growth and development stages (Eveleth and Tanner, 1976; Tanner, 1981; Steckel and Rose, 2002). As in subadults, poor nutrition and exposure to chronic disease prevents the genetic growth potential from being met before full maturation to adulthood ends the growth process. Since taller individuals experienced a healthier childhood, and stature is partially determined by limb bone length, tibia length is expected to be greater in the urban state than in non-states.

Laborers in an urban state should have shorter tibia lengths than in an empire since the empire is expected to have had better buffering against nutritional stress during growth and development.

Chronic Anemia

Cribra Orbitalia and Porotic Hyperostosis: In subadults, the growing skeleton adapts to chronic anemia by converting cortical bone in the cranium to marrow-containing diploë bone (Hengen, 1971; Stuart-Macadam, 1985, 1987, 1992; Walker et al., 2009). Chronic anemia can be caused by malnutrition or infection by parasites, though genetic predisposition is also a factor. Indicators of anemia in subadult remains should be less frequent at Armatambo compared to non-state sites. Children with anemia should have survived more often, rather than died as infants, due to greater parental investment and buffering using state food reserves.

Signs of anemia should be more prevalent in an urban state compared to an empire, due to better buffering against stress in the latter type of society.

Bacterial Infections

Periosteal Lesions: Chronic bacterial infections can cause pathological growth to occur on bone and its surrounding periosteal membrane, creating periosteal lesions (Cohen and Armelagos, 1984; Ortner, 2003). These infections can be caused by living in unhygienic conditions or by incidents of physical trauma. In prehistory, unhygienic conditions can result from increased population density of urbanization without adequate sanitation. Periosteal lesions should therefore be more frequent in urban state subadult remains than in less complex non-state sites because the higher population density of the urban state would provide the unhygienic conditions for chronic bacterial infection in the populations.

Relative to an urban state, an empire is expected to have better buffering against physiological stress from a greater ability to command resources in times of scarcity. Therefore, in an empire, children with periosteal lesions should have been likelier to survive to adulthood due to the greater availability of resources available to support subadult health. If subadults in an empire are more able to survive chronic bacterial infections, there will be fewer dead subadults bearing periosteal lesions in the skeletal population. The result when comparing skeletal populations is that the urban state should show more periosteal lesions in subadult remains than in the empire.

INDICATORS OF STRESS IN ADULTS

Since there are fewer ways stressors can affect bone after growth and development have stopped, health indicators for adults are more elusive than for subadults. In this study, four indicators of adult health are used to test the four models. One, periosteal lesions, reflects chronic bacterial infection in adults. Another two, trauma and degenerative joint disease, are indicative of activity patterns that have a pathological response on bone. Lastly, age at death is used as a general indicator of adult health.

Bacterial Infections

Periosteal Lesions: Chronic bacterial infections can also cause periosteal lesions to form in adulthood. Unlike cribra orbitalia and porotic hyperostosis, periosteal lesion manifestation in adults is an indicator of poor health in adulthood, not earlier in subadulthood. Since urbanization and accompanying poor sanitation is expected to be greater in the urban state sample, non-state sites in this study are expected to have fewer cases of periosteal lesions.

Unlike with subadults, periosteal lesions should be less common in an urban state than in an empire. The empire's more intense extraction of labor of it subjects is expected to weaken the health of adults. Stated as a simple dichotomy, extreme labor will make people more susceptible to disease. Since the body has to expend energy to adapt to physical forces or risk mechanical failure, less energy is available to fight infection.

Physical Activity

This dissertation interprets two signs of activity left on bone, degenerative joint disease and trauma, as indicators of poor health in adults. Both types of physical activity markers are the result of extreme activity, atypical of normal stressors on the body. Note that the environment can affect bone in ways not extreme enough to be considered poor health in this dissertation, including the formation of joint facets and changes to cross-sectional geometry (Larsen, 1997:185, 195).

<u>Degenerative Joint Disease (DJD):</u> Extreme physical stress can cause a pathological response in bone, known as osteoarthritis or DJD (Bridges, 1992; Conaghan, 2002; Weiss and Jurmain, 2007): While DJD forms with old age, continuous demanding labor in life accelerates the process, sometimes to extreme levels not seen with aging. As argued earlier, DJD is expected to be more common and more severe in the urban state compared to non-states. Males from the urban state are expected to have more joint disease than females in the same population. There should also be a significant difference in the manifestation of

degenerative joint disease between individuals with and without cranial deformation.

Adults in an urban state should have less DJD than those in an empire. The empire is expected to have a greater command of labor in order to expand, and to extract more labor from its subjects, at the cost of the health of the workers.

Trauma: A physical stressor on the body can exceed the bone's capacity to withstand the force, causing a break in the bone's structure (Nordin and Frankel, 1980; Larsen and Milner, 1994; Lovell, 1997). Accidental and labor-related trauma should be more common in an urban state than in non-state societies. Males in the urban state should have more signs of trauma than females. There may also be a significant difference in trauma prevalence between people with cranial deformation or without. Cranial trauma, likely due to violence, should be more common in the urban state than in non-states, reflecting an intensification of warfare that occurs with increased cultural complexity.

Non-violent trauma is expected to be less common in an urban state than in an empire since the empire is expected to force more physical labor on its workers than in an urban state. Violent trauma is expected to be higher in the urban state due to greater political instability inherent in being a smaller but still complex society. The size of an empire allows the oldest region, the core, to become more politically stable over time. The prevalence of trauma in the periphery of an empire is more difficult to predict since the strategy for imperial expansion, including whether violence is involved, could vary from place to place.

General Quality of Adult Health

Age at Death (Sattenspiel and Harpending, 1983; Lovejoy et al., 1985): Assuming a stable population (i.e. one in which fertility and mortality are near equal with no migration), and that a skeletal collection represents a random sample of that population, age at death can be used to indicate mortality levels. The urban state population is expected to show lower mean age at death, i.e. worse health, than less complex societies. In contrast, the health of adults should be worse in an empire than in an urban state, so in this comparison the urban state is should show higher mean age at death than in an empire. If a stable population cannot be demonstrated, then higher age at death should be found relative to the other non-state sites since higher age at death means lower fertility (i.e. worse health). Chapter 6 contains a demographic profile of the urban state skeletal collection used in this dissertation, and the test for population stability.

The Regional Focus of This Study

This study adds to the study of urban states by looking at health and the evolution of cultural complexity in one specific region: the Central Andean coast. The hypotheses presented here will be tested both within a skeletal population from a cemetery of **Armatambo**, an urban state settlement, as well as between Armatambo and earlier non-state sites in the same region. The following section shows what each intra-Armatambo and intersite comparison offers to the testing of the models described above. Overall, health is expected to be better for subadults and worse for adults at Armatambo compared to the non-state sites in this study. The reverse is expected when comparing health between Armatambo and a settlement of an empire.

Chapter 5 details the sites listed below.

COMPARISONS WITHIN ARMATAMBO

Armatambo was a large city in the coastal Ychsma state (Díaz and Vallejo, 2002, 2003, 2004; Díaz, 2004). Two comparisons will be made within the Armatambo skeletal collection to test two of the above models. Health between males and females will be compared to test Model A, that there is a difference between sexes. Health will also be compared between cranially deformed and undeformed people to test Model B, which states that health should differ in different social groups.

SEXUAL DIVISION OF LABOR IN AN URBAN STATE

Males, as laborers, are expected to have worse health outcomes than females. Males are expected to have undertaken more physical tasks causing more degenerative joint disease. More trauma, from work-related accidents or warfare and conscripts, is also expected. The relative increase in physical labor should also affect other aspects of male health. While males and females should experience equal amounts of bacterial infections due to unhygienic sanitary conditions, males are expected to experience more bacterial infection from injury. The mean age at death of males should also be less than the female mean due to the cumulative effect of increased physical stressors and disease.

ETHNIC IDENTITY IN AN URBAN STATE

Health and physical activity indicators will be examined to determine if there is a difference between individuals who possess and do not possess cranial deformation, a possible marker of ethnic affiliation. A difference is expected due to the state management of labor by ethnicity predicted by world systems theory (Wallerstein, 1974; Kuznar, 1999). In particular, degenerative joint disease will be more prevalent in one group relative to another. The group with higher DJD prevalence, whether cranially deformed or undeformed, should also exhibit more signs of bacterial infections and lower mean age at death than the other group due the presence of more stressors.

COMPARISONS BETWEEN SITES

Health and activity levels of individual buried in the urban state cemetery at Armatambo will be compared to people living in the same region representing various social systems. The following sites will be compared: Paloma, Cardal, Villa el Salvador, Tablada de Lurín, and Huaca Malena (Figure 1.1).

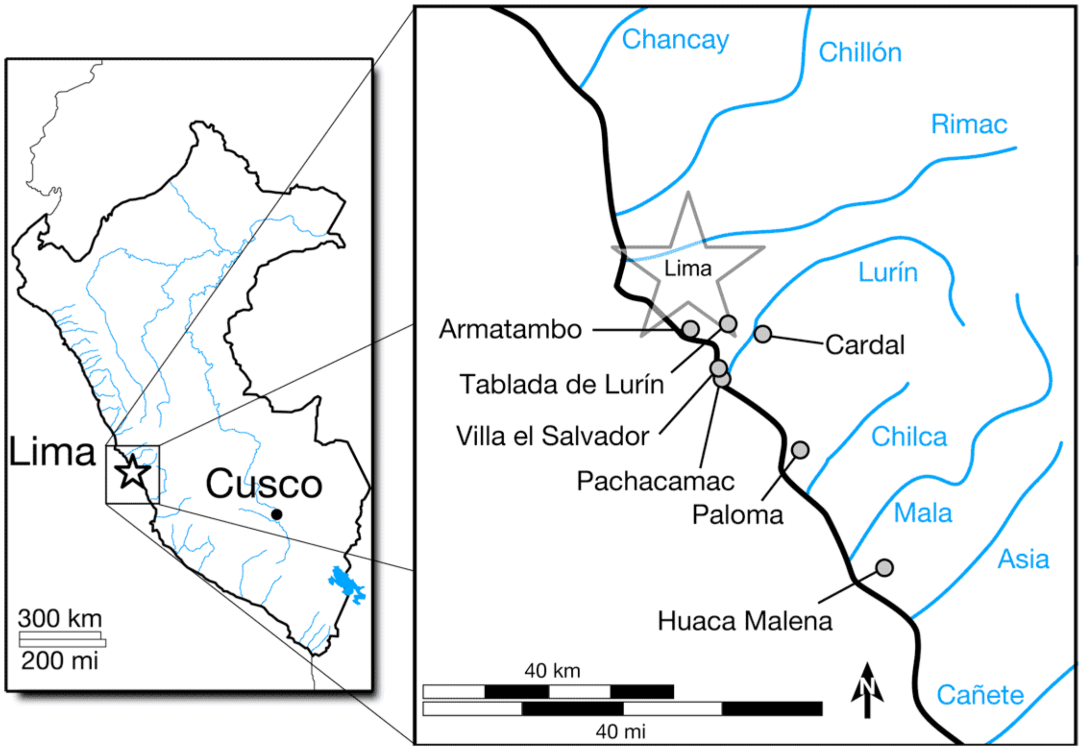


Figure 1.1: Maps of Perú Showing Key Sites

PALOMA

Paloma is a fishing village located in the Central Coast of Perú (see Benfer, 1982, 1984, 1990, 1999, 2008). Compared to Armatambo, egalitarian coastal villagers are expected to show no significant health differences by sex. Subadults may exhibit slightly worse health than at Armatambo. Activity markers at Armatambo should be more prevalent than at Paloma due to higher labor levels.

CARDAL

While Cardal (Burger, 1987; Burger and Salazar-Burger, 1991; Vradenburg, 1992) represents a transitional town in this study, one without marked class distinctions, it may actually be an exceptional case. Evidence points toward the population's decimation due to an epidemic of infectious disease (Vradenburg 1992). Nonetheless, the present model predicts that subadult health should be worse and adult health better at Cardal than at Armatambo because residents at Armatambo would have had greater access to resources, but required more adult labor.

VILLA EL SALVADOR AND TABLADA DE LURÍN (VES/TBL)

Both Villa El Salvador and Tablada de Lurín are cemeteries serving the large ritual center of Pachacamac, during a period of social flux (Stothert and Ravines, 1977; Stothert, 1980; Makowski, 1994, 2006; Pechenkina and Delgado, 2006). Armatambo should show better subadult health and worse adult health than this complex non-state city. Societies were more unstable in the time of VES/TBL, producing worse health outcomes for subadults. Labor should be more intense at Armatambo compared to VES/TBL due to the more-established hierarchy of rule at Armatambo.

HUACA MALENA

Huaca Malena is a city in the periphery of the Huari Empire (Tello, 2005[1959]; Menzel, 1968; Engel, 1987; Falcón and Pozzi-Escot, 2000). This imperial site will be used to test Model D, that subadult health should be worse and adult health better at non-state Armatambo when compared with imperial Huaca Malena. The greater access to resources under the imperial system would act as a better buffer against malnutrition. Assuming that the elite in an empire has a greater ability to demand labor form their subjects, adults at Huaca Malena should show higher activity levels and also worse health than at Armatambo.

The Structure of This Dissertation

The next chapter gives an overview of the archaeology of complex urban states in the New World to give contextual relevance to this study. Chapter 3 explores the regional focus of this study, the Central Andean coast, from the Preceramic through Inca occupation. Chapter 4 addresses other important theoretical issues: life history theory and the osteological paradox. The fifth chapter describes the skeletal materials used in this study, giving their archaeological provenience. Chapter 6 details the methods: the collection of the data, evaluations of the physiological stress indicators used in this study, and statistical analysis. Chapter 7 looks at paleodemographic data from the Armatambo collection. Chapter 8 presents the results, which are discussed in Chapters 9 and 10. In particular, Chapter 9 addresses the four hypotheses in light of the results and Chapter 10 compares health at Armatambo with several Inca sites, based on data found in other dissertations. Chapter 11 offers further directions for research and concludes this dissertation.

CHAPTER 2: URBAN STATES

This chapter looks at the challenges of studying the phenomenon of urban states through archaeology. Theory of the archaeology of states is summarized, and is followed with a brief overview of prehistoric states in the New World and the state of bioarchaeological research on the interaction between ancient labor and health.

Urban States: Definitions

Like culture, the definition of state is clear to all but hard to define precisely (Jones and Kautz, 1981:14). Here, a state is a society with a sovereign institutionalized authority (Wright, 1977; see Stanish [2001] for a review of alternative definitions). An urban state is then a state that includes one or more cities, settlements with high population density and an important role in politics, religion, and economy (Cowgill, 2004). The term city-state also describes this type of rule, but concentrated in a single urban settlement. An empire can be considered an expansive state where one dominant culture exerts heavy sociocultural control over subservient heterogeneous cultures and environments (Doyle, 1986). These general definitions permit one to highlight the common element of states from the prehistoric to colonial to modern times, namely an imbalanced exchange of goods and services among subgroups of a society.

States, including empires, are not random occurrences. As Carneiro (1970:733) states: “the origin of the state was neither mysterious or fortuitous… not the product of “genius” or the result of chance.” I add that these traits are not just constrained to the origin of the state, but also to the established, functioning state. Carneiro maintains that common processes have led to the formation and persistence of complex societies independently around the world. Researchers have proposed many plausible mitigating factors that push a simpler society towards complexity and stratification: warfare, agriculture (Fried, 1960), or environmental and social circumscription (Carneiro, 1970). Also, once a ruling elite is established, there must be mechanisms to propagate their dominance of the state: economic control (Earle et al., 1987), religion, ideology (Conrad and Demarest, 1981), and military power (Carneiro, 1970).

The prevailing model behind the archaeology of states (Hall and Chase-Dunn, 1993; Sinopoli, 1994; Lightfoot and Martinez, 1995; and Kardulias, 1999), the core-periphery model, was adapted from world systems theory of European nation-states (Wallerstein, 1974; Peregrine, 1996; Chase-Dunn and Hall, 1997; Kardulias, 1999; Frank, 2004[1966]). Of particular interest is the dichotomy between the origin area of the state (the core), and the border of state-controlled territory (the periphery). In an empire, especially, there is a large distance between core and periphery. Many aspects of the state can be viewed as flow between the core and periphery including military force, extraction of resources, trade of elite goods, and religious ideology. This basic concept has been amended to address theoretical concerns: for example, the addition of a near, or semi, periphery between core and periphery to address areas that have elements of both (Wallerstein, 1974; Terlouw, 1993), and a frontier boundary between the periphery and foreign territory (Paynter, 1982). The idea of a frontier has itself seen change, with the emphasis shifting from discrete boundaries to a zone of fluid interaction between populations (Green and Perlman, 1985; Schortman and Urban, 1992; Lightfoot and Martinez, 1995).

Besides the addition of more areas to the typology of the core-periphery model, the basic assumptions have also been challenged. Jennings uses the case study of the Huari-influenced site of Cotahuasi in the Andes as an example in which the core-periphery model does not adequately explain an imperial system. Jennings (2006a) warns against focusing too strongly on the core-periphery model because of three flaws: the inherent importance placed on core-peripheral links, the assumption of direct links between core and periphery, and the fact that interaction among peripheries is ignored. In sum, the criticism is that the core is assumed to play a major role of all aspects of the periphery (also see Lightfoot and Martinez, 1995; Stein, 1999). Stein (1999:155) states that "[f]rom an anthropological perspective, the most serious theoretical flaw in the world-systems model lies in the fact that the assumption of core dominance denies any kind of agency to the periphery." As the core-periphery model undergoes reexamination, many researchers are focusing on intra-periphery interactions, and how actions of the periphery affect the core (e.g. Kuznar, 1999).

The Origin Areas of Archaeological Urban States

Several regions of the world have historically been foci for the formation of urban states. The driving factors behind the formation of urban states in these regions, rather than in others, can be explored by finding common elements. In many regions where urban states developed, empires followed. Unfortunately, where empires developed, studies of pre-imperial states are often in their infancy.

In lower Mesopotamia of the Middle East, competing city-states led to the formation of the Akkadian Empire, starting in 2350 BC and ending a century later. The Akkadian Empire is considered the first in a long series of imperial rules in the region (Nissen et al., 1990; Liverani, 1993; Matthews, 2003). After a climatic disaster led to the collapse of the Akkadian Empire (Weiss et al., 1993), empires formed and dissolved from competing urban states several times in the next two millennia: most notably the Ur III (ca. 2100 to 2000 BC), Old Babylonian (ca. 1900 to 1600 BC), Assyrian (ca. 934 to 609 BC), and New Babylonian (Chaldean) (ca. 626 to 539 BC) Empires (Boardman et al., 1991; Sinopoli, 1994; Liverani, 2001; Wilkinson et al., 2005).

Another rich river valley, the Nile, formed the foundation of Egyptian imperial rule. However, urbanization of pre-imperial states was not strong (Cowgill, 2004). Still, by circa 3200 BC, the first pharaoh united the culturally distinct peoples of Upper and Lower Egypt, which developed into the Old Kingdom (2686 BC – 2160 BC) (Shaw, 2003). As seen in Mesopotamia, and as will be shown in the Andes, the first empire of the Nile River Valley collapsed into competing provincial states. This pattern of unification and dissolution occurred several times until the Assyrian Empire interrupted native rule, followed by annexation by Persia and Macedonia (Wilson, 1956; Bard, 2007).

South and East Asia also became the birthplaces of several ancient states and empires. A state, the Harappan, is hypothesized to have formed in the Indus Valley of South Asia as early as 2600 BC (Kenoyer, 1991; Manuel, 2010). The Indian subcontinent saw several imperial societies beginning with the Mauryan (ca. 322 BC to AD 187) (Sinopoli, 2001, 2006). As in other cases, the dissolution of the Mauryan Empire left competing city-states. The Satavahana Empire (ca. 100 BC to AD, 200) formed from this diversity. Later, in the second millennium AD, the Vijayanagara Empire controlled South India (ca. 1350 to 1700 AD) (Sinopoli and Morrison, 1995). East Asia also saw the development of urban states in the Longshan Period, third millennium BC (Dematte, 1999; Liu and Chen, 2001; Underhill et al., 2008). Competing states continued through the following periods, the Shang and Zhou dynasties (Shen, 1994; Yi-Hua, 2007). The line of Chinese imperial dynasties began with the Qin dynasty from the Wei Valley (221 to 210 BC) (Ho, 1967, Yates, 2001) and proceeded through more than a dozen dynastic lines of differing ethnic groups to 1912 (Fairbank and Goldman, 2006; Twitchett, 2009).

The Mediterranean became an origin point of urban states in 1600 BC with settling of the Greek peninsula by the Mycenaeans (Branigan, 2001). As opposed to the study of pre-imperial states in other regions, the growth of the Greek city-states following the decline of Mycenae has been covered thoroughly through archaeology and history (e.g. Sealey, 1987; Morris, 1989; Pomeroy, 1999;

Gates, 2003). By the first millennium AD, the first Mediterranean empire was formed. Influenced by Greek culture, the territories of the Roman, and later the Eastern Roman (Byzantine), Empire encircled the Mediterranean Sea (Garnsey and Saller, 1987; Browning, 1992).

Immense "world" empires repeatedly swept much of Eurasia, covering more than one of these zones. The Assyrian Empire, from Mesopotamia, invaded the Nile Valley but did not settle it as an Assyrian annex. Originating from the Iranian plateau, the Achaemenid Period of the Persian Empire (550 to 330 BC) controlled both Mesopotamia and the Nile River Valley (Olmstead, 1948; Kuhrt, 2007). The Mongolian Empire's immense territory at its peak included East Asia and Mesopotamia (Morgan, 2007).

In the Americas, the first urban states appeared later than in the Old World. Urban states formed in two broad regions: Mesoamerica (from central Mexico to the midpoint of Central America), and the Central Andes (southern Ecuador to northern Bolivia).

Mesoamerica was the home of many urban states. The Olmec may have had the first urban state in the region (1400 to 400BC), but this assertion is under debate (Clark, 2006; Pool, 2007). As seen in Mesopotamia and South Asia, several waves of consolidated state power and localized polities swept Mesoamerica. A more definitive urban state was at Monte Albán, in the Oaxaca Valley (~500 BC) (Marcus and Flannery, 1996; Blanton, 1999; Spencer, 2003). From 100 BC to AD 800, the urban state of Teotihuacan existed to the northwest of Monte Albán (Parsons, 1968; Millon, 1970; Cowgill, 1997; Linné, 2003). Trade existed between Teotihuacan and the contemporaneous Maya network of urban centers from AD 250 (Braswell, 2003). While the Maya experienced a decline around AD 900, urban states existed to colonial times (Andrews, 1993; Chase and Chase, 1996; reviewed in Marcus, 2003 and Chase et al., 2009). In the Valley of Mexico, the Aztec Empire was formed by the alliance of three powerful city-states in 1430 AD (Conrad and Demarest, 1984; Smith and Berdan, 1992; Smith, 2001; Smith and Montiel, 2001; Hodge and Smith, 1994).

In the Central Andes the Moche in the Early Intermediate Period (AD 100 to 600) is regarded as the first urban state (Bawden, 1996). The Huari and Tihuanaco empires developed in the following period, the Middle Horizon (600 to 1000 AD) (Schreiber, 1992; Silverman and Isbell, 2008). The two early empires collapsed, and large states (or small empires) such as the Chimú in the north coast developed (Moore and Mackey, 2008). Lastly, the Inca Empire briefly conquered the entire Andean region during the Late Horizon (1438 to 1532 AD). Andean prehistory is reviewed in more detail in the next chapter.

Labor and Health in Archaeological States

The control of labor is an important factor in the success of a state. The command of a large work force is needed for resource production and construction of the physical infrastructure. Many studies of societies transitioning to statehood have confirmed labor intensification due to the increased demands of the state compared to the previous, less complex social structures. Health then declines in the labor class under state control due to the intensification of labor, as a few case studies will illustrate.

The northern Mesopotamian city of Tell Leilan in Syria saw several changes in labor usage during Akkadian rule (Weiss, 1983, 1990). The irrigation infrastructure was upgraded and agriculture was intensified. Storehouses and administrative buildings were constructed, encircled by defensive walls. A bioarchaeological study of individuals at Tell Leilan found that the population was generally free from physiological stress markers except for indicators of anemia, which were higher than at other, non-state, sites in the region (McKenzie, 1999). Several cases of abnormal entheses (muscle markers) development were found that suggests intense physical activity, though osteoarthritis was not severe.

Studies of the Maya have looked at changes in health and labor through periods of state growth and decline (reviewed in Spence and White [2009]). A survey of several Mayan sites found generally poor health across time periods, with decreasing stature through time (Storey et al. 2002). The presence of tropical diseases was cited as a potential cause of poor health in this region. Wanner and colleagues (2007) examined skeletal remains from Xcambó, a coastal Mayan settlement. Biomechanics, the study of bone adaptation to physical stress, found a sexual division of labor. Women showed consistently low bilateral asymmetry through time, which the researchers interpret as related with food processing. Males showed high bilateral asymmetry, related to maritime trade. The amount of labor lessened for males over time with increased urbanization but remained the same for females.

In prehistoric Mexico, stature was found to decrease with increasing social complexity (Marquez Morfin et al. 2002), as Storey and colleagues (2002) found with the Maya. Also similar to the Maya case, health was generally poor. The researchers cite fish-borne parasites as a potential cause of the high chronic anemia rates found in the prehistoric Mexico sites. In the Aztec Empire, tributary provinces have been identified in the interior of the empire that produced food and goods for the urban center (Berdan, 1985; Smith and Berdan, 1992). These provinces moved goods through traditional pre-empire trade agreements and routes, but the trade network was intensified during imperial rule. An archaeological study of the Cuauhnahuac province found that labor production was increased and standard of living decreased during Aztec times due to the empire's demands (Smith, 1987; Smith and Berdan, 1992).

The study of the Roman Empire is an area in which bioarchaeological studies are becoming more commonplace (e.g. Killgrove, 2005). Two recent studies have extensively addressed health indicators associated with physical labor. In one, Paine and colleagues (2009) found that a high proportion (62%) of the adult population at the Italian city of Urbino showed some manifestation of degenerative joint disease (DJD). There was no statistically significant difference in DJD prevalence between the sexes. The high prevalence of DJD and other indicators of nutrition and trauma led the researchers to conclude that the Urbino population experienced generally poor health. In accordance with their bioarchaeological results, Paine and colleagues cite historical accounts that state that the citizens of Urbino were heavily stressed due to Roman taxation. In another study, Peck (2009) arrived at similar conclusions comparing health at a Pre-Roman site, East Yorkshire, with the Romano-British town of Eboracum. Higher rates of osteoarthritis, dental disease, and trauma were seen in the Roman site. Roman colonial presence is concluded to have led to sociocultural changes that caused a decline in health.

One area that has been greatly informed by the bioarchaeology of the lower class under state rule is the African Diaspora, or the anthropology of Africans removed from their home continent, mostly for the slave trade, during the age of European colonialism. These studies examine remains from a variety of regions, including New England, the Southern states, and the Caribbean. Blakey (2001) gives a detailed review of the bioarchaeology of the African Diaspora. Many studies of African slaves have found high levels of indicators of poor health, such as chronic anemia, bacterial infection, dental pathology, and osteoarthritis brought upon by heavy physical loading (Thomas et. al., 1977; Corruccini et al., 1985; Kelley and Angel, 1987; Rathbun, 1987; Owsley et al., 1987; Blakey et al. 1992, 1994; Dutcher 2009; Shuler, 2009). A sex difference, with males exhibiting poorer health than females, has also been frequently found. Elevated levels of trauma have been found in adolescents and women, atypical for skeletal populations (Blakey and Rankin-Hill 2004). Studies of the African Diaspora have consistently shown that slavery had an extreme negative effect on the skeletons of the laborers.

Chapter Summary

Several trends can be found in life cycles of ancient urban states. First generation states have appeared in only several distinct locations around the world, centered around rich river valleys. Only a subset was home to imperial societies. The common factor that most of these places share that contributes to the birth of urban states is the potential for abundant food production, either from agriculture or herding, realized by the massive organization of labor.

The amount of labor necessary to extract resources from these rich zones, and the health of the laboring subjects, appear to be inversely related. A review of bioarchaeological studies in a variety of urban states have shown that the presence of state rule is associated with an increase in labor, which is then related to worsening adult health. This dissertation will pursue the same relationship between urban statehood and health in the central coast of the Andes.

The next chapter gives the regional background to this study, the prehistoric Central Andean coast.

CHAPTER 3: ANDEAN PREHISTORY

This chapter will look at the periods of Central Andean cultural development that preceded the arrival of the Spanish, especially the periods with comparative skeletal material used in this study. While the Central Andes include the area from southern Ecuador through Perú to northern Bolivia (Figure 3.1), focus will be on the central coast of Perú, the river valleys surrounding modern Lima.

According to the Inca, whose accounts were recorded by various Spanish or Spanish-influenced chroniclers, there were no pre-Inca cultures: the Inca came north from the sacred Lake Titicaca region, founded Cuzco (or Cusco or Qosqo), and spread civilization across the barbaric groups of the Andes (e.g. Cobo, 1990[1653]). An uncritical acceptance of the historical record would stop there. Archaeology, on the other hand, has found evidence of complex Andean culture stretching back 10000 years on the coast with large monumental architecture appearing before 3000 BC (uncorrected radiocarbon dates will be used throughout this dissertation) (Engel, 1980, 1987; Moseley, 2001; Haas and Creamer, 2006). I will start with a brief overview of the unique environment of the region, and then proceed from the earliest documented human presence in the Andean region through time to the Inca.

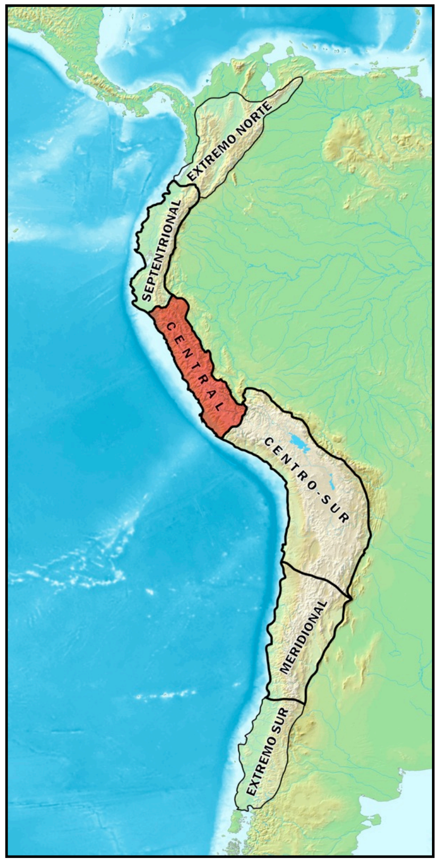


Figure 3.1: Cultural Regions of the Andes, with Central Andes Highlighted. Titles are in Spanish. Image adapted from Romero (2007).

The Andean Environment

The imperial development region of the central Andes is located in a unique environment that places a wide variety of ecosystems suitable for different types of subsistence in a narrow space (Sandweiss and Richardson III, 2008). Variation in environment exists both horizontally, from the Pacific Ocean east through the two Andean mountain chains to the tropical rainforest of the Amazon, as well as vertically in the Andes mountains (Figure 3.2). In the highlands, multiple ecological zones are readily reachable on foot, allowing for a diverse array of resources accessible at the household level (Murra, 1972, 1975; Brush and Guillet, 1985). Trade and reciprocity, critical components of Andean culture (Allen, 2002), expand the resource base further. Technological advances, such as terracing and irrigation, increase the amount of resources obtainable from these environments. The richness and diversity of the Andean region allowed people to settle and expand into the largest empire in the western hemisphere.

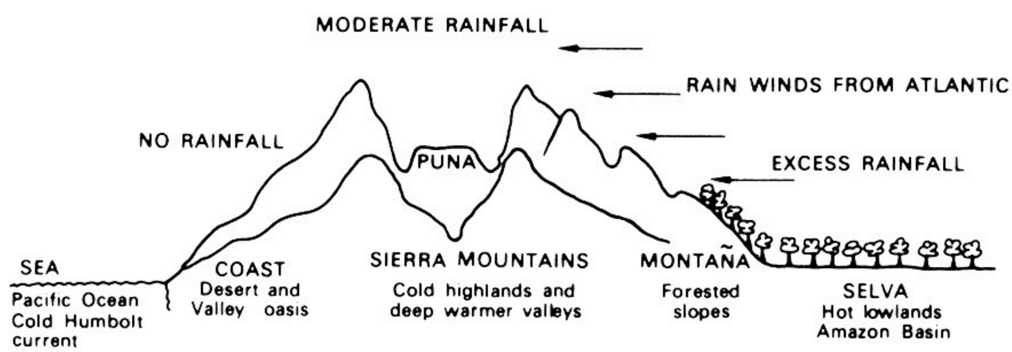


Figure 3.2: Cross Section of the Andean Region (West is Left). From Moseley (2001:30).

The Preceramic (to 1800 BC)

The Central Andes have a long history of human habitation. Foragers may have lived in the Central Andes since 12000 BC (MacNeish et al., 1975, 1981; Rick, 1980; Lynch et al., 1985). A modified Rowe-Lanning chronology (Rowe, 1962; Lanning, 1967) is used here to describe the vast changes in archaeologically established cultures in this region. The earliest time period is the Preceramic.

The Preceramic can be divided into three stages based on social complexity: Early (to 6000 BC), Middle (6000 to 2500 BC) and Late (2500 BC to 1800 BC). In the Early Preceramic, the oldest sites on the central coast are about 11000 years old (Engel, 1987), though climate change has inundated the prehistoric shoreline, destroying many potential fishing sites (Richardson III, 1998). The site of Quipa is the most reliably dated since it has two radiocarbon dates from house-poles: the first of about 8710 BC, and the second of which, in the presence of obvious later contamination, produced a date nearer to 7000 BC (Duncan et al., 2008). There are no skeletal remains from this Early Preceramic site. The Middle Preceramic saw a transition towards increasing sedentarism. Skeletal material from Paloma, one such village, will be used in this study. The Late (or Cotton) Preceramic is marked by the appearance of monumental architecture, cotton fiber, increasing reliance on agriculture, and increased long-distance trade (Engel, 1957, reviewed in Quilter, 1991ab; Pozorski and Pozorski, 2008). Monumental architecture proliferated during the Late Preceramic. For example in the "Norte Chico," a colloquial name for a stretch of several valleys on north coast of Perú, many sites feature ceremonial centers (Haas and Creamer, 2006). These sites were possibly organized by a common cosmology into a series of astronomical alignments (Benfer et al., 2010). These alignments persisted into the Initial Period and continued into Inca times.

One of the main debates in the archaeology of the Preceramic coast is whether the marine resources were a key factor in the development of more complex societies. The Marine Foundation of Andean Civilization hypothesis

(MFAC) states that abundant marine resources allowed coastal populations to grow, resulting in the complex societies of the Late Preceramic, when coastal monumental architecture begin to appear on the coast (Moseley, 1975b, 1992, 2004). The presence of fishing as a subsistence strategy dates back to the Early Preceramic, to the earliest sites in the south coast of Perú (Keefer et al., 1998; Sandweiss et al., 1998) and in Chile (Schiappacasse and Niemeyer, 1984). Evidence from the north coast of Perú at sites such as Aspero (Feldman, 1980, 1983) and Chupacigarro-Caral (Béarez and Miranda Muñoz, 2000) have bolstered the MFAC hypothesis, recently reviewed by Haas and Creamer (2006). The counter hypothesis is that the Andes developed in much the same way as complex societies around the world, in which agriculture provided the necessary subsistence base (Wilson, 1981).

The Initial Period (1800 to 900 BC)

The Initial Period saw a continuation of construction of ceremonial centers, such as Huaca la Florida (Patterson, 1985), Pampa de las Llamas-Moxeke (Pozorski and Pozorski, 1986; Pozorski, 1994, 1995), and San Jacinto (Burger, 1995). A common motif is a U-shape formed by a central flat-topped pyramid with long parallel mound “arms” jutting out from two sides, as seen on a giant scale at the Late Preceramic site of El Paraíso (Moseley, 1992). Circular sunken courts were another common construction. Some sites have both motifs. Sites bearing large constructions are typically located near land suitable for irrigation (Pozorski, 1986), and the spread and increasing reliance on agriculture is another hallmark of the Initial Period (reviewed in Pozorski and Pozorski, 2008).

Whether these impressive constructions signal the onset of institutionalized social differentiation is an issue of current debate. Pozorski (1987) and Pozorski and Pozorski (1986, 1992) argue that the prevalence of impressive architecture in the Initial Period signal the arrival of small states. Stanish (2001a), along with Burger (1995) and Schreiber (2001), disagree. They see at most the rise of chiefdoms and localized polities with no single group controlling more than one river valley. The sudden mushroom crop of architecture may also be the result of intersite competition for pilgrims or residents (Burger and Salazar-Burger, 1985; Haas and Creamer, 2006). The argument that the third millennium BC sites in the northern section of the central coast formed a state (e.g. Shady Solis, 2000) is not broadly accepted (Makowski, 2008). Researchers agree that the best solution is more focused research on the Initial Period to increase the available comparative material (Pozorski, 1986; Stanish, 2001a).

The Early Horizon (900 BC to AD 200)

At the end of the Initial Period, an iconographic style spread rapidly across the central Andes from the highland site of Chavín de Huantar, marking the Early Horizon (Burger, 1995, 2008; Rick, 2008). Chavín de Huantar appears to be a site designed to entice and impress visiting elites from the entire Andean region (Rick, 2004). The architecture bears many features geared towards religious ceremony: plazas, temple platforms, depictions of fantastical beings, and a labyrinthine gallery. Derivatives of motifs seen at Chavín are found along the entire Andean coast, attesting to the power of the religious site (Burger, 1993). Yet, the spread of the Chavín religious cult was completely ideological since no signs of warfare, migration, or hegemonic control have been found. Towards the middle of the Early Horizon, around 500 BC, ritual use of Chavín's monumental architecture decreased and the Chavín cult saw a slow decline in influence to obsolescence in the Andean world (Rick, 2004).

The Early Intermediate (AD 200 to 600)

With the wane of the Chavín influence, the Andean coast entered a period of independent polities, the Early Intermediate Period (EIP). The Moche or Mochica found great success in the north coast, producing impressive art and architecture (Bawden, 1996; Butters and Castillo, 2008). The central coast polities, such as the Lima, did not grow as large as their north coast neighbors (Earle, 1972), possibly because water for irrigation river valleys is more abundant in the northern river valleys, decreasing in quantity moving south along the coast (Cohen, 1975). As further evidence that water resources were the limiting factor in social complexity, monumental centers on the south coast are smaller still, although ceramics and textiles reached new peaks of development (e.g. Proulx and Silverman, 1993; Silverman, 1993). Still, the EIP marks the beginning of Pachacamac as an influential oracular and religious site on the central coast, which continues through the Late Horizon (Inca Period) (Uhle, 1903; Eeckhout, 1999, 2003, 2004ab; Shimada et al., 2004).

Early Intermediate Period social stratification on the central coast is not thought to have been rigid, based on the general lack of elite grave goods (Earle, 1972). However, valley polities rose. Since societies were in flux, health is likely to have declined due to unstable access to resources and an increase in warfare (Moseley, 2001; Arkush et al., 2005; Pechenkina and Delgado, 2006; though see Torres-Rouff and Junqueira, 2006). The localized EIP groups persisted for a number of centuries before the first true Andean empire appeared.

Skeletal materials from two EIP cemeteries of Pachacamac are used in this study: Villa El Salvador, and Tablada de Lurín. At these sites, skeletal health showed a remarkable decline in comparison to previous periods (Pechenkina, 2007). When pooled, the two sites provide a sample from an area whose people were under local sociopolitical control.

The Middle Horizon (AD 600 to 1000)

Two states controlled much of the Central Andes in the Middle Horizon. Most researchers consider these polities, the Huari (or Wari) and Tiahuanaco (or Tiwanaku), to be the first Andean empires (Schreiber, 1992; Bruhns, 1994; Moseley, 2001). This study will use skeletal material from the Huari-affiliated coastal site of Huaca Malena.

The Huari Empire

The Huari originated from the site of the same name in the Ayacucho Valley, and spread across the central and northern Andes, including the coast (Lumbreras, 1960; Rowe, 1963; Silverman and Isbell, 2008). Several features indicate Huari control in a given location: the presence of Huari-style ceramics and architecture, meticulous site and building planning, and the consolidation of settlements around arable land (Menzel, 1964; Schreiber, 1978; Cook, 1994). A preference for large bodies of water and other notable landscape features such as visible mountain peaks and unique stone formations (*huacas*) suggest that religious beliefs regarding water played a large role in Huari site planning (Glowacki and Malpass, 2003), although subsistence strategy was obviously another important determinant. In fact, it has been hypothesized that Huari, like some Christian states, spread first via religion before transitioning to military conquest (Menzel, 1964; Feldman, 1989). The level of Huari control apparently varied by region. Overall, the empire has been likened to a mosaic since there is high variability in how Huari rule manifested itself (Schreiber, 1992).

Broadly, Huari control in a particular zone can be categorized as either direct or indirect. Direct control means ethnic Huari people physically managed the settlement, taking over the leadership role from the local inhabitants. Indirect control means the settlement is economically or iconographically affiliated with the Huari Empire, but was managed with the preexisting local social structure. At least twelve distinct Huari zones of direct control, evidenced by "shifts in ceramic styles, settlement locations, and political systems" make up their empire

(Jennings and Alvarez, 2001:143). The Huari state had direct control over sites such as Pikillacta, Viracochapampa, Jincamocco, and coastal Cerro Baúl (McCown, 1945; Schreiber, 1978, 1992; McEwan, 1991; Cook, 1992; Nash, 2002; Nash and Williams, 2004). These sites show canon Huari architecture and drastic changes in social structure and material culture upon Huari intrusion. Examples of sites that show signs of indirect Huari control are Collota and Netahaha in the Cotahuasi Valley in the mountains of southern Perú (Jennings and Alvarez, 2001; Jennings, 2006ab). While settlements under indirect control have structures in the Huari style, the researchers found evidence that they were designed by the local elite rather than ethnic Huari: a close inspection of the architecture shows significant deviations from the "Huari canon" (Jennings and Alvarez, 2001). Therefore, rather than living under the thumb of foreign Huari overlords, local elites were in control of Cotahuasi Valley and they showed their status through a material association with the empire. This relationship between the Huari core and peripheral site differs markedly from the traditional model of an empire, where the presence of the ruling elite's style is taken as evidence of direct administrative control (Jennings, 2006b).

Sites on the coast exhibit Huari ceramics, but sparse Huari canon architecture, suggesting mostly indirect control (Schreiber, 1992). However, a number of Huari temples were constructed at Pachacamac, which overlooks the Pacific Ocean (Franco Jordán, 2004). A distinct Huari sub-style of ceramics, referred to as Pachacamac, appeared in the central coast in the middle of the Middle Horizon (Uhle, 1903; Rostworowski de Diez Canseco, 1992). The spread of the Pachacamac style beyond the home site shows a tangible diffusion of Huari ideology.

While studies of Huari material culture have been enlightening, up until recently there have been few studies on Huari Empire mortuary practices and bioarchaeology even though skeletal material is abundant (Valdez et al., 2007). Fortunately, this area of investigation is growing rapidly. Excavation at the secondary Huari city of Conchopata found at least seven types of interments, probably reflecting different social roles of the interred (Isbell, 2004). Major distinguishing features include individual versus multiple burials, amount of grave goods, and construction of the burial chamber, which varies from unadorned to stone-lined cists, to sealed niches cut into a wall. Tung (2003) found that indicators of chronic anemia were less common near the Huari core at Conchopata relative to the peripheral sites of Beringa and La Real. Trophy heads found at Conchopata bear evidence of being non-local raid victims (Tung, 2008; Tung and Knudson, 2008). Tung (2007) also found a higher incidence of trauma during the Huari period at three sites, suggesting that Huari control was achieved in part through violence.

THE TIAHUANACO EMPIRE

As the Huari Empire exerted control over the central and northern Andes, the Tiahuanaco Empire spread across parts of the central and southern Andes, in modern Perú, Bolivia, and Chile (summarized in Kolata and Kolata, 1993). From the highland urban center of Tiahuanaco in the Titicaca Basin, the empire spread through warfare and the formation of religious and economic ties. Fertile land in the Titicaca Basin, coupled with technology such as raised field agriculture, and rich animal resources, including fish and camelids, has been cited as an enabling factor allowing for Tiahuanaco to expand to the level of an empire (Lynch, 1983; Kolata, 1986, 1991).

The Tiahuanaco Empire expanded out of its center to form religious and trade connections with distant sites. The eastward expansion of the Tiahuanaco Empire controlled the *yungas*, the eastern highlands of the Andean mountain chain (labeled "Montaña" in figure 3.2). Cochabamba Valley, in the yungas, shows evidence of incorporation into the Tiahuanaco Empire though without direct rule from the core (Plunger, 2007). To the south, Tiahuanaco influenced San Pedro de Atacama in Chile, though the nature of the relationship between these polities is unknown (Rodman, 1992; Knudson, 2007; Torres-Rouff and Knudson, 2007). The northern Tiahuanaco border abutted the southern extent of the Huari Empire, where the two empires interacted.

The relationship between the Huari and Tiahuanaco empires is unique in the archaeology of complex states. Their respective material cultures share similar stylistic traits, leading to confusion as to whether the Huari and Tiahuanaco empires were in fact one far-reaching state (reviewed by Schreiber, 1992; Isbell, 2008). Yet, despite the current conceptualization of Huari and Tiahuanaco as separate powerful expansionist political entities in the same cultural region, there is no evidence of warfare between them, nor was one dependent on the other, as in the case of East Asia shadow empires (Barfield, 2001). Both empires had settlements in the Moquegua (or Middle Osmore) Valley, near the southern tip of Perú, but seemingly coexisted until the sites of both empires were abandoned at the end of the Middle Horizon (Goldstein, 1993; Nash and Williams, 2004).

Bioarchaeology of the Tiahuanaco Empire has explored the movement of imperial subjects throughout the territory. A study of non-metric trait distribution found evidence that the Tiahuanaco subjects at the coastal Moquegua Valley were transplants from the highlands, suggesting state-level manipulation of settlers (Blom et al., 1998). Similarly, strontium analysis points towards diverse peoples living at the Tiahuanaco urban core and the peripheral Chen Chen site (Knudson et al., 2004). Analysis of the distribution of cranial deformation types also found that diverse ethnic groups inhabited the Tiahuanaco core (Blom, 2005). These bioarchaeological studies of ethnic diversity in the Tiahuanaco Empire corroborate archaeological studies showing large variation in material culture (Janusek, 2002).

The Late Intermediate Period (AD 1000 to 1438)

The Middle Horizon ended with the dissolution of the Huari and Tiahuanaco empires and was followed by the Late Intermediate Period (LIP). Relatively little is known about the Late Intermediate compared to the horizons that bracket it. Covey (2008) theorizes that the LIP, marked by high local cultural diversity, is harder to conceptualize archaeologically than the more culturally homogenous horizons.

As in the Early Intermediate Period, independent local polities appeared in the highlands (Parsons et al., 1997) and on the coast (Dulanto, 2008) in the LIP. Also similar to the EIP, Late Intermediate Period cultures especially flourished in the north coast (Moore and Mackey, 2008; Dulanto, 2008). The most prominent north coast state was the Chimú (Keatinge, 1974; Moseley, 1975a; Keatinge and Conrad 1983). Three phases of Chimú expansion occurred from their capital of Chan Chan in the Moche Valley. By the Late Horizon, the Chimú state had grown to become a strong opponent of the Inca, though ultimately defeated.

In the central coast, smaller polities each controlled a small number of valleys. While some polities created smaller defensive settlements on valley ridges, large coastal cities also formed with little planning for defense (reviewed in Covey, 2008). The Ychsma (or Ichma, Ychma, or Ychima) were one coastal polity that controlled the Rímac and Lurín valleys, including the cities of Pachacamac and Armatambo (Rostworowski de Diez Canseco, 1977; Cobo, 1990[1653]; Silva Sifuentes and Jaime Tello, 2005). Ychsma architecture is defined by the presence of *tapiales*, molded rammed earth constructions (Díaz, 2004). To the north in the Chillón valley was a single valley entity that may have acted as a political buffer from another two-valley group further north, the Chancay (Dulanto, 2008).

The skeletal material from the LIP that is used in this dissertation originates from Armatambo, an important Ychsma city (Matos Mendieta, 1999; Díaz, 2004). Chapter Five contains a detailed description of the proveniences of the Armatambo skeletal collection.

The Late Horizon and the Inca Empire (AD 1438 to 1532)

The last period before the arrival of the Spanish is designated the Late Horizon. Its defining event was the rise of the Inca Empire from the central highlands (Figure 3.3). While the Inca postdate the sites used to test the four models of this dissertation, a review of Inca culture still informs this study. The Inca Empire, while unique in scale, is built upon the technology and traditions of the cultures before them. Also, historical accounts for the Andean region are only available for the Spanish colonial era because Andean cultures did not have a native writing system (with the possible exception of the *quipu* system of knotted cords [e.g. Urton 1998, 2005, 2008]). Therefore, ethnohistory of the Inca can offer insight on pre-Inca cultures.

Traditionally, Inca sources have pointed to a myth of a single historical event as the cause of Inca expansionism: an epic battle between the Inca and the neighboring Chanca invaders that was won through the determination and divine connections of Inca royal Pachacuti, who then led the Inca to empirehood (e.g. Rowe, 1946; Moseley, 2001). The folkloristic, mythical, and propagandizing elements are intertwined with a historical event, a common feature of the chronicles, which make Inca history malleable (Bauer, 1991, 1992a; D'Altroy, 2003; and see Ogburn, 2004, for another look at the Inca use of propaganda).

Figure 3.3: The General Extent of the Inca Empire at its Peak, (Shaded in Blue). This map was created using maps by Dalet (2007a-b).

Archaeology of the Inca heartland suggests a more nuanced history that adds to the general study of state development. Unable to isolate a single event, archaeology has looked at the long term processes that shaped Cuzco and its neighbors, priming the region for a second round of imperialism (see summaries in Bauer and Covey [2002] and Covey [2008]). Reaching back to the Middle Horizon, Huari presence in the Cuzco Valley could have prepared polities there to accept further imperial rule. The Inca were just one of these unassuming ethnic groups in the central highlands until 1000 AD, when they started consolidating the Cuzco valley: Cuzco urbanized and grew faster than its neighbors. Inca villages were built in strategic locations for administering control over nearby peoples. Agriculture was expanded with new irrigation canals and new terracing. These upgrades were constructed around the Inca settlements where they interfered with the agricultural production of competing polities reluctant to join the Inca. Disputes with neighboring polities also resulted in warfare, but as the Inca allied with groups both within and beyond the Cuzco Valley, they increased their chances of victory in these violent confrontations. By 1438, these processes made the Inca state a powerful political force as they left their heartland, eventually to conquer the majority of the Central Andes (Rowe, 1946; Conrad and Demarest, 1984; Bauer and Covey, 2002; Covey, 2006). The diverse toolkit of strategies used to incorporate groups in the central highlands proved useful in consolidating the entire Central Andes. At its peak, the Inca Empire (*Tawantinsuyu*: “Land of the Four Quarters”) had reached 4000km in length, ruling an enormous variety of environments and cultures.

Unlike the Huari, the Inca Empire conforms well to the core-periphery model, with Cuzco clearly the heart (Kuznar, 1996, 1999). Ideologically the capital was the center of the Inca world, situated 3300m above sea level in the eastern chain of the Andes, the Cordillera Blanca. Cuzco and the nearby Urubamba valley were where the elite managed estates of the past and current emperors’ resources gathered from their subjects. At Cuzco, elites held ceremonies that awed their subjects (Rostworowski de Diez Canseco, 1992; Cobo, 1990[1653]; de la Vega, 1995, 2006[1609]; Bauer, 1996). The layout was divided into a microcosm of the entire empire, both visualized and comprised of four quarters. Linear pathways imbued with religious meaning, *ceques*, radiated out from Cuzco to geographic features and sites of significance (*huacas*) all the way to the periphery, including meaningful constellations (Zuidema, 1990; Bauer, 1992b). More portable huacas from the entire territory, ceremonial objects such as mummies, were housed in Cuzco to consolidate religious power.

THE INCA EMPIRE ON THE CENTRAL COAST

The Inca had a strong command of much of the coast, perhaps surprising since the environment was so different from their highland home. However, some large fishing polities retained their independence until the Spanish conquest (Owen, 1993). Contact between coast and highland is an ancient Andean tradition, although language and cultural differences always existed. When confronted with the impressive polities of the central coast, such as the Ychsma, the Inca wisely made peaceful overtures. Instead of attacking Pachacamac, by that time the most influential religious site in the Central Andes (Rostworowski de Diez Canseco, 1992), the Inca built their own Temple of the Sun there to show their power and leverage the site's religious and political influence as their own.

The level of Inca intervention in coastal cultures varied (Stanish, 2001b). In the Locumba Valley of the south coast, the Inca managed from afar, preferring to oversee the valley from the piedmont (Covey, 2000). In some cases, the archaeological and ethnohistoric studies disagree: for example in the Chillón valley ceramic analysis indicates little Inca presence while the chronicles imply a strong imperial interest (Silva Sifuentes, 1992). Archaeological interpretations also differ, as in the Chincha Valley, where Rostwoworski de Diez Canseco (1970) interprets a lack of Inca integration while Sandweiss (1992) sees much Inca reorganization.

In the study area for this investigation, elite compounds in the Rímac Valley showed continuous occupation from the Late Intermediate to Late Horizon, suggesting that the Inca left local power structures at least partly intact (Villacorta, 2004; Makowski et al., 2008). The high prevalence of local pottery styles in the Rímac Valley even in the Late Horizon supports this hypothesis (Makowski and Centeno, 2004). Therefore, ethnohistory of the Inca in the central coast can cautiously be used to inform the local Late Intermediate occupation. Additionally, future work can compare the current data from the LIP to Late Horizon skeletal collections.

The End of First Generation Andean Culture Development

In 1532, amidst increasingly difficult efforts to conquer peoples in foreign environments (Hyslop, 1990; D'Altroy, 1992, 2003), the Spanish arrived in the last stages of an Inca civil war (Cobo, 1990[1653]). They defeated the Inca with the aids of rebel subjects, internal political strife, and a terrible epidemic that swept ahead of their path. Before their dissolution, the Inca radically shaped the

Andean way of life at all levels of society while at the same time preserving much of Andean culture and religious belief.

Chapter Summary

The Central Andes shows a clear case of growing complexity in cultural evolution. The process was not linear, as Andean cultures experienced periods of stylistic divergence and periods of relative uniformity. A religious cult, Chavín, first linked the disparate cultures of the coast and highlands with common stylistic motifs. Expansive empires swept the region twice, and smaller complex states also appeared multiple times. Understanding the processes that led to these broad cultural changes, as related to power and health, is a goal of this dissertation.

CHAPTER 4: THEORY

This chapter looks at the theoretical underpinning of the hypotheses tested in this dissertation. Life history theory explains the timing of human growth and development events. The osteological paradox addresses issues in interpreting ancient human remains as a once-living population.

Life History Theory

Life history theory provides an evolutionary framework for the study of human growth and development. Originating in biology, life history theory has proven enlightening in other fields such as psychology (e.g. Ellis, 2004; Kaplan and Gangestad, 2005) and anthropology (e.g. Flinn and England, 1995; Geary and Flinn, 2001; Geary, 2005, 2006; Walker et al., 2006). In brief, evolutionary factors affect the timing of key points in the life span (history) of a species (Kaplan, 1996; Kaplan, 1997; Hill and Hurtado, 1996). Humans show a specialized life history pattern unique among living species. For example, the long juvenile period unique to humans enables time for foragers as children to become experts at their subsistence, knowledge that as adults is then reinvested into providing for offspring (Kaplan, 1996). Another topic within life history theory, parental investment theory, deals with cross-generational issues involving the differential treatment of offspring.

According to parental investment theory, maximizing ones reproductive fitness is a balance between the benefits of raising a number of offspring and the high cost associated with the task (Lack, 1954; Fisher, 1958a; Lack, 1968; Gadgil and Bossert, 1970; Trivers, 2006[1971]; Smith and Fretwell, 1974; Hill and Hurtado, 1996; Benfer and Pechenkina, 1998). Reproduction, including care for offspring, takes energy from the finite stores of the body and the environment it occupies. Non-reproductive physiological processes devoted to growth or maintenance on the part of the adult might reduce the energy available for reproduction (Gadgil and Bossert, 1970). Added to the dichotomy of energy spent between reproductive and non-reproductive actions is time, which is also limited: care for an existing offspring takes resources from creating future potential young. Of course, history and context play an enormous role in determining where the balance of energy expenditure lies, and the methods the human actors use to maintain the balance successfully. For example, studies have shown that childcare is reduced as situations increase in extrinsic risk: especially war, famine, and high disease loads (Chisholm, 1993; Chisholm et al., 2005; Quinlan, 2007).

The mechanics of parental investment theory are intricate and involve countless decisions and actions at the level of the household. Having more offspring is beneficial if more individuals mean greater household production of resources in the future, counting for the resources invested in the non-productive developmental stages of the individual. However, if resources are limited, there is a point where large family sizes are costly and maladaptive as the elderly and preadolescent have to be subsidized by the able (Hagen et al., 2006). In such unpredictable situations, concentrating sparse resources in fewer children is a better reproductive strategy than diluting them amongst more, possibly more frail, offspring. Stressed children and adolescents, if they survive subadulthood, are more likely to mature into underperforming adults. Nutritional stress in childhood can affect physiology, reducing work potential (Martorell et al., 1992) and cognitive ability (Mendez and Adair, 1999; Grantham-McGregor, 2002; Walker et al., 2005), which then can reduce reproductive success. The hypothesis that subadult health affects later adult health is sometimes named the Barker hypothesis for the prenatal period (Barker, 1997), or the Developmental Origins of Health and Disease Hypothesis (DOHaD) for postnatal health (Le Clair, 2009). Armelagos and colleagues (2009) recently published a review of these hypotheses, as well as support from a bioarchaeological study.

The sexual division of labor, the cross-cultural trend of male and females pursuing different subsistence strategies in the same household, is another topic that has been explored through parental investment theory. Theory on the sexual division of labor effects Model A of this dissertation, which suggests a widening difference in health states between males and females in an urban state due to state organization. Bird (1999) reviews theories that attempt to explain the sexual division of labor in humans. While a cooperation model suggests that males and females obtain different resources in order to maximize productivity, experiments with birds suggest a conflict model. The conflict model states that external pressures have a role in keeping males from providing as much as their mates for their offspring. In particular, males may provide less than they could for their offspring in order to accomplish other tasks such as to seek out more mating partners or to guard their own mate from other males (however see Kaplan et al. [2000] for cases where males out-provision females). For humans in a state society, I suggest that an external pressure for males is the state demand for physical labor. This extra set of tasks for males would cause a sexual division of labor that should appear as different health and activity states in male and female skeletal remains. This contradicts Ruff's (1987) study in which he found that cross-sectional properties of lower limb leg bones, his measure of sexual dimorphism, were more similar between sexes in industrial societies relative to foraging and agricultural societies. In light of the different theories concerning the sexual division of labor and its relationship to social complexity, Panter-Brick (2002) emphasizes that research should examine the variability of the sexual division of labor rather than pursue simple dichotomies.

It is important to state that such hard choices are not merely artifacts from prehistory or relegated in modern times to the "third world." Observations concordant with sexual selection and parental investment theories have been seen in modern studies in a variety of contexts. Men and women seek qualities in mates that maximize their own reproductive success, following Trivers' model (Townsend and Levy, 1990; Feingold, 1992; Buss and Schmitt, 1993; Schmitt, 2005; Norman, 2007). Mutual compromises in reproductive strategies between paired males and females have also been found in modern peoples (Li et al., 2002; Jonason et al., 2009). Thus, parental investment theory is an important issue that has both modern ramifications and a past that can be explored.

At first the assumption that a human population would automatically find the right balance of energy expenditure in a complex web of factors seems suspect. Yet, there are two reasons to expect that a population would gravitate towards a successful balance between cost and benefits. Efficient management of energy is a trait that would result in higher reproductive fitness (Charnov, 1989; Winterhalder and Smith, 1992; Rogers, 1994). Another reason applies specifically to archaeology: a suboptimal group living in the past is less likely to exist long enough to leave an archaeological footprint. It takes a successful group to endure and amass material culture to be preserved and discovered. Following these considerations, an archaeological population can be assumed to at least have a somewhat successful command of their energy expenditure and thus to be subject to the hypotheses of life history theory. Changing adaptive strategies as a result of being incorporated into a state system might alter the life histories of a group dramatically, producing changes seen in a populational study of their remains.

BIOARCHAEOLOGY AND LIFE HISTORY THEORY

Archaeology can test life history theory in archaeological populations, though in ways modified from research on living peoples. Demography on skeletal populations cannot be conducted in the same manner as among living populations, as will be discussed later in this chapter. Studies of food production and intake have to be estimated based on items with differential rates of preservation and without the ability to attribute production to individuals (Pearsall, 1988; Lyman, 1994; Gremillion, 2002; Nagaoka, 2005).

What bioarchaeology has to offer that is not available in living studies are the skeletons of the individuals involved. Access to osteological data opens up a whole new view of human behavior that would be hard to acquire from other archaeological data, or from living people (Hill and Gunn, 1977). The skeleton gives the bioarchaeologist a rich, dense timeline of an individual's history of physiological stress from childhood to death. The skeletal record tells us how a people interacted with their environment at different stages of their life and it is not affected by personal bias, motive, or memory. However, skeletal data could be dramatically affected by bias in the cemetery population (Sattenspiel and Harpending, 1983).

In this dissertation, the document that is written on the bones of a skeletal population will be explored as a method of examining the predictions of life history theory, especially parental investment theory. The tenets of parental investment theory suggests that in a situation in which resources are abundant but production is taxing, subadults will be raised healthier in that group, while adult health worsens (Benfer and Pechenkina, 1998). As reviewed in Chapter 3, the Late Intermediate Period central coast probably showed these conditions.

The Late Intermediate Period site of Armatambo in particular shows an unusual sexual disparity: the skeletal population has a lower-than-expected number of young adult females ($t = 2.31$, $df = 37$, $p = 0.03$) (Figure 4.1). This finding is discussed in Chapter 9.

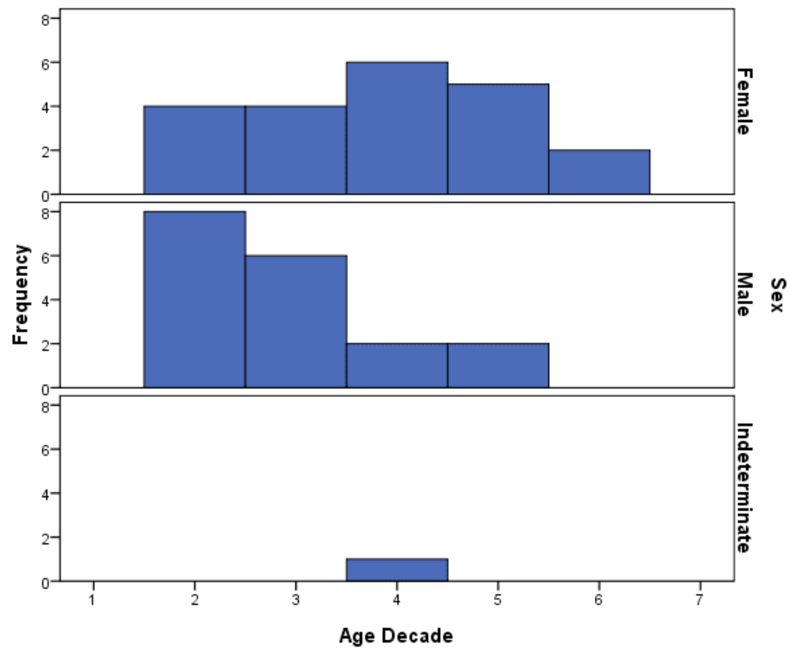


Figure 4.1: Distribution of Armatambo Adults by Age Decade, Separated by Sex

The Osteological Paradox

The preceding section showed what bioarchaeology can offer the study of human health. Still, the statistical interpretation of skeletal pathology is not intuitive. This section will discuss the complications that arise in making sense of skeletal indicators of health, and how these issues can actually be used to enhance interpretations of health and disease based on skeletal pathology.

What is the Osteological Paradox?

First named by Wood and colleagues (1992), the osteological paradox is a set of three issues that could cause a false interpretation of skeletal populations as representative of the living. The three issues are "demographic nonstationarity," "selective mortality," and "hidden heterogeneity."

The first subject addressed in the article by Wood and colleagues is "demographic nonstationarity," defined as "the departure of a population from the stationary state," (Wood et al., 1992:344). The article argues that populations cannot be regarded as stable for any length of time: factors such as migration and fertility are constantly in flux in a population, causing instability. A false assumption of demographic stationarity, that there is no net rate of change in the population, can produce a paradoxical result, an interpretation contrary to the actual health state, since the effect of fertility on the age-at-death of a non-stable skeletal population is non-intuitively greater than the effect of mortality. As a result, a higher mean age-at-death for a population, usually indicative of good overall health, actually represents poor health since it is more likely caused by low fertility (i.e. fewer people in younger age groups).

Hidden heterogeneity is the second issue in the osteological paradox. In this context, "hidden" means "not captured by observed covariates" during statistical analysis (Wood et al., 1992:345), and a covariate is a factor that confounds the statistical relationship between two other factors. A skeletal population is made of a mix of individuals who experienced different genetic and environmental influences in life. These factors produce differential frailty, or susceptibility, to disease that may be hidden in the skeletal population. As a result, population-wide summaries of disease experience do not realistically describe individual members of the group. For example, a test of porotic hyperostosis prevalence between males and females finds that males are far more likely than females to have had porotic hyperostosis. The conclusion would be that parental investment favored females. However, this conclusion is misleading if there is a confounding factor that separates males and females in this skeletal population: males are actually from a laborer subpopulation while the females are from an elite subpopulation. Knowing this fact, the comparison between sexes can now be seen as flawed, but if the researcher did not consider social standing in the skeletal population, the original comparison would stand erroneously as the final statement on the experience of chronic anemia between the sexes. Fortunately, in a real bioarchaeological study, such a situation is unlikely in complex societies, in which different ethnic groups and classes are distinguishable by mortuary customs, or other archaeological indicators of class, status, or identity.

The third aspect of the osteological paradox, selective mortality, is also relevant to this study. Selective mortality is the concept that the distribution of stress indicators in a skeletal population does not necessarily reflect the distribution of disease in the once-living population. In a living population, the distribution of age groups reflects those alive at a given moment in time. In a skeletal population, older individuals represent the healthier survivors of past disease episodes while younger individuals reflect the less healthy non-survivors of disease. Due to these differences, a skeletal age distribution may not reflect a living population: a skeletal population overestimates the prevalence of disease compared to the living population. Paleopathology has to address the disparity between skeletal and living samples to come up with reasonable conclusions.

Fortunately, the osteological paradox is not an unsolvable conundrum. Careful consideration of multiple health indicators across ages can provide sound interpretations to ward against demographic nonstationarity and hidden heterogeneity (Goodman, 1993; Cohen, 1994; Wright and Yoder, 2003), as can comparison of frequencies of stress indicators in children against adults. For example, if a skeletal population of children is found bearing no skeletal pathology, two mutually exclusive interpretations are possible:

1. The children tended to be healthy and the ones who died young died from causes not related to disease.
2. The children had extremely poor health and succumbed to acute diseases that left no pathology.

The addition of adults from the same skeletal population can possibly point towards one interpretation over the other. If the adults show many indicators of subadult stress, then subadult health in that population is likely to have been good, since subadults suffering from chronic disease managed as a whole to survive into adulthood. If the adults are also free of subadult stress indicators, there are still two mutually exclusive interpretations:

1. The population could have had good health since pathology was not common in any age group.
2. There remains the possibility that the entire population was unhealthy and thus frail to acute disease at all stages of life.

As stated by Wood and colleagues (1992:165), "It is more difficult to interpret the absence of such lesions in ancient skeletons. Their absence may indicate either that the causal condition was not present or that early death occurred before a distinctive skeletal response had time to develop." Other lines of evidence will have to be explored to determine the health state of these individuals. Interpretation for a skeletal population of children bearing indicators of pathology can similarly be directed with an analysis of adults from the same group.

RESPONSE TO THE PARADOX

Not surprisingly, the issues raised by the osteological paradox have been strongly critiqued by other researchers, as is healthy for scientific inquiry. The commenters of the 1992 article generally accept the points it makes and acknowledge the potential for further research to address them. Many of the commenters provide examples of how multiple lines of evidence from different fields can solidify interpretations on paleopathology (in particular, the individual responses by Cohen, Hutchinson, Lukacs, and Wilkinson). A common criticism is the mention of the issues Wood and colleagues do not address, such as bias from differential preservation, and problems with age and sex assessment (Katzenberg, in Wood et al., 1992; Jackes, 1993, 2000). Byers (1994) offers a method to test whether a metric indicator such as stature has an intuitive or paradoxical relationship to health by looking for skewness which would indicate selective mortality of a portion of the distribution. Unfortunately a large deviation from a normal distribution and a large sample size (over 150 for skewness and over 1000 individuals for kurtosis) are needed to support a paradoxical interpretation: otherwise the result is likely to be inconclusive (Byers, 1994:283).

Cohen's responses to the osteological paradox are the most impassioned, perhaps since the original article by Wood and colleagues singled out his and Armelagos' groundbreaking work on the Neolithic transition (Armelagos and Cohen, 1984) as an example of reinterpretable data. Cohen (1994, 1997) points out the ethnographic evidence that support their hypothesis that the transition to agriculture led to declining health. Also, Cohen maintains that the majority of deaths in a population are nonselective and randomly distributed relative to the health indicator, thus a skeletal population's lifetable, a depiction of a population's demographic data, could reflect its living counterpart. Wood and Milner disagree (reply to Cohen, 1994:635), stating that nonrandom death due to poor health is a fundamental assumption of paleopathology. In response to the demographic nonstationarity argument, Cohen points out that the growth rate of human populations has always been small (~0.1%), and that only a change of over five times the magnitude would cause fertility to affect age at death in a skeletal population. Also, where multiple generations are excavated in a cemetery, the effects of a recent change in fertility or migration would play out rapidly, so that the case proposed by Wood and colleagues may be rare. The differing interpretations of past populations show the need for more research to test the hypotheses underlying paleopathology and paleodemography.

Wright and Yoder (2003) give a look back at ten years of bioarchaeology after the introduction of the osteological paradox. They note little work specifically geared to answer the questions raised by Milner and colleagues, though advances have been made in peripheral issues such as age estimation and the identification of genetic markers of past disease. Close work with other fields was recommended to identify cultural subgroups in a skeletal population to address hidden heterogeneity.

Like other researchers, Wright and Yoder encourage the use of multiple indicators in statistical analysis. Still, it is important to note that relying on multiple indicators is a flawed solution, as multiple paradoxical manifestations of different stress indicators would still point towards an incorrect interpretation. Clearly, a more definitive method has to be used to test for the presence of the osteological paradox. Simulating what physiological stress data would look like given paradoxical conditions, and looking for the same pattern in real sets of data is one such method.

SIMULATING THE PARADOX: WHEN THE PRESENCE OF STRESS INDICATORS INDICATES GOOD HEALTH

The osteological paradox lives up to its name by being difficult to comprehend. To aid understanding, mathematical simulations can be generated to show how the presence of stress indicators in a skeletal population can actually reflect good health in the form of low mortality. This section will run through a simple model, with a hundred individuals afflicted with a non-specific indicator of stress (NSIS) in subadulthood. The point of this exercise is to look at the manifestation of NSIS in the adults of a model population given different levels of buffering against stress.

First, consider if buffering against subadult stressors was extremely poor: so poor, in fact, that no one in the population who develops the NSIS survives to adulthood (this follows the assumption that the conditions leading to the formation of NSIS are somehow correlated with increased chance of death, an assumption Cohen [1997:253)] disputes). This model population obviously demonstrates poor health since buffering against disease is nonexistent. But, as every subadult afflicted with the NSIS died before reaching adulthood, no adults show the NSIS. Just judging from the clean adult skeletons, one is likely to conclude that the population had generally good health, when the exact opposite is true for the children.

The reverse of the above scenario also shows the effect of selective mortality on a skeletal population. This time, buffering against NSIS is very effective in preventing subadult death due to disease: everyone sick enough to develop the NSIS survives into adulthood. In other words, no one dies from the underlying cause of the NSIS. The effect of excellent buffering against disease-related mortality on the adult skeletons is paradoxical: now every adult skeleton has the NSIS. While the adults show indicators of disease, this example reflects a healthier population than the previous case since here the disease caused no subadult deaths.

More-realistic models show what happens when contracting a disease raises mortality, but not to extreme levels. Table 4.1 shows the prevalence of an NSIS in adult skeletons given 100 afflicted subadults but different levels of mortality. These results were generated using an iterative Monte Carlo simulation (Manly, 1997) using the computer program Statistics101. Mortality is checked three times in sequence (labeled early, middle, and late adulthood) to simulate the passage of an individual's life.

Table 4.1: Simulation of NSIS Manifestation Given Different Mortality Rates

	Chance of Dying with NSIS				
	0%	**25%**	**50%**	**75%**	**100%**
	# Sick	**# Sick**	**# Sick**	**# Sick**	**# Sick**
Starting (Subadulthood)	100	100	100	100	100
Early Adulthood	100	76	60	16	0
Middle Adulthood	100	61	35	4	0
Late Adulthood	100	45	14	2	0

As the phases of adulthood progress, only a subset of infected individuals, the ones who survive, are able to leave a skeleton in the next phase. As seen in the extreme mortality cases, more adults manifest a subadult NSIS with lower mortality (better health) (Figure 4.2).

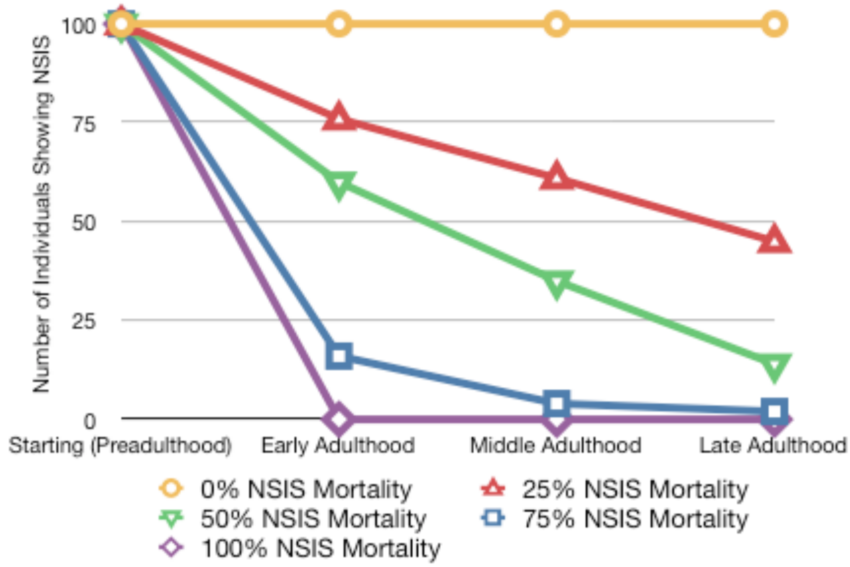


Figure 4.2: NSIS Manifestation Given Different Mortality Rates.

Changing the number of individuals with NSIS shows the paradox of manifestation in adults. Setting the starting number of individuals to 50 instead of 100 and running the same simulations shows a proportional decrease in NSIS manifestation through the adult stages (Figure 4.3: Calculations with 100 individuals [Figure 4.2] are faded).

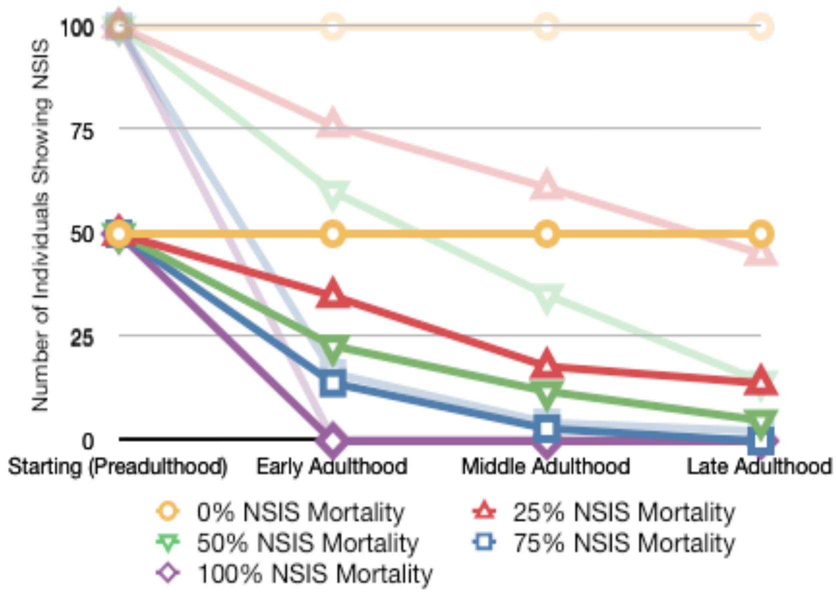


Figure 4.3: NSIS Manifestation Given Different Mortality Rates When Given 50 Starting Individuals.

The problem of interpreting subadult NSIS in adults is that the prevalence of NSIS in adults is related to how many individuals show it early in life. From just the analysis of adults, it is impossible to tell whether a certain recorded prevalence is due to health against chronic disease or levels of buffering against death. Shifting the starting number (signifying morbidity) effects adult NSIS manifestation (signifying mortality). Knowing subadult NSIS prevalence is critical in interpreting manifestation in adults.

What the above simulations show is that there are two broad components at work in defining health in a population that have to be addressed in bioarchaeological studies. One component of health is morbidity, a measure of disease prevalence. For subadult diseases, morbidity is not paradoxical: subadults without NSIS were healthier than those with NSIS. The "clean" subadults were individuals who were healthy enough to not contract a chronic disease, and died from unrelated causes, while subadults with NSIS were afflicted for a length of time. Assuming a random sample of subadult remains, a higher prevalence of an NSIS is an indicator of poorer health in the skeletal population. However, morbidity of subadult diseases cannot be ascertained solely from adult skeletons. Instead, adult skeletons reflect the second component of health: mortality, a measure of disease lethality. Given the contraction of a disease that causes NSIS, a healthier subadult is more likely to survive the episode and die as an adult that still bears the NSIS, barring other factors such as bone remodeling. A less healthy subadult with NSIS would have died young, before having the chance to leave an adult skeleton.

These exercises showed the trends that emerge given differing levels of mortality. When mortality is high, and health is low, NSIS is more common in adults. When mortality is low, and health is high, NSIS is less common in adults. Furthermore, there is a constant decrease with increasing age at death in prevalence with a paradoxical manifestation. Interpretation of results in bioarchaeology has to incorporate the role of differential morbidity and mortality on the manifestation of non-specific indicators of stress. A t-test comparing the age at death and presence of NSIS could point towards a paradoxical interpretation of health if a significant inverse relationship is found.

SUMMARY OF THE OSTEOLOGICAL PARADOX

The osteological paradox complicates paleopathology and bioarchaeology, but in a way which will enhance the disciplines. If the limitations of skeletal data produce multiple hypotheses, then new research will have to be generated to support or falsify them. The hypotheses in this study will be generated to account for possible paradoxical interpretations. The five NSIS used in this study will be examined for paradoxical results. The most solid conclusions have to account for multiple lines of evidence, whether in the frame of health indicators or in the grander realm of archaeology.

Chapter Summary

This chapter reviewed two theories that guide the study of the interaction between human biology and the environment. Life history theory provides testable hypotheses that offspring production and resource management are changed to maximize reproductive success. Developing new ways to estimate the health of the living from indicators of chronic diseases of skeletal populations brings bioarchaeology to a new level of analytical power.

CHAPTER 5: MATERIALS

This chapter will describe context of the skeletal material used in this dissertation. This study builds upon the work of many others who have studied health in the prehistoric Central Andean coast. While the physical region is kept constant, sites from varying time periods and social structures will be compared (Table 5.1; Figure 5.1). The skeletal collection from Paloma gives us a detailed look at a fishing village. Cardal shows an early population with the resources to produce monumental architecture. The Villa El Salvador and Tablada de Lurín cemeteries are from more organized but unstable agricultural societies. Huaca Malena is from one of the first Andean empires. Lastly, the skeletal collection from Armatambo represents the coastal occupation of an urban state. Table 5.2 shows the number of individuals analyzed in each collection. Unfortunately, archaeological context information for Armatambo could not be accessed at this time, as described below in the Armatambo subchapter.

Table 5.1: Chronology and Sources of Data for Sites Analyzed in this Study

	Period	Time Span	Sources
Paloma	Middle Preceramic	5850 - 2750 BC	Benfer (1990) Pechenkina et al., (2007)
Cardal	Initial Period	1800 - 900 BC	Vradenburg (1992) Pechenkina et al., (2007)
Villa El Salvador/ Tablada de Lurín	Early Intermediate	100 BC – AD 100	Pechenkina and Delgado (2006) Pechenkina et al., (2007)
Huaca Malena	Middle Horizon	AD 700 - 1100	Rhode and Abu Dalou (n.d.)
Armatambo	Late Intermediate	AD 1100 to 1470	This Study

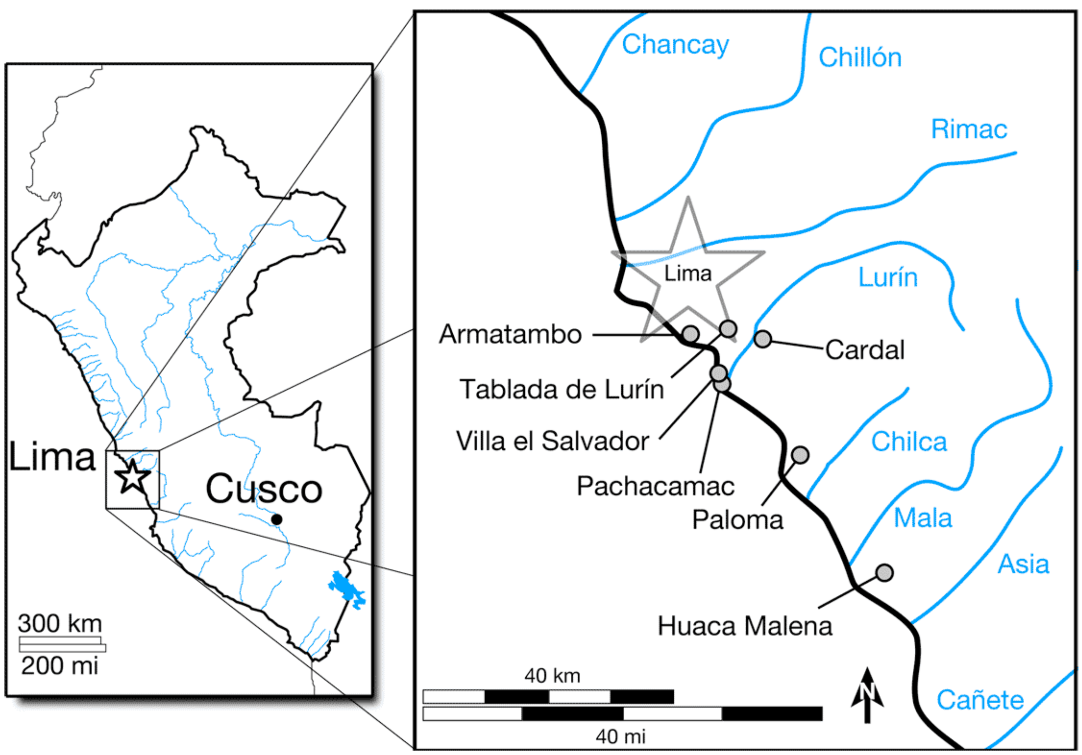


Figure 5.1: Maps of Perú, Showing Key Sites.

Table 5.2: Sample Sizes of Sites Analyzed in this Study

	Males	Females	Indeterminate	Subadults	Total n
Paloma	44	42	29	86	201
Cardal	16	14	4	14	48
Villa El Salvador/ Tablada de Lurín	67	90	5	44	206
Huaca Malena	8	8	1	2	19
Armatambo	20	21	2	13	56
Total	155	175	41	159	530

Paloma

Paloma (Middle Preceramic) is the oldest well-studied village in the central Andes (see Benfer, 1980, 1982, 1984, 1990, 1999, 2008; Benfer and Gehlert, 1980; Vradenburg et al., 1997; Pechenkina et al., 2007). The levels of occupation cover Preceramic IV and V of the Rowe-Lanning chronology (5850 to 2750BC) and are divided into three levels (400, 300, and, 200 from earliest to latest) that contain human remains. The earliest (level 600) and latest (level 100) did not produce any skeletons.

Multiple lines of evidence from Paloma show that marine resources were of primary importance. At Paloma the population reached a peak of around to 400 inhabitants, as predicted from demography and floor area using a probability sample (Vradenberg et al., 1997). These findings supported the earliest stage of the MFAC (Marine Foundations of Andean Civilization, Moseley [1981, 2004]) hypothesis (Chapter 3).

The material culture and bioarchaeology of the Paloma site indicate the inhabitants were primarily fishers who used agricultural resources from the surrounding fog oasis (*lomas*) to support their fishing subsistence strategy (Weir et al., 1988; Reitz, 2001). Shell middens attest to the importance of shellfish at the site. Remains of other sea animals such as sea lions, and many types of fish have also been recovered (Reitz, 1988, 2001).

However, although the aggregation of individuals into villages might be a precursor, Paloma does not represent a complex society. Social organization seems to be centered on the household although communal hearths were found among clusters of houses (Benfer, 2008). Most of the dead were apparently buried under the floor of what was presumed to be their own dwelling (Benfer, 1990, 2008). No signs of warfare were found.

Skeletal remains bear marks of a maritime subsistence strategy. Especially in the later level, the auditory canals of some males show pathological bone growth, external auditory exostoses, from prolonged contact with seawater (Benfer, 1990). Abdominal contents and coprolites provided considerable data on diet (Dering and Weir, 1982; Weir et al., 1988). Microscopically, trace element and isotope analysis also concur with a maritime subsistence.

Several changes in the village occurred over time. The population increased in size (Benfer, 1990). Health improved, with anemia steadily diminishing while stature increased (Pechenkina et al., 2007). Sexual dimorphism in bone robusticity declined. Local resources such as firewood were depleted, followed by a decline in local population as people moved to nearby Chilca 1 (Vradenburg et al., 1997). The faunal assemblage showed a transition from the collection of mammals and fish in the earlier level to more shellfish and more small schooling fish in the upper level (Reitz, 1988). Stable isotopes (Benfer, 2008) and trace element studies (Benfer, 1990; Edward and Benfer, 1993) showed a diet focused on marine resources. Males in the earliest strata showed evidence of more upper body muscle development, matching the change in subsistence strategy (Rhode, 2006). Most important for this dissertation, health improved over time as inferred from lower levels of cribra orbitalia (an indicator of anemia), increased stature, and decreasing percentages of deaths of children (Benfer, 1990; Vradenburg et al., 1997).

To summarize, Paloma in the Middle Preceramic was a fishing village with no sign of institutionalized social stratification, though the communal hearths suggest extended family groups. Throughout the occupation of the site, marine resources predominated, though their composition changed. Overuse of the lomas during a time of climatic stress, of desiccation, probably contributed to Paloma's abandonment in favor of a nearby river valley (Benfer, 2008).

In this dissertation, Paloma data were used from Benfer (1990) and Pechenkina and colleagues (2007).

Cardal

Cardal will give us a glimpse into the Initial Period, a time with dense settlements but without coercive hierarchical governments. Found in Cardal is the earliest studied skeletal population (Vradenburg, 1992, 2009) associated with monumental architecture, a feature almost always thought to signal class stratification (Vradenburg, 1992; Moore, 1996), although the excavators suggest that such stratification was not strong (Burger, 1987; Burger and Salazar-Burger, 1991). Located 1 km from the Lurín River, the main feature of Cardal is a U-shaped ceremonial center. The center construction dominates the site's 20 ha, of which under 3 ha is residential. Cardal was occupied from 1150 to 800 BC, matching late Initial Period style ceramics.

The subsistence strategy shows gradual change from the Middle Preceramic. Like Paloma, marine resources were important to the people of Cardal, and were the primary source of animal protein (Meadors, 1992; Umlauf, 1993; Tykot et al., 2006). Unlike the Middle Preceramic village, the majority of calories at Cardal were apparently derived from agricultural products, based on the site's proximity to prime agricultural land, plant remains, and the presence of related artifacts. Carbon isotope analysis of bone apatite suggest that maize was not as common as in a highland site of the same period (Tykot et al., 2006), despite the presence of maize phytoliths (Umlauf, 1993).

Cardal was built expressly to be a public site. The land appears to have been chosen for a monumental construction, because it is not easily arable (Burger and Salazar-Burger, 1991). The main temple of the site shows at least three phases of construction, with fill preserving friezes of the previous iteration. Surrounding the pyramid are several small sunken courts (Williams, 1980), possibly suggesting division of the inhabitants by lineages, first prefigured in the Paloma communal hearths. The residences at Cardal are compartmentalized into distinct cooking and storage areas (Burger and Salazar-Burger, 1991), similar to the final occupation of Paloma, when kitchens were reported as separate structures (Benfer, 2008).

Burials were found associated with the residences but also on the main stepped pyramid. Individuals were also found between temple phases. While sacrifices are common in the region, the temple burials resemble residential interments with a variety of ages and sexes along with associated artifacts. Burger and Salazar-Burger conclude that the top of the pyramid temple may have held a residence as well as ceremonial center towards the end of the occupation (Burger and Salazar-Burger, 1991:278, 281).

Burger and colleagues (1991) refrain from labeling the buried individuals at Cardal as “elite.” They cite several distinctly non-elite features of Cardal, including the participation of the temple residents, those who would be considered most elite, in subsistence activities and their lack of elite prestige items. Still the fact that certain individuals were interred on top of a pyramid and others were buried at its base (and hypothetically others lived in surrounding regions away from the complex) suggests that the society was not equal in some fundamental way.

Data from Cardal in Vradenburg’s thesis (1992) were used in this study.

Villa El Salvador and Tablada de Lurín

Villa El Salvador (VES) (Stothert and Ravines, 1977; Stothert, 1980; Vradenburg, 2001; Pechenkina et al., 2007) and Tablada del Lurín (TDL) (Makowski, 1994, 2006; León Canales, 1995; Tomaste Cagigao, 1998) are two Early Intermediate mortuary sites in the Lurín Valley. VES is located 1 km from Pachacamac, an important religious center, which was formed in the Early Intermediate and maintained power through the rest of Andean prehistory (Eeckhout, 2004abc; Franco Jordán, 2004, Makowski et al., 2008). Tablada de Lurín is further upstream, 4 km from Villa El Salvador (Figure 6.1).

Villa El Salvador is a cemetery site. Many burials are in seated positions facing the ocean (Pechenkina and Delgado, 2006). The cemetery appears to have been in use in the early Early Intermediate, and in disuse by the end of that phase. Previous work has found distinct ethnic groups buried at VES based on multiple lines of archaeological and bioarchaeological evidence (Pechenkina and Delgado, 2006; Rhode, 2006). For example, multidimensional scaling analysis of subadult health indicators found two distinct groups who experienced different health states (Pechenkina and Delgado, 2006). The primary dimension from multidimensional scaling also correlates with a difference in deliberate cranial deformation, supporting the hypothesis that distinct ethnic groups, marked by deformation, were present at the site.

At both Early Intermediate sites, the higher presence of maize suggests that the crop was becoming more of a staple than in the Initial Period (Falk et al., 2004). In comparison, maize was absent at Paloma and provided minimal calories at Cardal, where agriculture was rising in importance (Tykot et al., 2006).

The presence of grave goods associated with some of the burials show that localized vertical social stratification at Villa El Salvador was a more salient part of the cultures there than in Cardal or Paloma. The finding of distinct ethnic groups at VES also shows that Lurín Valley polities in the Early Intermediate were more heterogeneous than archaeology suggested (e.g. Earle, 1972).

Data from Villa El Salvador and Tablada de Lurín were obtained from Pechenkina and Delgado (2006) and Pechenkina and colleagues (2007).

Huaca Malena

Huaca Malena is a site dated to the Early Intermediate and Middle Horizon. The site is located south of the Lurín and Rímac valleys, in the Asia Valley, which was controlled by the Huari Empire. The Asia Valley is rich in resources, including agricultural land, coastal fishing, and islands of guano off the coast (used as fertilizer in agriculture through historic times). The valley is also in a prime location to control routes between the coast, altiplano, and the Huari homeland, Ayacucho (Falcón and Pozzi-Escot, 2004).

Huaca Malena has a long history of excavation as far back as 1925, by archaeologists Julio C. Tello, and Toribio Mejía Xesspe of the Museo de Arqueología y Antropología de la Universidad Mayor de San Marcos (Tello, 2005[1959]:185). Excavations at Huaca Malena site continued through the century (Menzel, 1968; Engel, 1987; Falcón and Pozzi-Escot, 2000, 2004). The site is most well known for the presence of elaborate textiles (Falcón, 2006ab).

Huaca Malena is comprised of six pyramids atop an artificial platform, which is thought to be part of a 16-hectare complex (Pozzi-Escot and Falcón, 2004). Two phases have been found, the first from the Early Intermediate, and the later from the Middle Horizon. The first phase saw the construction of monumental architecture. In the transition between phases, Huaca Malena was abandoned, but material culture from the second phase shows a new rise in prominence as an important cemetery with links to the Huari Empire (Pozzi-Escot and Falcón, 2004; Falcón, 2006a).

Three types of burials have been identified in the Huari phase at Huaca Malena: individuals were entombed in walls, placed in architectural fill, and placed obtrusively in architectural features of the previous phase (Falcón and Pozzi-Escot, 2000, 2004). In multiple burials, children are placed on top of adults. A common motif was that individuals were buried encased in elaborate bundles of textiles of wool and cotton filled with unwoven fibers and funerary offerings (Falcón and Pozzi-Escot, 2004; Falcón, 2006ab). The bundles displayed the individual's sex and occupation; for example the bundles are dressed in sexually differentiated clothing. One opened "male" bundle contained artifacts pertaining to fishing and water transportation such as fishing nets and miniature *caballitos de totora*, reed watercraft (Falcón and Pozzi-Escot, 2000). Camelid burials, probably offerings, were also found under the ramp of Platform A of the site. Huari ceramics of the Pachacamac style were found. Coastal Huari textiles of a style found at other sites in the Huari Empire were also present. Falcón and Pozzi-Escot describe four main stylistic categories: coastal Huari, central coast (e.g. Ancon and Pachacamac), Moche-Huari, and south coast (late Nasca). Unfortunately the presence of textiles and ceramics attracted looters who destroyed 65% of the platforms, and plundered the majority of the burials, disassembling the elaborate bundles (Falcón and Pozzi-Escot, 2000; Pozzi-Escot and Falcón, 2004).

Matthew P. Rhode and Ahmad Abu Dalou collected data from Huaca Malena in 2002. The author transcribed the original skeletal field data forms to a digital format. Data tables are in Appendix 2.

Armatambo

The site at the center of this dissertation is Armatambo (or Ichmatampu), a Late Intermediate to Late Horizon settlement in the Rímac river valley near the Pacific coast. The following summary draws from Díaz and Vallejo (2002), Díaz (2004), and Díaz and Vallejo (2004) unless otherwise cited. Armatambo was excavated in a salvage operation as a modern shantytown encroached on the site, destroying much of the archaeological record (Figure 5.2). Still, excavations of this site have given us important sources of data representing a prehistoric city run by an urban state. Ceramics combined with ethnohistory have identified the Late Intermediate inhabitants of Armatambo as the Ychsma (Díaz, 2004; see Feltham and Eeckhout [2004] for a description of Ychsma ceramics).

The role of Armatambo in Ychsma culture is still being explored. The site may have been the center of the Ychsma (or Ichma, Ychsma, or Ychima) culture in the Late Intermediate Period from 1000 to 1469 AD. However, Rostworowski de Diez Canseco (1988) sees Pachacamac as the religious and administrative center for the Ychsma. A median view is that both urban areas were important Ychsma centers and closely linked (Franco Jordán, 2004). The Armatambo site location is prime for a coastal settlement: it is protected from winds, has a view of Pachacamac, and was fed by the Surco Canal, which still irrigates the valley today (Torres López, 2008). Several types of structures have been identified in the 100 ha town, including pyramids, elite residences, and lower class dwellings. Compared to the other non-state sites in this study, Armatambo is the most urban with the greatest population and population density.

The Ychsma dead were wrapped in funerary bundles of cotton and small items, and then placed singly in pits (Díaz and Vallejo, 2002, 2004). Bodies within these bundles were in a flexed position. A few offerings of ceramics were typically present placed around the bundle in a semicircle.

The skeletal collection examined in this dissertation is one of several from prehistoric Armatambo. Specifically, this collection was excavated in the modern town of Asientamiento Humano Héroes del Pacífico (Human Settlement "Heroes of the Pacific," named after the Peruvian combatants in the 1879-1884 War of the Pacific). This skeletal collection will be referred to simply as Armatambo in this dissertation. The burials were excavated by a team led by Maritza Perez Ponce in 1997 (Perez Ponce, personal communication, 2010). I collected data from the

Armatambo skeletal collection with the assistance of two field schools, as detailed in the next chapter.

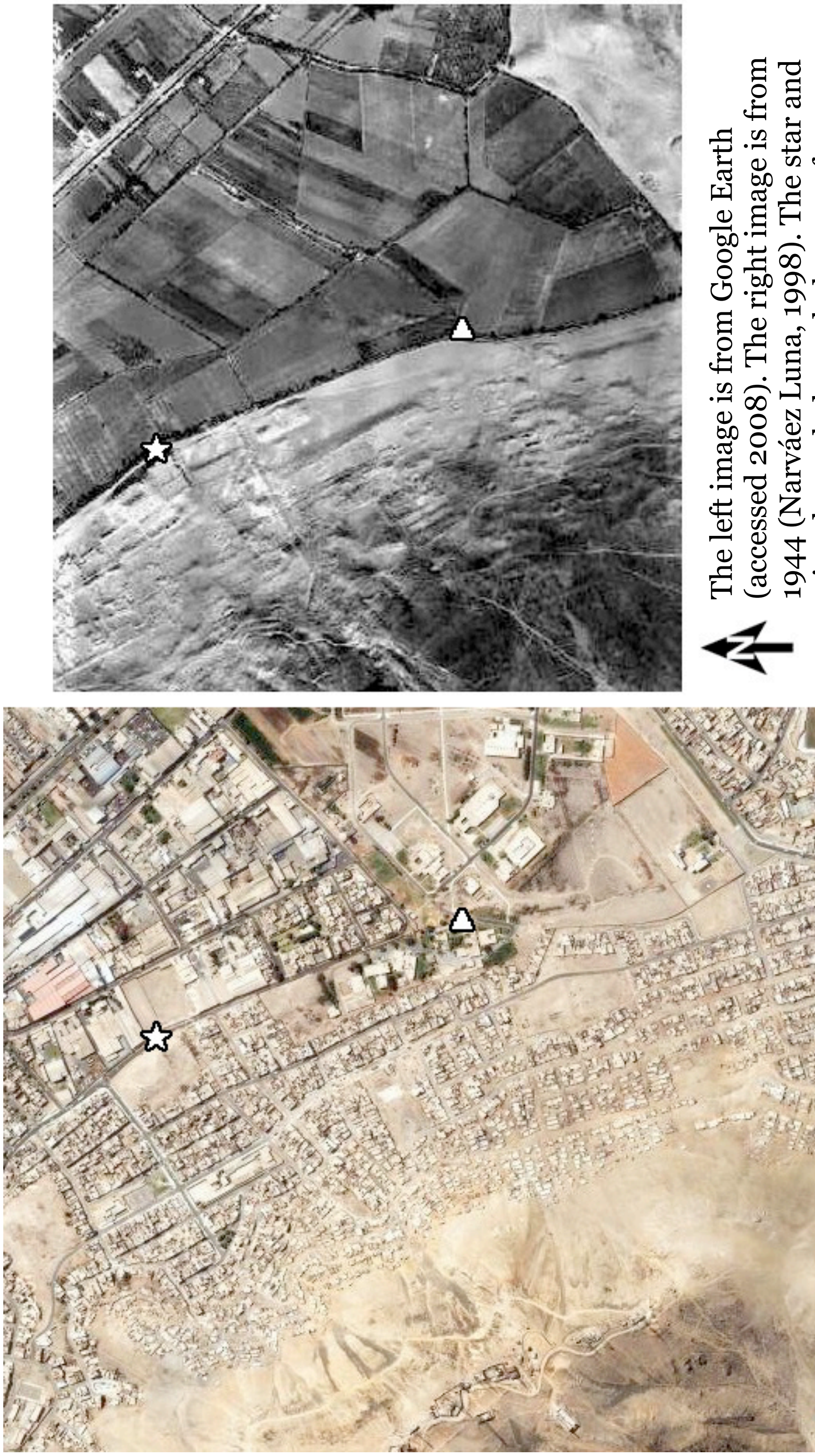
ARCHAEOLOGICAL CONTEXT OF THE ARMATAMBO SKELETAL POPULATION

Archaeological context is a source of information on the Armatambo skeletal population that unfortunately cannot be used at this time. I am working closely with the lead excavator of this collection to find out more about the mortuary context, including burial placement and associated artifacts. As is the nature of international collaboration, gaining access to information on the archaeological context of the Armatambo skeletal population has taken longer than expected. As a result, information on the archaeological context of the Armatambo skeletal population was not available at the time of this study.

Appendix 3 does contain a small amount of information on each burial, gleaned from the 2007 data collection. This information includes notable pathologies that were not part of the statistical analysis and also descriptions of artifacts that were found comingled with the archived skeletal remains.

Summary

The sites chosen for this study provide interesting contrasts to the urban city of Armatambo. The next chapter will detail the bioarchaeological tools used to study the skeletal remains from these six sites.



The left image is from Google Earth (accessed 2008). The right image is from 1944 (Narváez Luna, 1998). The star and triangle symbols mark the same features on each picture, the border between modern agricultural fields and the archaeological site. The right half is mostly agricultural fields. By 2008, modern constructions have covered much of the area.

Figure 5.2: Satellite and Aerial Imagery of Armatambo.

CHAPTER 6: METHODS

This chapter will describe the methods used in data collection and analysis of this dissertation. The first section details the data collection seasons for the Armatambo skeletal collection. Then the bioarchaeological indicators of physiological stress used in this dissertation will be reviewed in detail. For each indicator, the efficacy for answering bioarchaeological questions will be evaluated followed by a review of its use in Andean bioarchaeology, and lastly a description of how the data were collected. The last section of this chapter describes the statistical analyses used in this study.

Data Collection of the Armatambo Skeletal Collection

Data collection occurred over two sessions, the first in June and July of 2007, and the second in May of 2009. Both sessions took place at the Museo Nacional de Arqueología, Antropología, e Historia del Perú (MNAAHP) in Lima, where the remains are curated. In the 2007 season, a bioarchaeological field school through the University of Missouri-Columbia (MU) collected data on the Armatambo collection. This field school was organized by Robert Benfer and the author, and included students from the United States and Perú. The data include a skeletal inventory, sex and age estimations, selected measurements, pathology, and photographs. While the MU standards of skeletal data collection (based on standard methods from Buikstra and Ubelaker [1994], Bass [1995], and Burns [1999]) were followed, I created and used new forms to increase efficiency, using feedback from the students and observations of their work flow (Appendix 4). The second session involved the Anthropological Radiography Group (ARG), led by Kathleen Forgey and Dawn Sturk, along with a team of ten radiography and anthropology students. I was present to teach the basics of bioarchaeology to these students using the Armatambo collection, and also to choose the burials to be radiographed. The ARG radiographed a sample of the skeletal collection, focusing on the skull, tibiae, femora, and humerae. Anterior-posterior and lateral views were taken of each element.

During the 2009 field school, the portable radiograph experienced a malfunction when the switch that controlled the X-ray tube was stuck in the on position, causing the tube to burn out and need replacement. The problem was fixed, but several days of data collection were lost. As a result fewer individuals than anticipated were radiographed in the 2009 data collection session. Sample sizes in intra-Armatambo Harris line analyses, which depend on radiographs of long bones, were lower than desired, and the data set is not completely representative of the skeletal population in terms of the distribution of sex and age; by chance, younger adult males and older adult females were radiographed in the time available, while younger females and older males were not. Still, statistical analysis can remove age at death as a confounding variable when comparing Harris line counts, as discussed below.

Estimation of Sex

Sex was estimated from individuals in the Armatambo collection through the evaluation of a suite of traits in the pelvis and cranium following Buikstra and Ubelaker (1994), as well as the diameter of the humeral and femoral heads (Bass, 1995). None of the stress indicators in this study were used to estimate sex. A final estimate was given after looking for any trend in these data. In most cases, the majority of indicators agreed on sex; only one adult, missing a pelvis, was labeled indeterminate. The humeral and femoral head diameters alone were found to produce many indeterminate results in the Armatambo collection. For subadults, sex estimation was attempted using traits of the ilium following (Schutkowski, 1993; though see Cardoso and Saunders, 2008) though these data were not used in analysis.

Estimation of Age at Death

Age was estimated using a variety of techniques collected by Buikstra and Ubelaker (1994) and Bass (1995). Subadults were aged using dental eruption patterns and the epiphyseal union sequence. Ages for adults were primarily obtained through the Suchey-Brooks pubic symphysis system, along with the auricular surface of the ilium. Cranial sutures were used when the pelvis was not available. The 2007 team also estimated age from sternal rib ends, but estimates from this indicator were found to be far from those of the other estimators. As a group, the 2007 team decided to give sternal rib ends less weight than the pubic symphysis and auricular surface in arriving at a final estimation of age.

Interobserver Error

The 2007 field school collected most of the data from the Armatambo collection, which raises issues of interobserver error (discrepancies in measurements between independent investigators). However, several features of the 2007 field school reduced interobserver error. The field school was kept small, with five students total (four from the United States and one Peruvian). The students were split into two teams, each working on separate burials. When a team finished data collection for a burial, they presented their findings to the other team as well as Dr. Benfer and myself. Also, since there were two instructors for five students, the students had close supervision as data were collected. The small class size and frequent collaboration kept the team consistent in their recording of data.

Bioarchaeological Indicators of Physiological Stress

This section will describe the specific indicators of physiological stress collected in the sessions mentioned above.

Nine indicators of physiological stress measured from the skeleton will be used to estimate best the health of these ancient populations (Table 6.1). Indicators representing subadult health are: Harris lines in children and adults, maximum tibia length, corrected subadult age estimate (CSAE), responses to chronic anemia, and chronic osteoperiostitis. Adult age at death, degenerative joint disease, trauma, and chronic osteoperiostitis will provide an index of adult health.

One common indicator of stress will not be used in this study: tooth hypoplasias. While tooth hypoplasias are a powerful indicator of subadult health because the age of formation can be estimated, whole teeth have to be present for statistical analysis (Goodman and Rose, 1990). During the 2007 field school, I found that the high occurrence of extreme tooth wear in the Armatambo collection prevented the scoring of all but a few teeth, rendering tooth hypoplasias unobservable in this population.

Table 6.1: List of Stress Indicators Used in This Study

Indicator	Measured in Subadults or Adults	Indicates Stress in Subadults or Adults	Stressor Indicated
Harris Lines	Both	Subadults	Episodic physiological stress during growth and development.
Corrected Subadult Age Estimate	Subadults	Subadults	General health during early growth and development.
Maximum Tibia Length	Adults	Subadults	General health during later growth and development.
Cribra Orbitalia	Both	Subadults	Chronic anemia.
Porotic Hyperostosis	Both	Subadults	Chronic anemia.
Osteoperiostitis	Both	Both	Chronic bacterial infection.
Age at Death	Adults	Adults	General adult health.
Degenerative Joint Disease	Adults	Adults	Physical activity levels.
Trauma	Adults	Adults	Lifeway resulting in physical injury.

Bioarchaeological Indicators of Physiological Stress in Subadults

HARRIS LINES

A Harris line is a band of dense bone that has been associated with the subadult experience of many forms of physiological stress, including nutritional and physical (Harris, 1926, 1931; Follis and Park, 1952; Park, 1964)(Figure 6.1). Since there are many possible causes, Harris lines are considered a non-specific indicator of stress (NSIS). A single Harris line is indicative of a discrete stress event where growth is stalled and then recovers. Even though Harris lines mark interruptions to growth, the presence of Harris lines does not necessarily correlate with lower limb bone length, showing that confounding factors besides episodic stress determine limb bone length attained (Nowak and Piontek, 2002a). If one estimates the age of line formation, a fairly precise association between line formation and stress episodes can be achieved (Garn, 1967; Clarke, 1982; Maat, 1984; Byers, 1991; Farnum, 1996; Suter et al., 2008). The ability to show discrete stress episodes makes Harris lines very useful in determining the timing of subadult stress events.

A few issues complicate use of Harris lines in bioarchaeology. One is that Harris lines are only accessible through radiographs, which require extra effort and equipment to obtain. As such, radiographs and thus Harris line counts are not available for all of the collections in this study, as detailed below.

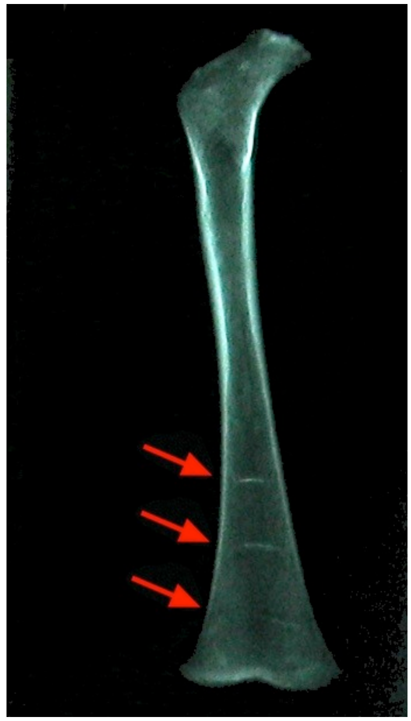


Figure 6.1: Three Visible Harris Lines on the Right Femur. ENT 49A (age at death ~4 years) from Armatambo.

Another problem affects the accuracy of Harris lines as a physiological stress indicator: bone remodeling has the potential to remove Harris lines, causing underestimation of the number of stress events in an individual (McHenry, 1968; Hughes et al., 1996; Grolleau-Raoux et al., 1997; Nowak and Piontek, 2002b). Bone remodeling is the natural process of replacing old bone with new material (White and Folkens, 2000; Lieberman et al., 2003). The remodeling effect on Harris lines is especially strong in older individuals, as their bone has had more time to remodel. Further complicating the issue, the rate of bone remodeling is not constant through life: the rate increases with age (Lieberman et al., 2003). If a significant correlation is found between the number of lines and age at death, the relationship between Harris line frequency and age has to be accounted for during statistical analysis.

Bioarchaeologists working in the Andean region have explored the use of Harris lines as an indicator of physiological stress. Allison and colleagues (1974) published an extensive study of Harris lines in the Andean region from prehistory to modern times. The study found that highland peoples had fewer Harris lines, indicating better subadult health than coastal peoples. Ubelaker (1981) noted Harris line counts in the skeletal collection from Ayalán, a site in coastal Ecuador. Eleven percent of adults (15 of 133) and 8% of subadults (4 of 50) showed Harris lines. A difference in the number of Harris line counts per individual appeared between individuals in two different types of burials: burials in urns had fewer lines than individuals not buried in urns. Estimating the age of formation, Ubelaker found that lines were most common in the seventh year of life. Williams (1983) examined Harris lines in the Paloma collection, one of the sites analyzed in this dissertation. She found a decrease in Harris line counts in males, but not females, across two phases of the occupation. Other studies mention the presence or absence of Harris lines without placing them in the framework of statistical analysis (Rosado and Vernacchio-Wilson, 2006). Previgliano and colleagues (2003) found no Harris lines in three mummified sacrificial children from the Late Horizon. The researchers concluded that these sacrifices were from a high social class since they lacked indicators of stress episodes.

COLLECTION OF HARRIS LINE DATA

In this dissertation, Harris lines were counted from anterior-posterior radiographs of the tibia and femur. I recorded Harris line counts for all of the collections in this study to eliminate interobserver error. Harris lines were counted using digitalized radiographs. For the Paloma collection, I used a digital camera to photograph each radiograph while it was lit using a light box. Kate Pechenkina, lead investigator of the VES skeletal collection, gave me digital files of the VES radiographs. For the Armatambo collection, I used digital photographs of the Armatambo radiographs, which were taken soon after the radiographs were dry from the development process.

The various sources of the digital photographs of radiographs meant that it was important to account for differences in photograph quality. If the camera or lighting conditions used to photograph the radiographs for one of the collections produced darker images than the other two collections, then the set with the darker images will be biased towards lower Harris line counts. To prevent bias due to photograph quality, image-editing software was used to adjust the levels of light and dark in each photograph. I used the "Levels" function in Adobe Photoshop CS4 to manipulate each photograph. Figure 6.2 shows the Levels window in the program. By moving the sliders along the x-axis of the histogram, the relative difference in brightness between light and dark areas are changed. The black slider to the left sets the black point, the level of darkness that is rendered as complete black in the image. The white slider on the right sets the white point, the level of brightness that is pure white. Moving these sliders back and forth reveals Harris lines hidden by suboptimal exposure of both the radiograph and photograph.

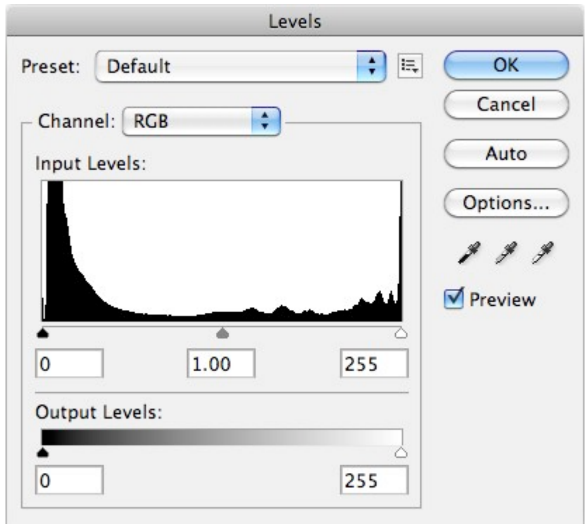


Figure 6.2: Levels Controls in Adobe Photoshop CS4

Specific criteria were used in determining whether a Harris line is present in a radiograph. A Harris line was counted if it is a thin band of dense bone that extends at least 1/4 of the width of the bone perpendicular to the long axis. Furthermore, the angle of the line relative to the wide axis had to be less than approximately 45 degrees. Lines originating from the medial and lateral edges of the shaft that intersect in the middle of the medullary cavity were counted as one line. When paired limb bones were present for an individual, the element with the most lines was used for analysis, to provide an estimate of the maximum number of discrete stress events the individual experienced. Using the higher count rather than an average of both limbs also allowed statistical techniques requiring whole integer count data to be used.

CORRECTED SUBADULT AGE ESTIMATE (CSAE)

Two separate measures of subadult age can be used to produce a stress indicator based on missed growth potential. Age predicted by subadult limb bone length is subtracted from that predicted by dental age, in order to provide an index of cross-sectional growth rate for children (Demirjian et al., 1985; Demirjian, 1986; Saunders et al., 1993). Dental age can act as a reference point for true chronological age since dental development is more genetically controlled and thus less subject to delay due to environmental stress. Dental age was estimated using the diagrams of Native American tooth eruption states found in Buikstra and Ubelaker (1994).

COLLECTION OF CORRECTED SUBADULT AGE ESTIMATE DATA

CSAE data involved a circuitous method of data transformation. Statistical tests of significance using the CSAE requires a test statistic based on the estimate of age from subadult femur length to be subtracted from an estimate of age from dental eruption rates. Pechenkina et al., (2007:109) provided means of femur lengths grouped by dental age estimates from birth to six years of age. Data from Armatambo, Cardal, and Huaca Malena were manipulated to fit the same format so that all data could be compared.

Arriving at age estimates from mean subadult femur lengths proved difficult. While Bass (1995) presents a data table of age estimation based on femur length after Johnston (1962), no equation is given to make point predictions suitable for statistical analysis. To remedy the lack of an equation for prediction, curve estimation software was consulted to create an equation for a line approximating the data table. The curve estimation functions of SPSS 17 were not able to generate a curve that adequately fits the range of the data without increased error as age increased. An online curve-fitting tool (found at http://www.zunzun.com) was used instead. The 2D function finder feature at zunzun.com was used on the Johnston (1962) data set with the criterion of fitting an equation with the lowest sum of squared absolute error. While none of the formulae satisfactorily fit the entire range of the Johnston data, the "modified geometric equation" was chosen because it produced the lowest squared absolute error for the range used in this study: ages 0 to 6 years. The equation produced by zunzun.com was:

$$y = 135.91x^{\left(\frac{-26.34}{x}\right)}$$

with y the estimated age in years, and x the femur length in centimeters. The equation generated estimated ages from the mean subadult femur lengths in each age bracket of the data set. These estimated ages are then subtracted from the dental age estimation from the same individual to arrive at a value representing the amount of stress affecting bone growth, the CSAE. Higher values represent more stress. In statistical analysis, each CSAE value for each age bracket was weighed by the bracket's sample size to reflect the distribution of the original data set.

MAXIMUM TIBIA LENGTH

Maximum tibia length is used as a proxy for stature. Stature is perhaps the best bioarchaeological NSIS of general subadult stress, especially insults to the immune system (Elo and Preston, 1992; Jantz and Jantz, 1999). While maximum potential for growth is genetically determined, growth rates and actual growth attained has strong environmental influences (Habicht et al., 1974). Adult stature represents the summation of stress events during growth and development while the stature of subadults is an indicator of childhood health (Tanner, 1981). There is a near perfect correlation between class and stature in modern societies, allowing stature to be used as an indicator of social status in economics (Komlos, 1994; Bogin, 1999; Steckel and Rose, 2002). Stature has also been used to gauge health in past peoples (e.g. Hoppa and Fitzgerald, 1999; Pechenkina et al., 2002; Steckel and Rose, 2002; Zakrzewski, 2003; Holt and Formicola, 2008; Raxter et al., 2008; Temple, 2008).

While stature can be measured precisely in modern individuals, stature has to be estimated in a skeletal collection. Variations of a technique called the Fully method estimate stature using measurements from all of the skeletal elements that contribute to standing height (Fully, 1956; Raxter et al., 2007, 2008). While accurate, the Fully method requires a near complete skeleton to retain its accuracy. Estimation of stature based on limb bones has also been explored (e.g. Pearson 1898; Trotter and Gleser, 1951, 1952, 1958). Stature estimation equations exist for ancient populations (e.g. Sciulli et al., 1990; Raxter et al., 2008; Auerbach and Ruff, 2010) but the regression process reduces the variability of the data, hindering its utility as a stress indicator. It is more parsimonious and statistically sound to use lower limb bone length itself as a proxy for adult stature to avoid the loss of variation caused by stature prediction formulae (Benfer, 1997; Pechenkina et al., 2007). The loss in variation due to the use of regression, calculated by subtracting the r-squared value from unity, approaches forty percent.

This study will use the maximum length of the tibia as an estimate of full adult stature (Buikstra and Ubelaker, 1994). Though the femur contributes more to stature, the tibia has shown higher plasticity than the femur, as it is more sensitive to environmental stress. Its length measures the effect of growth disruption, if any, during subadulthood.

Like Harris lines, maximum tibia length in adults may not accurately reflect subadult stress. "Catch-up growth," how the body compensates for past deficient growth in a later growth period (Cameron et al., 2005), reduces the accuracy of maximum tibia length as a stress indicator. Catch-up growth has been accounted for in longitudinal studies of living people (Black et al., 1984; Adair, 1999), but is more difficult in an archaeological population (Wall, 1991; Pinhasi, 2008). One strategy is to consider Harris lines and limb bone length together to detect instances of catch-up growth following physiological stress events (Mays, 1985, 1995). However the appearance of catch-up growth is variable. Some studies have not found catch-up growth in their samples (Martorell et al., 1994; Checkley et al., 2003; Assis et al., 2005). Differences in the age span examined in the study and type of measurement may be the reason behind these different conclusions. Also, catch-up growth may require improved health in later subadulthood, which may not be true across studies (Stinson, 1985; Allen and Uauy 1994; King and Ulijaszek, 1999).

COLLECTION OF MAXIMUM TIBIA LENGTH DATA

The 2007 field school participants recorded long bone lengths, including the tibiae, in tenths of centimeters using an osteometric board, following Buikstra and Ubelaker (1994). When both tibiae were present, the values were averaged.

POROTIC HYPEROSTOSIS AND CRIBRA ORBITALIA

Porotic hyperostosis (PH) is the general manifestation of bony response to marrow hypoplasia caused by chronic anemia, of which cribra orbitalia (CO) is a specific type (Schultz et al., 2001; Ortner, 2003). Both are considered NSIS. While iron-deficiency anemia, caused by disease, iron-deficient diet, or parasites, has traditionally been acknowledged as the cause of PH and CO (Hengen, 1971; Carlson et al., 1974; Stuart-Macadam, 1985, 1987, 1989, 1992; Holland and O'Brien, 1997), recent research suggests that megaloblastic anemia caused by vitamin B12 deficiency combined with unsanitary living conditions is a more etiologically-sound cause (Walker et al., 2009). In either case, anemia leads to marrow hypoplasia, wherein the body increases bone diploë (spongy marrow-containing bone) to create more red blood cells in response to low oxygen levels in the bloodstream. For children, the areas where marrow hypoplasias occur are the cranial vault and roof of the orbits. As a result, PH is typically found on the cranial vault of children past six months of age and, in its healed state, in adults (Mittler and Van Gerven, 1994; Blom et al., 2005). Cribra orbitalia manifests on the underside of the orbital roof (e.g. Cohen and Armelagos, 1984; Sullivan, 2005; Slaus, 2008; but see Wapler et al., 2004)(Figure 6.3). It has been suggested that CO is an earlier form of PH in children (Farnum, 2002; Blom et al., 2005).

Figure 6.3: Cribra Orbitalia on the Left Orbital Roof. (ENT 13 [~5 years] from Armatambo).

Cribra orbitalia and porotic hyperostosis have been used extensively in the bioarchaeology of the Andes. In this region, the presence of PH and CO appear to have increased over time from the Preceramic on (Pechenkina et al., 2007), to the Early to Late Intermediate Periods (Blom et al., 2005), and through early colonial times (Klaus, 2008a). The issue of artificial cranial deformation and its effect on the manifestation of porotic hyperostosis has also been examined and found to be manageable (Blom et al., 2005; Pechenkina and Delgado, 2006). While cranial deformation, a cultural practice found in the Andes, acts strongly on the same area of the cranium that expresses PH, careful interpretation can differentiate porosity due to PH from that which was caused by deformation.

COLLECTION OF CRIBRA ORBITALIA AND POROTIC HYPEROSTOSIS DATA

In this study, the 2007 field school team recorded PH and CO using visual examination without magnification. First, we noted the presence or absence of PH and CO (coded as 1 and 0, respectively). If present, the severity was also recorded as slight, moderate, or severe, (1, 2, and 3). Lastly, we looked for signs of healing (0 for lack of healing, 1 for healing).

PERIOSTEAL LESIONS

Periosteal lesions are NSIS that manifest as abnormal bone growth or bone loss. Lesions could be the result of a number of systemic infections as well as trauma (Cohen and Armelagos, 1984; Ortner, 2003; Steckel and Rose, 2002). In particular, only potent chronic disease processes are able to cause bony response; acute infections would either kill the subject or be eradicated by the immune system before they could alter bone. Bones are also highly resistant to infection relative to other tissues (Waldvogel, 1997).

Some confusion exists between the uses of descriptive terms for periosteal lesions resulting from osteoperiostitis (Ortner, 2003). In paleopathology, osteomyelitis is used to describe infection when it occurs in the marrow cavity. Periostitis is used when the bone lesions are only on the surface with no marrow cavity activity or cloaca, bone pores that drain accumulated pus from the internal structure of the bone (Figure 6.4). In the medical literature, osteomyelitis is used more liberally for bone infection caused by bacteria and periostitis is reserved specifically for infections of a bone's outer membranous covering, the periosteum (Lew and Waldvogel, 2004). The variability in term usage between fields exists because the purposes of these descriptive words differ. In medicine, osteomyelitis and periostitis serve as diagnoses based on an evaluation of symptoms and other evidence (e.g. life history). In paleopathology the same words are used only to describe observations of bone pathology with no assumption of medical diagnosis (Buikstra and Cook, 1980; Ortner and Aufderheide, 1991; Ortner, 2003; Grauer, 2008). This study will use the standards used in paleopathology unless specifically stated otherwise.

Most common types of bacteria that would produce periosteal lesions include *Staphyloccocus* and *Streptococcus* (Lew and Waldvogel, 2004; Ortner, 2003). In general, lesions appear on bones, especially vertebrae and long bones of the lower limb, as abnormal bone deposition or resorption (Lew and

Waldvogel, 2004). These lesions are the result of concurrent processes in which the immune response of leukocytes (white blood cells) lyse (dissolve) parts of the bone, cause pus to accumulate, which then stimulates new growth on the periosteum (Nair et al., 1996). Byproducts of the infectious bacteria may also produce molecules that stimulate bone resorption or deposition. Some infections, such as those caused by members of *Treponema pallidum*, are transmitted by interpersonal contact and spread systematically.

Figure 6.4: Severe Periostitis Seen on the Tibiae. (ENT 71 [male, ~25 years] from Armatambo). The medial aspect of the right tibia (top) and the anterior side of the left tibia (bottom) faces are visible. The color of this photograph has been digitally enhanced to show detail.

While assigning a case of osteoperiostitis to a specific cause is difficult if not impossible in paleopathology due to the lack of soft tissue and patient testimony, some particular patterns of pathology have been associated with certain diseases. Periostitis of the sternum, vertebrae, and ribs has been linked with tuberculosis, with infections focused on bones protecting the lungs (Spigelman et al., 1997; Roberts et al., 1998; McLellan et al., 2000; Donoghue et al., 2005). Periosteal lesions can also be caused by trauma that reaches bone. Lesions caused by trauma are especially common on the tibia since the anterior crest is close to the surface of the lower leg. Etiologically, lesions caused by trauma are contained to the impacted region while systemic infections cause bony response on multiple elements, symmetrically on the body (Ortner, 2003). Intense repeated activity may also cause changes visible in bone. Medically-defined periostitis, which may produce changes to cortical bone, has been found in athletes, caused by physical stress from the overuse of muscles (Meese et al., 1996).

In Perú, the symmetrical occurrence of periosteal lesions has been interpreted as treponemal disease, caused by members of *Treponema pallidum*, such as syphilis. (e.g. Vradenburg, 2001). The frequency of these lesions, most common on the tibia, increased and then decreased in pre-Inca times. Lesions were common on subadults at Paloma and Cardal, but minimal in the Villa El Salvador and Tablada de Lurín sample (Pechenkina et al., 2007). A second decline in treponemal infection prevalence in the Middle Horizon was also proposed. After the Inca Period, during the Spanish colonialism in the Lambayeque Valley in the north coast, lesions were found to have increased sharply again, supporting the hypothesis of worsening health in that period (Klaus, 2008ab).

COLLECTION OF OSTEOPERIOSTITIS DATA

The 2007 field school's visual examination of each bone noted the presence or absence of osteoperiostitis. Severity was also measured and compared using the same ordinal system as for cribra orbitalia. Since trauma (see below) can cause localized bone activity, periostitis was not coded as non-specific if it co-occurred with visible trauma (following Slaus, 2008).

Bioarchaeological Indicators of Physiological Stress in Adults

Besides osteoperiostitis, three other indicators will allow us to gauge adult health in Armatambo: age at death, degenerative joint disease, and trauma. In general, indicators of adult health are more elusive because the skeleton at that stage of life is no longer actively modeling except in certain cases such as in response to breakage, arthritic lipping, or other joint disease (White and Folkens, 2000).

AGE AT DEATH

Age at death is when an individual dies and enters the skeletal population. While age at death is often used as a variable to test other stress indicators for statistical significance, it can also be used as an indicator of its own. Dying at an earlier age suggests frailty stemming from biocultural factors, assuming that the majority of deaths are not randomly caused (Wood et al., 1992). The inverse of the average age at death estimates the crude birth and death rates in a stable population, while in a nonstationary population, the death rate is misestimated (Sattenspiel and Harpending 1983).

Caution has to be used in using low mean age at death as an indicator of poor health since fertility and mortality both affect the age range of a skeletal population (Sattenspiel and Harpending, 1983; Johansson and Horowitz, 1986; Wood et al., 1992; McCaa, 2002). In particular, fertility has a larger effect on age-at-death distributions than mortality in populations that have experienced a recent dramatic change in fertility, though this case is not likely in non-contraceptive populations (Milner et al., 1989).

One additional complication of using age at death as an indicator of fertility is that population growth through migration causes the same result in paleodemographic data–a decrease in mean age at death– due to the immigration of a younger segment of the population, some of which will die in their new home (Sattenspiel and Harpending, 1983). While some researchers have found reason to assume a stationary population (Benfer 1990; Eshed et al., 2004; Nagaoka and Hirata, 2007), this assumption has to be scrutinized especially in more urban settlements.

The accuracy of age at death estimates based on features of the skeleton has also been cited as an issue in using age at death as an indicator of population health (Bocquet-Appel and Masset, 1982; but see Van Gerven and Armelagos, 1983; Hoppa and Vaupel, 2002; reviewed in Jackes, 2000; and Pinhasi, 2008).

Several studies have found directional bias in various age indicators when used outside of their original context, for example, cranial sutures (Saunders et al., 1992), rib ends (Saunders et al., 1992, Loth and Iscan, 1989, Schmitt and Murail, 2004), auricular surface of the ilium (Saunders et al., 1992, Schmitt, 2004, Nagaoka and Hirata, 2007), and pubic symphysis (Hoppa, 2000). A loss of precision in older individuals was a common finding (Saunders et al., 1992, Wittwer-Backofen et al., 2008). In contrast, other studies have found that age indicators can be accurately used across populations (Yavuz et al., 1998, Garamendi et al., 2007). Since investigators now use the same set of indicators, specifically the ones described in Buikstra and Ubelaker (1994), comparisons across populations are merited even if the actual age differs consistently from the true age.

There are ways to limit the uncertainties of using age at death as an indicator of health. Consideration of multiple age indicators is one solution to the variable precision of age indicators, though there can be researcher bias in what indicators are judged to be more accurate (Lovejoy et al., 1985). Another option is to use wider age groups in statistical analysis, for example by decade, in order to reduce the effect of error from estimation bias (Ubelaker, 1974).

In the Andes, the age at death of populations at several sites have previously been explored. In Middle Preceramic Paloma, the earliest site used in this study, Benfer (1990) found increasing life expectancy and decreasing fertility over time. A study of age at death from the Nasca (end of the Early Horizon to Early Intermediate Periods) to Huari (Middle Horizon) cultures in the Nasca

Valley found more juvenile deaths in the later group (Drusini et al., 2001). The researchers interpret this result as showing worse health in the Middle Horizon since mean age at death was lower at that time than in the Nasca period. This dissertation includes skeletal populations from the Early Intermediate and Middle Horizon as well, allowing for another look at age at death between these periods.

Methods used in the collection of age at death estimations were detailed above.

Degenerative Joint Disease

Arthritic bone growth develops from repeated physical stressors on the musculoskeletal system (Bridges, 1992; Conaghan, 2002; Weiss and Jurmain, 2007). Along with infection and trauma, arthritis ranks as one of the most common types of skeletal pathology seen in the bioarchaeological record (Ortner, 2003; Lieverse et al., 2007). The many manifestations of abnormal bone growth at joint sites are covered under the descriptors osteoarthrosis, osteoarthritis, or "degenerative joint disease" (DJD).

Osteoarthritis has a varied etiology. DJD can appear on the joint surface itself or on its periphery (Figure 6.5). Pitting and eburnation (a polishing from repeated contact) are found on the surfaces of affected joints (Sokoloff, 1969). Bordering the joint surface, osteophytes (bony projections) and osteophytic lipping can form in response to joint stress. Common afflicted bones include the vertebrae, lower limb bones and the pelvis, as well as the upper limb bones, clavicles and scapulae.

Two special categories of DJD are studied in this dissertation. Schmorl's nodes are lesions that form on the joint surface of a vertebral body due to a prolapsed (slipped) cartilage disc (Schmorl, 1929; Faccia and Williams, 2008). Ankylosing spondylitis is the term for the fusing of the vertebrae (Ruffer, 1918; Bridges, 1992), though some researchers differentiate it from similar conditions such as diffuse idiopathic skeletal hyperostosis (DISH), caused by the ossification of vertebral elements, which fuses the bodies (Resnick, 1976; Rogers et al., 1985; Crubezy and Trinkaus, 1992; Arriaza et al., 1993; Rogers and Waldron, 2001). Rogers and colleagues (1985) found that early studies describing ankylosing spondylitis were mostly likely DISH as evidenced by the latter's "dripping wax" appearance on the anterior surface of the vertebral bodies. Due to the lack of exposure by paleopathologists to DISH, research on this disease is lacking, rendering cross-study comparisons difficult (Arriaza et al., 1993).

As the confusion between ankylosing spondylitis and DISH shows, analysis of degenerative joint disease lacks the standardization found in other indicators such as Harris lines. Some researchers recommend differentiating between different manifestations of DJD to give a finer view of mechanical stresses on the skeleton (Lovell, 1994; Maat et al., 1995; Sofaer Derevenski, 2000; Weiss and Jurmain, 2007). For example, a study of modern cases of Schmorl's nodes found that those located near the center of the vertebral body are likely to cause noticeable pain, especially when associated with osteophytes, projections of bone around the joint's edges. The association between Schmorl's nodes and pain in life can then be used to inform bioarchaeological reconstructions (Faccia and Williams, 2008). Rojas-Sepúlveda and colleagues (2008) tested a variety of grouping variables in an effort to move towards a standardized measure of DJD prevalence for cross-study comparison. They found that a method named "pitting excluded," whereby any indicator of DJD except for pitting in isolation was counted as indicating the presence of the disease, was the most accurate.

Similar to other bioarchaeological indicators of health, care has to be taken to not consider confounding factors that alter the relationship between degenerative joint pathology and high mechanical stress. A number of factors influence the appearance of joint disease, including variation in genetics, physiology, and biochemistry (Kellgren and Moore, 1952; Sokoloff, 1969; Rogers et al., 1987; Bullough, 1992, 1998; Sandell and Aigner, 2001, Weiss, 2005, Weiss and Jurmain, 2007; Brown et al., 2008; Ward et al., 2010). Age is a particularly important factor in DJD prevalence. A wide survey of archaeological skeletal material found that formations on the margins of joints are more likely to appear with advanced age (Jurmain, 1991; Maat et al., 1995; Knusel et al., 1997). Experiments on cadavers have found that indicators of DJD on the vertebrae are correlated with increased cartilage loss caused by high mechanical loading of the spinal column, a relationship that is strongest in older individuals (Brown et al., 2008).

Figure 6.5: Severe Joint Lipping of the Distal Right Femur. (ENT 42 [male, ~40 years] from Armatambo).

The limits of degenerative joint disease as an indicator of stress are still being explored. Unfortunately, DJD has for the most part proven unreliable in determining specific activities due to the complex synergy of the musculoskeletal system and the confounding factors mentioned above (Rogers et al., 1987; Waldron and Cox, 1989; Rogers and Dieppe, 1990; Knusel et al., 1997; Jurmain, 1999; Weiss, 2006; Weiss and Jurmain, 2007; though see Wells, 1962 1963; Walker and Hollimon, 1989; Gerszten et al., 2001; Cope et al., 2005). Instead, success has been found in differentiating specialized use of muscle groups or regions of the body such as the knee or elbow joints (Lieverse et al., 2007). Another promising approach is comparing DJD between the sexes to answer questions about sexual division of labor (Walker and Hollimon, 1989; Sofaer

Derevenski, 2000; Lieverse et al., 2007), though caution has to be used to ensure that physiological differences between sexes are not causing differential expression (Weiss and Jurmain, 2007).

The use of DJD is especially relevant to this dissertation because an impact on health due to intense labor is a key component of the main hypothesis. Other studies on the South American coast have found high prevalence of osteophytes on the vertebrae (Gerszten et al., 2001). DISH was found in individuals from 4000 BC in northern Chile with a trend of increasing severity over time (Arriaza, 1993). Further, in a study of burials from the Arica valley in Chile, a woman with severe cervical DJD growths was buried with a basket strap tied around her forehead (Gerszten et al., 2001). The researchers linked this individual's use of the device with her vertebral pathology. In 11th to 13th century AD Colombia, a study of a Muisca cemetery found high prevalence of joint pathology (Rojas-Sepúlveda et al., 2008), which the researchers used to support historical accounts of local salt mining, load-bearing, and transport.

Klaus' extensive study of Mórrope people in the Lambayeque Valley in the north coast of Peru found higher prevalence of DJD after the arrival of the Spanish than before colonial rule (Klaus, 2008ab; Klaus et al., 2009). Joints of the limb bones and the vertebrae bore elevated amounts of disease pathology in the Early and Middle Colonial phases relative to precontact levels. The increase in number and severity of osteoarthritic lesions is especially noticeable in females. Younger adults were also found to have more DJD when analyzed by age groups. Klaus interpreted these results to indicate the effect of the Spanish labor system on the workers. Specifically, heavy load bearing was cited as a task that would produce the observed pathology, though mining and threshing were also mentioned as possibilities. The higher prevalence in females was taken to reflect the use of local women as a "captive labor force," doing menial work at the Spanish settlement as the men were sent off in an Inca-style mita labor network (Klaus, 2008b:560). Thus, however severe native Andean rule was to the common laborer, there was worse to come.

COLLECTION OF DEGENERATIVE JOINT DISEASE DATA

The 2007 field school team recorded observations of the type, location, and severity of osteoarthritis in the Armatambo collection. The pitting excluded method supported by Rojas-Sepúlveda and colleagues (2008) was used in this dissertation to quantify DJD prevalence. Presence of DJD was ranked as mild, medium, or severe during data collection. Analysis looked for trends in specific locations (i.e. cervical, thoracic and lumbar vertebrae, along with the elbow and the knee) as well as overall in the body across sex and age.

TRAUMA

Unlike the other indicators described previously, which tend to be the result of long-term processes, trauma is a sudden stressor to the skeleton. Traumatic injuries can be broadly categorized as either a fracture (a break in a bone's structure), or a dislocation (a disruption to a joint between bones) (Lovell, 1997). Fractures can be caused by either direct or indirect trauma. Direct trauma produces pathology at the point of impact, while indirect trauma causes breakage away from where force is applied (e.g. biomechanical failure due to bending or torsion) (Nordin and Frankel, 1980).

An individual who survives the injury then undergoes a series of physiological processes that start to repair the damage (Sevitt, 1981; Frost, 1989a). The identification of the stage of healing at time of death can aid interpretation of lifestyle and survivorship, although factors such as cultural aids, health state, the onset of complications such as periostitis and osteoarthritis, and also variation in immune response have to be considered (Frost, 1989b; Lovell, 1997; Barbian and Sledzik, 2008)(Figure 6.6). Study of the manifestation of traumatic injury can also inform the researcher of the original cause. Postmortem trauma can be differentiated from premortem cases, which can give insight to cultural practices such as trophy taking (e.g. Finucane, 2008; Steadman, 2008; Tung, 2008).

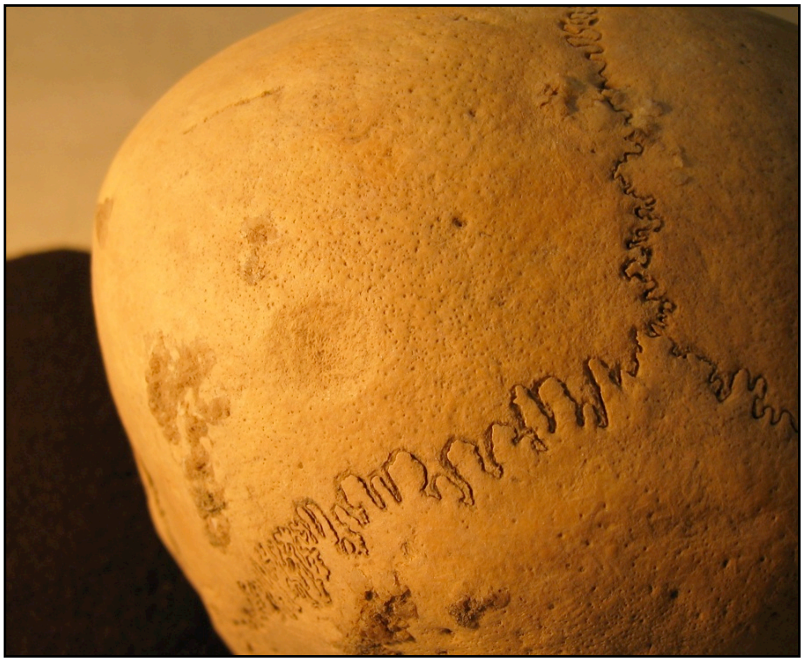


Figure 6.6: Healed Fracture. (The circular depression on the left parietal bone of ENT 25C (male, ~35 years) from Armatambo). Note: this cranium has been artificially deformed.

The word 'trauma' usually brings to mind intentional violent injury, and the study of murder, sacrifice, and warfare is prolific. Violent trauma seems to exist in much of human culture regardless of complexity or location (Walker, 2001b; reviewed in LeBlanc, 2003). The bioarchaeology of trauma works in tandem with forensic anthropology, and both fronts have seen much progress in the past decade (e.g. Larsen and Milner, 1994; Robb, 1997; Walker et al., 1997; Walker, 2001b; Dirkmaat et al., 2008; though see Iscan, 2001, for a critique of the forensic anthropology aspect). In general, interpersonal violence is often typified by trauma on the left side of male crania (Walker, 1989; Owens, 2007; Slaus, 2008; Tung, 2008). The type of weapon can sometimes be deduced from the shape of the injury: general categories include projectiles (e.g. bullets and arrowheads), sharp force (e.g. blades), and blunt force (e.g. clubs and maces) (Spitz and Fisher, 2006).

Worldwide, studies of violent trauma have found that complex relationships exist between the elite and their subjects. Bioarchaeological evidence of imperial violence in the Andes was covered in Chapter 3. To summarize, the transition to Huari empire rule in three sites was found to correlate with an increase in traumatic injury compared to earlier times (Tung, 2007). The same period in northern Chile also saw a rise in violence, possibly linked to extensive droughts (Neves et al., 1999, Torres-Rouff and Junqueira, 2006). Interactions between Europeans and Native Americans were also marked by high trauma prevalence (Larsen and Milner, 1994; Williamson et al., 2003; Hutchinson and Norr, 2006). Conversely, the Egyptian occupation of Nubia saw a decrease in violence over time (Buzon and Richman, 2007).

High mechanical loading, as well as causing degenerative joint disease and its bony response, can also have traumatic effects on bone. Schmorl's nodes, described in the DJD section, can also be thought of as a type of trauma. Spondylolysis is the separation of the neural arch and vertebral body (Merbs, 1989, 1996ab, 2001, 2002; Weiss, 2009). Also in the vertebrae, an avulsion fracture (when ligament or tendon tears the bone) can separate the transverse processes of the thoracic vertebrae (Upex and Knüsel, 2009). Both spondylolysis and avulsion fractures are associated with extreme physical loading, particularly in a bipedal posture, over a long duration.

Accidents are another type of trauma that can be inflicted in the course of labor (Grauer and Roberts, 1996; Judd and Roberts, 1999). Besides work related accidents, other factors contributing to accidental trauma include weather conditions, terrain (Jiménez-Brobeil et al., 2007), cultural practices, body mass, weight distribution (Edelstein and Barrett-Connor, 1993; Meyer et al., 1995), and diseases such as leprosy (Judd and Roberts, 1999) and osteoporosis (Mensforth and Latimer, 1989; Cumming et al., 1997). Caution has to be used, however, to differentiate between violence and accident (Lovejoy and Heiple, 1981; Wakely, 1996; Walker, 2001a). Walker (2001a:576) notes that trauma should only be attributed to intentional violence with "strong circumstantial evidence." Lovell (1997) found that parry fractures, bone breakage of the forearms usually ascribed to blocking a strike, have to be scrutinized to be sure that they are not accidentally inflicted. Lovejoy and Heiple (1981) examined trauma rates in the Libben of Ohio and found that the frequency of trauma was not clustered around male young adults, indicative of violence, but was equally prevalent in all age groups. They concluded that fractures in this population were primarily caused by accidents since all ages, not just able-bodied adult males, were afflicted.

Trauma to bone can also be inflicted through cultural practice not involving warfare or accidents. In the Andes, one particularly common type is cranial trepanation or trephination, where a section of cranial bone is removed through cutting, scraping, or boring (Verano, 2003). There are examples of cranial trepanation throughout the world in prehistory (reviewed in Clower and Finger, 2001; Arnott et al., 2003), and it is still practiced today in modern neurosurgery as craniotomy. South America has a particularly high concentration of prehistoric trepanation cases, surveyed extensively by Verano (2003). He found several distinct areas across the Andes where trepanation was common, including the earliest examples along the south coast during the Early Horizon. Trepanation was found late on the central coast during the Inca Period. Interestingly, the proportion of crania showing healing versus lack of healing increased over time, suggesting an improvement in survivability (see also Andrushko, 2007). Motive for trepanation worldwide can be varied, with spiritual (e.g. Broca, 1876) or medical (e.g. Tello, 1913; Daland, 1935; Popham, 1954) reasons being the likeliest factors. In particular, instances of trepanation seem to correlate with cranial fractures and the surgery may have been used to alleviate the effects of cranial trauma (Verano, 2003; Andrushko, 2007; though see Nystrom, 2007). Despite much anecdotal evidence, Andrushko and Verano (2008) found no conclusive example of cranioplasty, or dressing of the trepanation opening either with the original excised bone or a substitute material. It is possible that such plugs were made of materials that did not preserve in the archaeological record.

The documentation of trauma has received several recent treatments. Lovell's (1997) effective summary of the topic offers many suggestions for the collection of data on trauma in bioarchaeology and paleopathology. Researchers have noticed a lack of standardization and focus (Jurmain, 1999; Matos, 2009). Buikstra and Ubelaker (1994) and Ortner (2003) also give detailed suggestions on recording data on trauma.

COLLECTION OF TRAUMA DATA

Instances of trauma and their state of healing were assessed with the same numbering system used for DJD. Cranio-facial trauma, especially to the left side was considered indicative of violence. Trauma caused by physical stress associated with labor-intensive activities, such as spondylosis, was noted and categorized as mild, medium, or severe. Trauma data from Paloma and Villa El Salvador were not consulted for this dissertation since there was only one serious example among 201 individuals from Paloma (Benfer, 1990), and trauma data from VES has not been published.

Statistical Analysis

This section describes the statistical tests used in this study. Hypotheses were tested using various methods suited to the type of data analyzed. First, two methodological issues are addressed: the use of small sample sizes, and a consideration of the issue of statistical significance.

STATISTICAL ANALYSIS USING SMALL SAMPLE SIZES

Smaller-than-ideal sample sizes are an issue that is especially common in anthropology, because samples are not customized based on experiments designed in a laboratory but obtained from the world-at-large. Therefore, sample sizes are dictated by extraneous factors such as time spent excavating, archaeological sampling strategy, and random chance. In the case of this dissertation, the Armatambo collection was excavated under time pressure in a salvage operation, probably limiting the sample size in comparison to what could have been achieved with a more-controlled excavation. The encroachment of the modern population that sparked the excavation also undoubtedly destroyed a portion of the site.

Small sample sizes do not prevent statistical analysis in all but the most extreme cases. The main drawback of statistical analysis using small sample sizes is the reduction in statistical power. Statistical power is the ability to reject a false null hypothesis; correctly identifying a statistically significant difference when one exists (Sokal and Rolf, 1995). High statistical power means that smaller statistically significant differences that are true will be detected while low power means that only larger statistically significant differences will be found. Thus, given low sample sizes, large differences between samples will be found just as well as with larger sample sizes. Also, conclusions found with the analysis of small sample sizes can be explored in other similar skeletal populations. Benfer (1968) notes that the general process of testing one overarching hypothesis by splitting a large sample into separate tests of smaller samples is used often in scientific research.

THE INTERPRETATION OF STATISTICAL SIGNIFICANCE

In statistical testing using many commonly used statistical methods, a p-value is calculated and compared to a predetermined significance level (alpha) to determine whether a measured difference is statistically significant. Alpha represents the chance of obtaining the observed result if the null hypothesis is true, that there is no difference between the tested groups.

While hypothesis testing using a strict threshold (e.g. $p < 0.05$) is a staple of scientific research, some researchers have raised concerns that this method lacks the subtlety needed to appreciate statistical difference (Rosnow and Rosenthal, 1989; Sterne and Smith, 2001). R.A. Fisher, though first to designate a significant alpha-level of 0.05, also advocated a more holistic interpretation of p-values (Fisher, 1958b). Harsh criticism of statistical testing has pointed towards the baseless use of a discrete alpha-level to determine significance versus non-significance, or acceptance versus rejection (Gold, 1970:176; Labovitz, 1970; Skipper et al., 1970). Instead, Morrison and Henkel (1970) suggest using a scale of terms reflecting the level of support interpreted from the significance test, such as "lack of support," "weak support," and "strong support," (Morrison and Henkel, 1970:194). Such a scale has been named "degrees of belief," (Rozeboom, 1970:221) as opposed to a binary decision.

In this current study, for tests that produce a p-value, statistical difference will be evaluated on a continuum. Since the lower the p-value, the less likely that the null hypothesis state would produce the observed result, the odds are in favor of rejecting the null hypothesis with a lower p-value. It is important to note that the p-value cannot be taken as reflecting the chance a result is correct. Also, the odds are affected by sample size: with a sufficiently large sample size, any measured difference between groups will be statistically significant (Bakan, 1970:241). The most weight for rejecting the null hypothesis will be given for a p-value 0.05 and under. A statistical test is considered as "approaching significance," i.e. given some weight, if the p-value is between 0.05 and 0.10. Greater p-values, observed differences with no strong statistical support, are given the least weight in interpretation. One last note on statistical analysis in this dissertation: in order to show results suitable for a holistic appraisal of statistical significance, this study will present actual p-values for each statistical test rather than just state the achieved threshold.

ANALYSIS OF NORMALLY DISTRIBUTED DATA

Normally distributed data were analyzed with the general linear model (GLM). The GLM is the general model of parametric and linear statistical analysis that underlies many techniques common to scientific research, including the analysis of variance (ANOVA), analysis of covariance (ANCOVA), linear regression, and the t-test (Fennessey, 1968; Koerts and Abrahamse, 1969). The GLM allows for a high degree of adaptability to the research question, including the incorporation of covariates, confounding variables that can effect the statistical relationship of the variables of interest (Kim and Timm, 2006). In some comparisons, a distribution from one group is compared to a single reported mean from another group. In these cases, the one-sample t-test was used.

ANALYSIS OF PRESENCE/ABSENCE (CATEGORICAL) VARIABLES

The hierarchical log-linear model is a robust technique for comparing categorical data in this study. Unlike other methods, such as Fisher's Exact Test (Fisher, 1922), the hierarchical log-linear model can do multivariate analyses, or analyses between three or more variables, with presence/absence data (Knoke and Burke, 1980; Gilbert, 1993). The hierarchical log-linear model can include different "elements" that can be divided into "factors," sets of categorical variables, and "interactions," comparisons of data between factors.

The "hierarchical" in the hierarchical log-linear model describes the process by which a parsimonious model of significant factors and interactions between factors is calculated (Christensen, 1997). First, the natural log is taken of each datum (the "log" part of this technique's name). Then, a fully saturated model is considered, one that accounts for all elements entered into the model: every combination of factors and interactions. The algorithm then proceeds backwards, from the most complex interaction down to the individual factors, removing one from the model and calculating the difference in chi-square values between the new and old models. If there is no significant difference between the one-element-deleted and full model, producing a high p-value, the deleted element is removed permanently since its deletion caused no change to the overall model. If the removal of the effect causes a significant change in the chi-square value, the effect is placed back in the model since it "explains" part of the distribution of data. In this manner the algorithm weeds out insignificant effects, leaving the most parsimonious model that explains the distribution of data.

Due to this method of calculation, the resulting significance value is interpreted differently from other statistical tests such as the t-test (Knoke and Burke, 1980). The final output is a model that was calculated to be the most parsimonious in showing how the distribution of data relates to the given factors and interactions. The final element could be an interaction between factors: for example, between sex and cribra orbitalia prevalence (written as Sex*CO), which means that the distribution of CO differs between males and females. The final model could also just be a sole factor, such as CO, or multiple isolated factors: CO and Sex (but not interacting). In this case, the proportion of individuals with or without CO are different from each other, as are the proportion of individuals who are male and female, but not in a way which relates with the other elements in the model. Lastly, if none of the elements adequately explain the data set, then the final model will contain only the constant.

The hierarchical log-linear model produces a goodness-of-fit chi-square result for the final model as a gauge of how well it fits the data set. Unlike the typical chi-square test, in which a low p-value marks a significant difference between factors, a high p-value in hierarchical log-linear modeling indicates a good model that fits the data. Another way of interpreting this result is that the final pared-down model is not significantly different from the original data set. The final model and the chi-square value from the goodness-of-fit test will be reported for each hierarchical log-linear analysis run in this study. If the final model is identical to the initial saturated model, the chi-square value will be zero and the p value will be unity.

ANALYSIS OF HARRIS LINE DATA

Harris line count data analysis requires additional considerations. Subadults and adults were analyzed separately since their lines reflect different growth periods: lines present in subadult remains were laid down in early childhood while lines seen in adult remains were formed in adolescence. Furthermore, for adults, sexes were analyzed separately to account for differences in growth patterns. Histograms of the maximum Harris line count data in subadults showed possible non-normal distributions (Figures 6.7 and 6.8).

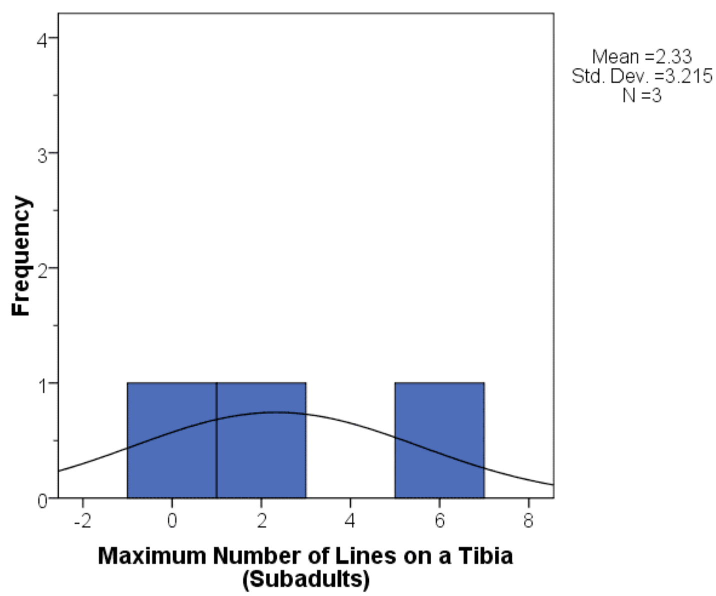


Figure 6.7: Histogram of Maximum Subadult Tibial Harris Line Counts

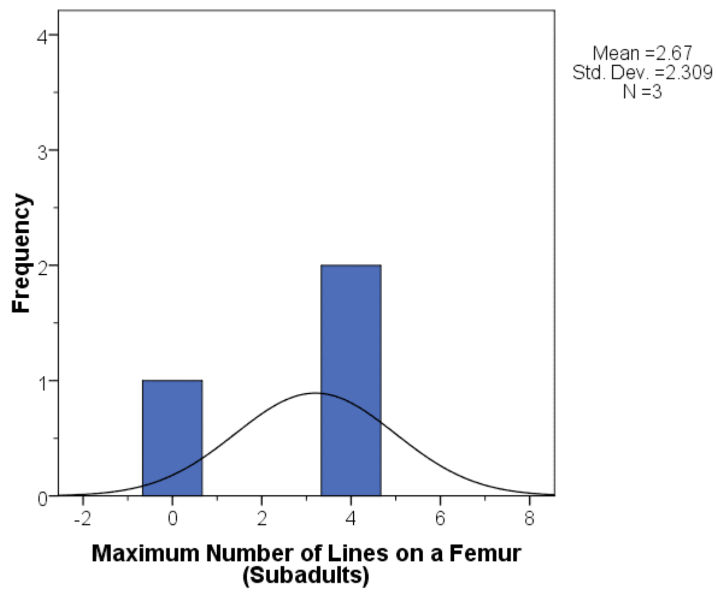


Figure 6.8: Histogram of Maximum Subadult Femoral Harris Line Counts

The one-sample Kolmogorov-Smirnov (K-S) test was applied and the result confirmed normality (Tables 6.2). The K-S test also found that adult Harris line counts for both lower limb long bones fit a normal distribution (Table 6.3).

Table 6.2: One-Sample Kolmogorov-Smirnov Test of Subadult Harris Line Counts

		Maximum Tibia Harris Line Counts	Maximum Femur Harris Line Counts
n		3	3
Normal Distribution Parameters	**Mean**	2.3	2.7
	Standard Deviation	3.2	2.3
Most Extreme Differences	**Absolute**	0.33	0.39
	Positive	0.33	0.28
	Negative	-0.23	-0.39
Kolmogorov-Smirnov Z		0.57	0.67
Asymptotic Significance (2-tailed)		0.90	0.77

Table 6.3: One-Sample Kolmogorov-Smirnov Test of Adult Harris Line Counts

		Maximum Tibia Harris Line Counts	Maximum Femur Harris Line Counts
n		8	8
Normal Distribution Parameters	**Mean**	4.0	5.9
	Standard Deviation	3.6	5.2
Most Extreme Differences	**Absolute**	0.25	0.16
	Positive	0.25	0.16
	Negative	-0.17	-0.13
Kolmogorov-Smirnov Z		0.71	0.47
Asymptotic Significance (2-tailed)		0.70	0.98

The GLM was used to test the Harris line count data for statistical significance. Since significant, though relatively small, negative relationships of Harris Lines by age have been found in other studies (Wells, 1964; Maat, 1984; Benfer, 1990; Grolleau-Raoux et al., 1997), a possible influence of Harris line counts by age was tested. If Harris line counts decrease with age, age must be analyzed separately to eliminate issues with Harris line resorption (Garn, 1967, Mays, 1995). In the Armatambo collection, surprisingly the inverse trend was found: adults over forty years of age showed more Harris lines than younger adults. Since age at death correlated with Harris line counts, albeit in an unexpected way, age-by-year was incorporated into statistical models as a covariate. This finding also has ramifications in the interpretation of Harris lines as a stress indicator, as discussed in Chapter 9.

For adults, general linear model analysis was run with maximum Harris line counts for each lower limb element set as the dependent variable, sex as a fixed factor, sites as a random factor, and age at death in years as a covariate. Tables 6.4a to 6.5b show the results. Harris line counts of the tibia was found to have a significant interaction with sex and site ($p = 0.06$), but not significant with sex and site independently. Table 6.5a suggests that the significant interaction term reflects that Armatambo females have more lines than those in other sites. The same analysis with the maximum femoral Harris line counts found no significant interaction term ($p = 0.72$). Age was found to have a significant positive relationship with femoral Harris line counts ($p < 0.01$). Based on these initial results, adult males and females were analyzed separately, with age in years as a covariate.

Table 6.4a: Descriptive Statistics for Tibial Harris Line Counts by Site and Sex Analysis

Sex	Site	n	Mean	Standard Deviation
Female	**Paloma**	14	1.7	1.5
	VES	21	3.7	2.7
	Armatambo	4	5.5	4.8
	Total	39	3.2	2.8
Male	**Paloma**	18	2.4	2.2
	VES	24	2.1	2.0
	Armatambo	4	2.5	1.3
	Total	46	2.3	2.0
Total	**Paloma**	32	2.1	2.0
	VES	45	2.8	2.5
	Armatambo	8	4	3.6
	Total	85	2.7	2.5

Table 6.4b GLM Results for Tibial Harris Line Counts by Site and Sex Analysis

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	**Hypothesis**	18.86	1	18.86	3.21	*0.08*
	Error	307.39	52	5.87*		
Age	**Hypothesis**	5.14	1	5.14	0.95	0.33
	Error	422.67	78	5.42**		
Sex	**Hypothesis**	12.41	1	12.41	1.02	0.39
	Error	34.58	3	12.12***		
Site	**Hypothesis**	24.62	2	12.31	0.76	0.57
	Error	31.93	2	16.21****		
Sex * Site	**Hypothesis**	31.94	2	15.97	2.95	*0.06*
	Error	418.26	78	5.36**		

* 0.07 MS(Site) + 0.934 MS (Error)

** MS (Error)

*** 0.64 MS (Sex * Site) + 0.37 MS(Error)

****1.02 MS(Sex * Site) - 0.02 MS(Error)

Table 6.5a: Descriptive Statistics for Femoral Harris Line Counts by Site and Sex Analysis

Sex	Site	n	Mean	Standard Deviation
Female	**VES**	23	4.2	3.4
	Armatambo	5	7.8	5.6
	Total	28	4.8	4.0
Male	**VES**	24	1.7	1.7
	Armatambo	3	2.7	2.5
	Total	27	1.8	1.8
Total	**VES**	47	2.9	2.9
	Armatambo	8	5.9	5.2
	Total	55	3.4	3.5

Table 6.5b: GLM Results for Femoral Harris Line Counts by Site and Sex Analysis

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	Hypothesis	4.64	1	4.64	0.50	0.50
	Error	101.24	12	9.38*		
Age	Hypothesis	89.41	1	89.41	11.94	**0.01**
	Error	374.32	50	7.49**		
Sex	Hypothesis	19.11	1	19.11	16.80	0.10
	Error	1.57	1	1.14***		
Site	Hypothesis	25.10	1	.	.	.
	Error	.	.	.		
Sex * Site	Hypothesis	0.99	1	0.99	0.13	0.72
	Error	374.32	50	7.49**		

* 0.12 MS(Site) + 0.89 MS (Error)

** MS (Error)

*** 0.98 MS (Sex * Site) + 0.02 MS(Error)

Analysis of Corrected Subadult Age Estimation Data

Corrected subadult age estimation (CSAE), calculated by subtracting age estimation from the femur from the age estimation from dentition, also requires additional processing. A one-sample Kolmogorov-Smirnov test found that the CSAE data deviated significantly from a normal distribution (Table 6.6; Figure 6.9).

Table 6.6 One-Sample Kolmogorov-Smirnov Test of CSAE

		Corrected Subadult Age Estimation
n		45
Normal Distribution Parameters	**Mean**	1.3
	Standard Deviation	0.89
Most Extreme Differences	**Absolute**	0.26
	Positive	0.16
	Negative	-0.26
Kolmogorov-Smirnov Z		1.754
Asymptotic Significance (2-tailed)		0.004

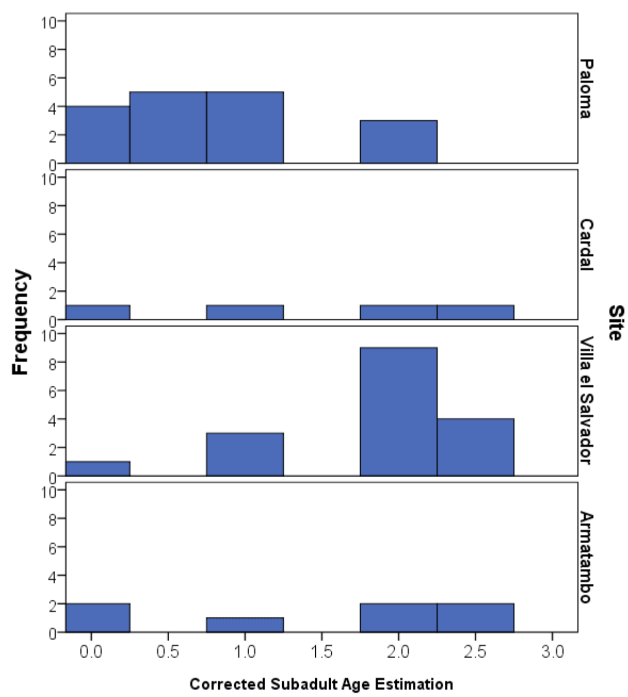


Figure 6.9: Histograms of CSAE Separated by Site

Since sample sizes are also uneven between sites, violating another assumption of the general linear model, GLM was not used to analyze CSAE data. Instead, the Kruskal-Wallis test, a one-way non-parametric analysis of variance, was used. The Kruskal-Wallis test rank-transforms the grouped data and compares group medians using the chi-square distribution (Kruskal and Wallis, 1952).

SUMMARY

Four main statistical tests were used to test the hypotheses of this dissertation. The general linear model, with independent t-test pairwise comparisons, was used on continuous and count data. Independent t-tests were used to compare published means and standard deviations. The log-linear model, with Fisher's Exact Test for pairwise comparisons, examined presence/absence data. Kruskal-Wallis test was chosen to look at non-parametric continuous data.

List of Statistical Models Used in This Study

This section lists the statistical analyses made in this study. The first set looks at the paleodemography of the Armatambo skeletal collection. Differences in age at death between adult males and females are examined. Evidence of population stability, an assumption of comparing age at death in skeletal populations, is also sought. The results of the first set of analyses are presented in Chapter 7. The second set of analyses is geared towards looking for a paradoxical manifestation of the NSIS data (i.e. the osteological paradox), following the simulations presented in Chapter 4. In summary, a paradoxical manifestation of a NSIS should show declining prevalence with age at death. Correlation will be used to look for a negative trend in count and continuous data, and the t-test will compare age at death between individuals with and without a certain stress indicator (Table 6.7). These results appear at the end of Chapter 7.

Table 6.7: List of Comparisons Made to Test for the Osteological Paradox

Comparison	Method	Purpose
Tibial Harris Line Counts and Age at Death within Armatambo	Correlation	Detect whether the manifestation of Harris lines is paradoxical relative to age at death
Femoral Harris Line Counts and Age at Death within Armatambo	Correlation	Detect whether the manifestation of Harris lines is paradoxical relative to age at death
Cribra Orbitalia and Age at Death within Armatambo	T-Test	Detect whether the manifestation of CO is paradoxical relative to age at death
Porotic Hyperostosis and Age at Death within Armatambo	T-Test	Detect whether the manifestation of PH is paradoxical relative to age at death
Osteoperiostitis and Age at Death within Armatambo	T-Test	Detect whether the manifestation of periosteal lesions is paradoxical relative to age at death
Tibia Length and Age at Death within Armatambo	Correlation	Detect whether tibia length is paradoxical relative to age at death

The third, and most expansive, set of analyses tests the research hypotheses described in Chapter 1. The comparisons made for each hypothesis depend on the availability of the data in for each site and whether the comparison addresses the hypothesis.

The hypothesis of Model A states that there should be sexual differentiation in heath and activity levels at Armatambo. Comparisons made between males and females include looking at subadult indicators of chronic stress left in adult remains, as well as adult health resulting from high physical activity or traumatic incidents (Table 6.8).

Table 6.8: List of Comparisons to Test the Hypothesis of Model A

Comparison Between Males and Females at Armatambo	Method	Purpose
Tibial Harris Line Counts	GLM, with age at death as covariate	Compare frequency of periodic stress episodes during subadulthood in surviving adults.
Femoral Harris Line Counts	GLM, with age at death as covariate	Compare frequency of periodic stress episodes during subadulthood in surviving adults.
Cribra Orbitalia	Log-Linear Model	Compare frequency of chronic anemia during subadulthood in surviving adults.
Porotic Hyperostosis	Log-Linear Model	Compare frequency of chronic anemia during subadulthood in surviving adults.
Osteoperiostitis	Log-Linear Model	Compare frequency of chronic bacterial infection during subadulthood in surviving adults.
Cervical Vertebrae DJD	Log-Linear Model	Compare frequency of physical activity stressing the cervical vertebrae
Thoracic Vertebrae DJD	Log-Linear Model	Compare frequency of physical activity stressing the thoracic vertebrae
Lumbar Vertebrae DJD	Log-Linear Model	Compare frequency of physical activity stressing the lumbar vertebrae
Schmorl's Nodes	Log-Linear Model	Compare frequency of physical activity resulting in intervertebral disc pathology

Comparison Between Males and Females at Armatambo	Method	Purpose
Elbow DJD	Log-Linear Model	Compare frequency of physical activity stressing the elbow joint
Knee DJD	Log-Linear Model	Compare frequency of physical activity stressing the knee joint
All DJD	Log-Linear Model	Compare frequency of physical activity anywhere in the body
Appendage Trauma	Log-Linear Model	Compare frequency of physical injury to the limbs
Cranial Trauma	Log-Linear Model	Compare frequency of physical injury to the cranium
Sharp Trauma	Log-Linear Model	Compare frequency of sharp physical injury anywhere on the body
Vertebral Trauma	Log-Linear Model	Compare frequency of physical injury to the vertebrae
Age at Death	GLM	Compare general health state in adults

Model B posits a difference in health and activity between individuals at Armatambo with and without cranial deformation, a marker of ethnicity. Harris line data are incomplete for evaluating this model, excluding it from this section. For the analyses of trauma, sex will also be included as a factor in log-linear analysis since, traditionally, trauma is more common in males. Table 6.9 lists the statistical comparisons used to test Model B.

Table 6.9: List of Comparisons to Test the Hypothesis of Model B

Comparison Between Between Cranially Deformed and Undeformed at Armatambo	Method	Purpose
Maximum Tibia Length	GLM, with Sex as Covariate	Compare general health during growth and development during subadulthood in surviving adults.
Cribra Orbitalia	Log-Linear Model	Compare frequency of chronic anemia during subadulthood in surviving adults.
Porotic Hyperostosis	Log-Linear Model	Compare frequency of chronic anemia during subadulthood in surviving adults.
Osteoperiostitis	Log-Linear Model	Compare frequency of chronic bacterial infection during subadulthood in surviving adults.
Cervical Vertebrae DJD	Log-Linear Model	Compare frequency of physical activity stressing the cervical vertebrae
Thoracic Vertebrae DJD	Log-Linear Model	Compare frequency of physical activity stressing the thoracic vertebrae
Lumbar Vertebrae DJD	Log-Linear Model	Compare frequency of physical activity stressing the lumbar vertebrae
Schmorl's Nodes	Log-Linear Model	Compare frequency of physical activity resulting in intervertebral disc pathology
Elbow DJD	Log-Linear Model	Compare frequency of physical activity stressing the elbow joint
Knee DJD	Log-Linear Model	Compare frequency of physical activity stressing the knee joint
All DJD	Log-Linear Model	Compare frequency of physical activity anywhere in the body
Appendage Trauma	Log-Linear Model, with Sex as Additional Factor	Compare frequency of physical injury to the limbs
Cranial Trauma	Log-Linear Model, with Sex as Additional Factor	Compare frequency of physical injury to the cranium

Comparison Between Between Cranially Deformed and Undeformed at Armatambo	Method	Purpose
Sharp Trauma	Log-Linear Model, with Sex as Additional Factor	Compare frequency of sharp physical injury anywhere on the body
Vertebral Trauma	Log-Linear Model, with Sex as Additional Factor	Compare frequency of physical injury to the vertebrae
Age at Death	GLM	Compare general health state in adults

Models C and D compare health and activity at Armatambo with other sites in the same region. Some comparisons are made using multivariate models, including multiple sites in the same analysis. When a significant difference in health indicator prevalence among sites is found in a multivariate analysis, individual comparisons between Armatambo and the other sites have to be used to find the exact nature of the statistical difference.

Maximum tibia length cannot be analyzed with multivariate techniques in this dissertation. Except for Armatambo and Huaca Malena, these data are reported as population means and standard deviations, not individual cases as the GLM requires. Pairwise comparisons using the independent t-test between Armatambo and each of the other sites will be made instead.

Table 6.10 lists the multivariate analyses testing Models C and D. Tables 6.11 to 6.14 shows the site-specific analyses for Paloma, Cardal, Villa El Salvador/Tablada de Lurín, and Huaca Malena, respectively. The tables denote whether just VES data or combined VES/TBL data were used in the comparison.

Table 6.10: List of Comparisons to Test the Hypothesis of Models C and D

Comparison Between Individuals at Armatambo and Other Sites	Method	Other Sites in Model	Purpose
Tibial Harris Line Counts, in Adults	GLM, with Sex as a Fixed Factor and Age at Death as Covariate	Paloma, VES	Compare frequency of periodic stress episodes during subadulthood in surviving adults.
Cribra Orbitalia in Subadults	Log-Linear Model	Paloma, Cardal, VES/TBL	Compare frequency of chronic anemia during early subadulthood.
Porotic Hyperostosis in Subadults	Log-Linear Model	Paloma, Cardal, VES/TBL	Compare frequency of chronic anemia during early subadulthood.
Cribra Orbitalia in Adults	Log-Linear Model, with Sex as an Additional Factor	Cardal, VES/TBL, Huaca Malena	Compare frequency of chronic anemia during subadulthood in surviving adults.
Porotic Hyperostosis in Adults	Log-Linear Model, with Sex as an Additional Factor	Cardal, VES/TBL, Huaca Malena	Compare frequency of chronic anemia during subadulthood in surviving adults.
Osteoperiostitis in Subadults	Log-Linear Model	Paloma, Cardal, VES/TBL	Compare frequency of chronic bacterial infection during subadulthood.
Corrected Subadult Age Estimate	GLM	Paloma, Cardal, VES	Compare genetic growth fulfilled during subadulthood.
Osteoperiostitis in Adults	Log-Linear Model, with Sex as an Additional Factor	Paloma, Cardal, VES/TBL, Huaca Malena	Compare frequency of chronic bacterial infection during adulthood.
Cervical Vertebrae DJD	Log-Linear Model, with Sex as an Additional Factor	Cardal, VES, Huaca Malena	Compare frequency of physical activity stressing the cervical vertebrae

Comparison Between Individuals at Armatambo and Other Sites	Method	Other Sites in Model	Purpose
Thoracic Vertebrae DJD	Log-Linear Model, with Sex as an Additional Factor	VES, Huaca Malena	Compare frequency of physical activity stressing the thoracic vertebrae
Lumbar Vertebrae DJD	Log-Linear Model, with Sex as an Additional Factor	Cardal, VES, Huaca Malena	Compare frequency of physical activity stressing the lumbar vertebrae
Elbow DJD	Log-Linear Model, with Sex as an Additional Factor	VES, Huaca Malena	Compare frequency of physical activity stressing the elbow joint
Knee DJD	Log-Linear Model, with Sex as an Additional Factor	VES, Huaca Malena	Compare frequency of physical activity stressing the knee joint
Appendage Trauma	Log-Linear Model, with Sex as Additional Factor	Cardal, Huaca Malena	Compare frequency of physical injury to the limbs
Cranial Trauma	Log-Linear Model, with Sex as Additional Factor	Cardal, VES, Huaca Malena	Compare frequency of physical injury to the cranium
Sharp Trauma	Log-Linear Model, with Sex as Additional Factor	Cardal, Huaca Malena	Compare frequency of sharp physical injury anywhere on the body
Vertebral Trauma	Log-Linear Model, with Sex as Additional Factor	Cardal, Huaca Malena	Compare frequency of physical injury to the vertebrae

Comparison Between Individuals at Armatambo and Other Sites	Method	Other Sites in Model	Purpose
Age at Death	GLM, with Sex as Additional Factor	Paloma, Cardal, VES/TBL, Huaca Malena	Compare general health state in adults

Table 6.11: List of Lone Pairwise Comparisons Between Armatambo and Paloma to Test the Hypothesis of Models C and D

Comparison Between Individuals at Armatambo and Other Sites	Method	Purpose
Tibial Harris Line Counts, in Subadults	GLM, with Age at Death as Covariate	Compare frequency of periodic stress episodes during subadulthood in dead subadults
Cribra Orbitalia in Adults	Log-Linear Model	Compare frequency of chronic anemia during subadulthood in surviving adults.
Porotic Hyperostosis in Adults	Log-Linear Model	Compare frequency of chronic anemia during subadulthood in surviving adults.
Maximum Tibia Length in Females	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.
Maximum Tibia Length in Males	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.

Table 6.12: List of Pairwise Comparisons Between Armatambo and Cardal to Test the Hypothesis of Models C and D

Comparison Between Individuals at Armatambo and Cardal	Method	Purpose
Maximum Tibia Length in Females	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.
Maximum Tibia Length in Males	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.

Table 6.13: List of Lone Pairwise Comparisons Between Armatambo and Villa El Salvador/Tablada de Lurín to Test the Hypothesis of Models C and D

Comparison Between Individuals at Armatambo and VES/TBL	Method	Purpose
Femoral Harris Line Counts, in Adults	GLM, with Age at Death as Covariate	Compare frequency of periodic stress episodes during subadulthood in surviving adults
Maximum Tibia Length in Females	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.
Maximum Tibia Length in Males	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.

Table 6.14: List of Lone Pairwise Comparisons Between Armatambo and Huaca Malena to Test the Hypothesis of Models C and D

Comparison Between Individuals at Armatambo and Huaca Malena	Method	Purpose
Maximum Tibia Length in Females	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.
Maximum Tibia Length in Males	Independent T-Test	Compare general health during growth and development during subadulthood in surviving adults.

Summary

Nine indicators of health and activity are used in this study to assess the health and activity level of the Armatambo skeletal collection. In most cases, the general linear model will be used to examine count and continuous data. Nominal data, specifically presence/absence data, will be examined with the hierarchical log-linear model.

CHAPTER 7: THE ARMATAMBO COLLECTION

This section will present descriptive data analysis of the Armatambo skeletal collection. Chapter 5 contains a description of the provenience of this skeletal collection. This dissertation is the first bioarchaeological study of the Armatambo skeletal population.

For the most part, skeletons from individual burials were used to test the hypotheses in this dissertation. In cases where more than one individual was present, indicators were used to attempt to differentiate between them (for example, if bones were of drastically different ages). Several burials were excluded from data analysis because they contained comingled individuals of similar age.

Table 7.1: Armatambo Burials Excluded from Study

Individual	Reason for Exclusion
ENT 61A	Two individuals
ENT 63A	Possible two individuals
ENT 64	Multiple individuals
ENT 54	Multiple individuals
ENT 25E	Multiple individuals

Forty-one adults and twelve subadults were included in data analysis. Table 7.2 and Figure 7.1 show the adult composition by sex. The number of males and females are nearly equal. Figure 7.2 shows the distribution of subadults by age in years. The distribution of subadult by age shows a mortality peak at the typical age of weaning (Farnum 1996). Table 7.3 and Figure 7.3 depict the adult age distribution, separated by sex. Appendix 1 shows the skeletal data for the Armatambo collection used in this study.

Table 7.2: Armatambo Sample Composition

	Males	Females	Indeterminate	Total
Subadults	.	.	.	14
Adults	19	21	1	41

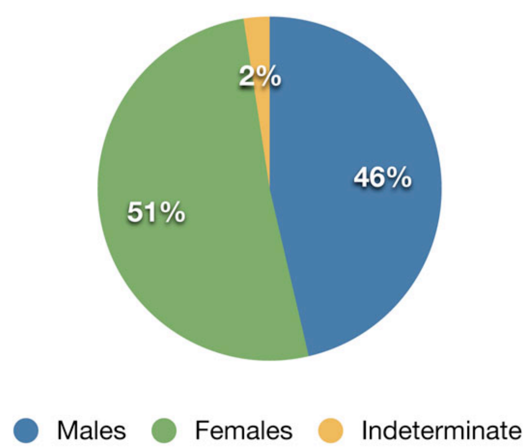


Figure 7.1: Armatambo Adult Sample Composition by Sex

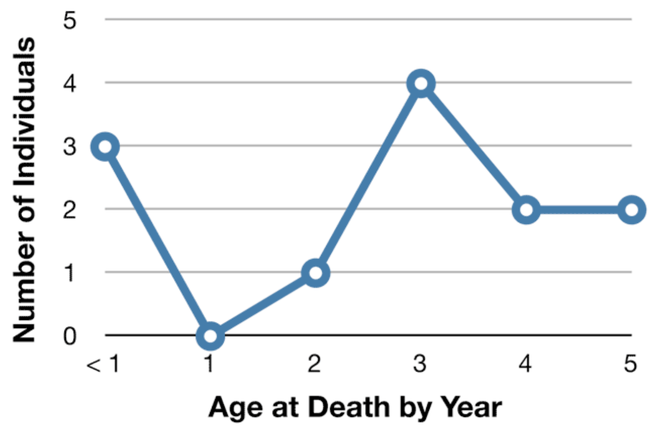


Figure 7.2: Armatambo Subadult Sample Composition by Age at Death.

Table 7.3: Armatambo Adult Groups by Age of Death by Decade

	20-29	30-39	40-49	50-59	60-69
Males	9	6	2	2	0
Females	4	4	6	4	3
Indeterminate	0	0	1	0	0
Total	13	10	9	6	3

An independent t-test of age at death in years of adults by sex found a statistically significant difference, with males having a lower average ($t = 2.31$, $df = 37$, $p = 0.03$) (Table 7.4), an unusual finding for a skeletal population. There are several processes that could produce a skeletal population with males trending towards a younger age at death while females tend to die older. Assuming that fertility affects a skeletal population's age distribution more than mortality, it is possible that preferential parental investment in males could have been a factor. If mortality is the key process in defining the skeletal population, then poorer health in males might have caused them to die younger than females. Alternatively, this collection could have been a biased sample of Armatambo burials as the excavation was done under time pressure in a salvage operation.

Table 7.4: Armatambo Mean Adult Age at Death

Sample	n	Mean (years)	Standard Deviation
Males	18	32.2	10.3
Females	21	41.3	13.9

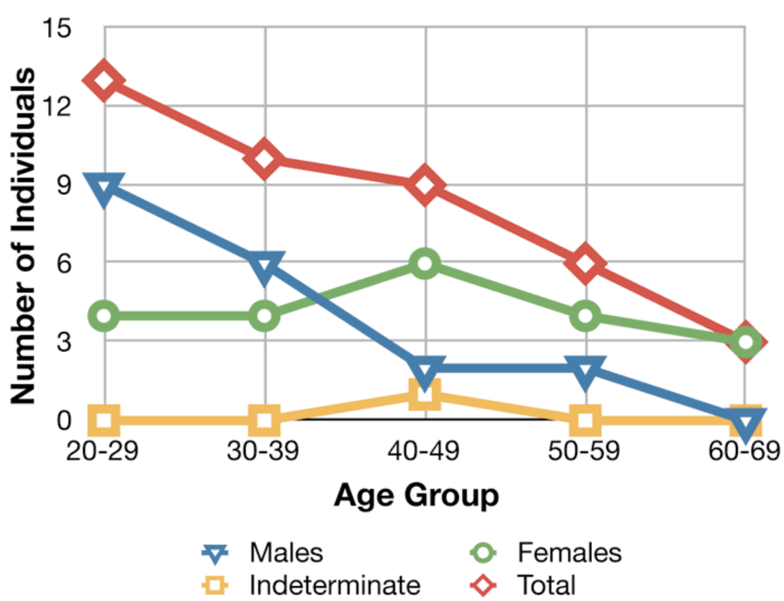


Figure 7.3: Armatambo Adult Sample Composition by Age Group

Testing for Population Stability at Armatambo

A skeletal population has to meet the assumption of stationary population conditions in order for it to be modeled accurately as a life table (Weiss and Wobst, 1973). Weiss states that over the long term, a population tends to be effectively stable. Even rapid cultural change, such as "the quick acquisition of the horse, the machete, or the cultivated plant" (Weiss and Wobst, 1973:10), would only cause a momentary change in demography that would stabilize after "a few decades of adjustment."

Paloma is one site in which the skeletal collection was found to conform to a stationary population (Benfer 1990). Modeled as a life table, a growth rate of approximately 0.2% was found (Vradenburg et al., 1997), close to the 0.1% that Cohen (1994:630) gave as an example of acceptably low growth rate to meet the assumption of a stationary population. Also, the proportion of dead subadults at Paloma was calculated as 43% (Table 7.5).

Table 7.5: Proportion of Subadults Within the Sites in this Study

	Subadults	Total n	Subadult to Adult Ratio
Paloma	86	201	0.43
Cardal	14	48	0.29
Villa El Salvador/Tablada de Lurín	44	206	0.21
Huaca Malena	2	19	0.11
Armatambo	13	56	0.23

Comparatively, the other sites in this dissertation exhibit lower proportions of dead subadults, concordant with agricultural societies where food buffering would supplement childhood nutrition beyond that of a fishing society. In addition, Armatambo's subadult frequency is similar to those of Villa El Salvador/Tablada de Lurín and Cardal, suggesting similar birthrates in a stable population for these four sites. Huaca Malena showed a lower percentage of subadults than the other sites in this study, suggesting a relatively lower birthrate.

Test for the Osteological Paradox

Following the model presented in Chapter 4, a paradoxical manifestation of stress indicators will appear as a significant *negative* correlation between the prevalence of the indicator and age at death. This section attempts to find this pattern in the data for five NSIS data recorded in the Armatambo collection.

Correlation analysis was used to look for a paradoxical manifestation of NSIS in Harris line counts of both the tibia and femur compared in separate tests with age at death (Table 7.6; Figures 7.4 and 7.5). The correlation coefficients for both tests were positive, and the results were in the significant range. Examination of Harris line counts across sites (Chapter 6) also found a positive relationship between age at death and Harris line counts. While these trends were in the opposite direction than expected given the paradoxical data, the implication is that Harris line counts are affected by factors outside of subadult health. Therefore, in the interpretation of Harris line count analyses, possible confounding factors such as differential mortality have to be considered.

Table 7.6: Pooled Correlations Between Harris Line Counts and Age at Death

Subadults and Adults	n	Pearson Correlation	p (2-tailed)
Maximum Tibial Harris Lines	**11**	**0.64**	**0.04**
Maximum Femoral Harris Lines	*11*	*0.57*	*0.07*

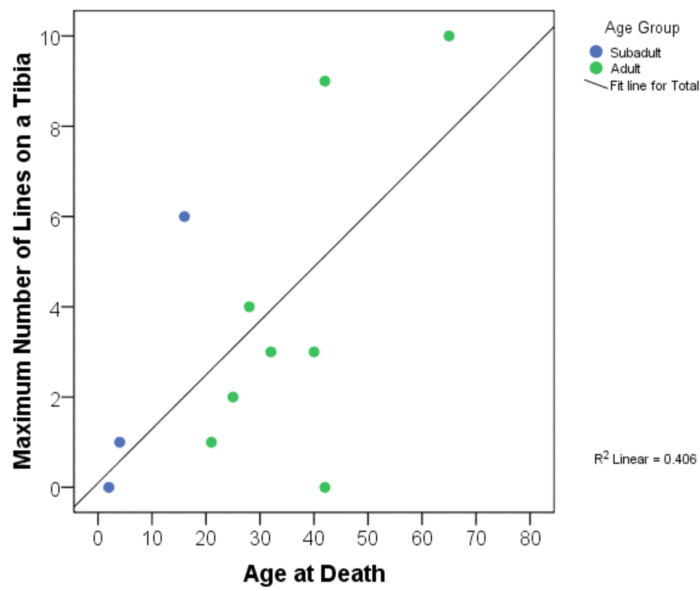


Figure 7.4: Scatterplot of Maximum Tibial Harris Line Counts and Age at Death for Both Subadults and Adults in Armatambo.

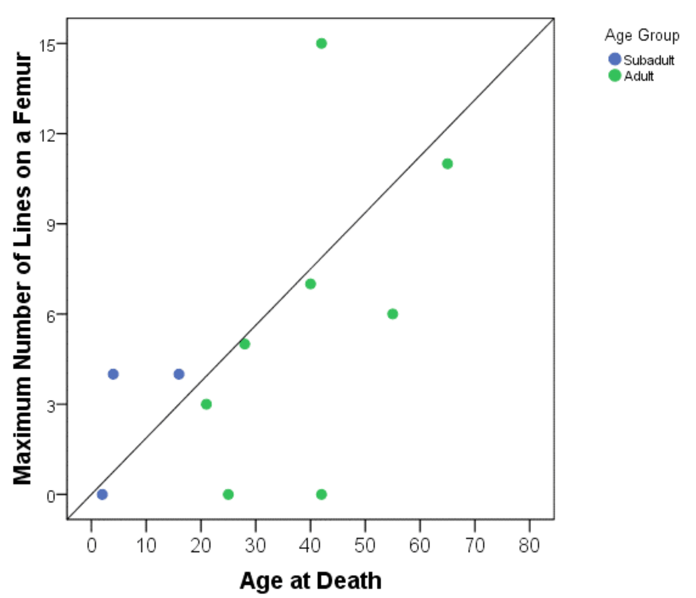


Figure 7.5: Scatterplot of Maximum Femoral Harris Line Counts and Age at Death for Both Subadults and Adults in Armatambo.

Comparisons of prevalence between three NSIS (CO, PH, and periosteal lesions) and age at death were carried out using the independent t-test to test for a difference in mean age at death between individuals with and without the stress indicator. No statistically significant relationship was found in any of these comparisons, ruling out paradoxical interpretations (Table 7.7).

Table 7.7 Correlation Comparisons Between Age at Death and NSIS of Pooled Specimens

	Mean Age at Death of Unaffected (n)	Mean Age at Death of Affected (n)	t	df	p
Cribra Orbitalia	33.9 (21)	18.4 (6)	1.34	25	0.19
Porotic Hyperostosis	28.4 (23)	38.1 (16)	0.16	25	0.88
Periosteal Lesions	28.2 (33)	29.2 (16)	-0.17	47	0.86

Lastly, a correlation analysis between maximum tibia length and age at death was used to look for a paradoxical manifestation. The sexes were analyzed separately to account for differences in tibia length between males and females. Neither male or female tibia length showed a strong correlation with age at death, ruling out a paradoxical interpretation (Table 7.8).

Table 7.8: Correlation comparisons Between Age at Death and Maximum Tibia Length, Separated by Sex

	Maximum Tibia Length		Age at Death				
	Mean	Standard Deviation	Mean	Standard Deviation	n	r	p
Females	325.3	12.8	42.5	14.6	13	0.01	0.48
Males	345.5	13.9	31.8	11.2	15	0.29	0.15

In summary, one of the non-specific indicators of stress, Harris line counts, was found to correlate positively with age at death in the Armatambo collection. Possible explanations for this finding, including the osteological paradox, will be discussed in Chapter 9.

CHAPTER 8: RESULTS

This chapter presents the results of the statistical analyses outlined at the end of Chapter 6. To summarize the four models this dissertation, Model A looks for a difference in health states between adult males and females in the Armatambo collection. Model B looks for a difference in health states between cranially deformed and undeformed adults, also in the Armatambo collection. Model C expands the scope of the study to see if subadult health of the Armatambo collection was improved compared to collections from less-complex societies. Model C also examines adult activity levels and health to see if both were more extreme in the Armatambo collection when compared to the non-state collections. Lastly, Model D compares the Armatambo skeletal collection to one from an earlier Andean empire. Model D is expected to show worse subadult health, better adult health and lower activity levels in the Armatambo collection when compared to the imperial skeletal collection. Comparisons of the results with the hypotheses they test are in Chapter 9.

Model A: Males vs. Females at Armatambo

The hypothesis for Model A states that a difference in health and activity patterns should appear between males and females at Armatambo. To test the

Model A hypothesis, seven indicators were compared between females and males. For assessing subadult health, Harris line counts of the adult tibia and femur, CO, and PH were compared between the sexes. Periosteal lesions, DJD, trauma, and age at death were compared in adults to see whether overall health and health related to activity patterns differed between males and females.

INDICATORS OF SUBADULT STRESS

HARRIS LINES

General linear models were used to compare Harris line counts, including individuals with no lines, with sex as a fixed factor and age at death in years as a covariate. Greater Harris line counts reflect worse health. Separate models were run for tibial and femoral Harris line counts. The GLM found no difference in either type of Harris line counts between males and females, though without age correction females had almost three times as many lines as males in the small sample of eight individuals (Tables 8.1a to 8.2b).

Table 8.1a: Descriptive Statistics for Tibial Harris Line Counts by Sex Analysis

Sex	n	Mean	Standard Deviation
Males	4	2.5	1.3
Females	4	5.5	4.8
Total	8	4.0	3.6

Table 8.1b: GLM Results for Tibial Harris Line Counts by Sex Analysis

Parameter	Type III Sum of Squares	df	Mean Square	F	p
Corrected Model	48.77	2	24.38	2.82	0.15
Intercept	9.50	1	9.50	1.10	0.34
Age	30.77	1	30.77	3.56	0.12
Sex	3.54	1	3.54	0.41	0.55
Error	43.23	5	8.65		
Total	220.00	8			
Corrected Total	92.00	7			

Table 8.2a: Descriptive Statistics for Femoral Harris Line Counts by Sex Analysis

Sex	n	Mean	Standard Deviation
Males	3	2.7	2.5
Females	5	7.8	5.6
Total	8	5.9	5.2

Table 8.2b: GLM Results for Femoral Harris Line Counts by Sex Analysis

Parameter	Type III Sum of Squares	df	Mean Square	F	p
Corrected Model	56.07	2	28.04	1.06	0.42
Intercept	0.33	1	0.33	0.01	0.92
Age	6.67	1	6.67	0.25	0.64
Sex	3.19	1	3.19	0.12	0.74
Error	132.80	5	26.56		
Total	465.00	8			
Corrected Total	188.88	7			

CHRONIC ANEMIA (CRIBRA ORBITALIA AND POROTIC HYPEROSTOSIS)

Hierarchical log-linear analyses were used to compare CO and PH prevalence between males and females to see if the sexes had different experiences with chronic anemia. Neither indicator showed statistical significance relative to sex (Table 8.3).

Table 8.3: Hierarchical Log-Linear Models of the Prevalence of Cribra Orbitalia, Porotic Hyperostosis and Periosteal Lesions Between Sexes at Armatambo

	Females		Males					
	n	**Frequency**	**n**	**Frequency**	**Final Model**	X^2	**df**	**p**
Cribra Orbitalia	11	0.18	10	0.20	Cribra Orbitalia	0.06	2	0.97
Porotic Hyperostosis	9	0.11	9	0.11	Porotic Hyperostosis	0.00	2	1.00
Periosteal Lesions	19	0.26	15	0.40	Periosteal Lesions	1.18	2	0.56

INDICATORS OF STRESS IN ADULTS

OSTEOPERIOSTITIS (PERIOSTEAL LESIONS FROM CHRONIC BACTERIAL INFECTION)

Chronic bacterial infection rates also did not differ between the sexes within Armatambo, according to a hierarchical log-linear model, though males showed more than females (Table 8.3 [above]).

DEGENERATIVE JOINT DISEASE

DJD in six regions of the human body were compared between the sexes at Armatambo using hierarchical log-linear: cervical, thoracic, and lumbar vertebrae, Schmorl's nodes (on the superior and inferior surfaces of vertebral bodies), elbows, and knees. Furthermore, the prevalence of any DJD on an individual was also examined between males and females. Of these tests, one region showed a difference in DJD prevalence between the sexes: Schmorl's nodes were more common in males than females (Figure 8.1). Females tended not to have Schmorl's nodes, while the male mean is near 50%. Other vertebral DJD prevalences did not differ, however, nor DJD prevalences in the elbow or knee joints (Table 8.4). Figures 8.2 to 8.4 show that DJD prevalence is similarly high in males and females, meaning that adults possessed DJD somewhere on the body. While all but one comparison was statistically non-significant, it should be noted that males were more affected than females in all comparisons save lumbar osteoarthritis, for which the sexes were tied.

Table 8.4: Hierarchical Log-Linear Models of the Prevalence of Osteoarthritis Between Males and Females at Armatambo

	Females		Males					
	n	Frequency	n	Frequency	Final Model	χ^2	df	p
Cervical DJD	18	0.44	12	0.50	Constant	1.47	3	0.69
Thoracic DJD	18	0.72	13	0.77	Thoracic Osteoarthritis	0.90	2	0.64
Lumbar DJD	19	0.79	14	0.79	Lumbar Osteoarthritis	0.76	2	0.68
Schmorl's Nodes	**19**	**0.11**	**14**	**0.50**	**Schmorl's Nodes * Sex**	**0.00**	**0**	**1.00**
Elbow DJD	16	0.31	13	0.54	Constant	2.69	3	0.44
Knee DJD	16	0.19	13	0.38	Knee Osteoarthritis	1.71	2	0.43
All DJD	19	0.95	15	1.00	All Osteoarthritis	1.66	2	0.44

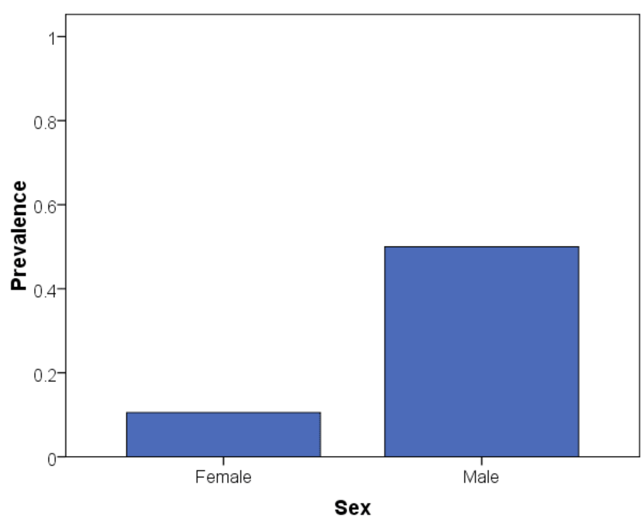


Figure 8.1: Prevalence of Schmorl's Nodes Between Sexes at Armatambo

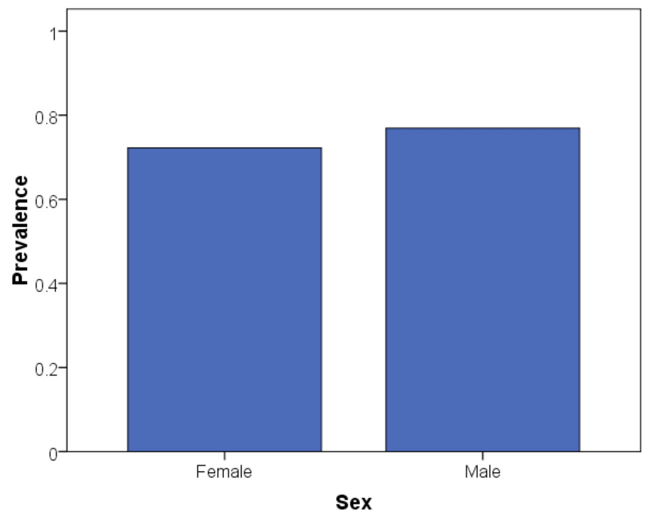


Figure 8.2: Prevalence of Thoracic DJD Between Sexes at Armatambo.

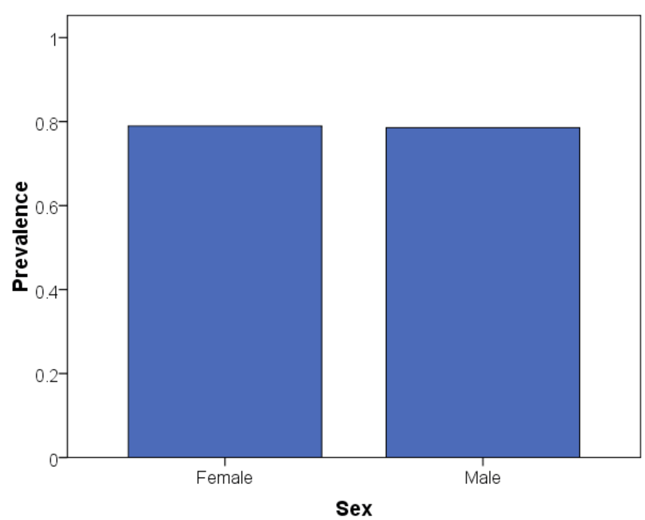


Figure 8.3: Prevalence of Lumbar DJD Between Sexes at Armatambo

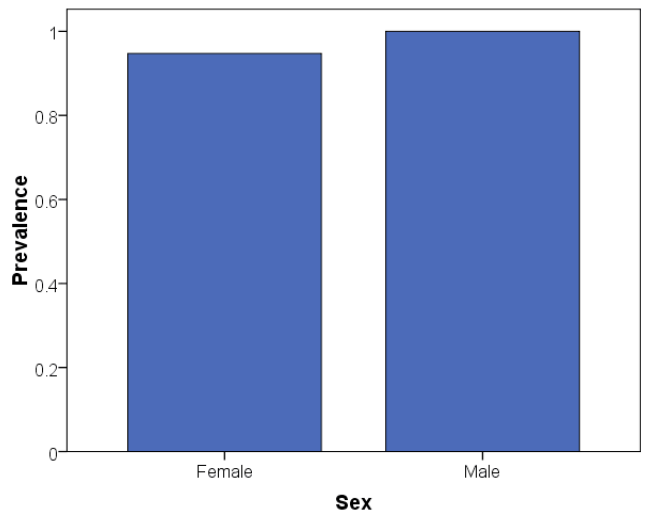


Figure 8.4: Prevalence of Any Osteoarthritis Between Sexes at Armatambo.

TRAUMA

Prevalences of four types of trauma, caused by sudden extreme physical forces, were examined between the sexes using the hierarchical log-linear model. The vertebral trauma showed a difference between the sexes at Armatambo; males were more likely to have vertebral trauma than females. The other categories of trauma in this study–appendicular, cranial, and sharp–were not significantly different between the sexes (Table 8.5; Figure 8.5).

Table 8.5: Hierarchical Log-Linear Models of the Prevalence of Trauma Between the Sexes at Armatambo

	Females		**Males**					
	n	**Frequency**	**n**	**Frequency**	**Final Model**	**χ^2**	**df**	**p**
Appendage Trauma	18	0.06	14	0.21	Appendage Trauma	2.34	2	0.31
Cranial Trauma	15	0.20	11	0.36	Cranial Trauma	1.48	2	0.48
Sharp Trauma	21	0.19	18	0.06	Sharp Trauma	1.93	2	0.38
Vertebral Trauma	**18**	**0.06**	**12**	**0.42**	**Vertebral Trauma * Sex**	**0.00**	**0**	**1.00**

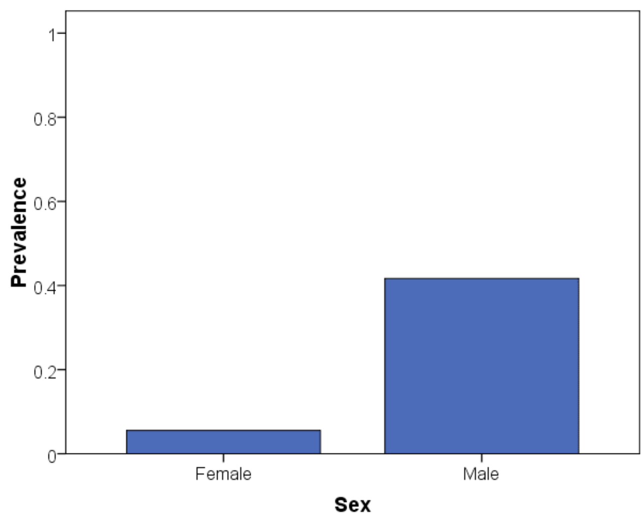


Figure 8.5: Prevalence of Vertebral Trauma Between Sexes at Armatambo.

AGE AT DEATH

As described in Chapter 7, the independent t-test found that females had higher age at death, better overall health, than males ($t = 2.31$, $df = 37$, $p = 0.03$).

While the female skeletal population was relatively evenly distributed between the second and fifth decades (mean: 41.3 years, S.D.: 13.9), males tended to be younger (mean: 32.2 years, S.D.: 10.3) (Figure 8.6). One adult whose sex could not be determined is also plotted in figure 8.6, though he/she was not in the comparison of age at death between sexes. Based on this plot, the indeterminate individual would be predicted to be a female.

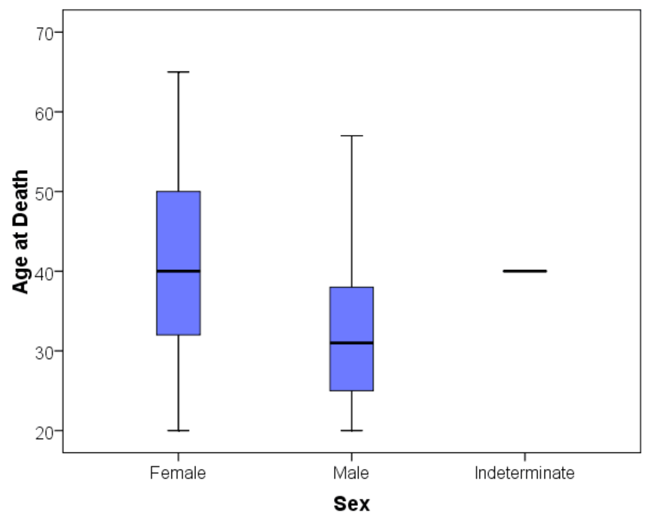


Figure 8.6: Box Plot of Age at Death by Sex.

SUMMARY

There was some support for the hypothesis of Model A. While indicators of subadult health were all statistically similar, a few differences appeared in the analysis of adult health. Males were more likely to have Schmorl's nodes and vertebral trauma. Females have a higher mean age at death than males. Interpretation of these results in relation to the model appears in Chapter 9.

Model B: Ethnic Groups at Armatambo

The hypothesis for Model B is that health states differed between subpopulations at Armatambo marked by the presence or absence of cranial deformation, a marker of social affiliation. In many ways, the analyses that test the hypotheses for Model B mirror those from the previous section. Chronic anemia and bacterial infections are examined, as well as DJD, trauma, and age at death. Unlike the Model A analyses, Harris lines are not compared for Model B since no adults with cranial deformation were radiographed. Instead, maximum tibia length is examined between ethnic groups as a measure of health during growth and development.

In some of the statistical models generated to test the Model B hypothesis, sex was also included as a factor in order to look for a significant interaction effect with cranial deformation type. Sex was included in looking at maximum tibia length, Schmorl's nodes, and the indicators of trauma.

INDICATORS OF SUBADULT STRESS

MAXIMUM TIBIA LENGTH

GLM analysis with maximum tibia length as the dependent variable and the fixed factors of sex and presence or absence of cranial deformation (abbreviated as "cranial deformation") found unsurprisingly that tibia length was greater in males than females (Tables 8.6a-b; Figure 8.7). Tibia length was found to be similar between the cranially deformed and undeformed. No interaction between sex and cranial deformation was present.

Table 8.6a: Descriptive Statistics for Analysis of Maximum Tibia Length and Cranial Deformation in Armatambo Adults

Sex	Deformation	n	Mean	Standard Deviation
Females	Absent	5	321.6	10.82
	Present	3	329.5	11.95
	Total	8	324.6	11.15
Males	Absent	5	349.2	16.59
	Present	1	343.5	.
	Total	6	348.3	15.02
Total	Absent	10	335.4	19.65
	Present	4	333.0	12.01
	Total	14	334.7	17.37

Table 8.6b: GLM Results for Analysis of Maximum Tibia Length and Cranial Deformation in Armatambo Adults

Parameter	Type III Sum of Squares	df	Mean Square	F	p
Corrected Model	2067.86	3	689.29	3.72	0.05
Intercept	1041806.79	1	1041806.79	5616.21	0.00
Sex	998.40	1	998.40	5.38	**0.04**
Deformation	2.79	1	2.79	0.02	0.91
Sex * Deformation	106.71	1	106.71	0.58	0.47
Error	1855.00	10	185.50		
Total	1572394.00	14			
Corrected Total	3922.86	13			

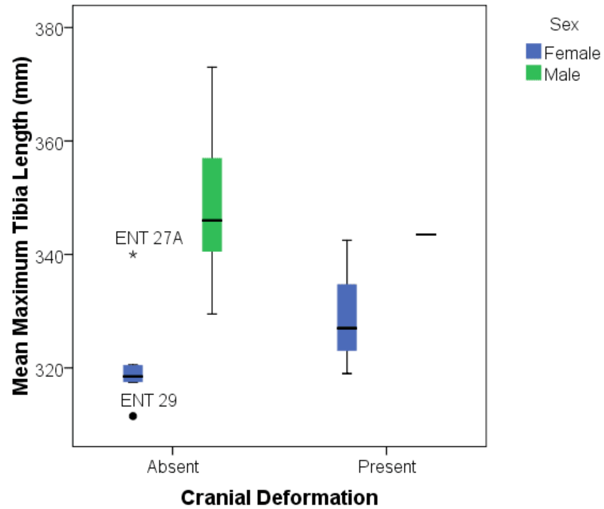


Figure 8.7: Box Plot of Tibia Length, Sex, and Cranial Deformation.

CHRONIC ANEMIA

As in Model A, the prevalence of two indicators of chronic anemia, cribra orbitalia and porotic hyperostosis, were examined between groups within the Armatambo collection. The hierarchical log-linear model found cribra orbitalia prevalence to be equivalent between the deformed and undeformed crania (Table 8.7; Figure 8.8). While figure 8.8 suggests that individuals without cranial deformation are slightly more likely to have CO than those without deformation, the difference was not statistically significant. Another indicator of chronic anemia, porotic hyperostosis, was significantly more common in the cranially deformed (Figure 8.9). The difference in CO and PH prevalence between deformed and undeformed crania could be the result of differential experience of anemia between the two subpopulations (Farnum, 1996), as discussed in the following chapter.

Table 8.7: Hierarchical Log-Linear Models of the Prevalence of Chronic Anemia and Periosteal Lesions by Ethnic Groups at Armatambo

	Deformed		Undeformed					
	n	**Frequency**	**n**	**Frequency**	**Final Model**	χ^2	**df**	**p**
Cribra Orbitalia	10	0.00	8	0.25	Cribra Orbitalia	2.77	2	0.25
Porotic Hyperostosis	**6**	**0.33**	**10**	**0.00**	**Porotic Hyperostosis * Deformation**	**0.00**	**0**	**1.00**
Periosteal Lesions	10	0.10	5	0.20	Constant	4.03	3	0.26

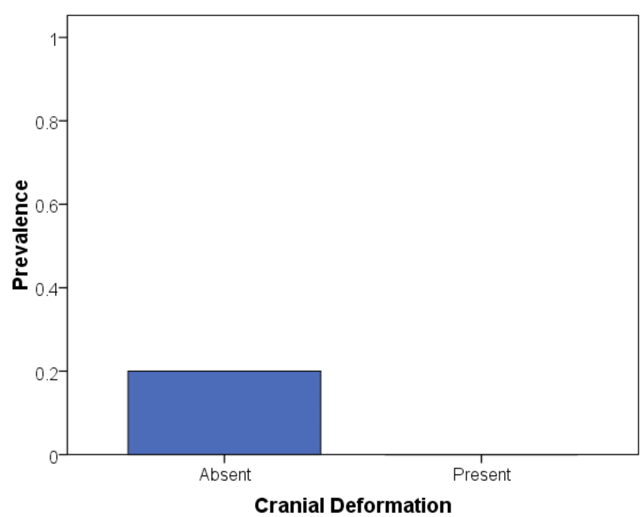


Figure 8.8: Bar Chart of Adult CO Prevalence and Cranial Deformation

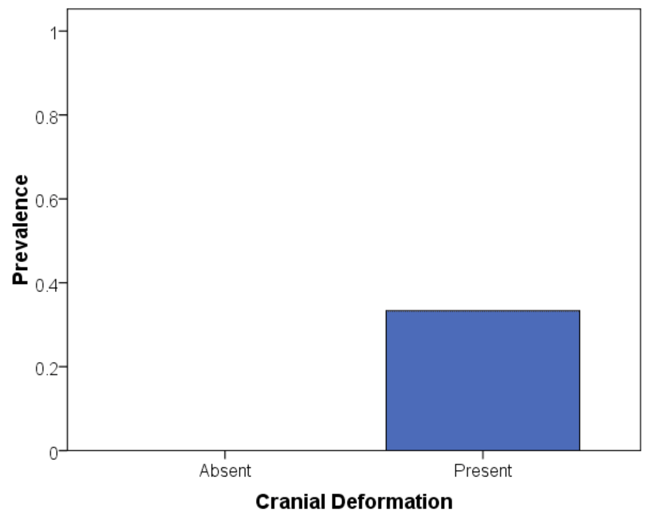


Figure 8.9: Bar Chart of Adult PH Prevalence and Cranial Deformation.

INDICATORS OF STRESS IN ADULTS

OSTEOPERIOSTITIS (PERIOSTEAL LESIONS FROM CHRONIC BACTERIAL INFECTION)

The hierarchical log-linear model found no statistically significant relationship between periosteal lesion rates and cranial deformation, though lesions were more prevalent in the undeformed (Table 8.7 [above]).

DEGENERATIVE JOINT DISEASE

The hierarchical log-linear model was used to compare the presence of cranial deformation with prevalence of Schmorl's nodes, a type of lesion caused by excessive vertebral loading, and DJD in the vertebrae, elbow, and knee joints. DJD can be caused by normal aging but is exacerbated by high physical pressure over time.

Since Schmorl's nodes were found to be more common in males than females during the analyses testing Model A, sex was included as a factor in the hierarchical log-linear analysis of Schmorl's nodes and ethnicity. The log-linear model for Model B also found that males were more likely to have Schmorl's nodes than females, but there was no difference between ethnic groups, nor was there a significant interaction.

No statistically significant difference was found in the prevalence of DJD in the different joints of the body examined in this study in the deformed or undeformed (Table 8.8 and 8.9; Figure 8.10). Still, cranially undeformed individuals had higher values than deformed individuals.

Table 8.8: Hierarchical Log-Linear Models of the Prevalence of Osteoarthritis by Ethnic Groups (Armatambo)

Indicator	Deformed		Undeformed					
	n	Frequency	n	Frequency	Final Model	χ^2	df	p
Cervical DJD	5	0.40	5	0.60	Constant	3.55	3	0.32
Thoracic DJD	5	0.60	10	0.90	Thoracic Osteoarthritis	3.48	2	0.18
Lumbar DJD	5	0.80	10	0.90	Lumbar Osteoarthritis	1.97	2	0.37
Elbow DJD	5	0.40	10	0.60	Constant	2.30	3	0.51
Knee DJD	5	0.20	10	0.30	Constant	5.27	3	0.15
All DJD	5	0.80	10	1.00	All Osteoarthritis	4.04	2	0.13

Table 8.9: Hierarchical Log-Linear Models of the Prevalence of Schmorl's Nodes by Ethnic Groups and Sex(Armatambo)

Sex	Cranial Deformation	Schmorl's Nodes		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Females	**Deformed**	4	0.25	Sex*Schmorl's Nodes	5.21	0	0.27
	Undeformed	5	0.00				
Males	**Deformed**	1	1.00				
	Undeformed	5	0.80				

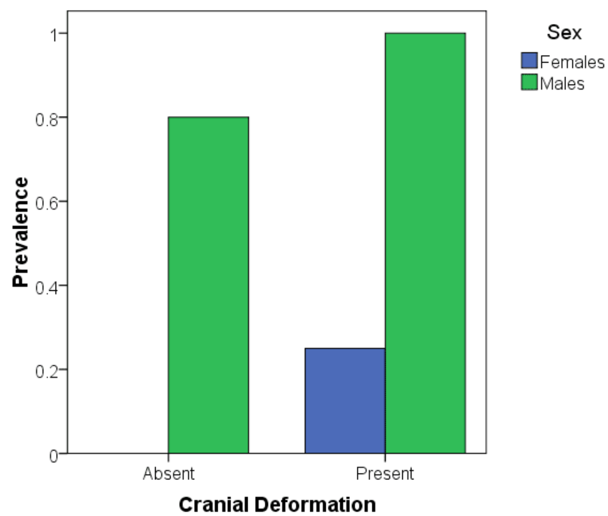


Figure 8.10: Bar Chart of Schmorl's Node Prevalence, Sex, and Cranial Deformation.

TRAUMA

None of the types of trauma, indicating extreme physical force, differed significantly between deformed and undeformed individuals (Tables 8.10 to 8.13). Surprisingly, the hierarchical log-linear model of vertebral trauma by sex and cranial deformation did not find a statistically significant relationship (Table

8.13), as was found in the Model A analyses. The difference in findings is most likely because, when sex and cranial deformation are considered together, the sample size shrinks as not all individuals with an estimated sex have a recovered cranium to record the presence of deformation. Graphs of sharp trauma prevalence divided by sex and deformation suggest some difference in distribution, but the hierarchical log-linear model found no statistically significant difference (Figure 8.11). Sharp trauma prevalence did not differ with cranial deformation (Table 8.12), though a graph of the data shows that only cranially deformed females had this type of injury (Figure 8.12). Also, no females lacking cranial deformation showed cranial trauma.

Table 8.10: Hierarchical Log-Linear Model of the Prevalence of Appendage Trauma by Ethnic Groups and Sex (Armatambo)

Sex	Cranial Deformation	Appendage Trauma		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Females	**Deformed**	4	0.25	Appendage Trauma	5.90	6	0.43
	Undeformed	5	0.00				
Males	**Deformed**	1	0.00				
	Undeformed	5	0.20				

Table 8.11: Hierarchical Log-Linear Model of the Prevalence of Cranial Trauma by Ethnic Groups and Sex (Armatambo)

Sex	Cranial Deformation	Cranial Trauma		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Females	Deformed	5	0.60	Constant	8.40	7	0.30
	Undeformed	5	0.00				
Males	Deformed	3	0.67				
	Undeformed	5	0.40				

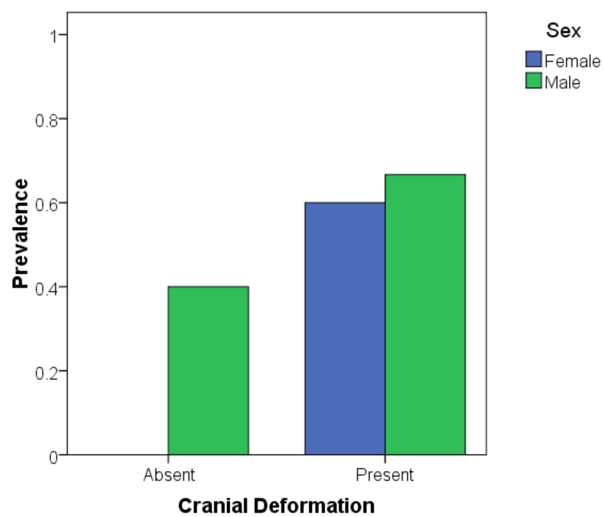


Figure 8.11: Bar Chart of Cranial Trauma, Sex, and Cranial Deformation

Table 8.12: Hierarchical Log-Linear Model of the Prevalence of Sharp Trauma by Ethnic Groups and Sex (Armatambo)

Sex	Cranial Deformation	Sharp Trauma		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Females	Deformed	5	0.40	Sharp Trauma	6.56	6	0.36
	Undeformed	0	0.00				
Males	Deformed	3	0.00				
	Undeformed	0	0.00				

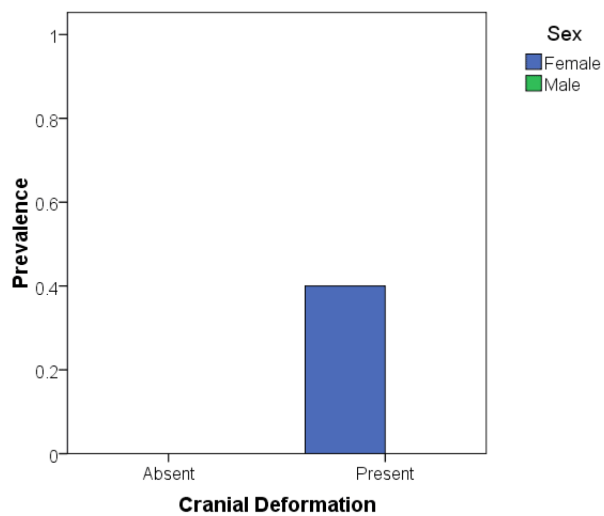


Figure 8.12: Bar Chart of Sharp Trauma, Sex, and Cranial Deformation

Table 8.13: Hierarchical Log-Linear Model of the Prevalence of Vertebral Trauma by Ethnic Groups and Sex (Armatambo)

Sex	Cranial Deformation	Vertebral Trauma		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Females	**Deformed**	4	0.25	Vertebral Trauma	13.19	7	0.30
	Undeformed	5	0.00				
Males	**Deformed**	1	0.00				
	Undeformed	5	0.60				

AGE AT DEATH

Although cranially undeformed females lived on the average nine years longer than those deformed, suggesting better general adult health, there was no statistically significant difference between the age at death distributions for individuals with or without cranial deformation (Tables 8.14a-b; Figure 8.13). The general linear model was used with sex and cranial deformation presence as fixed factors. As in the analysis of vertebral trauma with sex and deformation state as factors, a statistically significant relationship between sex and the dependent variable (in this case, age at death) disappeared. As in the previous case, the narrowing of the sample size due to the inclusion of two factors in the model is the most likely reason for this difference.

Table 8.14a: Descriptives of Age at Death by Ethnic Groups and Sex (Armatambo)

Sex	Deformation	n	Mean	Standard Deviation
Females	**Absent**	5	45.4	17.9
	Present	5	36.4	12.9
	Total	10	40.9	15.5
Males	**Absent**	5	39.2	7.8
	Present	3	40.7	14.4
	Total	8	39.8	9.7
Total	**Absent**	10	42.3	13.4
	Present	8	38.0	12.6
	Total	18	40.4	12.9

Table 8.14b: GLM Results Age at Death by Ethnic Groups and Sex (Armatambo)

Source	Type III Sum of Squares	df	Mean Square	F	p
Corrected Model	212.41	3	70.80	0.38	0.77
Intercept	28002.98	1	28002.98	150.22	0.00
Sex	60.81	1	60.81	0.33	0.58
Deformation	4.01	1	4.01	0.02	0.89
Deformation * Sex	117.38	1	117.38	0.63	0.44
Error	2609.87	14	186.42		
Total	32185.00	18			
Corrected Total	2822.28	17			

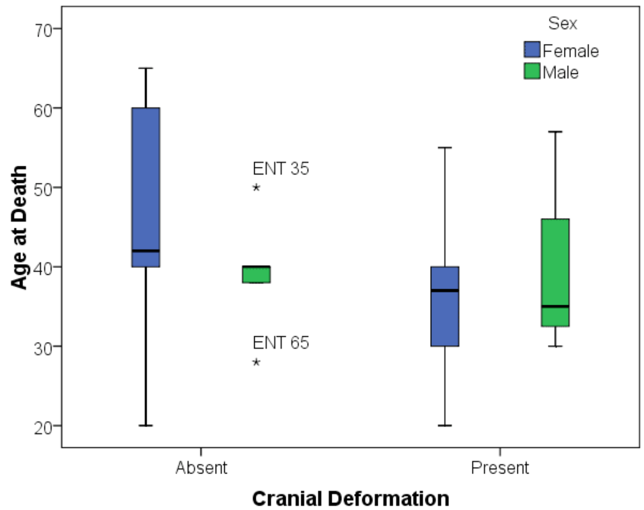


Figure 8.13: Box Plot of Adult Age at Death, Sex, and Cranial Deformation.

SUMMARY

Only a few differences in stress indicator prevalence were found between adults at Armatambo with and without cranial deformation. One indicator of chronic anemia, porotic hyperostosis, was significantly more common in the cranially deformed.

In adults, comparisons of periosteal lesions, DJD, and trauma produced no significant differences in health or activity between the cranially deformed and undeformed. Age at death also showed no statistically significant difference, though the female mean for the undeformed is nine years greater than the female deformed mean.

Models C and D: Intersite Comparisons

Models C and D compare indicators of health and activity among Armatambo and other sites in the central coast region of the Andes. The hypothesis for Model C is that Armatambo, an urban state cemetery site, should show better subadult health and worse adult health (and higher activity levels) than four sites from non-urban states: Paloma, Cardal, and the grouped sites of Villa El Salvador and Tablada de Lurín (referred to as VES/TBL though in some analyses only Villa El Salvador data were used, denoted by the abbreviation VES). Model D posits the opposite difference between Armatambo and an earlier site, Huaca Malena, from the Huari Empire. Individuals at Armatambo are expected to have worse subadult health but better adult health and activity levels than Huaca Malena.

First, the results of multivariate comparisons of stress indicators will be presented, followed by the analyses that could only be done pairwise between Armatambo and one of the other sites in each statistical test.

MULTIPLE SITE COMPARISONS

Many indicators of health and activity used in this dissertation are available for multiple sites. With these data, I look for parsimonious statistical models that accounts for multiple intersite comparisons. This section describes the results of these multiple site tests. The results presented here are for adult tibial Harris line counts, chronic anemia in subadults and between adult males and females (except for Paloma), periosteal lesions, corrected subadult age estimation, age at death, DJD, and trauma.

SUBADULT HEALTH

Harris Lines

Harris lines indicate periods of episodic physiological stress during growth and development. GLM with age by year as covariate, site as a random factor, sex as a fixed factor, and maximum Harris line count as the dependent variable, was used to look for a difference in adult males and females among sites. An overall statistically significant difference among the sites was found in female tibial Harris line counts (Tables 8.15a-b; Figure 8.14). Pairwise GLM comparisons between Armatambo and the other sites found a possible significant difference in Harris line counts between Armatambo and Paloma ($F = 3.76$, $df = 15$, $p = 0.07$), but not between Armatambo and Villa El Salvador ($F = 0.13$, $df = 22$, $p = 0.73$). Armatambo showed higher mean Harris line counts than both Paloma and Villa El Salvador. Unlike in females, no statistically significant difference was found in the tibial Harris line counts in adult males (Tables 8.16a-b).

Table 8.15a: Summary Statistics of Adult Female Tibial Harris Lines By Site

Site	n	Mean	Standard Deviation
Paloma	14	1.7	1.5
VES	21	3.7	2.7
Armatambo	4	5.5	4.8
Total	39	3.2	2.8

Table 8.15b: GLM Results for Adult Female Tibial Harris Lines By Site

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	**Hypothesis**	4.02	1	4.02	0.53	0.47
	Error	220.50	29	7.62*		
Age	**Hypothesis**	9.97	1	9.97	1.49	0.23
	Error	234.56	35	6.70**		
Site	**Hypothesis**	44.24	2	22.12	3.30	**0.05**
	Error	231.94	35	6.63**		

* .06 MS(Site) + 0.94 MS (Error)

** MS (Error)

Table 8.16a: Summary Statistics of Adult Male Tibial Harris Lines By Site

Site	n	Mean	Standard Deviation
Paloma	18	2.4	2.2
VES	24	2.1	2.0
Armatambo	4	2.5	1.3
Total	46	2.3	2.0

Table 8.16b: GLM Results for Adult Male Tibial Harris Lines By Site

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	**Hypothesis**	15.91	1	15.91	3.90	*0.06*
	Error	175.95	43	4.09*		
Age	**Hypothesis**	0.00	1	0.00	0.00	0.98
	Error	183.28	42	4.36**		
Site	**Hypothesis**	1.56	2	0.78	0.18	0.84
	Error	183.28	42	4.36**		

* 0.08 MS(Site) + 0.92 MS (Error)

** MS (Error)

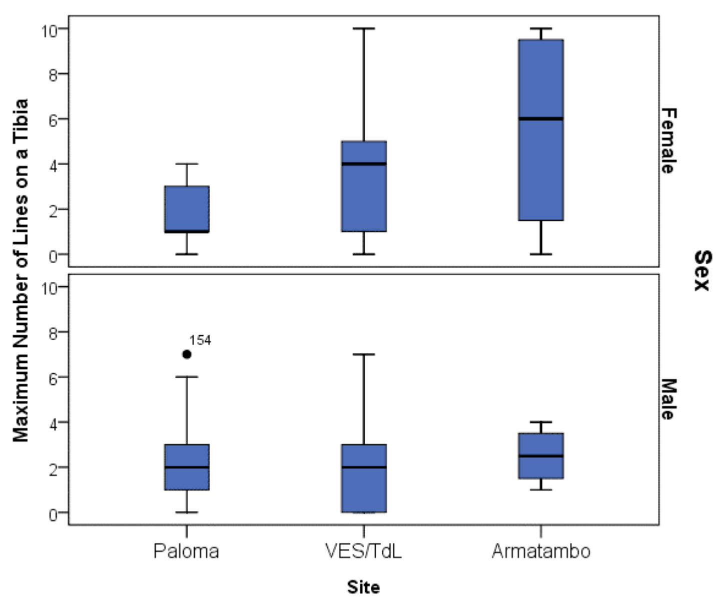


Figure 8.14: Box Plots of Adult Tibial Harris Line Counts, Sex and Site.

Chronic Anemia

Chronic anemia prevalence is inferred from cribra orbitalia and porotic hyperostosis. The hierarchical log-linear model of adult cribra orbitalia prevalence and site found a significant difference in CO prevalence among sites (Table 8.17). Follow-up pairwise Fisher's Exact Tests between Armatambo and the other sites found that Armatambo had significantly less CO than Villa El Salvador and Tablada de Lurín (Figure 8.15). CO prevalence was greater at Armatambo than at Paloma, but lower than at Cardal, though neither comparison was significantly different.

Table 8.17: Hierarchical Log-Linear Model of the Prevalence of Cribra Orbitalia in Subadults Among Sites

	Cribra Orbitalia		**Hierarchical Log-Linear Result**				**Pairwise Fisher's Exact p with Armatambo**
	n	**Frequency**	**Final Model**	**χ^2**	**df**	**p**	
Paloma	44	0.18	**Site*Cribra Orbitalia**	**0.00**	**0**	**1.00**	0.34
Cardal	3	0.67					0.41
VES/TBL	44	0.73					*0.07*
Armatambo	6	0.33					.

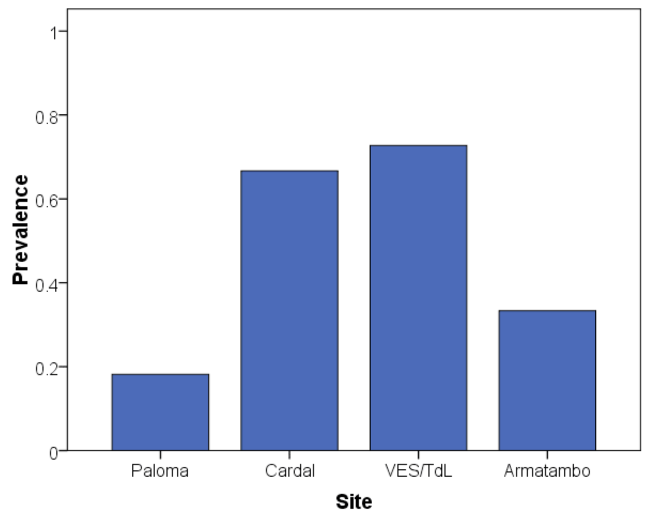


Figure 8.15: Bar Chart of Subadult CO Prevalence Across Sites.

A similar hierarchical log-linear model analysis, with subadult PH prevalence instead of CO, showed a significant value in PH prevalence among sites (Table 8.18). Pairwise Fisher's Exact Tests found that PH was statistically more common at VES/TBL than at Armatambo. Armatambo had the same prevalence as Cardal, and a higher value than Paloma, though neither comparison was statistically significant (Figure 8.16).

Table 8.18: Hierarchical Log-Linear Model of the Prevalence of Porotic Hyperostosis in Subadults Among Sites

	Porotic Hyperostosis		**Hierarchical Log-Linear Result**				**Pairwise Fisher's Exact p with Armatambo**
	n	**Frequency**	**Final Model**	χ^2	**df**	**p**	
Paloma	36	0.14	**Site*Porotic Hyperostosis**	**0.00**	**0**	**1.00**	0.43
Cardal	9	0.22					0.71
VES/TBL	39	0.56					*0.07*
Armatambo	9	0.22					.

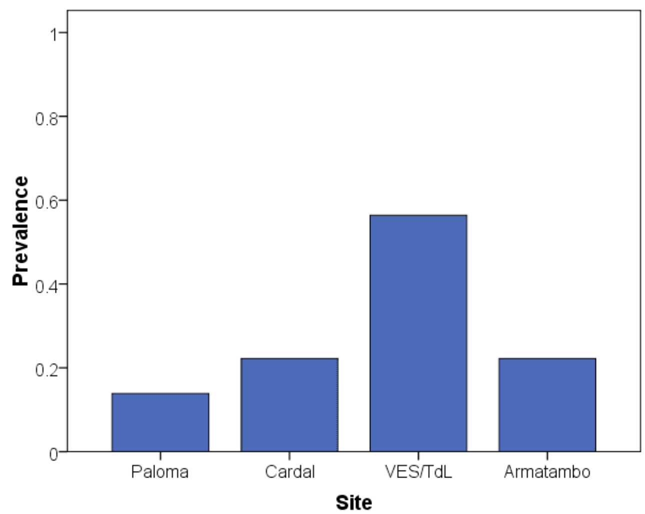


Figure 8.16: Bar Chart of Subadult PH Prevalence Across Sites.

Analyses of adult CO prevalence among sites added another factor to the hierarchical log-linear model, sex, in order to make comparisons between males and females. Paloma data were presented with sexes combined in the published sources accessed for this dissertation, thus the comparison of adult CO between

Armatambo and Paloma was conducted separately, presented below. CO prevalence was found to differ among sites (Table 8.19; Figure 8.17). Fisher's Exact Tests of CO prevalence between Armatambo and the other sites found that VES/TBL adults are more likely than Armatambo adults to have CO. CO prevalence was less common at Armatambo than Cardal, but more common than at Huaca Malena, though differences were not statistically significant. The distribution of CO prevalence also differed by sex, with males more likely to have this NSIS, a finding that does not directly relate to the hypotheses of Models C and D.

Table 8.19: Hierarchical Log-Linear Model of the Prevalence of Cribra Orbitalia in Adults Among Sites

Site	Sex	Cribra Orbitalia		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo (Both Sexes)
		n	Frequency	Final Model	χ^2	df	p	
Cardal	**Female**	7	0.29	**Site*Cribra Orbitalia Sex**	**1.53**	**8**	**0.99**	0.28
	Male	8	0.38					
VES/TBL	**Female**	41	0.49					**0.01**
	Male	38	0.58					
Huaca Malena	**Female**	5	0.00					0.25
	Male	3	0.00					
Armatambo	**Female**	11	0.18					.
	Male	10	0.20					

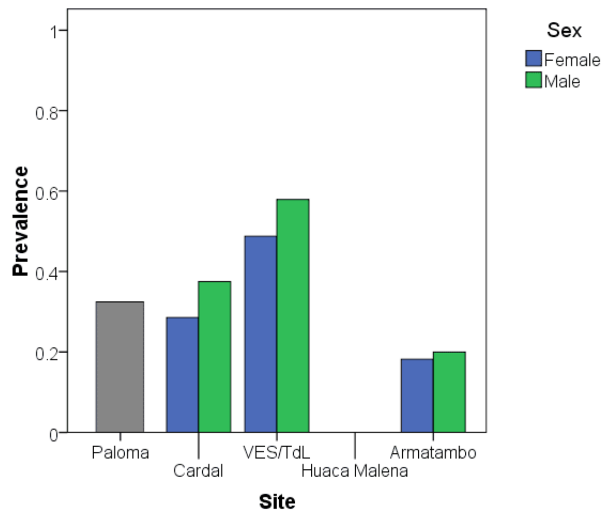


Figure 8.17: Bar Chart of Adult CO Prevalence, Site, and Sex. (A composite of two charts from SPSS).

Statistical analysis of PH prevalence in adults between the sites included sex as a factor, but excluded Paloma as in the adult CO analysis. The hierarchical log-linear model of this analysis found two significant two-way interactions that involve porotic hyperostosis rates (Table 8.20). PH prevalence differed both between the sites and the sexes, though not in a three-way interaction between the factors. Thus, Fisher's Exact Tests were used on the combined sexes to look at PH prevalence across sites. As in the analysis of CO in adults, PH was found to be more common at VES/TBL than at Armatambo while no differences existed between Armatambo and the other two sites, Cardal and Huaca Malena (Figure 8.18).

Table 8.20: Hierarchical Log-Linear Model of the Prevalence of Porotic Hyperostosis in Adults Among Sites

Site	Sex	Porotic Hyperostosis		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo (Both Sexes)
		n	Frequency	Final Model	X^2	df	p	
Cardal	**Female**	12	0.08	**Site*Porotic Hyperostosis** **Sex*Porotic Hyperostosis**	**2.00**	**8**	**0.98**	0.64
	Male	9	0.11					
VES/TBL	**Female**	40	0.43					**0.01**
	Male	41	0.54					
Huaca Malena	**Female**	5	0.00					0.47
	Male	3	0.00					
Armatambo	**Female**	9	0.11					.
	Male	9	0.11					

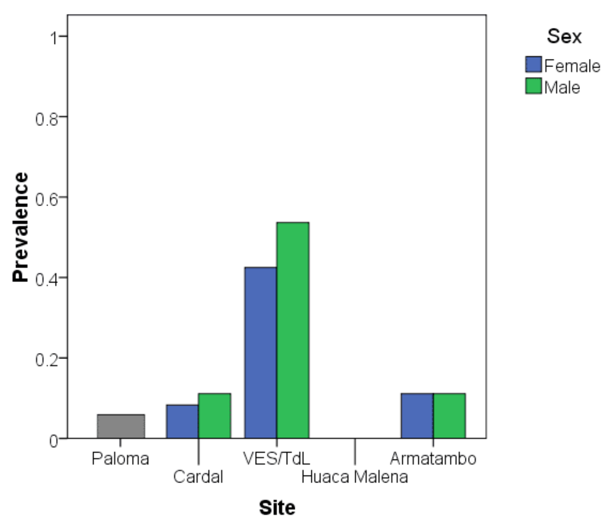


Figure 8.18: Bar Chart of Adult PH Prevalence, Site, and Sex (This chart is a composite of two charts from SPSS).

Examination of the data in Table 8.20 suggests that the sex difference in porotic hyperostosis prevalence lies solely in the VES/TBL sample, the site with the largest sample size in this comparison, with males more likely to possess PH.

Periosteal Lesions

Periosteal lesions indicate chronic bacterial infection that has reached bone. Prevalence of periosteal lesions was compared among subadults of Paloma, Cardal, VES/TBL, and Armatambo, using a hierarchical log-linear model (Table 8.21). The final model showed a significant difference in periosteal lesion prevalence among sites. Fisher's Exact Tests of pairwise comparisons with Armatambo found three significant comparisons: periosteal lesions are more common at Armatambo than at Paloma or VES/TBL, but less common than at Cardal (Figure 8.19).

Table 8.21: Hierarchical Log-Linear Model of the Prevalence of Periosteal Lesions in Subadults Among Sites

	Periosteal Lesions		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo
	n	**Frequency**	**Final Model**	χ^2	**df**	**p**	
Paloma	57	0.11	**Site* Periosteal Lesions**	**0.00**	**0**	**1.00**	**0.04**
Cardal	12	0.75					**0.04**
VES/TBL	42	0.00					**0.01**
Armatambo	15	0.33					.

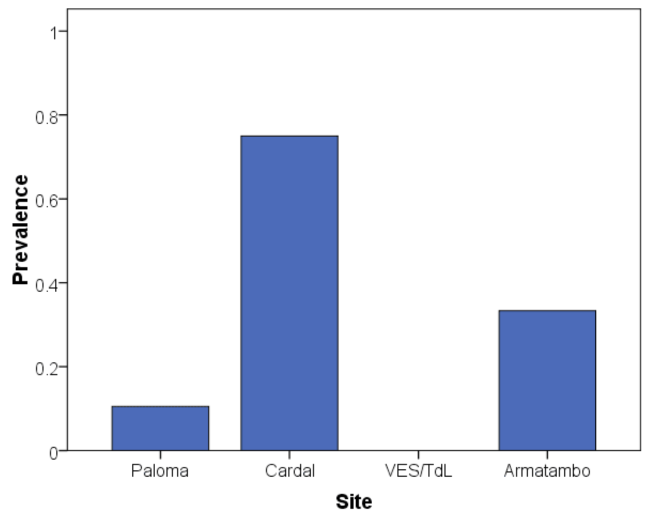


Figure 8.19: Bar Chart of Subadult Periosteal Lesion Prevalence Across Sites.

Corrected Subadult Age Estimate (CSAE)

The CSAE shows the gap in subadults between an estimate of genetic growth potential (dental age estimation) and an age estimate based on actual growth reached (femur length). The Kruskal-Wallis ANOVA was chosen to analyze CSAE data. The procedure ranks CSAE values across all sites, and the site medians are compared for statistical differences (see Chapter 6). The K-W test found a significant difference in CSAE among sites (Table 8.22).

Table 8.22: Kruskal-Wallis Test of CSAE Among Sites

Site	n	Median Rank	χ^2	df	p
Paloma	17	15.2	**11.39**	**3**	**0.01**
Cardal	4	24.0			
VES	17	29.8			
Armatambo	7	24.8			
Total	45				

As in the GLM and hierarchical log-linear model, pairwise comparisons were needed to determine whether this difference involved Armatambo. Three pairwise K-W tests were run comparing Armatambo with Paloma, Cardal, and VES. None showed a significant difference in CSAE (Tables 8.23a-c). Histograms of the data separated by site suggest that the significant difference is between Paloma and VES (Figure 8.20). A K-W comparison between Paloma and VES confirmed that Paloma has significantly lower CSAE, better health, than VES (Table 8.24).

Table 8.23a: Kruskal-Wallis Test of CSAE Between Armatambo and Paloma

Site	n	Mean Rank	χ^2	df	p
Paloma	17	11.3	1.87	1	0.17
Armatambo	7	15.5			
Total	24				

Table 8.23b: Kruskal-Wallis Test of CSAE Between Armatambo and Cardal

Site	n	Mean Rank	χ^2	df	p
Cardal	4	5.9			
Armatambo	7	6.1	0.009	1	0.92
Total	11				

Table 8.23c: Kruskal-Wallis Test of CSAE Between Armatambo and Villa El Salvador

Site	n	Mean Rank	χ^2	df	p
VES	17	13.0			
Armatambo	7	11.0	0.4	1	0.54
Total	24				

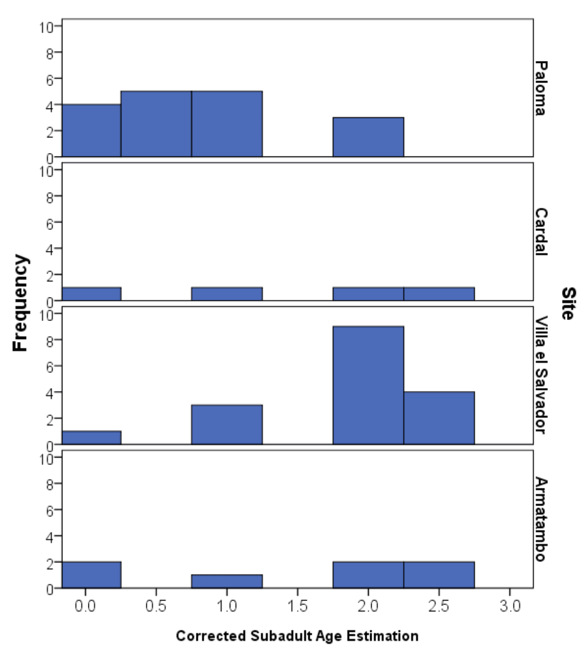


Figure 8.20: Histograms of Unranked CSAE Data Across Sites

Table 8.24: Kruskal-Wallis Test of CSAE Between Paloma and VES

Site	n	Mean Rank	χ^2	df	p
Paloma	17	11.7			
VES	17	23.4	**12.55**	**1**	**0.00**
Total	34				

INDICATORS OF ADULT HEALTH

Periosteal Lesions

Adult periosteal lesion prevalence was compared across sites with a hierarchical log-linear model that also included sex. The final most-parsimonious hierarchical log-linear model includes all three factors in a significant three-way interaction (Table 8.25; Figure 8.21). Next, Fisher's Exact Tests were used to compare periosteal lesion prevalence at Armatambo with the other sites, with males and females separated to parse out the significant interaction. Two of these comparisons were significant: Armatambo females are less likely to have lesions than their Cardal counterparts, while Armatambo males are more likely than Huaca Malena males to have this stress marker.

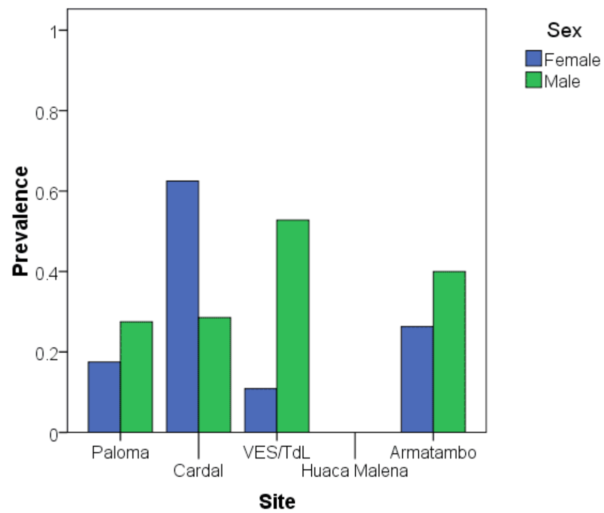


Figure 8.21: Bar Chart of Adult Periosteal Lesion Data, Site, and Sex.

Table 8.25: Hierarchical Log-Linear Model of the Prevalence of Periosteal Lesions in Adults Among Sites

Site	Sex	Periosteal Lesions		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo (Sexes Separate)
		n	Frequency	Final Model	χ^2	df	p	
Paloma	**Female**	40	0.18	**Site*Sex* Periosteal Lesions**	**0.00**	**0**	**1.00**	0.32
	Male	40	0.28					0.28
Cardal	**Female**	8	0.63					*0.09*
	Male	7	0.29					0.49
VES/TBL	**Female**	46	0.11					0.12
	Male	36	0.53					0.30
Huaca Malena	**Female**	6	0.00					0.22
	Male	6	0.00					*0.09*
Armatambo	**Female**	19	0.26					.
	Male	15	0.40					.

Age at Death

In general, a higher mean age at death indicates that a population has good health. The general linear model for age at death in adults as the dependent variable used sex as a fixed factor, and site as a random factor. This test found a significant interaction between sex and site in regards to age at death, necessitating further statistical exploration to determine the actual statistical differences present. (Table 8.26; Figure 8.22).

Pairwise independent t-tests were used to compare Armatambo age at death with those of other sites (Tables 8.27 and 8.28). In all of these comparisons, Armatambo females showed higher age at death at statistically significant or near significant levels, while males did not. Recall that females were older than males, but not at a statistically significant level.

Table 8.26: Results of GLM with Age at Death with Sex and Site as Factors

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	**Hypothesis**	143467.32	1.0	143467.32	693.27	0.00
	Error	976.62	4.7	206.94		
Sex	**Hypothesis**	55.81	1.0	55.51	0.14	0.72
	Error	1685.44	4.4	386.28		
Site	**Hypothesis**	909.43	4.0	227.36	0.52	0.73
	Error	1765.55	4.0	441.39		
Sex * Site	**Hypothesis**	1765.55	4.0	441.39	4.35	**0.002**
	Error	16023.60	158.0	101.42		

Table 8.27: T-Test Results of Female Age at Death by Site

Sample	n	Mean	Standard Deviation	t	df	p
Paloma	21	31.9	10.4	2.54	37	**0.02**
Cardal	*11*	*32.1*	*10.3*	*1.93*	*30*	***0.06***
VES/TDL	*26*	*34.9*	*8.8*	*1.95*	*45*	***0.06***
Huaca Malena	7	20.4	2.8	6.52	24	**0.00**
Armatambo	21	41.3	13.9	.	.	.

Table 8.28: T-Test Results of Male Age at Death by Site

Sample	n	Mean	Standard Deviation	t	df	p
Paloma	18	32.4	9.3	-0.07	37	0.95
Cardal	9	32.6	13.7	-0.08	25	0.94
VES/TDL	29	33.6	7.8	-0.53	45	0.60
Huaca Malena	8	36.5	8.9	-1.03	24	0.31
Armatambo	18	32.2	10.3	.	.	.

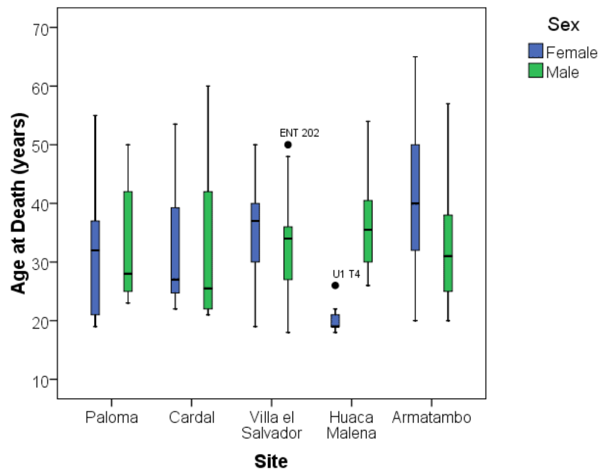


Figure 8.22: Box Plot of Age at Death, Site, and Sex.

Degenerative Joint Disease

Multiple-site comparisons of DJD prevalence were carried out for the three types of vertebrae, the elbow, and the knee joints in separate hierarchical log-linear models.

Of the vertebrae, neither the cervical or lumbar regions showed significantly different DJD prevalence rates among sites (Tables 8.29 and 8.31; Figures 8.23). DJD of the thoracic vertebrae, however, was different among sites (Table 8.30). Pairwise Fisher's Exact Tests found a that Armatambo adults were significantly more likely than Villa El Salvador adults, and nearly significantly more likely than Huaca Malena adults, to have thoracic vertebrae DJD. No difference between the sexes was found.

Table 8.29: Hierarchical Log-Linear Model of the Prevalence of Cervical Vertebrae DJD in Adults Among Sites

Site	Sex	Cervical Vertebrae DJD		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Cardal	**Female**	12	0.42	Site	16.50	12	0.17
	Male	8	0.63				
VES	**Female**	30	0.67				
	Male	31	0.68				
Huaca Malena	**Female**	4	0.00				
	Male	4	0.75				
Armatambo	**Female**	18	0.44				
	Male	12	0.50				

Table 8.30: Hierarchical Log-Linear Model of the Prevalence of Thoracic Vertebrae DJD in Adults Among Sites

Site	Sex	Thoracic Vertebrae DJD		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo (Both Sexes)
		n	Frequency	Final Model	χ^2	df	p	
VES	**Female**	30	0.33	Site * Thoracic Vertebrae DJD	5.00	6	0.54	**0.02**
	Male	31	0.48					
Huaca Malena	**Female**	7	0.29					*0.09*
	Male	7	0.71					
Armatambo	**Female**	18	0.72					.
	Male	13	0.77					

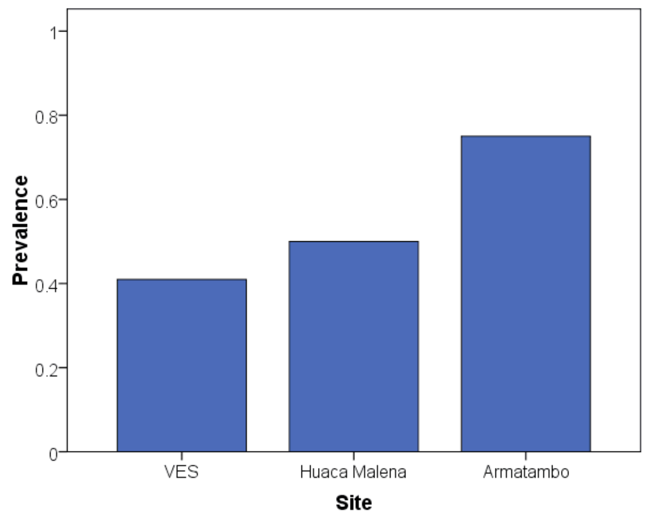


Figure 8.23: Bar Chart of Thoracic DJD Prevalence and Sites.

Table 8.31: Hierarchical Log-Linear Model of the Prevalence of Lumbar Vertebrae DJD in Adults Among Sites

Site	Sex	Lumbar Vertebrae DJD		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Cardal	**Female**	12	0.42	Site Lumbar Vertebrae DJD	7.88	11	0.72
	Male	8	0.63				
VES	**Female**	29	0.76				
	Male	31	0.77				
Huaca Malena	**Female**	4	0.50				
	Male	6	0.67				
Armatambo	**Female**	19	0.79				
	Male	14	0.79				

Armatambo has higher elbow joint DJD but lower knee joint DJD prevalence than Villa El Salvador, based on hierarchical log-linear models of each indicator (Tables 8.32 and 8.33; Figure 8.24). While the data suggest that

Armatambo could have significantly higher elbow and knee DJD prevalence than Huaca Malena, pairwise comparisons between Armatambo and Huaca Malena were just outside the range of significance.

Table 8.32: Hierarchical Log-Linear Model of the Prevalence of Elbow Vertebrae DJD in Adults Among Sites

Site	Sex	Elbow DJD		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo (Both Sexes)
		n	Frequency	Final Model	χ^2	df	p	
VES	**Female**	30	0.50	**Site * Elbow DJD** **Sex * Elbow DJD**	**0.33**	**4**	**0.99**	*0.07*
	Male	29	0.72					
Huaca Malena	**Female**	4	0.50					0.16
	Male	6	0.67					
Armatambo	**Female**	19	0.79					.
	Male	14	0.79					

Table 8.33: Hierarchical Log-Linear Model of the Prevalence of Knee Vertebrae DJD in Adults Among Sites

Site	Sex	Knee DJD n	Knee DJD Frequency	Hierarchical Log-Linear Result: Final Model	X^2	df	p	Pairwise Fisher's Exact p with Armatambo (Both Sexes)
VES	Female	30	0.47	Site * Knee DJD Sex * Knee DJD	1.46	4	0.83	**0.003**
	Male	27	0.78					
Huaca Malena	Female	4	0.00					0.11
	Male	4	0.00					
Armatambo	Female	16	0.19					.
	Male	13	0.38					

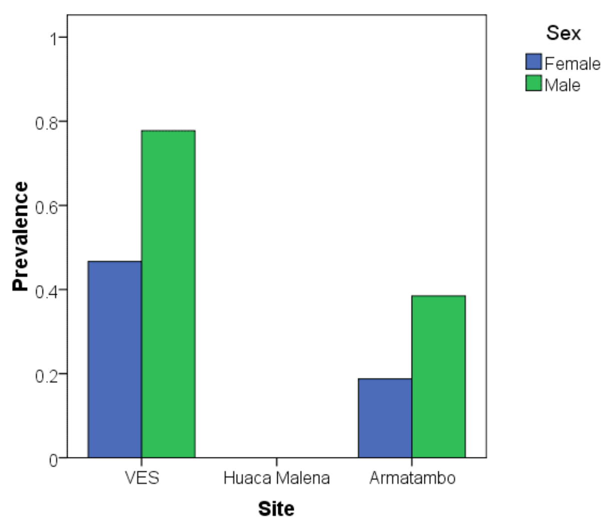


Figure 8.24: Bar Chart of Knee Joint DJD Prevalence, Site and Sex.

In both hierarchical log-linear models of elbow and knee joint DJD, prevalence also differed between males and females in a consistent manner across sites. Examination of the data tables suggests that males are more likely to have DJD of the elbow (Fisher's Exact $p = 0.03$) and knee (Pearson Chi-Square = 16.231, $df = 3$, $p = 0.001$) than females (choice of statistical method was based on sample size).

Trauma

Appendage, cranial, sharp, and vertebral trauma were compared among sites in separate hierarchical log-linear models. In each of these models, sex was added as an additional factor to detect interactions between sex, site, and the activity indicator.

The log-linear model for appendage trauma found a significant difference in prevalence of the indicator among sites (Table 8.34; Figure 8.25). Fisher's Exact Tests, however, found no significant difference between Armatambo and either Cardal or Huaca Malena. An additional Fisher's Exact Test found that Huaca Malena has significantly higher appendage trauma prevalence than Cardal, possibly accounting for the overall significant log-linear model (Fisher's Exact $p = 0.02$).

Table 8.34: Hierarchical Log-Linear Model of the Prevalence of Appendage Trauma in Adults Among Sites

Site	Sex	Appendage Trauma		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo (Both Sexes)
		n	Frequency	Final Model	χ^2	df	p	
Cardal	**Female**	7	0.43	Site* Appendage Trauma	2.63	6	0.85	0.11
	Male	6	0.67					
Huaca Malena	**Female**	8	0.00					0.17
	Male	8	0.00					
Armatambo	**Female**	18	0.06					.
	Male	14	0.21					

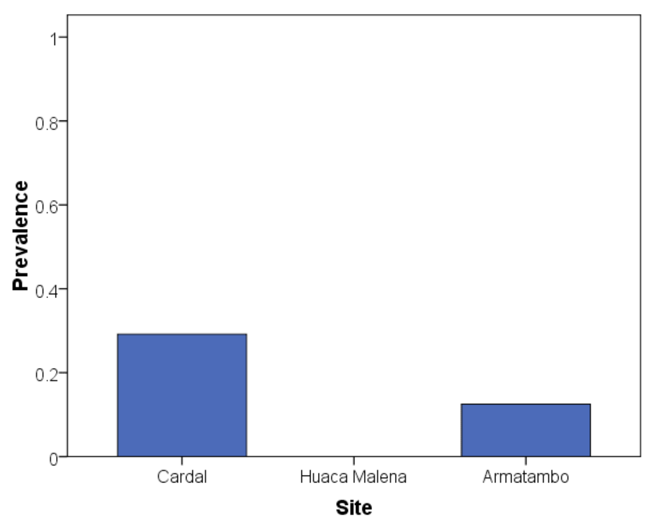


Figure 8.25: Bar Chart of Appendage Trauma and Site.

Analysis of cranial trauma prevalence between males and females at Cardal, VES, Huaca Malena, and Armatambo using the hierarchical log-linear model found no significant difference among sites (Table 8.35).

Table 8.35: Hierarchical Log-Linear Model of the Prevalence of Cranial Trauma in Adults Among Sites

Site	Sex	Cranial Trauma		Hierarchical Log-Linear Result			
		n	Frequency	Final Model	χ^2	df	p
Cardal	Female	7	0	Site Cranial Trauma	11.19	11	0.43
	Male	6	0.17				
VES	Female	30	0.33				
	Male	31	0.48				
Huaca Malena	Female	7	0.29				
	Male	7	0.71				
Armatambo	Female	18	0.72				
	Male	13	0.77				

Sharp trauma prevalence differs among sites, according to the hierarchical log-linear model (Table 8.36; Figure 8.26). Pairwise comparisons found that Armatambo has significantly higher sharp trauma prevalence than Cardal, but not Huaca Malena.

Table 8.36: Hierarchical Log-Linear Model of the Prevalence of Sharp Trauma in Adults Among Sites

Site	Sex	Sharp Trauma		Hierarchical Log-Linear Result				Pairwise Fisher's Exact p with Armatambo (Both Sexes)
		n	Frequency	Final Model	χ^2	df	p	
Cardal	**Female**	7	0.00	*Site* Sharp Trauma*	*1.93*	*6*	*0.93*	*0.08*
	Male	6	0.00					
Huaca Malena	**Female**	8	0.00					0.15
	Male	8	0.00					
Armatambo	**Female**	21	0.19					.
	Male	18	0.06					

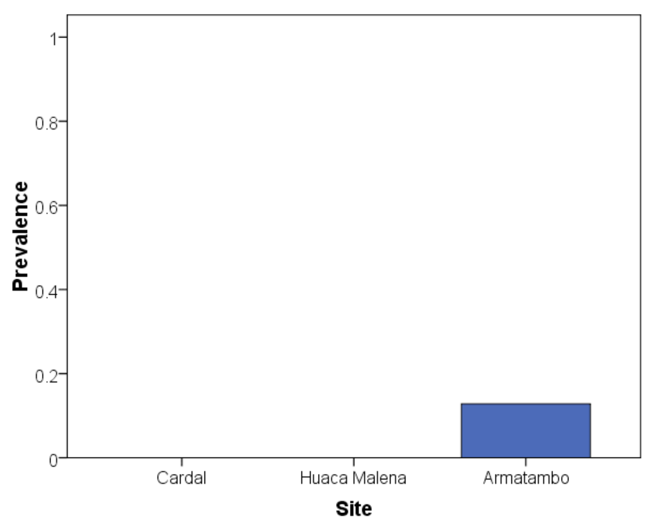


Figure 8.26: Bar Chart of Sharp Trauma Prevalence and Site.

A hierarchical log-linear model of vertebral trauma prevalence found a difference between the sexes, but not among sites (Table 8.37; Figure 8.27). Overall, males are more likely to have vertebral trauma than females (Pearson Chi-Square = 7.484, df = 2, p = 0.024).

Table 8.37: Hierarchical Log-Linear Model of the Prevalence of Vertebral Trauma in Adults Among Sites

Site	Sex	Vertebral Trauma		Hierarchical Log-Linear Result			
		n	**Frequency**	**Final Model**	χ^2	**df**	**p**
Cardal	**Female**	7	0.00	Sex* Vertebral Trauma Site	6.86	6	0.33
	Male	6	0.17				
Huaca Malena	**Female**	5	0.00				
	Male	6	0.00				
Armatambo	**Female**	18	0.06				
	Male	12	0.42				

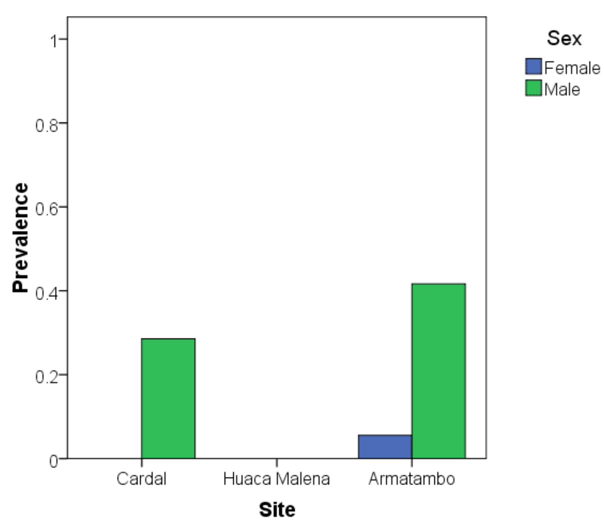


Figure 8.27: Bar Chart of Vertebral Trauma, Site, and Sex.

LONE PAIRWISE COMPARISONS

The results in this section are from statistical tests run between Armatambo and one of the other sites. The sample size was not sufficient for multivariate comparisons in these cases. These comparisons are subadult tibial Harris line count analysis with Paloma, adult femoral Harris line analysis with Villa El Salvador, adult cribra orbitalia and porotic hyperostosis analysis with Paloma, and maximum tibia length analysis with each of the other sites.

INDICATORS OF SUBADULT STRESS

Harris Lines

General linear model using site as a random factor and age in years as a covariate was used to analyze differences in tibial Harris line counts in subadults between Paloma and Armatambo. No statistically significant difference in line counts between paired sites was found (Tables 8.38a-b).

Table 8.38a: Summary Statistics of Subadult Tibial Harris Lines By Site

	n	Mean	Standard Deviation
Armatambo Subadults	3	2.3	3.2
Paloma Subadults	10	3.0	2.9
Total	13	2.9	2.9

Table 8.38b: GLM Results of Subadult Tibial Harris Lines By Site

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	**Hypothesis**	0.21	1	0.21	0.03	0.88
	Error	16.57	2	7.70*		
Age	**Hypothesis**	47.04	1	47.04	9.11	**0.01**
	Error	51.63	10	5.16**		
Site	**Hypothesis**	10.09	1	10.09	1.96	0.19
	Error	51.63	10	5.16**		

* 0.51 MS(Site) + 0.49 MS (Error)

** MS (Error)

The general linear model, using site as a random factor and age at death in years as covariate, was used to study the number of adult femoral Harris lines between Armatambo and Villa El Salvador. Harris line counts of the femur found the same result: both females and males at Armatambo and Villa El Salvador did not have significantly different Harris line counts (Tables 8.39a-b and 8.40a-b). Counter-intuitively, age at death was significantly positively correlated with both male and female femoral Harris line counts, as was found for just Armatambo in Chapter 6 (Figures 8.28 and 8.29). In contrast, correlation between Harris line counts and age at death was negative for females at Paloma (Benfer, 1990).

Table 8.39a: Descriptives of Female Femoral Harris Lines By Site

	n	Mean	Standard Deviation
VES	23	4.2	3.4
Armatambo	5	7.8	5.6
Total	28	4.8	3.8

Table 8.39b: GLM Results for Female Femoral Harris Lines By Site

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	**Hypothesis**	9.80	1	9.80	0.96	0.34
	Error	261.03	25	10.17*		
Age	**Hypothesis**	103.88	1	103.88	9.33	**0.05**
	Error	278.22	25	11.13**		
Site	**Hypothesis**	1.64	2	1.64	0.15	0.70
	Error	278.22	25	11.13**		

* 0.10 MS(Site) + 0.90 MS (Error)

** MS (Error)

Table 8.40a: Descriptives of Male Femoral Harris Lines By Site

	n	Mean	Standard Deviation
VES	24	1.7	1.7
Armatambo	3	2.7	2.5
Total	27	1.8	1.8

Table 8.40b: General Linear Model Results for Male Femoral Harris Lines By Site

Source		Type III Sum of Squares	df	Mean Square	F	p
Intercept	**Hypothesis**	0.19	1	0.19	0.05	0.82
	Error	38.67	11	3.56*		
Age	**Hypothesis**	6.08	1	6.08	1.93	0.18
	Error	75.54	24	3.15**		
Site	**Hypothesis**	5.59	1	5.59	1.78	0.20
	Error	75.54	24	3.15**		

* 0.17 MS(Site) + 0.83 MS (Error)

** MS (Error)

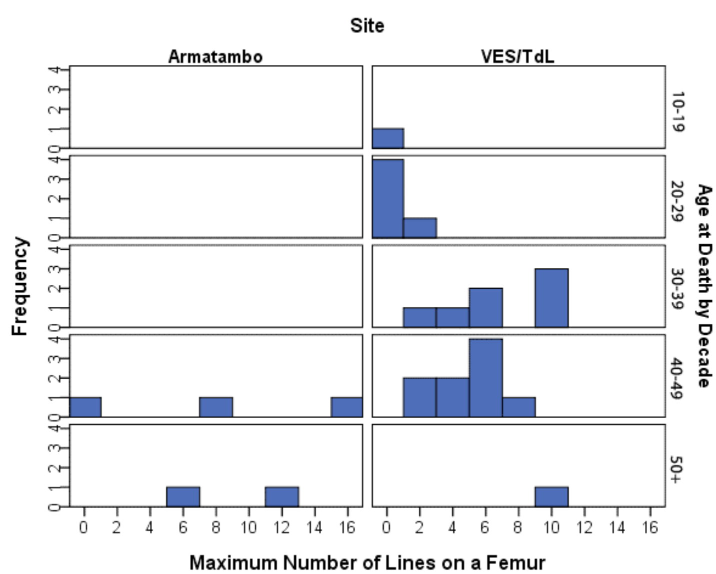


Figure 8.28: Histograms of Female Femoral Harris Lines.

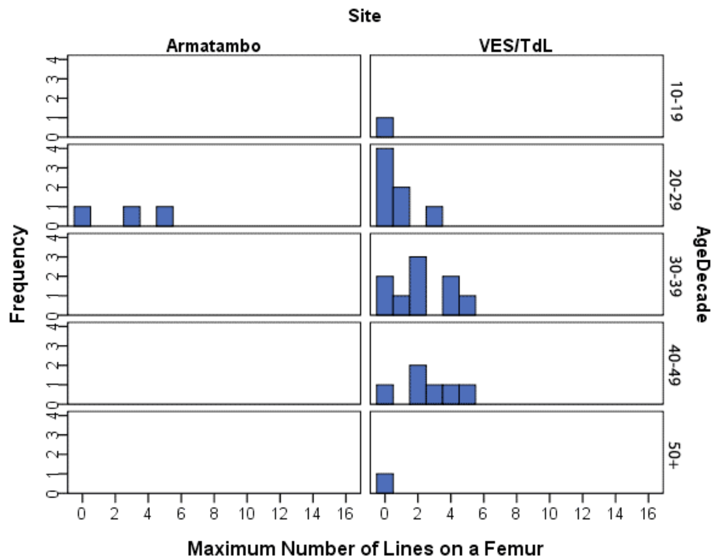


Figure 8.29: Histograms of Male Femoral Harris Lines.

Chronic Anemia

Fisher's Exact Test found that the prevalence of indicators of anemia did not differ in comparisons between adults at Paloma and Armatambo when analyzed with sexes combined (Table 8.41).

Table 8.41: Comparisons of Chronic Anemia Prevalence Between Armatambo and Paloma

	Paloma		Armatambo		
Adults	**n**	**Frequency**	**n**	**Frequency**	**Fisher's Exact p**
Cribra Orbitalia	68	0.32	21	0.19	0.19
Porotic Hyperostosis	68	0.06	18	0.11	0.37

Maximum Tibia Length

T-tests using the reported mean, standard deviation, and sample size were used in pairwise comparisons to look for statistically significant tibia lengths between Armatambo and each of the other sites in this study. These results are summarized in tables 8.42 and 8.43. Analysis of Paloma and Armatambo found that Armatambo males were significantly shorter. A sex difference in stature appeared, as females did not show the same trend among sites. Armatambo adults had significantly higher values than at Cardal, though the sample for Cardal males was only one individual. Comparisons between Villa El Salvador and Armatambo showed that tibia lengths were nearly identical between these two sites. Lastly, the difference between Armatambo and Huaca Malena female tibia length approached significance, with a longer average length at Huaca Malena, while males showed no difference.

Table 8.42: Pairwise T-Test Results of Female Maximum Tibia Length by Site

Sample	n	Mean	Standard Deviation	t	df	p
Paloma	14	332.7	16.7	1.25	25	0.22
Cardal	**3**	**300.3**	**12.7**	**2.84**	**14**	**0.01**
VES	27	323.7	15.8	0.31	38	0.76
Huaca Malena	*2*	*345.0*	*9.9*	*1.90*	*13*	*0.08*
Armatambo	13	325.3	13.9	.	.	.

Table 8.43: Pairwise T-Test Results of Male Maximum Tibia Length by Site

Sample	n	Mean	Standard Deviation	t	df	p
Paloma	**21**	**372.0**	**21.1**	**4.32**	**34**	**0.00**
Cardal	**1**	**292.1**	**.**	**10.99**	**14**	**0.00**
VES	31	344.0	18.4	0.28	44	0.78
Huaca Malena	3	340.8	16.4	0.57	16	0.58
Armatambo	15	345.5	12.8	.	.	.

SUMMARY

Many interesting contrasts in health and activity appeared between Armatambo and the other sites in this study. This summary groups the results by stress indicator, regardless of the type of statistical test used. Tables grouping results by site are at the end of this section (Tables 8.44 to 8.51). An interpretation of these results is found in the next chapter.

Armatambo adult females showed more tibial Harris lines than Paloma females. Males showed no difference. Subadult Harris line counts were also similar between Armatambo and Paloma. No difference in adult femoral Harris line counts was found between adults interred at Armatambo and Villa El Salvador.

Armatambo subadults were less likely to have cribra orbitalia and porotic hyperostosis than the combined Villa El Salvador and Tablada de Lurín sample. Adults showed the same pattern in cribra orbitalia prevalence, however porotic hyperostosis was more likely in VES/TBL adults than in Armatambo adults.

Comparisons between Armatambo and Paloma, Cardal, and Huaca Malena found no statistically significant difference in chronic anemia indicators.

Periosteal lesions in subadults at Armatambo were more prevalent than at Paloma or VES/TBL but less than at Cardal. Similarly, adult females at Armatambo were less likely than those at Cardal to have periosteal lesions. However, Armatambo males are more likely to have lesions than males at Huaca Malena. Other comparisons of periosteal lesion prevalence were not statistically significant.

No statistically significant difference in corrected subadult age estimate was found between Armatambo and the other sites, though it was revealed that VES has a higher median CSAE than Paloma.

Looking at maximum tibia length, different relationships were found for males and females. Armatambo males were significantly shorter than Paloma males, but taller than Cardal males. In females, the Armatambo sample has a higher mean tibial length than Cardal but a lower mean than Huaca Malena.

A consistent trend appeared in the analysis of age at death, separated by sex. Armatambo females have a higher mean age at death than any of the other sites. Males did not show any difference.

Looking at adult activity indicators, DJD prevalence appeared in the thoracic vertebrae, the elbow, and knee joints. Armatambo adults were more likely to have thoracic vertebrae DJD than adults at VES and Huaca Malena. Since the analyses for Model A found that age at death was not significantly related to thoracic DJD, age at death is ruled out as a confounding factor. Elbow

DJD was less common in VES adults than Armatambo adults. The knee joint showed the opposite difference: VES adults were more likely to have DJD in the knee than Armatambo adults. While Armatambo did not differ from other sites in the prevalence of appendage, cranial, or vertebral trauma, the Armatambo collection showed more sharp trauma than at Cardal.

The next chapter will discuss these findings in reference to the hypotheses they were designed to test.

Table 8.44: Summary of Comparisons of Nominal Data Between Paloma and Armatambo

	Paloma		Armatambo		
Subadults	**n**	**Frequency**	**n**	**Frequency**	**Pairwise Fisher's Exact p**
Cribra Orbitalia	44	0.18	6	0.33	0.34
Porotic Hyperostosis	36	0.14	9	0.22	0.43
Periosteal Lesions	**57**	**0.11**	**15**	**0.33**	**0.04**

Adults of Both Sexes Unless Otherwise Stated	**n**	**Frequency**	**n**	**Frequency**	**Pairwise Fisher's Exact p**
Cribra Orbitalia	68	0.32	21	0.19	0.19
Porotic Hyperostosis	68	0.06	18	0.11	0.37
Periosteal Lesions (Females)	40	0.18	19	0.26	0.32
Periosteal Lesions (Males)	40	0.28	15	0.40	0.28

Table 8.45: Summary of Comparisons of Continuous and Count Data Between Paloma and Armatambo

	Paloma			Armatambo					
Subadults	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	**F**	**df**	**p**
Tibial Harris Line Count (Subadults)	10	3.0	2.9	3	2.3	3.2	Model Not Significant		
	n	**Median Rank**		**n**	**Median Rank**		**χ^2**	**df**	**p**
CSAE	**17**	**11.30**		**7**	**15.5**		**1.87**	**1**	**0.17**
Adults	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	**F**	**df**	**p**
Tibial Harris Line Count (Females)	*14*	*1.7*	*1.5*	*4*	*5.5*	*4.8*	*3.76*	*15*	*0.07*
Tibial Harris Line Count (Males)	18	2.4	2.2	4	2.5	1.3	Model Not Significant		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**	**t**	**df**	**p**
Age at Death (Females)	**21**	**31.9**	**10.4**	**21**	**41.3**	**13.9**	**2.54**	**37**	**0.02**
Age at Death (Males)	18	32.4	9.3	18	32.2	10.3	-0.07	37	0.95
Maximum Tibia Length (Females)	*14*	*332.7*	*16.7*	*13*	*325.3*	*13.9*	*1.25*	*25*	*0.22*
Maximum Tibia Length (Males)	**21**	**372.0**	**21.1**	**15**	**345.5**	**12.8**	**4.32**	**34**	**0.00**

Table 8.46: Summary of Comparisons of Nominal Data Between Cardal and Armatambo

	Cardal		Armatambo		
Subadults	**n**	**Frequency**	**n**	**Frequency**	**Pairwise Fisher's Exact p**
Cribra Orbitalia	3	0.67	6	0.33	0.41
Porotic Hyperostosis	9	0.22	9	0.22	0.71
Periosteal Lesions	**12**	**0.75**	**15**	**0.33**	**0.04**

Adults of Both Sexes Unless Otherwise Stated	**n**	**Frequency**	**n**	**Frequency**	**Pairwise Fisher's Exact p**
Cribra Orbitalia	7	0.29	11	0.18	0.28
Porotic Hyperostosis	12	0.08	9	0.11	0.64
Periosteal Lesions (Males)	7	0.29	15	0.40	0.49
Periosteal Lesions (Females)	*8*	*0.63*	*19*	*0.26*	*0.09*
Knee DJD	12	0.33	16	0.19	0.14
Cervical DJD	12	0.42	18	0.44	Model Not Significant
Lumbar DJD	12	0.42	19	0.79	Model Not Significant
Cranial Trauma	7	0.00	15	0.20	Model Not Significant
Appendage Trauma	7	0.43	18	0.06	0.11
Sharp Trauma	*7*	*0.00*	*21*	*0.19*	*0.08*
Vertebral Trauma	7	0.00	18	0.06	Model Not Significant

Table 8.47: Summary of Comparisons of Continuous and Count Data Between Cardal and Armatambo

	Cardal		Armatambo				
Subadults	**n**	**Median Rank**	**n**	**Median Rank**	χ^2	**df**	**p**
CSAE	4	5.9	7	6.1	0.01	1	0.92

	Cardal			Armatambo					
Adults	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	**t**	**df**	**p**
Age at Death (Females)	*11*	*32.1*	*10.3*	*21*	*41.3*	*13.9*	*1.93*	*30*	*0.06*
Age at Death (Males)	9	32.6	13.7	18	32.2	10.3	-0.08	25	0.94
Maximum Tibia Length (Females)	**3**	**300.3**	**12.7**	**13**	**325.3**	**13.9**	**2.84**	**14**	**0.01**
Maximum Tibia Length (Males)	**1**	**292.1**	**.**	**15**	**345.5**	**12.8**	**10.99**	**14**	**0.00**

Table 8.48: Summary of Comparisons of Nominal Data Between VES/TBL and Armatambo

	VES or VES/TBL		Armatambo		
Subadults	**n**	**Frequency**	**n**	**Frequency**	**Pairwise Fisher's Exact p**
Cribra Orbitalia	*44*	*0.73*	*6*	*0.33*	*0.07*
Porotic Hyperostosis	*39*	*0.56*	*9*	*0.22*	*0.07*
Periosteal Lesions	**42**	**0.00**	**15**	**0.33**	**0.01**

Adults of Both Sexes Unless Otherwise Stated	**n**	**Frequency**	**n**	**Frequency**	**Pairwise Fisher's Exact p**
Cribra Orbitalia	**41**	**0.49**	**11**	**0.18**	**0.01**
Porotic Hyperostosis	**40**	**0.43**	**9**	**0.11**	**0.01**
Periosteal Lesions (Females)	46	0.11	19	0.26	0.12
Periosteal Lesions (Males)	36	0.53	15	0.40	0.30
Cervical DJD	30	0.67	18	0.44	Model Not Significant
Thoracic DJD	**30**	**0.33**	**18**	**0.72**	**0.02**
Lumbar DJD	29	0.76	19	0.79	Model Not Significant
Elbow DJD	*30*	*0.50*	*16*	*0.31*	*0.07*
Knee DJD	**30**	**0.47**	**16**	**0.19**	**0.003**
Cranial Trauma	31	0.10	15	0.20	Model Not Significant

Table 8.49: Summary of Comparisons of Continuous and Count Data Between VES/TBL and Armatambo

	VES or VES/TBL			Armatambo					
Subadults	**n**	**Median Rank**		**n**	**Median Rank**		**χ^2**	**df**	**p**
CSAE	17	13		7	11		0.4	1	0.54
Adults	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	**F**	**df**	**p**
Tibial Harris Line Count (Females)	21	3.7	2.7	4	5.5	4.8	0.13	22	0.73
Tibial Harris Line Count (Males)	24	2.1	2.0	4	2.5	1.3	Model Not Significant		
Femoral Harris Line Count (Females)	23	4.2	3.4	5	7.4	4.8	Model Not Significant		
Femoral Harris Line Count (Males)	24	1.7	1.7	3	2.7	2.5	Model Not Significant		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**	**t**	**df**	**p**
Age at Death (Females)	*26*	*34.9*	*8.8*	*21*	*41.3*	*13.9*	*1.95*	*45*	*0.06*
Age at Death (Males)	29	33.6	7.8	18	32.2	10.3	-0.53	45	0.60
Maximum Tibia Length (Females)	27	323.7	15.8	13	325.3	13.9	0.31	38	0.76
Maximum Tibia Length (Males)	31	344.0	18.4	15	345.5	12.8	0.28	44	0.78

Table 8.50: Summary of Comparisons of Nominal Data Between Huaca Malena and Armatambo

Adults of Both Sexes Unless Otherwise Stated	Huaca Malena		Armatambo		
	n	**Frequency**	**n**	**Frequency**	**Pairwise Fisher's Exact p**
Cribra Orbitalia	5	0.00	11	0.18	0.25
Porotic Hyperostosis	5	0.00	9	0.11	0.47
Periosteal Lesions (Females)	6	0.00	19	0.26	0.22
Periosteal Lesions (Males)	*6*	*0.00*	*15*	*0.40*	*0.09*
Cervical DJD	4	0.00	18	0.44	Model Not Significant
Thoracic DJD	*7*	*0.29*	*18*	*0.72*	*0.09*
Lumbar DJD	4	0.50	19	0.79	Model Not Significant
Elbow DJD	6	0.17	16	0.31	0.16
Knee DJD	4	0.00	16	0.19	0.11
Appendage Trauma	8	0.00	18	0.06	0.17
Cranial Trauma	5	0.00	15	0.20	Model Not Significant
Sharp Trauma	8	0.00	21	0.19	0.15
Vertebral Trauma	5	0.00	18	0.06	Model Not Significant

Table 8.51: Summary of Comparisons of Continuous and Count Data Between Huaca Malena and Armatambo

	Huaca Malena			Armatambo					
Adults	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	**t**	**df**	**p**
Maximum Tibia Length (Females)	*2*	*345.0*	*9.9*	*13*	*325.3*	*13.9*	*1.90*	*13*	*0.08*
Maximum Tibia Length (Males)	3	340.8	16.4	15	345.5	12.8	0.57	16	0.58
Age at Death (Females)	**7**	**20.4**	**2.8**	**21**	**41.3**	**13.9**	**6.52**	**24**	**0.00**
Age at Death (Males)	8	36.5	8.9	18	32.2	10.3	-1.03	24	0.31

CHAPTER 9: DISCUSSION I - THE MODELS

The hypotheses described in Chapter 1 can be tested with the results presented in the previous two chapters. In this chapter, some considerations of the statistical tests used in this study will be explained: a reiteration of the tests for any possibly paradoxical manifestation of data, and a consideration of the number of statistical models. Then, each of the hypotheses for each model will be summarized, followed by a discussion of whether the results support the hypothesis. In brief, Model A looks at differences in health between the sexes at Armatambo. Model B looks for health differences between individuals possessing two types of possible markers of social affiliation, artificially deformed crania and undeformed crania. Model C compares health of the Armatambo skeletal collection with collections from non-states while Model D compares the Armatambo collection with a collection from an empire.

Statistical Meta-Analysis

Comparisons between age at death and NSIS prevalence in Chapter 7 found that one of the indicators, Harris line counts, showed a significant positive relationship between count prevalence and age at death. While a paradoxical manifestation was modeled to produce a negative correlation, an unexpected positive correlation was found. Possible interpretations of this finding are discussed below. Due to the unexpected trend in the Harris line count data, a paradoxical interpretation of Harris line counts has to be considered, namely that individuals more resistant to episodic stress episodes in subadulthood lived longer adult lives. Other stress indicators showed no trend in either direction so non-paradoxical interpretations are appropriate.

The meta-analysis of the statistical results has to be considered, especially since a large number of tests were conducted in this study. Sixty-four statistical models were generated to test the hypotheses, not including individual pairwise comparisons used to interpret significant models. The high number of models mean that, taken as a whole, a small percentage of models was significant by chance and does not reflect a true statistical relationship; the cumulative error rate increases with the number of tests such that at least one finding will be statistically significant due to chance (Selvin, 1970). The exact percentage depends on the alpha level of the statistical tests. With an alpha-level of 0.05, approximately one in twenty tests are expected to be statistically significant due to random errors. The probability of finding at least one statistically significant result due to chance approaches unity with 45 to 50 tests of a single hypothesis (LeBlanc, 2004). With 64 initial tests, as in this dissertation, the chance of at least one random significant with an alpha level of 0.05 test is 96.25% (Uitenbroek, 1997). Weakening the individual tests in a set by requiring larger probabilities using Bonferroni techniques (Mason et al., 2003:211) is appropriate in cases such as medical research in which it is undesirable to permit even one false inference. For example, with 64 tests, the alpha level of each test would have to be lowered to below 0.0009 to maintain an overall level of 0.05 (Uitenbroek, 1997). However, in the current investigation, the differences in each individual comparison, which are predicted by overarching models, are the focus of this investigation. Each individual test can be taken as reflecting the chance of a Type I error, the likelihood of finding the result given that the null hypothesis is true (Bakan, 1970; Gold, 1970; Kish, 1970).

As a side note, the problem of randomly erroneous statistical results extends beyond this dissertation. For example, the same proportion of random error exists whether I used 64 tests in one dissertation, or 64 separate dissertations. Taken on a larger scale, there is a percentage of all statistical tests in any professional journal that is wrong due to random errors.

The issue of low sample size also has to be considered since some of the statistical models in this study were constructed from relatively few observations. In particular, the Harris line analyses a minimum of three individuals from the Armatambo skeletal collection and some Cardal only had one case for comparing maximum tibia lengths in males. However, as discussed in Chapter 6, tests with low sample size can still detect large differences among populations to give insight to further analyses.

To remedy the presence of random errors and the use of low sample sizes, looking for complimentary results between models gives some assurance that a true phenomenon is being observed since it is not likely for erroneous models to align with the same conclusion. As the following discussion of the hypotheses shows, the results do show clear trends both within Armatambo and among sites.

Replication is another method of confirming accurate statistical tests (Rosnow and Rosenthal, 1989). While replication with archaeological samples cannot be as stringent as in laboratory experiments, analogous comparisons can be made between groups. In Chapter 10, data from Armatambo is compared to data from the Inca Empire, with results extremely similar to the comparison between Armatambo and the Huari Empire site of Huaca Malena.

Model A: Sexual Division of Labor at Armatambo

Hypothesis: Armatambo males are expected to have worse health than females since males are traditionally assigned the more physical labor-intensive tasks.

Alternative Hypotheses: Male health could be equivalent or better than that of females.

Health between the sexes was statistically similar in most areas, counter to the hypothesis that there would be a detectable difference between males and females. Overall, health seems to have been good in the Armatambo sample. While on average females had more tibial and femoral Harris lines than males, the difference was not statistically significant. Levels of cribra orbitalia and porotic hyperostosis were similarly low in both groups, at most 20% prevalence, reflecting generally good resistance against chronic anemia caused by malnutrition. The prevalence of periosteal lesions (26-40%) also shows good health. These values for periosteal lesion prevalence are lower than in other dense settlements such as Dickson Mounds in Illinois (67%; Lallo and Rose, 1979) and Georgia Bight agriculturalists under the Spanish (59%; Larsen, 1982).

Comparisons with earlier settlements in coastal Perú will be discussed below in the Models C and D sections.

Two closely related indicators showed more extreme physical activity in males: vertebral trauma (e.g. collapsed vertebral bodies), and the presence of Schmorl's nodes, vertebral body deformation due to ruptured intervertebral discs. While only 11% of females showed Schmorl's nodes, they were present in half of the males. Other types of trauma, caused by violence or accident, did not show any difference between males and females.

Figure 9.1 shows an example of vertebral trauma in the lumbar region of a male from Armatambo. The vertebral bodies of the fourth and fifth lumbar, the two lowest in the vertebral column, are compressed and show more DJD relative to the first three lumbar vertebrae. This individual likely experienced chronically extreme levels of physical pressure directed superior-inferiorly along the vertebral column.

Prevalence of osteoarthritis, however, showed no sexual differentiation. Both sexes showed high levels of thoracic and lumbar osteoarthritis, between 70 and 80%. Individuals were extremely likely to have DJD somewhere on their body. All males bore some type of DJD as did 18 of 19 (95%) of females. The lack of correlation between DJD prevalence and age shows that old age was not a significant factor in DJD prevalence in this collection. In general, studies of osteoarthritis show higher prevalence in males (reviewed in Larsen, 1997).

Figure 9.1: Lumbar Vertebrae of ENT 39 (Male, ~57 Years) from Armatambo. Lateral view; anterior is to the right of photograph.

Female age at death was significantly higher than male age at death. Using a conventional interpretation of age at death as an indicator of mortality, assuming a stable population, this finding suggests that female adults experienced a better overall health state than males, who in general tended to die younger. Most prehistoric demographic profiles find peaks of male deaths in the thirties and females in the twenties (presumably from childbirth). At Armatambo, the male peak was at 32 years of age, while the female peak was at 41 years of age.

Taken together, subadult health appears good in those who survived to adulthood at Armatambo, while males experienced more health stressors as adults. Males, while dying younger relative to females, showed more vertebral trauma and Schmorl's nodes, which one might associate with age and repeated opportunities for stress to exceed the bone's capacity to bear the weight. Males also were more likely to have periosteal lesions than females, though the difference was not statistically significant. The conclusion is that males experienced more physically demanding labor that affected the lumbar vertebrae and may have contributed to a shorter lifespan. Females also experienced high physical stresses in other regions such as the elbow and knee joints, but at the same level as males. High DJD in both sexes mean that both males and females experienced extreme physical loads, but had different tasks since males show more vertebral pathology.

Bird (2001) offers some explanation of why sexual division of labor was less than expected in the Armatambo collection:

> "Sex differences are predicted to be weaker or more cooperative where both males and females gain greater benefits from investing in offspring and their common goals are likely to result in cooperative foraging on resources that provide high consumption benefits. This might occur where large game is not available, where resources are captured more synchronously and predictably, or are more narrowly shared… and where men gain more benefits from provisioning and fewer from competition…."

Similarly, Codding and colleagues (2011:1) state that "…men's and women's foraging interests converge when high-energy resources can be reliably acquired, but diverge when higher-energy resources are associated with higher levels of risk." While these studies focus on foraging peoples, analogies can be made for urbanized state peoples. Living in an urban state society may produce some of the conditions Bird cited as factors in limiting sexual division of labor. The acquisition of large game is probably no longer a key subsistence strategy for those living in an urban center. Also, state-provided buffering against famines increases the predictability of resources, another of the factors Bird mentions as reducing the sexual division of labor. Addressing Codding et al. (2011), what constitutes " higher levels of risk" in the context of urban state labor is an interesting way to expand on theories concerning the sexual division of labor. Further work can consider how theories on the sexual division of labor in foraging societies translate to the state level.

The implications of these results give a conflicting message about the status of those individuals making up the Armatambo collection. While good subadult health is expected to be the common state in high status individuals, the high levels of DJD and vertebral trauma in adults suggest low status for this sample. Possibly, factors such as good nutrition and hygienic conditions allowed even the lower classes to have healthy subadulthoods. Future research involving the analysis of artifacts associated with these burials could be used to determine how these individuals fit into the Ychsma social structure. I am working closely with the excavator of the Armatambo collection to gain access to information on the burial context.

Model B: Social Division of Labor at Armatambo

Hypothesis: Individuals with and without cranial deformation will exhibit differing rates of stress indicators, reflecting differential social roles along ethnic lines.

Alternate Hypotheses: Stress indicators do not differ between individuals with and without cranial deformation, reflecting homogenous social roles.

As in the comparison between the sexes at Armatambo, analyses of NSIS by social group showed fewer differences than hypothesized. Harris lines, periosteal lesions, and tibia length all showed no statistically significant difference between groups, unlike the case at Villa El Salvador where there were distinct differences in health between cranially deformed and undeformed groups (Pechenkina and Delgado, 2006).

The analyses of chronic anemia indicators, CO and PH, show a difference in the subadult experience of malnutrition between the two inferred social groups whose deformation state presumably indicated social identity. While no cranially deformed adults showed cribra orbitalia, CO was manifested in a quarter of the undeformed adults. Conversely, a third of the cranially deformed individuals had porotic hyperostosis while no undeformed adults had this indicator. The timing of CO and PH manifestation may be the cause of this difference in expression between the two social groups. Several studies of CO and PH prevalence have concluded that cribra orbitalia is an earlier expression of chronic anemia than porotic hyperostosis in subadults (Stuart-Macadam, 1989; Farnum, 1996; Blom et al., 2005). Since cribra orbitalia was present in cranially undeformed individuals, these people experienced chronic anemia earlier in subadulthood than the cranially deformed. In contrast, the cranially deformed showed porotic hyperostosis but not cribra orbitalia, signaling a later onset of subadult chronic anemia, perhaps associated with weaning to contaminated food.

Poor health in adults due to high activity levels as inferred from DJD was not statistically significant between the two ethnic groups. The lack of statistical significance in the degree of osteoarthritis between the cranially deformed and undeformed also suggests that this ethnic marker did not differentiate labor at Armatambo, though the undeformed have consistently higher percentages. Both groups had similarly high amounts of thoracic and lumbar osteoarthritis, while the cervical vertebrae region showed less than the other two vertebral regions.

No indicators of trauma showed a statistically significant difference between individuals with and without cranial deformation. Still, while two undeformed individuals, one male and one female, bore cranial trauma, five deformed individuals were afflicted. One of these five (ENT 45B: female, age 55) had the only perimortem injury, one that was caused around the time of death. Prevalence of sharp trauma was not statistically different, though the only cases were both cranially deformed females (ENT 56: female, age 65; notch on the right fifth rib and ENT 68: female, age 40: trauma on the frontal bone). This result is surprising since typically males are the recipients of sharp trauma (Larsen, 1997).

Periosteal lesion prevalence and age at death were not statistically different between the two social groups, suggesting similar experiences with chronic bacterial infections.

Overall, the interpretation is that Model B fails: lifeways did not differ between social groups in the Armatambo collection. Cranially undeformed subadults who lived to adulthood experienced earlier onset of chronic anemia than cranially deformed, but both groups showed similar rates of chronic anemia over the entire subadulthood. Other indicators show that individuals in Armatambo shared similar lifeways in subadulthood and adulthood, regardless of the presence of cranial deformation. I suggest that at Armatambo, urban state rule agglutinated rather than segregated heterogeneous cultures. These results of stress indicator prevalence between cranially deformed and undeformed individuals will be directly compared below to those interred at Villa El Salvador, which also has ethnic groups marked by cranial deformation. Comparison with VES is discussed below in the Villa El Salvador section of Model C.

Model C: Urban States and Less Complex Societies

Hypothesis:Urban state society is expected to show better subadult health and worse adult health than less complex societies

Alternate Hypothesis: Subadult health is worsened while adult health is improved in the Late Intermediate.

Alternate Hypothesis: Both subadult and adult health worsened in the Late Intermediate.

The hypothesis for Model C was tested by comparing Armatambo to three older sites on the central coast: Paloma, Cardal, and Villa El Salvador/Tablada de Lurín. Overall, the main hypothesis shows some support in each of these intersite comparisons. These results show that urban state rule overturned a trend towards declining subadult health over time even though physical activity levels in adults increased.

Summary of Comparisons Between Armatambo and Paloma

The expectation for differences in health between Armatambo and Paloma was that Armatambo would show only slightly better health (Table 1.1). However, indicators of subadult stress suggest that Armatambo subadults had slightly worse health than their Paloma counterparts, though most of the differences are not statistically significant. Armatambo subadults had more CO and PH than at Paloma, but these differences were not statistically significant. Adults at Armatambo also had more PH than at Paloma, but also had less CO (neither were statistically significant). Fewer subadults at Paloma have periosteal lesions (11% compared to 33% at Armatambo), suggesting better resistance against infection at Paloma. Adult tibia length, the product of subadult health, was significantly lower in Armatambo males relative to Paloma, and lower, but not significantly different, in females.

Harris line counts show change over the period of growth and development. Low Harris line counts suggest that health in early subadulthood was similarly good in Armatambo and Paloma. A change occurred in adolescence: as evidenced by adult female Harris line counts that increased dramatically at Armatambo relative to Paloma. The period of increase in Harris line counts corresponds to the age when subadults begin participating in adult labor roles. Males show no change in Harris line counts between the two sites.

The higher Harris lines counts in adult females at Armatambo in comparison to Paloma has several possible interpretations. The intuitive interpretation is that females experienced poorer health– more stress– in adolescence at Armatambo than at Paloma. The t-test for a paradoxical manifestation of stress indicators (Chapter 7) found that Harris lines show a significant positive relationship with age at death. Therefore, a paradoxical interpretation of differential mortality has to be considered: adult females were healthy because they were able to survive repeated stress episodes. A paradoxical interpretation, however, is not likely for two reasons. The first is that modeling of the osteological paradox in Chapter 4 concludes that high Harris line counts should be found in people of all ages at death if these individuals were healthier, not just the oldest individuals. Seen another way, paradoxical data should have a negative trend with age at death, not a positive slope. Also, this interpretation contradicts the Developmental Origins of Health and Disease Hypothesis that states that stress experienced during development has negative impacts on adult health (Armelagos et al., 2009), although see Goodman and Leatherman (1998) for a contrary claim.

Another explanation is that there may have been a reversal in health states between subadulthood and adulthood for females in which subadults who were more nutritionally stressed (i.e. developed more Harris lines) actually lived healthier adult lives, raising average age at death.

One more possibility is that cortical thinning with advanced age (Mays, 2001) allows more Harris lines to show in radiographs, while in younger adults lines are present but hidden under the thicker bone. Cortical thinning answers the problem of why adult females, who tended to die older, had more Harris lines while males did not. More rapid bone loss in females with advanced age is a likely reason for the positive correlation between Harris line counts with age at death. Cortical thinning was noted in the oldest radiographed individual, ENT 56 (female, ~65 years), which supports this interpretation.

Adults show no difference in periosteal lesion prevalence between sites. Considering both subadult and adult results, rates at Armatambo appear stable between subadults and adults, while Palomans experienced an increase with age to a level similar to Armatambo.

A higher mean age at death for females suggests better overall health at Armatambo. Males show no difference in age at death between Paloma and Armatambo.

Overall, the series of statistical comparisons between Armatambo and Paloma show relatively slight differences in health. The generally good state of health at Paloma, a fishing village, was matched at Armatambo, an urban settlement, despite the different social structures. Stress for subadults of both sexes at Armatambo was slightly worse than at Paloma, yet female adults tended to live longer and had comparable maximum tibia lengths. Females also show higher Harris line counts but differential mortality and cortical thinning may be confounding factors. It is possible that adult females at Armatambo had healthier lives than their Paloma peers.

SUMMARY OF COMPARISONS BETWEEN ARMATAMBO AND CARDAL

Comparison between Cardal and Armatambo also shows some support for the hypothesis that subadult health improved while adult health suffered under and urban state. Mean tibia length is greater for both sexes at Armatambo, suggesting better health during growth and development or early death for those whose growth was flagging. The more urban Armatambo show significantly lower prevalence of subadult periosteal lesions than at Cardal, though not too surprising since Cardal has been noted for its unusually high level of treponemal disease relative to other Andean sites (Vradenburg, 2001; Pechenkina et al. 2007:107). However, cribra orbitalia and porotic hyperostosis in adults show no statistically difference between these sites.

In adults, there are four notable differences between Cardal and Armatambo. As in subadults, Armatambo females show a lower prevalence of osteoperiostitis than at Cardal. Males at Armatambo have more lesions than Cardal males, but the difference was not statistically significant. Females at Armatambo have a higher mean age at death, suggesting better overall adult health. The higher prevalence of lumbar osteoarthritis for females at Armatambo (not statistically significant) may be inconclusive evidence for the physical cost of a labor-intensive economic system. Instances of trauma to the limbs show possible lifeway differences between Armatambo and Cardal. While not statistically significant, Armatambo adults of both sexes had far greater prevalences of limb trauma than at Cardal (Armatambo: males: 21%, females: 6%; Cardal males: 67%, females: 43%; Fisher's exact $p = 0.11$). In Armatambo, limb trauma typically manifests as a midshaft break to the humerus or tibia (i.e. ENT 35 and 71). Using a conservative interpretation of trauma, these injuries appear to be accidental. In Cardal, fusion of the foot phalanges is the most prevalent trauma to the limbs. Vradenburg (1992) did not offer an interpretation of the cause of these injuries, but foot phalanx fusion is not typical of interpersonal violence. Therefore there appears to be some fundamental difference in lifestyle between the two sites that led to these specific traumas. Armatambo females were also more likely to have sharp trauma than Cardal females. Four females at Armatambo had one instance of sharp trauma each, while no females at Cardal had this type of injury. At Armatambo, these wounds occurred on the ribs and frontal bone, likely locations for interpersonal violence, though typically rare for females.

More so than the comparison between Armatambo and Paloma, Armatambo skeletal remains showed comparable or better subadult health than those at Cardal with respect to tibia length, bacterial infections, and indicators of chronic anemia. These finding support the main hypothesis. In adults, Armatambo females showed more instances of sharp trauma and possibly more lumbar osteoarthritis but also higher mean age at death and less periosteal lesion prevalence. The conclusion is that the elevated treponemal infection rate at Cardal in females resulted in worse health relative to females at Armatambo.

Summary of Comparisons Between Armatambo and Villa El Salvador/Tablada de Lurín

Several indicators show differences in health states between Armatambo and Villa El Salvador and Tablada de Lurín. Armatambo inhabitants have significantly fewer signs of chronic anemia in both the subadult and adult skeletal populations, supporting the hypothesis that subadults in the Late Intermediate

Period Armatambo had generally better health than in Early Intermediate Period Villa El Salvador and Tablada de Lurín. Armatambo, however, also show higher rates of subadult periostitis as there were no cases out of 42 individuals at VES/TBL. It is possible that children with bacterial infection died before exhibiting marks of infection or healing.

Indicators of health during growth and development show no substantial differences between Armatambo and VES/TBL. These include Harris line counts in subadults, males, and females, as well as subadult stature and adult tibia length. As in the comparison of Harris lines in Armatambo, a positive correlation between age at death and Harris line counts was found in females in the Villa El Salvador collection. The same factors discussed earlier should be considered: differential mortality and increased cortical thinning in older females.

The results from comparison of osteoarthritis between sites produced interesting contrasts. The patterning of osteoarthritis differs between Armatambo and Villa El Salvador/Tablada de Lurín. Armatambo showed significantly more DJD in the thoracic vertebrae in both sexes. General osteoarthritis prevalence was also higher at Armatambo. However, VES/TBL showed more osteoarthritis of the knee. Levels of lumbar osteoarthritis were equally high (77-79%) in both sites. As with the comparison of limb trauma between Armatambo and Cardal, the different relative prevalences of DJD between Armatambo and VES/TBL indicates lifestyle differences between sites. Investigations at Villa El Salvador by Pechenkina and Delgado (2006) and Rhode (2006) found evidence that there were two groups represented in the VES skeletal collection: coastal fishers and highland farmers. Rhode (2006) found that males at VES were fairly evenly divided between fishing and farming while females tended towards fishing. Archaeological evidence of occupations practiced by the Armatambo collection is forthcoming, but from the results presented here, it is hypothesized that the pattern of occupations differed from the VES dichotomy of farmers and fishers. Chapter 10 discusses some possibilities for occupations practiced by the adults in the Armatambo collection.

Mean female age at death is higher at Armatambo signifying better overall health through the entire lifespan.

As in comparisons with Paloma and Cardal, subadult health at Armatambo was comparatively good when compared to VES/TBL, while adults showed some poor health due to high physical activity, supporting the hypothesis. In total, subadults at Armatambo were less likely to have chronic anemia, but more likely to have periosteal lesions than subadults at Villa El Salvador and Tablada de Lurín. General growth and development was similar between the two sites. Thoracic vertebrae and elbow osteoarthritis was greater for both males and females at Armatambo, yet females from the Late Intermediate sites had longer average lifespans.

COMPARISONS OF DIFFERENCES IN HEALTH BETWEEN SOCIAL GROUPS IN ARMATAMBO AND VILLA EL SALVADOR

As in Armatambo, individuals buried at Villa El Salvador can be divided into two groups based on the presence or absence of cranial deformation (Pechenkina and Delgado, 2006). Both skeletal populations have the same kind of deformation, tabular, in which the cranium is bound to a hard and flat surface. The presence of deformation was found to correlate with subadult health at Villa El Salvador in two key areas: deformed individuals were more likely to have porotic hyperostosis but also greater limb bone length, than those without cranial deformation.

At Armatambo, the same difference in health in terms of porotic hyperostosis prevalence between the cranially deformed and undeformed was found. The cranially deformed at both sites were more likely to have porotic hyperostosis. While studies have found that porotic hyperostosis is not solely attributable to the presence of cranial deformation (Blom et al., 2005; Pechenkina and Delgado, 2006), a confounding factor may be involved.

Unlike at Villa El Salvador, maximum tibia length did not vary between the cranially deformed and undeformed at Armatambo, signifying another difference in the heterogeneity of ethnic groups between these sites.

While certain indicators of health showed a distinctive pattern between the social marker of cranial deformation at Armatambo, patterning was not as strong as at Villa El Salvador. While both sites were host to people of multiple social or ethnic backgrounds, these groups had more different health experiences in the Early Intermediate relative to the Late Intermediate. Thus, assuming that cranial deformation reflects social or ethnic identity, Armatambo seems to have homogenized ethnic groups rather than maintain or accentuate the differences in lifeways as was seen at Villa El Salvador.

Overview of the Model C Hypothesis

The Armatambo skeletal population shows a reversal in the pattern of decreasing subadult health seen from the Middle Preceramic to the Early Intermediate. The relatively good subadult health at Armatambo supports the hypothesis that a small urban state organization supported subadult health. Subadult health states between Armatambo and Paloma were similar, despite the great differences in social structure and complexity between the two sites. Compared with the Cardal skeletal population, the one from Armatambo showed better health by having fewer periosteal lesions and greater maximum tibia length. General growth and development were similar between the two sites. Armatambo showed fewer signs of chronic anemia but more periosteal lesions than both Cardal and Villa El Salvador.

Previous comparisons among the skeletal collections from Paloma, Cardal, and Villa El Salvador found that those at Paloma showed better health in all examined indicators of subadult stress among the three sites (Pechenkina et al., 2007). Considering the three intersite comparisons of subadult health between Armatambo and the other sites, Armatambo appears to reverse some trends in worsening childhood health over time in the central coastal Andes that have been pointed out by other researchers (Pechenkina et al. 2007). While the sites of Paloma, Cardal, and Villa El Salvador/Tablada de Lurín show increasing prevalence of cribra orbitalia and porotic hyperostosis through time in their skeletal populations, the one at Armatambo counters the trend in the Late Horizon with levels comparable to what was found Paloma and Cardal.

The hypothesis that Armatambo subadults had better health than their pre-urban state counterparts is partially supported in all of the intersite comparisons. The similarities in health state between Paloma and Armatambo show that health at the Late Intermediate site was comparably good, though the urban plan of Armatambo probably contributed to higher prevalence of periosteal infection. While growth-affecting stress episodes are more common for Armatambo females, their survival into adulthood shows that health buffering was high, a conclusion also supported by higher mean age at death.

Evidence was also found to support the hypothesis that adult activity levels were more extreme under urban state rule compared to what was observed at Cardal and Villa El Salvador. While data on thoracic vertebrae osteoarthritis from Cardal were not available for this dissertation, lumbar osteoarthritis was found to be less common than at Armatambo (although not statistically significant). Levels of osteoarthritis of the thoracic vertebrae are higher in Armatambo than in Villa El Salvador. Figure 9.2 shows the lumbar vertebrae (L) of ENT 39 (male, ~57 years) from Armatambo. Note the osteophytic lipping on L3 (upper right of photograph) and L4 (lower left), and severe wear on the body as well as spondylolysis of L5 (lower right). In figure 9.3, Schmorl's nodes are visible on center of the vertebral bodies of the tenth to twelfth thoracic vertebrae of ENT 44 (male, ~21 years) from Armatambo.

Figure 9.2: Lumbar Vertebrae of ENT 39 (Male, ~57 Years) from Armatambo, Anterior view.

Figure 9.3: Thoracic Vertebrae 10-12 of ENT 44 (Male, ~21 Years) from Armatambo, Inferior view.

Cranial and sharp trauma was also more common for females at Armatambo than at Cardal, signifying either more violence or hazardous working conditions at the later site. In either case the hypothesis is supported that adult health worsened in the urban state.

One consistent difference between Armatambo and earlier sites does not support the hypothesis that adult health worsened at Armatambo. Female age at death is significantly higher in Armatambo than in the three other sites, suggesting better health for females in the Late Intermediate (Table 9.4; Figure 9.5).

The next section examines the Model D hypothesis, which compares the urban state of Ychsma Armatambo with an imperial Huari settlement.

Model D: An Urban State versus an Empire

Hypothesis: an urban state will be predicted to have relatively weaker control of the labor output of it subjects, and thus worse subadult and generally better adult health, than an empire. In this comparison, an empire is regarded as an expansive urban state with more access to resources.

Alternative Hypothesis: adult health is better in an empire because of the greater amount and variety of resources available to the subjects

Alternative Hypothesis: Another alternative to the hypothesis of this model is that the size, complexity, or success of an empire is not the result of improved subadult health and adult health relative to a non-state state.

Overview of the Model D Hypothesis

Indicators of subadult stress preserved in adults did not conclusively show that Armatambo subadults had worse health states. While not significant, comparisons of chronic anemia were uniformly higher at Armatambo than at

Huaca Malena. One indicator, tibia length, showed better health for subadult females at Armatambo and no difference in males.

A greater proportion of adults at Armatambo had periosteal lesions than those at Huaca Malena, though the difference was not statistically significant.

In adults, rates of cranial and sharp trauma were higher at Armatambo than at Huaca Malena. Except for one individual with a healed broken clavicle (ENT U2 T4, male, ~40 years), there are no traumatic injuries in the Huaca Malena population.

Activity levels for females were found to be higher in the Armatambo population than in Huaca Malena collection: the presence of DJD is more common for females at Armatambo. Levels of thoracic vertebrae were higher for females at Armatambo than at Huaca Malena. Armatambo had higher DJD prevalences in all other regions examined in this study, but the levels were not statistically significant. In addition, vertebral trauma rates were the same for females at Armatambo and Huaca Malena.

Males show a different pattern of DJD than females between the Armatambo and Huaca Malena skeletal populations, in contrast to the comparison of females. Males at Armatambo showed far more vertebral trauma than males at Huaca Malena. Thoracic and lumbar DJD were greater in Armatambo males (although not statistically significant), while cervical DJD was actually less. As with females, elbow and knee joint DJD were more common at Armatambo, but not to a significant level.

As in the comparisons between sites used to test Model C, female age at death in Armatambo is significantly higher than at Huaca Malena, indicating better health in the Late Intermediate.

Adult health appears to be worse at Armatambo than at Huaca Malena. Adults may have experienced more extreme physical activity in Armatambo than at Huaca Malena. Imperial rule, which covers more diverse territories and provides greater access to resources, may have provided additional buffers against poor health than available to a more localized urban polity. Females seem to have experienced more physical stress in the Late Intermediate, but the high mean age at death indicates good overall health.

Summary

In each of the comparisons with less complex societies (Paloma, Cardal, and Villa El Salvador/Tablada de Lurín), the Ychsma city of Armatambo showed some indications that subadult health was relatively good, but adult health suffered more from physical stresses. The results show that the development of Late Intermediate urban states was partially successful in reversing the decline of subadult health in the region. As the main hypothesis stated, worse adult health may have been the price paid for the improvements seen in subadult health. Armatambo showed greater incidence of osteoarthritis of the thoracic vertebrae. Age at death, especially for females, indicate better adult health at Armatambo, even as both sexes experienced more intense activity levels relative to earlier sites.

These findings are counter to the decline in health seen in the Andean region as societies grew in complexity. As Pechenkina and colleagues (2007) found, the trend of worsening health started in the Middle Preceramic and continued through at least the Early Intermediate. They cite the rise of maize agriculture and the decline hygiene with urbanization as likely causal factors.

A different result was found when comparing the Armatambo skeletal population with Huaca Malena, an earlier but more complex imperial settlement. Indicators of chronic anemia and general growth and development trended towards worse subadult health at Armatambo, but only one of these indicators, maximum tibia length in females, approached statistical significance. An increase in physical activity was found for adults at Armatambo when compared to the Huaca Malena population. Physical activity appeared more extreme in the Armatambo collection. While most indicators of physical activity showed no statistical significance, all but one, age at death in females, trended towards worse health in females. This seemingly non-random array of findings may show a weak difference in health and physical activity between the Armatambo and Huaca Malena populations.

The next chapter will summarize the bioarchaeology of Armatambo presented in this dissertation, and relate this study to the bioarchaeology of the Inca Empire.

CHAPTER 10: DISCUSSION - ARMATAMBO AND THE BIOARCHAEOLOGY OF THE INCA

This chapter places the bioarchaeology of Armatambo in the context of the region and the overall archaeology of empires. The first section combines the bioarchaeology of Armatambo with previous archaeological and ethnohistorical research of this Late Intermediate Period city. Then data from this study will be compared with two recent dissertations on the Inca Empire: the work of Melissa Scott Murphy, who conducted a bioarchaeological study of the Inca coastal site of Puruchuco-Huaquerones, which is located very near Armatambo (2004), and the work of Valerie Andrushko (2007), who conducted a thorough study of health in the core and near-periphery of the Inca empire. The following sections then show how knowledge gained from Armatambo informs the archaeology of empires in general, and the theories outlined in Chapter 4.

Life at Armatambo

The bioarchaeological evidence presented above produces an overall image of life and health for this sample of individuals from Late Intermediate Period Armatambo. Aspects of life at Armatambo discussed here include health during growth and development, indicators of physical activity and occupation, and a possible pattern in mortuary practices.

HEALTH DURING GROWTH AND DEVELOPMENT

Indicators of subadult stressors suggest that individuals from Armatambo experienced better health during subadulthood than expected for an urban population. Whether general health improved or declined with the development of urban state rule differs between studies. Bioarchaeological studies of Old World imperial states have generally concluded that health declined for all age groups. Following Cohen and Armelagos (1984) and Cohen and Crane-Kramer (2007), the effects of intensive agriculture and urbanization have been seen as a devastating combination that lowers health in complex societies. This association between subsistence and disease is true for the Early Intermediate (Pechenkina et al. 2007). However, at Armatambo, subject populations were either more free from subadult health stressors or had enhanced buffering that lowered mortality, or both. Despite a presumed dependence on maize agriculture (Hastorf and Johannessen [1993] found evidence of maize agriculture in the central highland Mantaro Valley during the LIP and depictions of maize have been found at Armatambo and neighboring Pachacamac [Díaz, 2004:585]) and despite living in a prehistoric urban settlement, subadults at Armatambo showed improved health in some areas, reversing the trend seen in the region.

Compared with previous studies of Mesoamerican skeletal populations (Chapter 3), the central coastal Andean series studied in this dissertation shows generally better health than both the Mayan (Storey et al. 2002) and Mexico Basin (Marquez Morfin et al., 2002) series. Also, unlike what was observed in Mesoamerica, no overall decline in stature (or maximum tibia length) was seen in the central coast with the exception of the decline from Paloma in the Middle Preceramic to the later sites.

Signs of Labor and Occupation

The extent of DJD in the Armatambo collection is placed in context when compared with other studies of health and urban labor. Comparisons of general osteoarthritis prevalence between urban populations show that DJD was unusually prevalent in the Armatambo collection. At Demetrias, a Hellenistic town formed by the Macedonian state (300 to 1 BC), individuals of possibly higher status (associated with grave goods) have between zero and 4% DJD prevalence (Vanna, 2007). Adults in Roman Urbino were stressed by high physical activity (Peck, 2009) but DJD prevalence was less than encountered at Armatambo (62% at Urbino versus over 95% at Armatambo). Indicators of adult physical activity between the sexes at Armatambo agree with the bioarchaeological studies of empires reviewed in Chapter 2. Like Urbino (Paine et al., 2009) and Eboracum (Peck, 2009), both in the Roman Empire, osteoarthritis at Armatambo did not differ between the sexes. The command and intensification of physical labor appears to be one of the strong constants of ancient state rule, regardless of region.

Archaeological and historical evidence from the colonial era in the New World suggests trade was an important industry at Armatambo in Inca times and it is likely that trade was also important at the city in the Late Intermediate (Chapter 5). Evidence of trade via land routes has been noted (Díaz and Vallejo, 2002:359), but the prime position of Armatambo on the coast also opens the possibility of sea trade. Activities associated with trading could include load lifting and the carrying of loads over long distances. Sea trade could involve load lifting as well as the building of watercraft and propelling the vehicles using oars. Bioarchaeological study of degenerative joint disease and other markers at the site found evidence that the inhabitants were possibly engaged in labor related to trade. Specifically, the high prevalence of joint disease in the thoracic and lumbar vertebrae suggests heavy load bearing (El-Khoury and Whitten, 1993; Jurmain and Kilgore, 1995). Both sexes show high prevalence of osteoarthritis overall.

Several individual cases from Armatambo have especially interesting pathology related to labor. One burial (ENT 39: male, ~57 years) has an indentation on his frontal bone. This deformity is very similar to pathology related to load bearing using a basket with a tumpline (Gerszten et al., 2001). ENT 39 also shows strong cervical vertebrae osteoarthritis: C2 and C3 are fused, and most elements have osteophytes or joint lipping, more likely results of supporting weight on the forehead. Figure 10.1 shows the fused cervical vertebrae on this adult (upper left: posterior view, upper right: anterior view, bottom: lateral view, left side). Other individuals, such as ENT 56 (female, ~65 years) also show strong cervical vertebrae DJD (Figure 10.2: the dens (superior projection) of C2 and its articulation on C1 show joint lipping) and could also have used a tumpline (the frontal bone of ENT 56 is not present).

Figure 10.1: Fused C2 and C3 of ENT 39

Figure 10.2: DJD on C1 and C2, from ENT 56.

Interestingly, use of this type of basket has previously been typified as a female task (Gerszten et al., 2001). One of Guaman Poma's (2001) illustrations from his text on postcolonial Andean lifeways shows the use of a similar basket during a harvest of potatoes (Figure 10.3). In this drawing, the standing figure on the right is depicted using a basket held using a tumpline slung around the forehead. My translation of the Spanish translation of the Quechua is "Labor.. [sic] Time to dig up potatoes from the earth." The individual in the illustrations appears to be wearing female clothing. A male showing indicator of habitual use of this device as seen in ENT 39 may indicate that usage of tumplines was not always a female activity.

Another method of carrying cargo is also seen in Guaman Poma's illustrations, as well as modern photographs: here the load is supported by the back, but the supporting strap is tied around one's chest or arms rather than the forehead (Figures 10.4 and 10.5). In figure 10.4, the central standing figure and figure on the left looking backward are clearly seen holding cargo on their backs using straps held on the chest. My translation of the title reads "May. The Great Search. Month of Harvest." The text on the bottom left says "They arrive to the food depository."

Figure 10.3: Illustration of Tumpline Usage. In: (2001[1615]:1157). Image courtesy of the Royal Library (Copenhagen) (Item GKS 2232 4°; Felipe Guaman Poma de la Ayala; Nueva Corónica y Buen Gobierno; http://www.kb.dk/permalink/2006/poma/1157/en/text/).

Figure 10.4: Illustration of Basket Strap Usage. In: Guaman Poma (2001[1615]:246).Image courtesy of the Royal Library (Copenhagen) (Item GKS 2232 4º; Felipe Guaman Poma de la Ayala; Nueva Corónica y Buen Gobierno; http://www.kb.dk/permalink/2006/poma/246/en/text/).

The kneeling figure on the left of figure 10.5, who is getting kicked by his Spanish boss, is carrying a Spanish trunk by tying it to his back using a rope secured about the sternum.

Figure 10.5: Strap Used to Carry a Heavy Item on One's Back. In: Guaman Poma (2001[1615]:541). Image courtesy of the Royal Library (Copenhagen) (Item GKS 2232 4°; Felipe Guaman Poma de la Ayala; Nueva Corónica y Buen Gobierno; http://www.kb.dk/permalink/2006/poma/541/en/text/).

My translation of the title is:

> "Chapter of Travelers. Spanish from the tambo and criollos mestizos [males with second generation status and some Andean ancestry] and mulattos [individuals of Spanish and African ancestry] and criollas mestizas [females with second generation status and some Andean ancestry] and Christian [native European] Spanish."

Figure 10.6 shows an elderly man carrying a bundle supported on the right shoulder with a strap slung around the opposite clavicle. My translation of the title is "The Second Street [age level]. A walking elderly man." Figure 10.7 is a photograph of a man in Cuzco in modern times carrying a basket using the same general type of strap.

Figure 10.6: Old Man Carrying a Load with a Strap (2001[1615]:198). Image courtesy of the Royal Library (Copenhagen) (Item GKS 2232 4°; Felipe Guaman Poma de la Ayala; Nueva Corónica y Buen Gobierno; http://www.kb.dk/permalink/2006/poma/198/en/text/).

Figure 10.7: Modern Man with Strap and Basket. Photograph courtesy of Diana Biggs (2007; http://www.flickr.com/photos/tracingdiana/1801020560/).

These variations on the method of using a strap around the head or body to secure a load on one's back documented in different periods of Andean cultural history are especially relevant to the dissertation because it was noted during data collection of the Armatambo skeletal population that degenerative joint disease was common in the sternum, clavicles, and ribs. Cases of severe degenerative joint disease and trauma were found in the shoulder girdle, sternum and first ribs of several individuals in the Armatambo collection. These bones are likely to be the ones most physically stressed by the usage of straps around the chest and arms to carry loads on one's back. Fisher's Exact Test found that none of these indicators differed by sex, with males having more DJD in all elements except for the sternal body and manubrium (Table 10.1). Figure 10.8 shows the inferior view of the lateral side of the left clavicle of ENT 56 (female, ~65 years). Joint lipping can be seen on the articulation with the scapula. Ossification of the cartilage between the first ribs and the manubrium was seen in 3 individuals (ENT 39: male, ~57 years; ENT 41: male, ~25 years; ENT 64: female, ~32 years) (Figure 10.9). Interestingly, these three individuals are of different ages and sexes, suggesting that neither age nor sex were predominant factors in the manifestation of sternal and shoulder girdle DJD. Given the historical evidence of bearing loads using strap around the head or upper body, and the repeated occurrence of joint pathology on the clavicles, scapulae, first ribs, and humeri, I conclude that load bearing might have been an activity practiced by the Armatambo skeletal population.

Table 10.1: Prevalence of Shoulder Girdle DJD at Armatambo, Separated by Sex

	Females		**Males**		
	n	**Frequency**	**n**	**Frequency**	**p**
Manubrium	15	0.13	11	0.09	0.62
Sternum Body	16	0.19	11	0.18	0.68
Clavicle	17	0.06	11	0.27	0.15
Scapula	13	0.15	10	0.20	0.60
Humeral Head	14	0.07	11	0.18	0.41
1st Rib	18	0.17	13	0.31	0.31

Figure 10.8: Left Clavicle with DJD.

Figure 10.9: DJD and Ossified Cartilage of the Manubrium and First Ribs

Indicators of other occupations were also found in the Armatambo collection. Two individuals (ENT 37A: male, ~40 years; ENT 42: male, ~40 years) possessed auditory exostoses, a condition caused by frequent contact with ocean water (Hutchinson et al., 1997). Found in males at Paloma (Benfer, 1990), auditory exostoses were linked with deep-sea mollusk gathering that occurred offshore near the site. Strong muscle markings on the radius, clavicles, pelvis, and femur were also noted on ENT 37A. Interestingly, these markings were stronger on the left upper limb and the right lower limb. The emphasis on one of each opposed pair of limbs may be related to coastal fishing, with one leg repeatedly used to hop off the sea floor while the opposing arm held a net or other tool (Chalco, personal communication, 2007). ENT 42 did not show the same pattern, but instead had strong vertebral pathology and osteophytes on the lower limbs, a pattern which is traditionally associated with farming (Rhode, 2006). As a side note, neither of these individuals was cranially deformed.

Another possible interpretation of the auditory exostoses is that the afflicted individuals were seafarers engaged in trade via waterways. Movement of goods by watercraft along the coast has been recorded in the history of the region in the colonial era. In fact the first encounter between the Spanish and the people (and material riches) of the Andean coast was between a Spanish boat and an Andean raft off the coast of modern Ecuador (Xeres, 1872[1547]; Cobo, 1990[1653]). Rafts were constructed from reeds or balsa logs. Rafts made from balsa logs could be very large, able to carry fifty men according to one account (Xerez 1872[1547]:15), or even an estimated thirty-six tons (Heyerdahl, 1955, 1957). The large rafts bore technology such as a keel, wooden masts and cotton sails. Rafts were numerous: Pedro Pizarro's (1844[1571]:365) account of the Spanish conquest mentions that the Lord of Chincha, local ruler of a south coast polity, commanded 100,000 rafts, most likely an exaggeration but still indicative of a large number. Of the individuals at Armatambo with auditory exostoses, ENT 42, with vertebral and lower limb DJD, seems to fit the profile of a trader better than fisher: the DJD could have been caused by repeated walking while bearing a heavy load on the vertebral column while the auditory exostoses could have developed from contact with water while loading or unloading cargo from rafts. Further research in the archaeology of the site can look for evidence linking these specific individuals to physical labor involved in fishing or the movement of goods.

POSSIBLE RITUAL MORTUARY PRACTICE

One pattern noticed during data collection of the Armatambo skeletal population is the association between older women and infant burials. Five ($n = 5$, mean age at death = 49.0, stdev = 15.57) women were buried with an infant or child. Four of the five were older than 40 years of age, and one was estimated to have been 25 years old at time of death. Although older on the average, compared to females without an associated subadult burial ($n = 16$, mean age at death = 38.94, stdev = 12.94), the unpaired t-test showed no statistically significant difference in age ($t = 1.45$, $df = 19$, $p = 0.16$). Only one burial contained only a male and a subadult. Excavators labeled some of these subadults as offerings (*ofrendas*), possibly because most of the women buried with subadults are near the end of, or past, their reproductive age, making it unlikely that the children are the offspring of the deceased. Furthermore, child sacrifice was a common practice in the Andes, with bioarchaeological evidence found in the Moche state and both the Huari and Inca Empires (e.g. Bourget, 1997; Rostworowski de Diez Canseco, 2003, Wilson et al., 2007, Tung and Knudson, 2010). Tung and Knudson (2010) found evidence that residents of Conchopata in the Huari Empire abducted non-local children and turned them trophy heads for display. In contrast, the Inca sacrificed the children of those in their own empire to solidify political bonds with peripheral groups. A review of Inca sacrificial practices (Ceruti, 2004) indicated that children of elites were typically the ones sacrificed (an interesting contrast exists with the Aché Indians of Paraguay, who sacrificed the worse-off subadult as an offering when an elder died [Hill and Hurtado, 1996]). The results of this dissertation possibly agree with Ceruti's finding since the health of buried subadults at Armatambo was generally good.

SUMMARY OF LIFE AND HEALTH AT ARMATAMBO

The convergence of archaeological, ethnohistorical, and bioarchaeological evidence paints an image of Armatambo as a busy coastal city, functioning as a port or trade center in a dense central coast environment within the greater Ychsma state.

Despite being a dense population with trade connections to other regions, health for subadults at Armatambo was generally good compared to other prehistoric urban areas.

In adults, the evidence of higher DJD prevalence at Armatambo relative to earlier people led to investigations of what physical activity documented in the region could have produced these markers. Several possibilities were explored, including the movement of cargo supported by one's back, forehead, and shoulder girdle, as well as fishing and seafaring.

Lastly, an interesting mortuary practice was reported: older women were often buried with an infant. Excavators identified the infant remains as offerings, consistent with traditional Andean practices.

Comparison Between Armatambo and the Inca Empire

The bioarchaeology of Ychsma Armatambo can be compared to the bioarchaeology of the following period, when the Inca Empire swept across the Andean region. In particular, two bioarchaeological studies have attempted to test hypotheses on the effect the Inca had on the health of their subjects, and those data can be compared with those presented in this dissertation.

Murphy (2004) and colleagues (2010) studied the skeletal collection at Puruchuco-Huaquerones, an Inca site in the Rímac Valley of the central coast. Archaeology of the site has suggested that it was possibly an administrative center or elite palace. Murphy found that burials were differentiated into four groups by the prevalence of associated prestige items. Despite these inferred social distinctions, indicators of health were statistically similar among these groups.

Andrushko (2007) conducted a sweeping survey of skeletal material in the Inca core and near-periphery. Overall, the populations studied appeared healthy, with low frequency of stress indicators across all age groups. Comparing health between the Inca core and periphery, individuals from sites closer to the core of the Inca Empire tended to have more periosteal lesions from chronic bacterial infection. Andrushko concluded that the higher prevalence of periosteal lesions towards the core was due to the more urbanized character of older, more established Inca settlements compared to newer settlements away from the core. The distribution of osteoarthritis between the core and near-periphery showed a different pattern than the distribution of periosteal lesions. DJD was more common in the near-periphery, where physical labor and production of goods might have been more common.

The following section will compare health at Armatambo with those of Inca sites to examine changes in health between the Late Intermediate and the Late Horizon. Armatambo was located on what would become the western extreme of the Inca Empire periphery, a far different environment than the Inca core in the highlands. Comparison of the results of this dissertation with Murphy's similar bioarchaeological study in the same region will provide a view of health over time in the central coast. Also, comparison of health at Armatambo with the Inca core and near-periphery will show how health in the Ychsma state compared to health in different aspects of the Inca Empire.

Data presented in Murphy (2004) and Andrushko (2007) will be compared to the data in this dissertation to examine health states between Late Intermediate Period Armatambo and several regions of the Inca Empire. Table 10.2 lists the sites used in these comparisons. Andrushko grouped the Inca sites in her study into two general regions. The four sites placed into the core group are located within 15 km of Cuzco, the Inca capital (Andrushko, 2007:65). Three of the core sites, Kusichanca, Qotakalli, and Sacsahuaman were probably ritual complexes. Qhataqaspatallacta was a residence and storage area. The near-periphery sites are located "at a distance of 20 to 150km from Cuzco city," (Andrushko, 2007:52). The functions of the near-periphery sites varied greatly. For example sites served as elite residences (Machu Picchu and Colmay), trade centers (Wata), or had domestic, political, and religious functions (Chokepukio and Kanamarca). Several indicators of stress were examined in each of the studies and comparable data were published, including tibia length, femur length, cribra orbitalia, porotic hyperostosis, general periosteal lesions, as well as elbow, knee and vertebral osteoarthritis. While the described methods of data collection were similar and based on the same accepted standards, interobserver error is an important consideration in analyzing these results (e.g. Waldron and Rogers, 1991, Jacobi and Danforth, 2002).

Table 10.2 Late Horizon Comparative Sample

Sample	Region	Source
Armatambo	Central Coast	This Study
Puruchuco-Huaquerones	Central Coast	Murphy (2004)
Kusicancha	Core	Andrushko (2007)
Qhataqasapatallacta	Core	Andrushko (2007)
Qotakalli	Core	Andrushko (2007)
Sacsahuaman	Core	Andrushko (2007)
Aqnapampa	Near Periphery	Andrushko (2007)
Cotocotuyoc	Near Periphery	Andrushko (2007)
Chokepukio	Near Periphery	Andrushko (2007)
Colmay	Near Periphery	Andrushko (2007)
Kanamarca	Near Periphery	Andrushko (2007)
Machu Picchu	Near Periphery	Andrushko (2007)
Wata	Near Periphery	Andrushko (2007)

Fishers Exact Test was used to compare pairs of site regions, as in the previous individual pairwise data analysis of this dissertation. The binomial test was used to test presence/absence data against a single mean frequency.

Comparison Between Armatambo and Puruchuco-Huaquerones

COMPARISON OF STUDY RESULTS

This study found the same result as Murphy (2004) in looking a difference between health states in individuals of different ethnic backgrounds. Both studies saw no large differences in health states between groups defined by markers of social division. In Murphy's study, social division was defined by artifact distribution; in this dissertation, possible social division was defined by cranial deformation.

STATISTICAL ANALYSIS ACROSS STUDIES

Statistical analysis of the indicators of anemia between Puruchuco-Huaquerones and Armatambo showed differing results. Levels of cribra orbitalia in both subadults and adults were not statistically different, though it was more common at Puruchuco-Huaquerones (Table 10.3; Figure 10.10). Unlike cribra orbitalia, rates of porotic hyperostosis manifestation showed a strong difference between Armatambo and Puruchuco-Huaquerones (Figure 10.11). Both subadults and adults show higher prevalence of PH at Puruchuco-Huaquerones. When all ages are pooled, a significant difference persists.

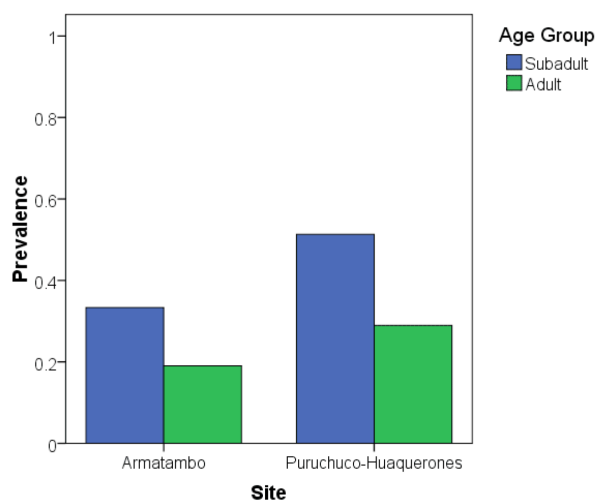


Figure 10.10: Cribra Orbitalia Prevalence in Armatambo and Puruchuco-Huaquerones

Table 10.3: Fisher's Exact Test Results of Cribra Orbitalia, Porotic Hyperostosis, and Periosteal Lesions (Central Coast)

	Armatambo		Puruchuco-Huaquerones		
Subadults	**n**	**Frequency**	**n**	**Frequency**	**Fisher's Exact p**
Cribra Orbitalia	6	0.33	76	0.51	0.34
Porotic Hyperostosis	**9**	**0.22**	**76**	**0.72**	**0.01**
Adults	**n**	**Frequency**	**n**	**Frequency**	**Fisher's Exact p**
Cribra Orbitalia	21	0.19	114	0.29	0.26
Porotic Hyperostosis	**18**	**0.11**	**114**	**0.48**	**0.00**
Pooled	**n**	**Frequency**	**n**	**Frequency**	**Fisher's Exact p**
Cribra Orbitalia	*27*	*0.22*	*190*	*0.38*	*0.08*
Porotic Hyperostosis	**27**	**0.15**	**190**	**0.58**	**0.00**
Periosteal Lesions	50	0.31	41	0.20	0.13

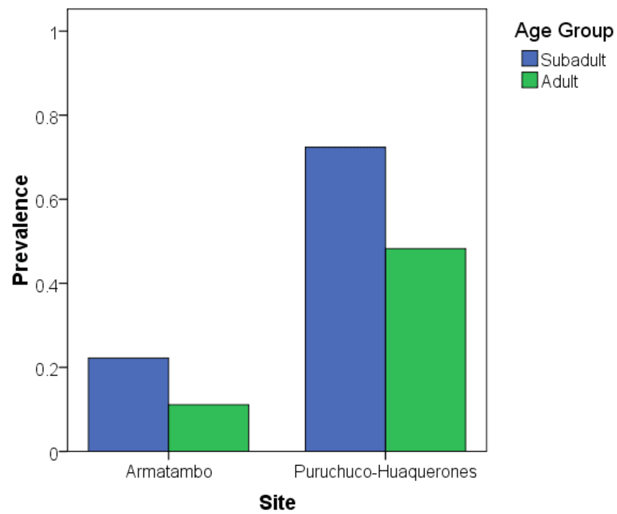


Figure 10.11: Porotic Hyperostosis Prevalence in Armatambo and Puruchuco-Huaquerones

General periosteal lesion prevalence was not significantly different between Armatambo and Puruchuco-Huaquerones in the pooled age group comparison (Table 10.2 [above]; Figure 10.12). Based on these results, it appears that disease processes producing PH were more prevalent for the individuals interred at Puruchuco-Huaquerones than at Armatambo. Yet, other diseases linked to chronic anemia and poor sanitation, cribra orbitalia and periosteal lesions, show no statistically significant difference between the two coastal sites. It is possible that nutrition and disease loads for individuals past the age of cribra orbitalia formation were especially poor for subadults from Puruchuco-Huaquerones relative to other periods of growth and development, leading to the formation of PH but not CO in later childhood.

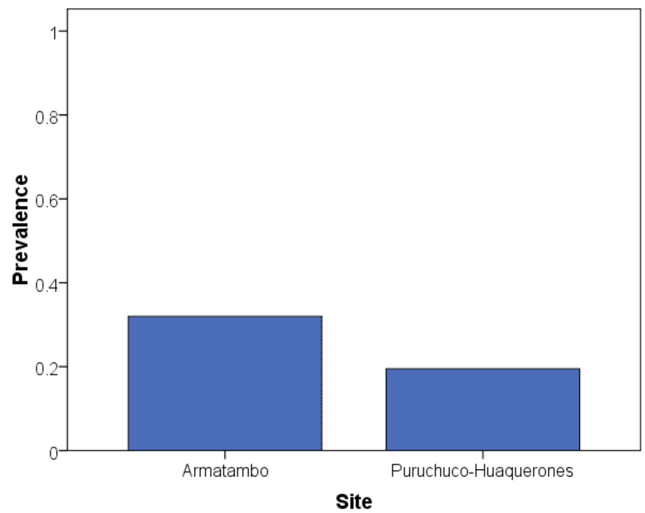


Figure 10.12: Periosteal Lesion Prevalence in Armatambo and Puruchuco-Huaquerones

Limb bone length analysis produced conflicting results. Tibia length of females was identical between the two sites (p = 1.00) (Table 10.14a) while Armatambo males had a significantly higher mean than males from the Puruchuco-Huaquerones collection (Table 10.14b). Femur length was also similar between sites for both sexes (Table 10.15a-b). The overall conclusion is that growth and development of subadults between the Armatambo and Puruchuco-Huaquerones samples were largely similar.

Table 10.4a: Results of T-Tests of Maximum Tibia Length in Females (Andean Coast)

Females	n	Mean (mm)	Standard Deviation	t	df	p
Puruchuco-Huaquerones	41	325.3	10.80	0.00	52	1.00
Armatambo	13	325.3	13.90	.	.	.

Table 10.4b: Results of T-Tests of Maximum Tibia Length in Males (Andean Coast)

Males	n	Mean (mm)	Standard Deviation	t	df	p
Puruchuco-Huaquerones	**60**	**336.6**	**15.00**	**2.110**	**73**	**0.04**
Armatambo	15	345.5	12.80	.	.	.

Table 10.5a: Results of T-Tests of Maximum Femur Length in Females (Andean Coast to Core)

Females	n	Mean (mm)	Standard Deviation	t	df	p
Andrushko (2007) Inca Core	27	393.8	18.90	1.14	40	0.26
Andrushko (2007) Inca Near-Periphery	**16**	**406.3**	**21.32**	**3.16**	**29**	**0.00**
Puruchuco-Huaquerones	42	386.1	13.30	0.53	55	0.60
Armatambo	15	388.0	7.03	.	.	.

Table 10.5b: Results of T-Tests of Maximum Femur Length in Males (Andean Coast to Core)

Males	n	Mean (mm)	Standard Deviation	t	df	p
Andrushko (2007) Inca Core	11	401.2	20.63	0.46	23	0.65
Andrushko (2007) Inca Near-Periphery	*13*	*419.6*	*28.34*	*1.69*	*25*	*0.10*
Puruchuco-Huaquerones	63	402.5	16.50	0.43	75	0.67
Armatambo	14	404.6	16.69	.	.	.

Analysis of DJD prevalence found several statistically significant differences between Armatambo and Puruchuco-Huaquerones. The vertebral joints showed more osteoarthritis in Armatambo than at Puruchuco-Huaquerones as seen in table 10.6 and figures 10.13 to 10.15 (note that the charts also show DJD prevalence in Andrushko's pooled sample of core and near-periphery skeletal populations, labeled "Pooled Inca Empire"). DJD in the thoracic and lumbar vertebrae were more common at Armatambo than at Puruchuco-Huaquerones. One joint region, the elbow, had statistically more DJD in adults at Puruchuco-Huaquerones compared to Armatambo adults. The knee joint showed no intersite difference. Age was not significantly related to the presence of osteoarthritis, suggesting that these large differences in DJD prevalence reflect differences in physical activity levels between Armatambo and Puruchuco-Huaquerones, and not demographic differences between the populations.

Table 10.6: Fisher's Exact Tests of DJD Prevalence (Central Coast)

	Armatambo		Puruchuco-Huaquerones		
	n	Frequency	n	Frequency	Fisher's Exact p
Elbow DJD	**29**	**0.41**	**135**	**0.63**	**0.03**
Knee DJD	29	0.28	135	0.42	0.12
Cervical DJD	30	0.47	134	0.34	0.14
Thoracic DJD	**32**	**0.75**	**134**	**0.19**	**0.00**
Lumbar DJD	**33**	**0.79**	**134**	**0.13**	**0.00**

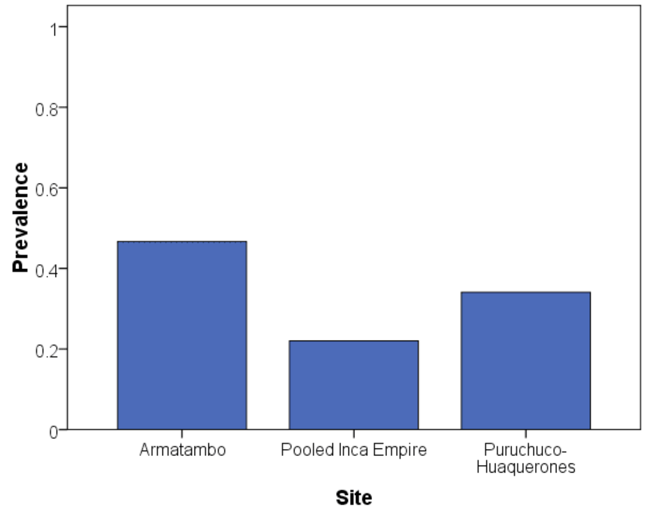


Figure 10.13: Bar Chart of Cervical DJD Prevalence (Andean Coast to Core)

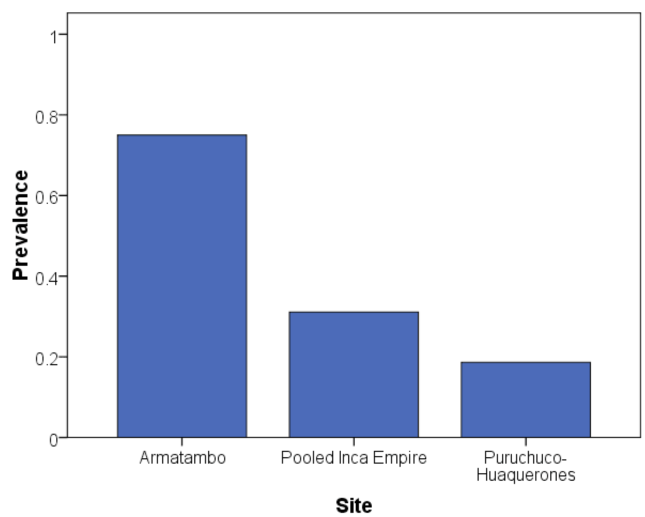


Figure 10.14: Bar Chart of Thoracic Osteoarthritis Prevalence (Andean Coast to Core)

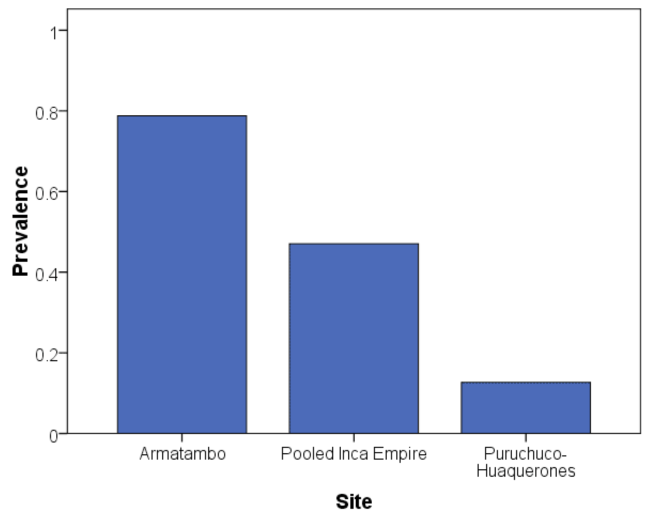


Figure 10.15: Bar Chart of Lumbar DJD Prevalence (Andean Coast to Core)

In summary, the significantly higher rate of porotic hyperostosis at Puruchuco-Huaquerones in both subadults and adults suggests that chronic anemia morbidity was higher than at Armatambo. The lack of a significant difference in cribra orbitalia rates, however, suggests that the difference in morbidity was not present in the earliest stages of childhood, but rather occurred later. As found in comparison with other pre-Inca sites, labor at Armatambo placed extreme physical stress on the vertebrae. In contrast, labor for the individuals at Puruchuco-Huaquerones stressed the elbow, perhaps through use of the foot plow (Figure 10.3).

COMPARISONS AMONG ARMATAMBO, THE INCA CORE, AND NEAR PERIPHERY

As with the above comparison between Murphy's study and this dissertation, data presented in Andrushko's doctoral work could also be compared to data from this dissertation, though in some cases mathematical transformations were needed to make the data sets comparable.

The indicators of anemia were available for comparison between both studies. Andruskho combined cases of cribra orbitalia and porotic hyperostosis for both subadults and adults into one indicator of chronic anemia in her study. Armatambo chronic anemia data were calculated in the same format for comparison. The binomial test was used to compare the distribution of chronic anemia prevalence to the group mean of Andrushko's data set, separated into Inca core and near periphery regions as described above. Results found that the prevalence of chronic anemia at Armatambo was significantly higher than what was found in the Inca core and in the near periphery (Tables 10.7a-b).

Table 10.7a: Binomial Test Results of Cribra Orbitalia, Porotic Hyperostosis, and Periosteal Lesions (Armatambo and Inca Core)

	Armatambo			Andrushko (2007) Core		
	n	Frequency	Standard Deviation	n	Frequency	Binomial Test Exact p
Combined CO and PH	27	0.41	0.50	.*	0.02	0.00
Periosteal Lesions	50	0.32	0.47	.*	0.20	0.03

Table 10.7b: Binomial Test Results of Cribra Orbitalia, Porotic Hyperostosis, and Periosteal Lesions (Armatambo and Inca Near Periphery)

	Armatambo			Andrushko (2007) Near-Periphery		
	n	Frequency	Standard Deviation	n	Frequency	Binomial Test Exact p
Combined CO and PH	27	0.41	0.50	.*	0.08	0.00
Periosteal Lesions	50	0.32	0.47	.*	0.06	0.00

The presence of osteoperiostitis was more common at Armatambo than in both the Inca core and near-periphery samples (Tables 10.7a-b). Unlike the findings of Andrushko's study, rates of periosteal lesions did not differ between the sexes at Armatambo.

Analysis of femur length found that females in the Inca near periphery were less healthy than at LIP Armatambo (Table 10.5 [above]). No difference was found between males at Armatambo and the Inca core, nor were there any differences between Armatambo and the Inca near-periphery.

Osteoarthritis was more evident in Armatambo than in the Inca core and near periphery. Statistical analysis using Fisher's Exact Test found differences in osteoarthritis in all three sections of the vertebral column (Table 10.8; Figures 10.14 to 10.16). Armatambo had more DJD in all vertebral types than Andrushko's combined sample.

Table 10.8: Prevalence of Vertebral Osteoarthritis (Coast to Core)

	Armatambo		Andrushko (2007) Grouped		
	n	Frequency	n	Frequency	Fisher's Exact p
Cervical DJD	30	0.47	227	0.22	0.01
Thoracic DJD	32	0.75	254	0.31	0.00
Lumbar DJD	33	0.79	253	0.47	0.00

The Armatambo skeletal population showed some signs of worse health compared to populations studied in the core and near periphery of the Inca Empire. While both this dissertation and Andrushkos' found that health in subadulthood was good compared to previous time periods, Armatambo had more chronic anemia and periosteal lesions than the Inca core and near periphery samples. As with the comparison between Armatambo and Puruchuco-Huaquerones, Armatambo adults also showed worse health than those in the Inca core and near-periphery, in the form of pathology related to high physical activity. Cranial trauma was also more common at Armatambo.

Summary of Comparisons Between Armatambo and the Inca Empire

Comparison between Armatambo and both the core and near periphery of the Inca Empire paralleled the Model D comparison between Armatambo and Huaca Malena of the Huari Empire. Armatambo showed signs of worse subadult and adult health in both cases. In comparison to the Inca sites, the Late Intermediate Period Armatambo population had more signs of chronic anemia and bacterial infections than the Inca core and near-periphery populations. The Armatambo population also showed more vertebral DJD than the Puruchuco-Huaquerones, Inca core, and Inca near-periphery populations. Comparisons between Armatambo and Puruchuco-Huaquerones did show conflicting results. Elbow joint DJD was more common in the Puruchuco-Huaquerones population than at Armatambo. Subadults in later childhood were also more likely to have chronic anemia at Puruchuco-Huaquerones than at Armatambo. I conclude that imperial rule had a more positive effect on health than an urban state society, even though Inca core and Armatambo were both urban areas. The greater access to a larger variety of resources in an empire due to its wider territory may be a contributing factor in supporting subadult health. As was speculated in the discussion for Model D, less labor might have been needed in an expansive empire to extract the same resources in an urban state, causing higher prevalence of DJD in the latter type of society. The differences in findings between this dissertation and prior work on the bioarchaeology of states both in the Andes and elsewhere have to be explored to see what factors in a state society affect the prevalence of physiological stress indicators, especially in subadults.

CHAPTER 11: CONCLUSION

This dissertation looked at the bioarchaeology of health and physical activity at Armatambo, a city in the Ychsma state of the Central Andean region. Four models were proposed relating health differences within the Armatambo skeletal collection and between Armatambo and other sites in the same region. This section summarizes the results of the statistical analyzes used to test these models, followed by sections that describe how this dissertation contributes to the theories that started the investigation, and how further research can continue the exploration of health and social complexity.

Model A stated that there should be a difference in health and activity levels between males and females in both subadulthood and adulthood in the Armatambo collection. The reasoning is that in a complex society, males would be assigned more demanding labor to the point of negatively impacting their health while females would be given less demanding work. The results did not support this model. Two comparisons of stress indicators found that adult males experienced more extreme physical activity: vertebral trauma and Schmorl's nodes. Notably, both reflect stress to the vertebral column. Most of the other health indicators used to test Model A were similar between males and females. Indicators of chronic anemia and chronic bacterial infection were low for both sexes. Based on these findings, parental investment in subadults did not appear to differentiate by sex. The result of analysis in DJD prevalence suggests that labor was physically demanding for all adults, not just for males. Model A therefore appears to lack support in the Armatambo collection.

Model B stated that groups within Armatambo marked by a possible indicator of ethnic affiliation, cranial deformation, should show signs of different health and physical activity. The hypothesis for this model was informed by world systems theory, which states that social roles in a complex society are often defined by ethnic lines. This study found that stress indicators were similar between adults with and without cranial deformation at Armatambo, contrary to the hypothesis of Model B and the findings of Pechenkina and Delgado (2006:226), who found that "[i]ndividuals subjected to cranial modification exhibited anemia indicators more frequently, but grew to become taller adults than the individuals with unmodified skulls." At Armatambo, subadults with and without cranial deformation had comparable levels of chronic anemia though the timing of the disease may have had slight differences. Adults showed no statistically significant differences in the prevalence of periosteal lesions, DJD or trauma between the cranially deformed and undeformed. Based on these results, either health and labor did not split along ethnic lines at Armatambo, or cranial deformation was not an indicator of ethnicity at this urban settlement.

Model C compared health and activity levels among four skeletal populations from the Central Andean coast. This model proposed two differences in health between the urban state population of Armatambo and non-state societies. The first difference is that health related to nutrition and infection, especially evident in subadulthood, should be better in an urban state relative to non-state societies because a state could provide better buffering against famine. The second difference is that state-level societal organization should allow the elites to extract more labor from their workers than in non-state societies, worsening health in the adult state population.

Comparisons between the skeletal population at Armatambo and the skeletal population of Paloma, a Middle Preceramic Period fishing village, found weak evidence supporting Model C. Most comparisons found no statistically significant difference in stress indicator prevalence between the Armatambo and Paloma skeletal populations. Contrary to the hypothesis, the Armatambo collection showed some signs of worse health in subadulthood compared to Paloma. For example, the Armatambo collection had more periosteal lesions in subadults and a higher tibial Harris line counts in females than the Paloma collection. Overall, what few significant differences in health existed between the Armatambo and Paloma skeletal populations contradicted Model C. However, given that the Paloma collection shows generally better health compared to collections from other Andean sites (Pechenkina et al., 2007), it is not surprising that the Armatambo collection did not exhibit better health than the Paloma collection. The fact that many comparisons between the Armatambo and Paloma skeletal populations were close enough to not be statistically significant shows the good state of health seen at the Late Intermediate Period urban site.

Support for Model C was found in the comparison between the Armatambo and Cardal populations. Armatambo subadults were significantly less likely to have had chronic bacterial infections than Cardal subadults. Also, Armatambo adults had greater mean tibia length (better health during the growth and development period) than their Cardal peers. Some indicators, however, did not show a large difference in subadult health between the Armatambo and Cardal collections. For example, the Armatambo and Cardal populations had similar prevalences of chronic anemia indicators. Analysis of adult health and activity found one possible indication that the Armatambo population experienced more extreme physical stressors. Lumbar vertebrae DJD may have been more common in the Armatambo population. Still, females at Armatambo had fewer instances of periosteal lesions and higher mean age at death, suggesting better health than Cardal females. Overall there are some indications that health in subadults was better at Armatambo than at Cardal. In adults, Armatambo females might have had better health than Cardal females, contrary to the model.

Comparison of health between the Armatambo and the combined Villa El Salvador and Tablada de Lurín skeletal populations found more evidence supporting Model C than in the comparisons with Paloma and Cardal collections. In subadults, the prevalences of cribra orbitalia and porotic hyperostosis were lower in the Armatambo population than at VES/TBL, to levels that approached significance. Adult differences in CO and PH were statistically significant and showed better health at Armatambo. Adults at Armatambo were far more likely to have DJD in the thoracic vertebrae, as the model predicted. However, more periosteal lesions were found in the Armatambo subadult skeletal population than in the VES/TBL sample. Also, the VES/TBL sample had significantly more knee DJD, a surprising finding that does not support Model C. As in the comparisons with the Paloma and Cardal collections, Armatambo females had a significantly older mean age at death than Villa El Salvador/Tablada de Lurín females, suggesting better female health at Armatambo.

Looking overall at the three intersite comparisons testing Model C, it appears that the model is more supported as the Armatambo collection is compared to more complex, but not state level, socities. Comparison of health indicators between urban Armatambo and the Paloma fishing village showed equal or worse health at the urban state. Looking at Armatambo and the loosely stratified population at Cardal, subadults showed better health in several areas at the urban site, which supported the model. Adults at Armatambo possible indicators of worse health than adults at Cardal, though these differences were not statistically significant. Greater differences in health appeared between the Armatambo and VES/TBL skeletal populations as predicted by the model. Overall, when compared to non-state stratified societies such as Cardal and VES/TBL, urban state organization shows an enhanced ability to command work from the laborers though with at least some dividends in improved subadult health.

The last model tested in this study, Model D, compared Armatambo with Huaca Malena, an earlier site, but part of a more complex imperial society.

Taking the premise of Model C further, an empire, defined by a greater variety of territory and resources, should show even better subadult health and worse adult health than is found in a localized urban state. The results show that while subadult health was better at Huaca Malena, supporting Model D, physical labor for adults was actually less extreme than at Armatambo, which does not support the model. While not statistically significant, the Armatambo population had higher prevalences of all subadult stress indicators and all categories of adult DJD and trauma than the Huaca Malena population. I believe these results show that imperial organization provides two broad improvements in health over urban state organization. One is that buffering against nutritional stress is better in an empire, as evident in indicators of subadult health. The second improvement is that labor in an empire is less physically demanding than in an urban state. These two statements were then tested with a comparison among the skeletal population at Armatambo and various populations from the Inca Empire.

Data from the dissertations of Murphy (2004) and Andrushko (2007) were used to further explore Model D. Conflicting results were found among samples. Comparison between the Armatambo population and individuals from Central Andean coast site of Puruchuco-Huaquerones showed significantly higher prevalences of chronic anemia than individuals from Armatambo. Looking at adults, the population at Armatambo did have more cases of extreme physical stress to the vertebrae than the population at Puruchuco-Huaquerones, as predicted by Model D, but Armatambo also showed less elbow DJD. I found different results when comparing health in the Armatambo skeletal collection with samples closer to the core of the Inca Empire. The Armatambo skeletal population showed worse health in both subadults and adults than in both the Inca core and near-periphery samples, similar to the comparison between the Armatambo and Huaca Malena skeletal populations. For instance, both chronic anemia and degenerative joint disease were far more prevalent in the Armatambo collection. The difference in results when comparing the Armatambo population with Puruchuco-Huaquerones and with the Inca core and near-periphery groups needs further investigation to find out how health differs between urban states and empires. It is possible that Puruchuco-Huaquerones is atypical of Inca territories since the cemetery is located on the western edge of the imperial periphery. Interobserver error is another factor that could have produced the varying results. Collaboration on research in the future will help clarify the results of the inter-study comparisons.

The next sections describe how this study contributes to three areas of research in the social sciences. The areas are the study of anthropology in general, the overarching theories that generated the hypotheses, and the methods used in the sub-discipline of bioarchaeology

Contributions to Anthropology

This study contributed to the field of anthropology in several ways. First is the addition of a new case study from the Late Intermediate Period, an infrequently studied period in Andean prehistory. Moving forward, data collected from the Armatambo skeletal collection, presented in Appendix 1, can fuel further investigations by other researchers in the study of health and social complexity.

Also, this study tested hypotheses concerning health in a prehistoric urban state. The results showed that most indicators did not differ by sex in the Armatambo skeletal collection. Also, groups differentiated by the presence or absence of cranial deformation show few differences in health. Both of these findings are surprising and bear further investigation to see whether this pattern is found in other states.

Lastly, this study also contributed to the study of changing social complexity, one of the core issues of anthropology. Data collected from the Armatambo collection were also compared to data collected from other types of societies by other researchers, with results that expanded on some of the initial research questions. Interplay between social complexity and health was not as simple as the models had predicted though there are some indications that subadult health improved with state and empire level complexity. Knowing that there is a complex relationship between social complexity and health, further work can test more refined hypotheses concerning the interaction between these factors.

Contributions to Theory

The results of this dissertation can feed back to the theories discussed in Chapter 4 that informed the hypotheses addressed in this study.

World systems theory contributed the ideas that labor in a complex society is divided along lines of ethnicity and sex, and that social complexity may have an effect on the health of its constituent population. This study looked for signs of these phenomena in a skeletal population from an archaeological urban state. While world systems theory originated in the study of modern capitalism, exploration of how world systems theory applies to past societies can help refine the concept to cover more of human history (Peregrine 1996). The use of bioarchaeology in particular uses the biological remains of the actors themselves to address the interplay between social complexity and health. In particular, this study looked at commoner populations across different types of societies. The results of this study showed less stratification of labor between groups of different sexes and supposed ethnicities than expected in an urban state, which does not agree with world systems theory. Based on this finding, further work can look for the factors that cause pre-modern non-capitalist societies to differ from the model proposed by world systems theory.

Life history theory, especially parental investment theory, informed this study by stating that tradeoffs occur in the rearing of offspring based on the availability of resources. Exploration of these theories in humans typically occurs in two time periods, the present and the evolutionary past. This study approached parental investment theory in an intermediate time period, the archaeological past, through bioarchaeological methods. As in the use of bioarchaeology in testing world systems theory, approaching parental investment theory in an archaeological population greatly increases the potential number of samples for study by including past peoples. The direct examination of past health through the bodies of the deceased also avoids issues of using ethnographic analogy to infer past lifeways from modern peoples (e.g. Upham, 1987). The bioarchaeological approach also offers the means to examine subadult health, either alone or in comparison with adult health. Examination of subadult health and its relation to social age categories can inform studies of parental investment in relation to energy demands (Halcrow and Tayles, 2011). Bird's (1999) theory about the determinants of sexual division of labor and how it applies to complex societies can also be explored through bioarchaeology. As a launching point for further work, this study found some indication that a complex society mitigated certain aspects of poor subadult health, possibly by increasing labor in adults.

Contributions to Bioarchaeological Methodology

This study introduced three new tools to produce better bioarchaeological analyses. I presented a statistical test for selective mortality, a new way of calculating the corrected subadult age estimate, and the use of graphics-manipulating software to view radiographs.

A statistical solution to the issue of selective mortality was proposed since current solutions to identify paradoxical interpretations of physiological stress indicators in a skeletal population do not fully address the problem of the osteological paradox. Simple modeling of paradoxical data (Chapter 4) found that if individuals with a stress marker were more likely to die young than those without the marker, then there should be a negative correlation between stress prevalence and age at death. A positive association between one stress indicator, Harris line counts, and age at death was found in this study. This result was unexpected and further work can explore what a positive association means to the interpretation of stress indicators. The current hypothesis is that cortical thinning with age is revealing more Harris lines in older women compared to younger women and men of all ages.

Another method of quantifying subadult growth stunting, the corrected subadult age estimate, was developed for this study. The CSAE builds upon work by Pechenkina et al. (2007). To review, an estimation line was calculated based on published data on subadult femoral growth rates. The estimated age from femur length produced by this equation was then subtracted from an estimate of age based on dental eruption state. The difference represents missed femur growth potential, which can be interpreted as an indicator of physiological stress. The current implementation is preliminary, focusing on the small age range (0 to 6 years) in the subadult skeletal collections used in this study. The calculation of an estimation equation that fits the greater range of the published data is needed to expand the usefulness of this technique.

A new method of counting Harris lines was used in this study. In past studies, radiographs were examined “as-is,” with an attempt to standardize the exposure, but no correction after the radiograph was taken. In this dissertation, Adobe Photoshop CS4 image editing software was used to manipulate the tonal balance of digitized radiographs to enhance the contrast between the lighter Harris line and the darker bone around it. This technique reveals otherwiseobscured lines in the image. This method of viewing Harris lines improves the accuracy of Harris line counts by removing some of the variation in radiograph quality as a factor.

Further Work

This study found interesting patterns in health and activity levels in urban state rule in the Central Andes. There are many elements to explore to confirm and expand upon the results. More data can be sought from the Armatambo skeletal collection, the Andean region, or in the other locations where urban state societies developed.

FURTHER WORK ON THE ARMATAMBO COLLECTION

Bioarchaeological questions can be explored further with the Armatambo skeletal collection. As mentioned in Chapter 5, fewer individuals than anticipated were radiographed in the 2009 data collection session due to mechanical difficulties. As a result, sample sizes in Harris line analyses were lower than desired. While statistical models were used to address correct for bias caused by uneven sample sizes, a new project to radiograph the collection would fill out the data set.

Dental pathology is another source of data for further testing hypotheses concerning health at Armatambo. The data collection session of 2007 recorded information on tooth wear, and the presence of caries and abscesses. Severe wear and a high amount of carious lesions (colloquially known as cavities) were noted during data collection. As mentioned in Chapter 1, linear enamel hypoplasias were excluded from this dissertation because too few teeth were whole enough to record this indicator. Other data on tooth pathology were not addressed in this study since a thorough dental study would have greatly increased the size of the project while not necessarily testing Models C and D. While the concepts of buffering and nutrition were factors in formulating the four models examined in this study, pathology from diet was not part of the models in terms of either stress visible in subadulthood or signs of extreme adult physical activity. However, the observation of severely worn teeth is an interesting finding in and of itself, and future models incorporating dental pathology may be helpful in studying health and state.

The presence of cranially deformed and undeformed individuals at Armatambo is another feature of the site that can be further investigated. Two techniques beyond the scope of the study can be used to explore the geographic origins of the Armatambo skeletal population to see whether the interred are native to the region or immigrants. The cranially deformed and undeformed may or may not share a common geographic origin. Strontium analysis could be used to identify where subadulthood occurred, whether in the highlands or coastal regions. Stable isotopes of carbon and nitrogen would enhance our knowledge of the dietary composition of individuals. A comparative database of stable isotope analysis results exists for the Andean region in different time periods (e.g. Knudson et al., 2004; Tung and Knudson, 2008; Knudson and Torres-Rouff, 2009; Slovak et al., 2009; Conlee, et al, 2009). Another method, the statistical analysis of digitally-recorded cranial measurements, has recently been made for several Inca sites in the central coast, including Puruchuco-Huaquerones (Bethard, personal communication 2010). Comparison of these measurements can give a view of phylogenetic distance among these groups through time. aDNA analysis could also shed light on phylogenetic distance. Recently, Hermann Gorbahn obtained aDNA from Paloma skeletal material (Benfer, personal communication 2010). Since aDNA is from the least well-preserved genetic material, the likelihood of success for later material from the Late Intermediate Period is good.

As mentioned in Chapter 5, attempts to access archaeological data for the Armatambo skeletal collection are ongoing. These data, including the presence of mortuary goods, and placement of burials relative to each other, and would enhance the reconstruction of the lifeways of these individuals. These data could be compared to the results of this study, and together be used to create new hypotheses to test. Historically, archaeological contextual data have been difficult for bioarchaeologists to access in Perú, but I am optimistic that the data will be available in the near future.

FURTHER WORK IN THE ANDEAN REGION

There are several avenues of research exist in the rich prehistory of the Andean region that can be explored to supplement this dissertation.

One way of expanding the research presented here would be to look at skeletal pathology from time periods not represented in this study. The Early

Horizon is notable since it contains the first cultural horizon in the region, but one that spread in a non-militaristic fashion.

The Late Intermediate can be further explored to address the few instances of small sample size present in this study. The number of significant models, higher than expected by chance, shows that there are large meaningful differences between the skeletal populations used in this dissertation. However, a larger sample size from the same time period as the Armatambo site can be used to pursue more subtle differences between groups.

The differential pattern of DJD between sites provides a new direction of study to determine exactly how these societies differed in physical activity. Studies of bilateral asymmetry can be used to look at preferential limb use between sites with the goal of investigating occupational differences. A study of cross-sectional geometry between groups could also be used to explore how labor is distributed between groups.

While I did not collect the bioarchaeological data from the Huaca Malena collection, this dissertation represents the first published findings from the Huaca Malena data set, with permission from the investigators. My study was conducted with its focus on Armatambo, but interesting findings appeared regarding health at Huaca Malena relative to the other sites. Like Armatambo, Huaca Malena appeared to reverse the trend of worsening subadult health seen in Pechenkina and colleagues' (2007) study of the Central Andean coast. Unlike what was seen in the Armatambo collection, markers of extreme physical activity were less prevalent in the Huaca Malena collection. Still, the mean age at death of

Huaca Malena females was extremely low compared to all of the other sites. Further work can compare bioarchaeological data from Huaca Malena with other Huari sites, such as Conchopata, Beringa, and La Real (Tung, 2003). There are also additional materials from Huaca Malena for study.

FURTHER WORK BEYOND THE ANDEAN REGION

While the Andean region has recently become a hotbed of research on the bioarchaeology of empires, as Chapter 2 discussed there are several areas around the world where the evolution of urban states and its impact on health can be investigated. A similar study of state subjects can be conducted far from the Andes to generate a data set with which to compare Armatambo and Huaca Malena. Such a large-scale study can look for common trends in the formation of all states. The scope of comparative data can also be expanded to include bioarchaeological studies of Mesoamerican states.

Last Words

This study has provided evidence of mechanisms by which an urban state society can sustain its population. Subadult health appears to have been well buffered by the resources a state system provides. In contrast, adults appear to have been worked harder physically under this type of society, even when compared to empires. It is tempting to link the two trends: subadult health was improved in part by the heightened extraction of labor from their parents. Study of prehispanic life histories will yield more insights. Further work can continue to explore the interaction between elites and their subjects, and how this relationship differs in urban states.

APPENDIX 1: ARMATAMBO SKELETAL DATA

Armatambo Adults

Individual	Catalog	Sex	Age	Deformation	Date	Harris Lines: Right Distal Femur	Harris Lines: Left Distal Femur	Harris Lines: Mean Femur	Harris Lines: Right Distal Tibia	Harris Lines: Left Distal Tibia
ENT 25A	188	M?	30	Tabular Erect	July 2, 2007		.	.	.	.
ENT 25B	188	F?	30	Tabular Erect	July 3, 2007	.	.	.	.	.
ENT 25C	188	M	35	Tabular Erect	July 3, 2007	.	.	.	.	.
ENT 25D	188	F?	22	.	July 4, 2007	.	.	.	.	.
ENT 27A	103	F	60	0	July 5, 2007	.	.	.	.	.
ENT 29	165	F	20	0	June 27, 2007	.	.	.	.	.
ENT 30	111	F	50	.	June 21, 2007	.	.	.	.	.
ENT 31A	102L	M	32	.	June 15, 2007	.	.	.	.	.
ENT 32A	106	M?	21	.	June 12, 2007	.	.	.	.	.
ENT 32C	106	M	37	.	June 15, 2007	.	.	.	.	.
ENT 32D	106	I	40	.	June 18, 2007	.	.	.	.	.
ENT 32E	106	F	45	.	June 18, 2007	.	.	.	.	.
ENT 34	108	F	40	0	June 19, 2007	7	8	7.5	6	8
ENT 35	109	M	50	0	June 19, 2007	.	.	.	.	.
ENT 37A	110	M	40	0	June 25, 2007	.	.	.	.	.
ENT 39	166	M	57	Tabular Erect	June 21, 2007	.	.	.	.	.
ENT 41	112	M	25	.	August 3, 2007	.	.	.	.	.
ENT 42	114	M	40	0	July 4, 2007	.	.	.	.	.
ENT 43A	188	F	50	.	July 12, 2007	.	.	.	.	.
ENT 44	116	M	21	.	July 24, 2007	3	2	2.5	1	0
ENT 45B	86	F	55	Tabular Erect	July 6, 2007	.	.	.	.	.
ENT 46	118	F	20	Tabular Erect	July 25, 2007	.	.	.	.	.
ENT 47B	119	F	25	.	July 13, 2007	.	.	.	.	.
ENT 48	88	F	40	.	July 18, 2007	.	.	.	.	.
ENT 49B	120	F	65	0	July 11, 2007	.	.	.	.	.
ENT 50	94	F	42	0	July 12, 2007	8	12	10	7	9
ENT 51A	80	M	32	.	July 12, 2007	.	.	.	.	3
ENT 56	75	F	65	.	July 16, 2007	11	8	9.5	9	10
ENT 59B	121	F	55	.	July 27, 2007	6	.	6	.	.
ENT 60	164	M	38	0	July 18, 2007	.	.	.	.	.

Individual	Harris Lines: Mean Tibia	Cribra Orbitalia	Porotic Hyperostosis	General Periosteal Lesions	Elbow Osteoarthritis	Knee Osteoarthritis	Cervical Vertebrae Osteoarthritis	Thoracic Vertebrae Osteoarthritis
ENT 25A	.	0	0	.	.	.	.	.
ENT 25B	.	0	0	.	.	.	.	.
ENT 25C	.	0	0	.	.	.	.	.
ENT 25D	.	0	0	.	.	.	.	.
ENT 27A	.	0	0	1	0	1	1	1
ENT 29	.	1	0	0	0	0	0	1
ENT 30	.	.	.	0	0	.	.	.
ENT 31A	.	1	0	1	1	0	1	0
ENT 32A	.	.	.	1	0	0	0	1
ENT 32C	.	1		.	.	.	.	.
ENT 32D	.	.	.	0	.	.	.	1
ENT 32E	.	.	.	0	0	0	0	0
ENT 34	7	1	0	0	0	0	0	1
ENT 35	.	0	0	1	1	0	0	1
ENT 37A	.	0	0	1	1	1	1	1
ENT 39	.	0	1	0	1	1	1	1
ENT 41	.	.	.	1	1	1	1	1
ENT 42	.	0	0	0	1	1	0	1
ENT 43A	.	.	.	0	1	1	0	1
ENT 44	0.5	.	.	0	0	1	0	0
ENT 45B	.	0	.	0	0	0	0	1
ENT 46	.	0	.	1	0	0	0	0
ENT 47B	.	.	.	0	0	0	0	1
ENT 48	.			0	0	0	0	1
ENT 49B	.	0	0	0	1	0	1	1
ENT 50	8	0	0	0	1	0	0	0
ENT 51A	3	.	.	0	.	.	.	1
ENT 56	9.5	.	.	1	1	1	1	1
ENT 59B	.	.	.	0	.	.	1	1
ENT 60	.	0	0	0	0	0	0	1

Individual	Lumbar Vertebrae Osteoarthritis	Schmorl's Nodes	General Osteoarthritis	Appendage Trauma	Cranial Trauma	Sharp Trauma	Vertebral Trauma
ENT 25A	.	.	.	.	0	0	.
ENT 25B	.	.	.	.	1	0	.
ENT 25C	.	.	.	.	1	0	.
ENT 25D	.	.	.	.	0	0	.
ENT 27A	1	0	1	0	0	0	0
ENT 29	1	0	1	0	0	0	0
ENT 30	1	0	1	0	.	0	.
ENT 31A	1	0	1	0	0	0	0
ENT 32A	1	1	1	0	.	0	0
ENT 32C	.	.	.	.	0	0	.
ENT 32D	.	.	1	.	.	.	.
ENT 32E	0	0	1	0	.	0	0
ENT 34	1	0	1	0	0	0	0
ENT 35	1	1	1	1	0	0	1
ENT 37A	1	1	1	0	1	0	0
ENT 39	1	1	1	0	1	0	0
ENT 41	1	0	1	1	.	1	1
ENT 42	1	1	1	0	0	0	1
ENT 43A	1	0	1	0	0	0	0
ENT 44	0	1	1	0	0	0	1
ENT 45B	1	0	1	1	1	1	0
ENT 46	0	0	0	0	0	0	0
ENT 47B	1	0	1	0	0	0	0
ENT 48	1	0	1	0	0	0	0
ENT 49B	1	0	1	0	0	0	0
ENT 50	0	0	1	0	0	0	0
ENT 51A	.	.	1	0	.	0	.
ENT 56	1	1	1	0	.	1	0
ENT 59B	1	0	1	0	0	0	0
ENT 60	1	1	1	0	1	0	1

Individual	Catalog	Sex	Age	Deformation	Date	Harris Lines: Right Distal Femur	Harris Lines: Left Distal Femur	Harris Lines: Mean Femur	Harris Lines: Right Distal Tibia	Harris Lines: Left Distal Tibia
ENT 62	78	M	22	.	August 1, 2007	.	.	.	.	.
ENT 64	128	F	32	.	August 6, 2007	.	.	.	.	.
ENT 65	122	M	28	0	July 19, 2007	5	3	4	3	4
ENT 67	124	M	20	.	July 26, 2007	.	.	.	.	.
ENT 68	125	F	40	Tabular Erect	July 20, 2007	.	.	.	.	.
ENT 70	126	F	33	.	August 2, 2007	.	.	.	.	.
ENT 71	127	M	25	.	August 2, 2007	.	0	0	0	2
ENT 73	130	F	42	.	August 3, 2007	0	0	0	0	0
ENT 74	131	F	37	Tabular Erect	July 31, 2007	.	.	.	.	.
ENT 75CB	132	M	26	.	July 20, 2007	.	.	.	.	.

Individual	Harris Lines: Mean Tibia	Cribra Orbitalia	Porotic Hyperostosis	General Periosteal Lesions	Elbow Osteoarthritis	Knee Osteoarthritis	Cervical Vertebrae Osteoarthritis	Thoracic Vertebrae Osteoarthritis
ENT 62	.	.	.	0	.	.	.	.
ENT 64	.	.	.	0	.	.	1	0
ENT 65	3.5	0	0	0	1	0	0	1
ENT 67	.	.	.	0	0	0	1	0
ENT 68	.	0	1	0	1	0	1	1
ENT 70	.	.	.	0	0	0	1	1
ENT 71	1	.	.	0	0	0	1	1
ENT 73	0	.	.	1	.	0	1	1
ENT 74	.	0	0	0	0	0	0	0
ENT 75CB	.	.	.	0	0	0	.	.

Individual	Lumbar Vertebrae Osteoarthritis	Schmorl's Nodes	General Osteoarthritis	Appendage Trauma	Cranial Trauma	Sharp Trauma	Vertebral Trauma
ENT 62	0	0	1	0	.	0	.
ENT 64	1	0	1	.	.	1	0
ENT 65	1	0	1	0	0	0	0
ENT 67	0	0	1	.	.	0	0
ENT 68	1	1	1	0	1	1	0
ENT 70	1	0	1	0	.	0	0
ENT 71	1	0	1	1	.	0	0
ENT 73	0	0	1	0	.	0	0
ENT 74	1	0	1	0	0	0	1
ENT 75CB	1	0	1	0	.	0	.

Armatambo Subadults

Individual	Catalog	Sex	Age	Deformation	Date	Harris Lines: Right Distal Femur	Harris Lines: Left Distal Femur	Harris Lines: Mean Femur	Harris Lines: Right Distal Tibia	Harris Lines: Left Distal Tibia
ENT 13	188	I	5	Absent	July 2, 2007	.	.	.	.	.
ENT 27B	103	M?	0	.	July 6, 2007	.	.	.	.	.
ENT 31B	102L	I	0.833	.	June 15, 2007	.	.	.	.	.
ENT 33	188	M?	3	Tabular erect	July 20, 2007	.	.	.	.	.
ENT 37B	111	F?	4	.	June 21, 2007	.	.	.	.	.
ENT 43B	117	F?	3	Tabular erect	July 24, 2007	.	.	.	.	.
ENT 45A	118	M	2	Tabular erect	July 9, 2007	.	.	.	.	.
ENT 47A	88	M?	3	Absent	July 13, 2007	0	0	0	0	0
ENT 49A	94	F?	4	Absent	July 11, 2007	.	.	.	.	.
ENT 51B	75	I	.	.	July 12, 2007	3	4	3.5	1	1
ENT 52	87	F	3	.	July 27, 2007	.	.	.	.	.
ENT 65B	129	I	5	Tabular erect	August 1, 2007	.	.	.	.	.
ENT 75A	170	M	0.833	Tabular erect	June 8, 2007	2	4	3	4	6

Sex was estimated for subadults using indicators on the os coxae, but were not used in data analysis.

Individual	Harris Lines: Mean Tibia	Cribra Orbitalia	Porotic Hyperostosis	General Periosteal Lesions
ENT 13	.	1	1	0
ENT 27B	.	.	.	1
ENT 31B	.	.	.	1
ENT 33	.	1	0	0
ENT 37B	.	1	0	0
ENT 43B	.	.	.	0
ENT 45A	.	.	.	0
ENT 47A	0	0	0	0
ENT 49A	.	1	0	0
ENT 51B	1	0	0	0
ENT 52	.	.	.	0
ENT 65B	.	.	.	0
ENT 75A	5	1	0	1

APPENDIX 2: HUACA MALENA SKELETAL DATA

Huaca Malena Adults

Individual	Sex	Age	Deformation	Date	Cribra Orbitalia	Porotic Hyperostosis	General Periosteal Lesions	Elbow Osteoarthritis	Knee Osteoarthritis
FF 38	F	19	None	Jul 13, 2002	0	0	0	0	0
FR-1	M	41	Tabular erect	Jul 7, 2002	0	0	0	0	0
H2 0015A	M	35	.	Jul 9, 2002	.	.	.	.	.
H2 0018	F	18	Tabular erect	Jul 8, 2002	0	0	.	0	.
H2 0018	F?	.	.	Jul 9, 2002	.	.	0	.	.
H2 0020C	M	54	.	Jul 8, 2002	.	.	.	.	.
H2 0021A	F?	22	.	Jul 9, 2002	.	.	0	1	.
H2 0021C	M?	27	.	Jul 9, 2002	.	.	0	0	.
O AF 055A	M?	36	.	Jul 11, 2002	.	.	0	.	.
Q2 UI Q2 UC	.	.	.	Jul 9, 2002	.	.	1	.	.
T2	M	26	.	Jul 10, 2002	.	.	0	0	0
U1 T4	F	26	N/A	Jul 11, 2002	0	0	0	0	0
U2 T1	F	19	.	Jul 10, 2002	.	.	0	0	0
U2 T10	F	20	Annular oblique	Jul 12, 2002	0	0	.	.	.
U2 T4	M	40	Tabular erect	Jul 12, 2002	0	0	0	1	0
U2 T5A	F	19	None	Jul 13, 2002	0	0	0	0	0
U2 T6	M?	33	None	Jul 9, 2002	0	0	0	0	0

Individual	Cervical Vertebrae Osteoarthritis	Thoracic Vertebrae Osteoarthritis	Lumbar Vertebrae Osteoarthritis	Schmorl's Nodes	General Osteoarthritis
FF 38	0	0	0	0	0
FR-1	1	1	1	0	1
H2 0015A	.	.	.	.	.
H2 0018	.	1	.	.	.
H2 0018	.	1	.	.	0
H2 0020C	.	0	.	.	0
H2 0021A	.	.	.	.	1
H2 0021C	.	1	1	0	1
O AF 055A	.	1	1	0	1
Q2 UI Q2 UC	.	.	.	.	1
T2	1	0	1	0	1
U1 T4	0	0	.	1	1
U2 T1	.	0	1	0	1
U2 T10	0	0	1	0	1
U2 T4	0	1	0	0	1
U2 T5A	0	0	0	0	0
U2 T6	1	1	0	1	1

APPENDIX 3: ARMATAMBO SKELETAL COLLECTION NOTES

This section describes various other observations made during the data collection of the skeletal collection from Armatambo. The goals are to highlight interesting features that were not mentioned in the main text, show these features to other investigators so they may provide special insight, and to bring these individuals to life in some way, however minor.

ENT 25: This burial contained four crania but few other bones.

ENT 25A (Male, ~30 years, tabular deformation): Present teeth are chipped, probably postmortem.

ENT 25B (Female, ~30 years, tabular deformation): Aging and sexing of this cranium was noted as difficult. A healed circular depression is present on the left parietal bone.

ENT 25C (Male, ~35 years, tabular deformation): Disarticulated calvarium and maxilla. Abscesses found on teeth, as well as alveolar resorption.

ENT 25D (Female, ~22, tabular deformation): Excavators placed the cranium in a plastic bag with associated artifacts, including wool and feathers. This individual's hair and scalp are also present, and the remains of the brain was noted when the interior of the cranium was examined through the foramen magnum. Hair is lighter reddish brown with a bowl haircut (Figure A3.1). Data collection used only the face in order to preserve the associated artifacts. Sex estimation was difficult but investigators settled on female due to relative gracility.

Figure A3.1: Cranium of ENT 25D.

ENT 27: This burial had an elderly woman and an infant.

ENT 27A (Female, ~60 years, No deformation): Skeletal aging indicators were maximized, except for sternal rib ends. Most teeth had been lost premortem and the alveoli have been resorbed. The left humerus was dislocated such that the humeral head split from the tuberosity and formed a new articulation with the scapula (indicated by an arrow in figure A3.2). The left forearm is shorter than the right, possibly indicating disuse. Possibly related, the right first rib is larger than the left. The vertebrae did not articulate well though they were certainly placed in the correct order and belong to the same individual. Investigators noted that the box for ENT27 was unusually light despite containing a nearly complete skeleton, concluding that this individual had pronounced bone loss associated with old age.

Figure A3.2: Dislocated left shoulder joint of ENT 27A.

ENT 27B: All age indicators are at the lowest level, suggesting that this individual was stillborn.

ENT 29 (Female, ~20 years, not deformed): Tooth wear was noted as not severe relative to other individuals in this collection, concordant with the lower age at death. The pronator ridge of the right ulna was noticeably larger than on the left.

ENT 30 (Female, ~50 years, deformation unknown): Except for osteophytic lipping was noted on the sacrum, foot phalanges, thoracic and lumbar vertebrae, and pelvis, no other pathology or unique features were found.

ENT 31A (Male, ~32 years, deformation unknown): This individual had high robusticity in several areas of the body. The clavicles showed deeply furrowed costal impressions. The left radius has a pronounced sulcus on the radial tuberosity. The styloid processes of the ulnae are large and "hook-like." Both left and right ischial spines on the os coxae were protruding. Lastly, a toenail and fingernail were found with the remains.

ENT 32: This burial had five individuals, with ages at death between 16 and 45, though two could not be sexed reliably.

ENT 32A (Male, ~21 years, deformation unknown): The manubrium had extreme porosity on the dorsal surface.

ENT 32B (Indeterminate, ~16 years, deformation unknown): Only the cranium was recovered from this individual.

ENT 32C (Male, ~32 years, deformation unknown): This individual is represented only by a partial cranium. Healed cribra orbitalia was noted.

ENT 32D (Indeterminate, ~40 years, deformation unknown): While sex could not be determined during data collection, the later age at death corresponds with the female distribution rather than males (Figure 8.6). There are indicators of asymmetrical experience of physical stress. Asymmetry was found in the thoracic vertebrae: the right side is longer dorsiventrally. Also, the left clavicular notch on the manubrium is lower than the right. On the sternal body, the costal notch for the second left rib is more inferiorly positioned than the right. The clavicles are robust, and combined with the other features listed led investigators to interpret that this individual carried heavy weight on the shoulders, especially the left. ENT 32D has an associated child left femur, tibia, and talus. No pathology was noted here. An age estimate of six years was found based on femur length (Bass, 1995).

ENT 32E (Female, ~45 years, deformation unknown): This individual had only four lumbar vertebrae in life. Age indicators of the os coxae were noted to differ greatly between the right and left sides. The preauricular sulci, dorsal pitting, and muscle attachment sites are very pronounced. The left femur also had strong muscle attachments. Several extra bones were found: the anterior margin of a child's foramen magnum, a child's left proximal first phalanx, and adult lumbar vertebra (possibly second), and an animal bone (possibly from a rodent).

ENT 34 (Female, ~40 years, no deformation): The sternal end of the right clavicle is slightly wider than on the left. The left radius is 5mm longer than the right.

ENT 35 (Male, ~50 years, no deformation): All pelvic muscle attachment sites are extremely rugose. The fifth lumbar vertebra has a healed break between the superior articular process and the transverse process, suggesting that the muscles held the arch and body together. An extra talus and fragments of several bones were included with this individual. Several molars were lost premortem.

ENT 37A (Male, ~40 years, no deformation): The cranium shows various trauma: 3 depressions on the right side of the frontal bone, and a depression on the right parietal. When examined from the basilar view, the cranium shows a latero-anterior shift to the right. The right femoral head is posterio-inferiorly placed compared to the left. The left tibia showed a small, healed fracture on the lateral side of the distal articular facet. An unidentified bone not belonging to this individual was included with the remains.

ENT 39 (Male, ~57 years, tabular deformation): This individual had a broken nose that healed poorly. The left first rib also has a healed break at the vertebral end. Bilateral asymmetry was noted in the femora: the right has a more pronounced linea aspera and third trochanter. Pronounced muscle attachment sites and joint wear were found on several carpals and metatarsals.

ENT 41 (Male, ~25 years, unknown deformation): Extreme muscle and ligament attachment sites are present throughout the skeleton. Figure A3.3 shows the enlarged attachment site for the deltoideus muscle, on the superior surface of the right clavicle. Joint lipping was also common, unusual for a younger male.

Figure A3.3: Enlarged Muscle Attachment Site on the Right Clavicle.

ENT 42 (Male, ~40 years, no deformation): Mandibular molars were lost premortem. Maxillary molars are very loose in sockets, suggesting alveolar resorption. The right first rib is larger than the left. Also, costal impressions on the clavicles are pronounced and the attachment for the serratus anterior on the second rib is larger on the right side. Hand phalanges were wrapped in textiles. External auditory osteomas suggest extended contact with the ocean.

ENT 43 contained an older woman and an infant.

ENT 43A (Female, ~50 years, unknown deformation): The cranium was extremely well preserved, including the nose, eyelids, and tongue. Hair is present on the head, wrapped in textiles. Data collection of the cranium was undertaken with great care, preferring to not record certain data if they were not readily accessible. The visible teeth were noted as being more intact than other individuals of the same age in this collection. The left shoulder girdle is encased by dried skin, preventing some data collection. The right forearm is noticeably larger than the left.

ENT 43B (Possible female, ~3 years, tabular deformation): Cribra orbitalia present. Teeth have many abscesses. Found with adult hand, left talus, and a right rib. Textiles are also present.

ENT 44 (Male, ~21 years, unknown deformation): A note stated that the cranium had been removed. Femoral and tibial curvatures were pronounced. The lumbar vertebrae were compressed. The right third rib shows a healed fracture towards the sternal end.

ENT 45: Another burial with an older female and a child.

ENT 45A (Possible male, ~2 years, tabular deformation): Bone activity present on much of the skeleton, possibly treponematosis. The cranial bones were noted as oddly thin. An extra left humerus and possible extra rib fragments are included with this burial.

ENT 45B (Female, ~50 years, tabular deformation): The upper limbs have enlarged features, including a raised section between radial and coronoid fossa of the humeri, and the interosseous crest of the left radius.

ENT 46 (Female, ~20 years, tabular deformation): This individual has thirteen thoracic and four lumbar vertebrae. Femoral curvature is pronounced, and the proximal shaft is flared. Silver staining is present on the roof of the mouth, zygomatic arch, the maxilla, and TMJ. Much hair is present, showing a short hairstyle.

ENT 47: This burial contains a younger woman and an infant.

ENT 47A (Possible male, ~3 years, no deformation): A cranium, one rib, and one epiphysis represent this infant.

ENT 47B (Female, ~25 years, unknown deformation): No cranium is included with these remains. Less pathology was found compared to the other, older, females in the collection.

ENT 48 (Female, ~40 years, unknown deformation): Aging was noted as difficult. No cranium is present. The mandible shows many worn or missing teeth.

ENT 49: This is another burial with an older woman and an infant.

ENT 49A (Female?, ~4 years, no deformation): Harris lines were found. Otherwise, no notes were recorded.

ENT 49B (Female, ~65 years, no deformation): Forearms and chest are stained green. All teeth have been lost premortem. This individual had a deviated septum. A large lesion is present on the frontal and parietal bones (caries sicca?) (Figure A3.4).

Figure A3.4: Possible Lesion on the Frontal and Parietal Bones.

ENT 50 (Female, ~40 years, no deformation): The right limbs are longer than the left. Hair and nails were preserved.

ENT 51: Unlike other multiple burials, this has a male and an infant.

ENT 51A (Male, ~32 years, deformation unknown): Much of the upper body is missing. Crystals, possibly salt, formed on the remains postmortem.

ENT 51B (Indeterminate, unknown age, deformation unknown): Only represented by a few limb bones.

ENT 56 (Female, ~65 years, deformation unknown): The skeleton is extremely robust, but indicators of sex on the os coxae are strongly female. Extreme lipping and polishing are present on many bones, concordant with an older age estimate. Eburnation on the knee joint fits a bent position. Fifth lumber was sacralized. Investigators noted that he pronator ridges of the ulnae are extremely large, with the left bigger than the right.

ENT 57 (Male, ~16, tabular deformation): Cranial deformation is slight, and possibly just due to normal variation in cranial shape. Teeth are in good shape relative to others in the collection. Formation of what appears to be dirt may indicate placement of an object over the head (Figure A3.5). An attempt to dislodge one of these granules with mild pressure was unsuccessful. A clavicle or rib belonging to a child or animal is associated with this burial.

Figure A3.5: Circular Formation of Granules on Cranium

ENT 59B (Female, ~55, deformation unknown): Aging of this individual was contentious. Parts of the skeleton seem younger than the 55 years obtained from the os coxae. An included note in Spanish estimates the age as "no more than 30 or 40 years." Silver-colored stains were found on the right anterior scapula and midshaft of the right humerus (elements on the left are not present). The lower third of both ulnae and radii are stained brown. The small size of the skeleton was noted. The stature estimation equation by Sciulli and Giesen (1993) using the femur produced an estimate of 4 feet, 11 inches. While not recorded as a separate individual, unfused subadult occipital bones are present in this burial.

ENT 60 (Male, ~38 years, no deformation): The occipital was not observable because hair and a textile wrap were present on the cranium. Many teeth are present, but bear carious lesions and wear. The cortical bone of the left calcaneous is unusually thin.

ENT 62 (Male, ~22 years, deformation unknown): The large size of the bones relative to other males in the collection was noted. The right radius and ulna have flared interosseous crests. The left forearm was not recovered.

ENT 64 (Female, ~32 years, deformation unknown): Burial included bones from a more robust individual than the interred female: a right scapula, left navicular, and third and forth metacarpals.

ENT 65 (Male, ~28, no deformation): Robust male, with proportionally short limbs. Teeth were worn but mostly present. Investigators also noted a deviated septum. The bodies of the seventh to ninth thoracic vertebrae favor the right side.

ENT 67 (Male, ~20 years, deformation unknown): A relatively large male. No cranium or lower limbs were recovered. The sternal body is curved and fused to the manubrium. Also, the coccyx is fused to the sacrum. Unusual bone growth was noted on the medial epicondyle of the right humerus (Figure A3.6).

Figure A3.6: Bony Growth on the Medial Epicondyle of the Right Humerus

ENT 68 (Female, ~40 years, tabular deformation): The os coxae have many female features, but the cranium is robust. The auricular surfaces show much bony activity. Also, bony nodules in the retroauricular areas join with the sacrum. The maxillary teeth show more pathological processes than the mandibular teeth.

ENT 70 (Female, ~33 years, no deformation): The individual was sexed as female, though the bones tended to be more robust than usual. Lipping was found on many joints, unusual for a middle-aged woman.

ENT 71 (Male, ~25 years, no deformation): This individual shows a unique bone growth process on several elements, including the long bones of both limbs (Figure 6.3). Figure A3.6 shows a radiograph of the left tibia. An approximation of the original shape of the bone has been added to the image. The growth resembles examples of treponematosis found in Ornter (2003). Afflicted bones are extremely heavy. Despite young age, the vertebrae have extreme joint lipping. Muscle markers are also unusually rugose. The mandible shows intense alveolar resorption and abscesses. A sixth lumbar was found that articulates with the fifth lumbar and the sacrum. A few other elements belonging to another individual were included with this burial: three left ribs, two metacarpals, and a third molar.

Figure A3.7: Radiograph of Tibia with Unusual Bone Deposition

ENT 73 (Female, ~42 years, no deformation): Like ENT 71, bony activity was found on several elements, including the feet, patellae, tibiae and fibulae. A small rib, possibly non-human, was included with this burial.

ENT 74 (Female, ~37 years, tabular deformation): As with ENT 68, the os coxae showed many female features, while the cranium has robusticity more typical of a male. Articulation of the skeleton concluded that the cranium and os coxae belonged to the same individual. Hair and textiles cover the left parietal and occipital bones. Many teeth were lost in life and many abscesses are present. Muscle markers were pronounced in several areas, including, strangely, the head of the fibula. Unusual protuberances were also found on the iliopubic ramus of the pubic bones. Figure A3.7 shows this feature, along with a pronounced ventral arc on the right pubis.

Figure A3.7: Bony Protuberance on the Right Pubis

ENT 75: This burial contained a young adult male and multiple subadults. One subadult, ENT 75B, was represented only a few ribs and vertebrae comingled with ENT 75A.

ENT 75A (Possible male, ~10 months, possible cranial deformation): This subadult showed several signs of stress, including cribra orbitalia, unusual TMJ wear, and a maxillary sinus infection.

ENT 75C (Male, ~26 years, no deformation): This individual was relatively devoid in skeletal pathology. An extra animal vertebra and human hamate were found with this burial.

Instructions for the Skeletal Inventory Coding Form
Keith Chan

Thank you for looking at my skeletal inventory coding form! I designed this form with the students of our 2007 bioarchaeological field school to be easier and faster than other forms we had used. This guide will walk you through the elements of each page, clarifying the intended use and offering tips that helped our group. If you have any questions, please email me at chekeichan@gmail.com. A pdf of these forms and instructions can be accessed at www.keithcchan.com.

Page 1 - Skeletal Inventory Coding Form

Upper left - Record-keeping information to make organization easier.

Upper right - Key information pertaining to this individual. This, and the previous section, are repeated on every page in case the pages are separated.

Body - Inventory information is recorded as general quartiles (i.e. 0%, 25%, 50%, 75%, 100%). Sides are relative to you. Stand at the head of the articulated skeleton. Don’t get hung up on the number. If it helps, imagine what a quarter of the bone looks like, then a half, and three quarters.

Page 2 - Sexing and Aging Form

Skeletal Sexing - It may help to cross out elements that do not apply.

Skeletal Aging - Follow fusion sequence from Buikstra and Ubelaker and chart of fusion timing from Buikstra and Ubelaker (1994) or White and Folkens (2000). Write the overall result after "Age Range."

Dental aging techniques - Mark third molar eruption, wear, and molar 2 - molar 1 height if possible.

Overall Sex - Circle the final result based on the above indicators.

Overall Age - Write the range of ages and the probable (typically mean or mode) based on the above indicators.

Page 3 - Skeletal Inventory Coding Form

This provides a visual depiction of the skeletal inventory from page 1 (page 2 changes the topic to alleviate boredom!). Depending on which method is faster, color in whether bones are present or absent. Also choose the adult or juvenile skeleton and cross out the one you are not using. Images are from Bass (1995), and the UMC Anthropology Coding Form.

Page 4 - Cranial Deformation and Measurements Form

Deformation - This form was designed for Andean remains, where deformation is an important indicator of ethnic origin. Mark the elements deformed if applicable and then sketch the shape so it can be categorized later.

Cranial Measurements - Measurements not listed can be added to the space at the end of the page.

Page 5 - Dental Pathology and Inventory Form

To make the orientation easier, place the cranium face first on the cushion, with the teeth facing you. Place the mandible with the condyles closest to you.

Scott System - The same orientation as above is also used here.

Page 6 - Cranial Pathology Coding Form

The “pathology matrix” looks bizarre but once you learn how it works it makes pathology coding far easier than before. This system allows one to code any number of pathology without fear of running out of room. Each block represents one instance of pathology.

Coding is done using the existing UMC Skeletal Coding Instructions (ask an MU alumnus for a copy. Consult that key for the codes used for each category. The name is for the bone element (e.g. 9 = maxilla). Specificity is the type of pathology (for some location-specific pathology, such as cribra orbitalia, name and specificity will be the same). State is whether healing has occurred. “L x W” are for measurements. Location is for the anatomical location (e.g. posterior). Notes are for anything else.

Check off every item on the checklist to ensure that the element was examined, even if there is no pathology or the element is not present.

Page 7 - Postcranial Pathology Coding Form

This is the same as the previous page, except with codes for postcranial elements. Tip!: The codes for the cranial and vertebral elements are different than the postcranial elements. This means that you can save paper by writing the postcranial pathology on the blank spaces of the cranial form! Another tip: to not confuse the number one with the lower case L, write the one with serifs: "1."

Page 8 - Photo Log

Document the photos taken of this individual. The first image should be of any identifying information, such as the burial number. Under "Camera," you can write the name of the photographer or the camera used. With the date taken, subject, and camera ID, the image should be able to be traced back to this burial.

Page 9 - Additional Notes

Write any observations for this individual, including notable features, impressions, ruminations, or anything else that is relevant. Drawings can go on the back.

References

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Site: Recorder: Date:	**Skeletal Inventory Coding Form**	Individual: Catalog #: Sex: Age: Deformed?:

Cranium: Mark % Quartile Present (100%, 75%, 50%, 25%, 0%)

	Left	**Single**	**Right**		**Left**	**Single**	**Right**
Frontal:		______		Maxilla:	______		______
Parietal:	______		______	Nasal:	______		______
Occipital:		______		Ethmoid:		______	
Temporal:	______		______	Lacrimal:	______		______
Zygomatic:	______		______	Vomer:		______	
Palate:	______		______	Sphenoid:		______	

Mandible: Mark % Quartile Present

	Left	**Right**		**Left**	**Right**
Body:	______	______	Ramus:	______	______

Postcranium (Long Bones): Mark % Quartile Present for Each Third

	Left				**Right**		
	Proximal	Midshaft	Distal		Proximal	Midshaft	Distal
Humerus:	______	______	______	Humerus:	______	______	______
Radius:	______	______	______	Radius:	______	______	______
Ulna:	______	______	______	Ulna:	______	______	______
Femur:	______	______	______	Femur:	______	______	______
Tibia:	______	______	______	Tibia:	______	______	______
Fibula:	______	______	______	Fibula:	______	______	______

Postcranium (Other Bones): Mark % Quartile Present

	Left	**Single**	**Right**		**Left**	**Single**	**Right**
Clavicle:	______		______	Sacrum:		______	
Scapula:	______		______	Coccyx:		______	
Hyoid:		______		Talus:	______		______
Manubrium:		______		Calcaneus:	______		______
Sternal Body:		______		Tarsals:		______	
Xiphoid:		______		Metatarsals:		______	
Ilium:	______		______	Carpals:		______	
Ischium:	______		______	Metacarpals:		______	
Pubis:	______		______	Phalanges:		______	
Patella:	______		______			______	

	Left	**Right**		**Single**
Rib 1:	______	______	C1:	______
Ribs 2-6:	______	______	C2:	______
Ribs 7-10:	______	______	C3-C7:	______
Ribs 11-12:	______	______	T1-T12:	______
			L1-L5	______

Site: Recorder: Date:	**Sexing and Aging Form**	Individual: Catalog #: Sex: Age: Deformed?:

Skeletal Sexing: Note whether feature is indicative of female (F), possible-female (F?), indeterminate (I), possible-male (M?), or male (M)

Greater sciatic notch: ______
Pubis squareness: ______
Subpubic angle: ______
Auricular surface platform: ______
Preauricular sulcus: ______
Iliac flare: ______
Ventral arc: ______
Dorsal pitting: ______
Sacral curvature: ______
______

Mastoid process: ______
Glabella: ______
Nuchal crest (undeformed only): ______
Superior orbital edge: ______
Zygomatic extension: ______
Benfer's shelf: ______
Mandible chin shape: ______
Ascending ramus angle: ______
______

General bone robusticity/size: ______
Humeral head diameter (mm): 43 <, 44-46, > 47 ______
Femoral head diameter (mm): 42.5 <, 42.6-47.4, > 47.5 ______

Infant Features
Mandible shape: ______
Auricular surface elevation: ______
Arcuate line: ______
Sciatic Notch: ______

Skeletal Aging

Epipheseal Closure: Mark % Quartile Fused (100%, 75%, 50%, 25%, 0%)

Occipital: ______
Neural arch: ______
Neural arch to centrum: ______
Distal humerus: ______
Medial humerus: ______
Proximal radius ______
Distal fibula/tibia: ______
Distal femur: ______
______

Proximal fibula: ______
Acromion of scapula: ______
Iliac crest: ______
Humeral head: ______
Head of femur: ______
Lesser trochanter: ______
Proximal tibia: ______
Greater trochanter: ______
______

Distal radius: ______
Sacrum S3-S5: ______
Sacrum S2-S3: ______
Sacrum S1-S2: ______
Medial clavicle: ______
Spheno-occipital synchrondrosis: ______

Age Range: ______

M3 Eruption (y/n): ______ **M3 Wear (light/heavy):** ______ **M2 Height - M1 Height:** ______

Joint Surfaces	**Left**	**Right**	**Age Range**
Pubic symphysis (Todd), p.22 Standards:			
Auricular surface, p.25 Standards:			
Sternal rib end, p.138 Bass:			

Overall Sex (circle)				
F	F?	Indeterminate	M?	M

Overall Age	
Range:	Probable age:

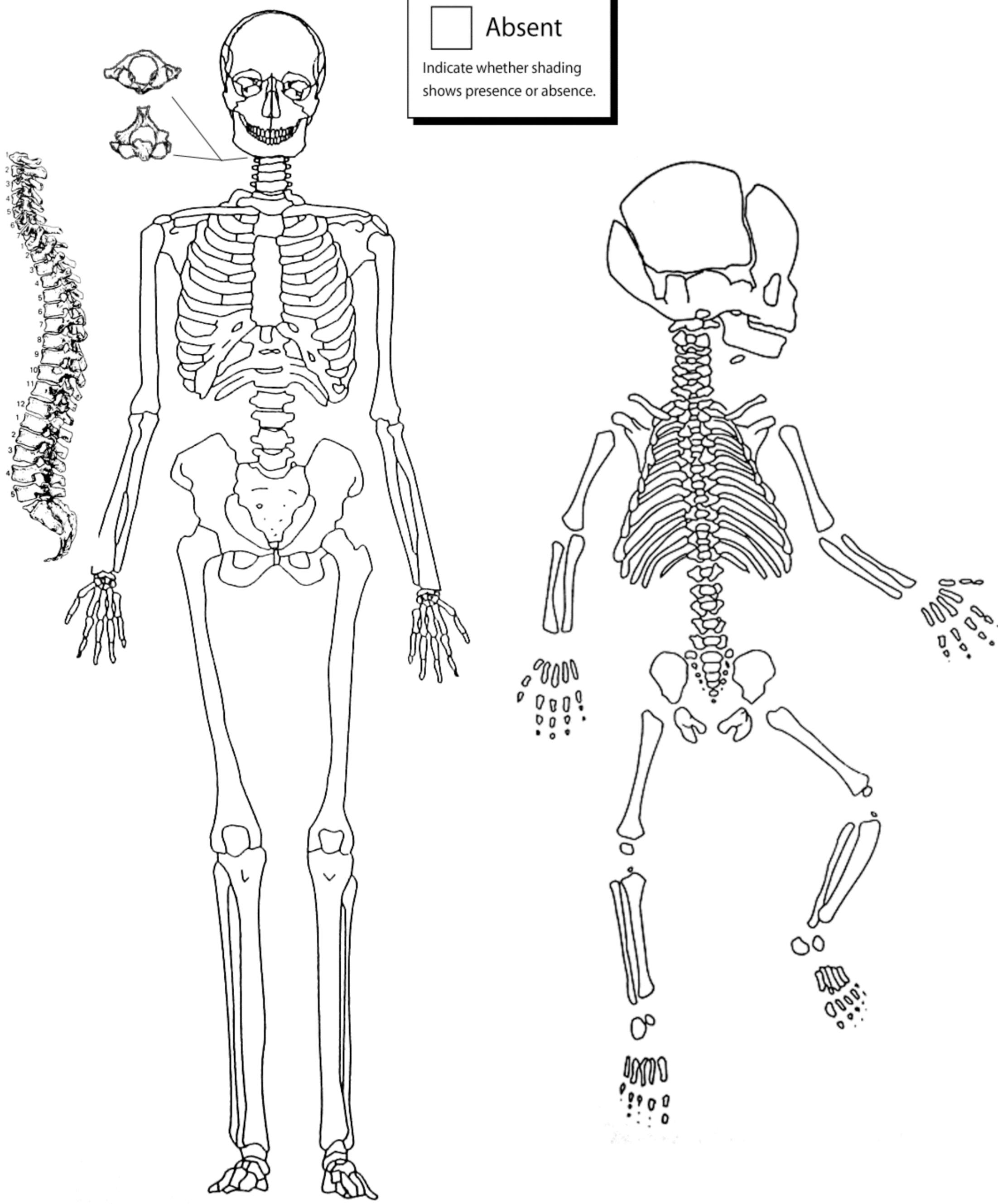
2/9

Site:		Individual:
Recorder:	**Skeletal Inventory Coding Form**	Catalog #:
Date:		Sex: Age: Deformed?:

☐ Present

☐ Absent

Indicate whether shading shows presence or absence.



Site:	Individual:
Recorder:	Catalog #:
Date:	Sex: Age: Deformed?:

Cranial Deformation and Measurements Form

Deformation:

Purposely deformed?	Yes/No

Affected Element	Yes/No
Occipital	
Frontal	
Parietal	
Other:	

Draw general shape of deformity →

Cranial Measurements

(# indicates *Standards* description, p.79-84)

#	Cranium	mm
1	Max cranial length (g-op)	
2	Max cranial breadth (eu-eu)	
3	Bizygomatic breadth (zy-zy)	
4	Basion-bregma height (ba-b)	

Postcranial Skeletal Measurements:

#	Clavicle	Left	Right
35	Max length:		

#	Humerus	Left	Right
40	Max length:		
41	Epicondylar breadth:		
42	Max diameter of head:		
n/a	Anterior-posterior diameter:		
n/a	Medial-lateral diameter:		

#	Radius	Left	Right
45	Max length:		

#	Ulna	Left	Right
48	Max length:		

#	Pelvis	Single
n/a	Bi-iliac breadth	

#	Femur	Left	Right
60	Max length:		
61	Bicondylar length:		
62	Epicondylar breadth:		
63	Max head diameter:		
66	Anterior-posterior diameter:		
67	Medial-lateral diameter:		

#	Tibia	Left	Right
69	Max length:		
72	Max diameter at nutrient foramen:		
73	Medial-lateral diameter at nutrient foramen:		

#	Fibula	Left	Right
75	Max length:		

Site: Recorder: Date:	**Dental Inventory and Pathology Form**	Individual: Catalog #: Sex: Age: Deformed?:

Maxilla																
	Left															**Right**
	M3	M2	M1	PM4	PM3	C	I2	I1	I1	I2	C	PM3	PM4	M1	M2	M3
Presence:																
Hypoplasias:																
Caries:																
Calculus:																
Abscess:																
Buccal-Lingual Diameter:																

Mandible																
	Left															**Right**
	M3	M2	M1	PM4	PM3	C	I2	I1	I1	I2	C	PM3	PM4	M1	M2	M3
Presence:																
Hypoplasias:																
Caries:																
Calculus:																
Abscess:																
Buccal-Lingual Diameter:																

Scott System (by quadrants)		**Left**					**Right**			
	Buccal	**M3** Distal	**M2** Distal	**M1** Distal	Lingual	Lingual	**M1** Distal	**M2** Distal	**M3** Distal	Buccal
Maxilla										
		Mesial	Mesial	Mesial			Mesial	Mesial	Mesial	
Mandible										
		Distal	Distal	Distal			Distal	Distal	Distal	

Key

Presence	
1	Present (in occlusion)
2	Present (no occlusion)
3	Missing
4	Missing (premortem)
5	Missing (postmortem)
6	Present (damaged)
7	Present (unobservable)

Hypoplasias	
0	None
1	Horizontal grooves
2	Horizontal pits
3	Nonlinear pits
4	Single pit

Calculus	
0	None
1	Minor staining on CEJ
2	Moderate staining (< crown)
3	Severe staining (> crown)

Carious Lesions	
0	None
1	Occlusal surface
2	Mesial-distal surface
3	Buccal-lingual surface
4	Cervical lesions
5	Root lesions
6	Pulp exposure

Abscesses	
0	None
1	Small
2	Moderate
3	Large

Site:		Individual:
Recorder:	**Cranial Pathology Coding Form**	Catalog #:
Date:		Sex: Age: Deformed?:

Cranial Checklist

#	Name	✓
1	Frontal	
2	Cribra orbitalia	
3	Parietals	
4	Porotic hyperostosis	
5	Occipital	
6	Temporal	
7	Malar	
8	Sphenoid	
9	Maxilla	
10	Mandible	
11	Mandibular condyle	
12	TMJ	

Vertebrae and Ribs Checklist

#	Name	✓
→	C1-C7	
→	T1-T-12	
→	L1-L5	
→	Ribs 1-12	

Model

Name	Specificity	Side
Severity	State	L x W
Location	Notes	

Site:
Recorder:
Date:

Postcranial Pathology Coding Form

Individual:		
Catalog #:		
Sex:	Age:	Deformed?:

Postcranial Checklist

#	Name	✓
a	Manubrium	
b	Sternal body	
c	Clavicle	
d	Scapula	
e	Humerus	
f	Radius	
g	Ulna	
h	Carpals	
i	Metacarpals	
j	Phalanges	
k	Os coxae	
l	Sacrum	
m	Femur	
n	Tibia	
o	Fibula	
p	Patella	
q	Calcaneus	
r	Talus	
s	Tarsals	
t	Metatarsals	
u	Phalanges	

Model

Name	Specificity	Side
Severity	State	L x W
Location	Notes	

Site:		Individual:
Recorder:	**Photo Log**	Catalog #:
Date:		Sex: Age: Deformed?:

Date	Subject	Camera

Site: Recorder: Date:	**Additional Notes**	Individual: Catalog #: Sex: Age: Deformed?:

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