Extrinsic Effects of Cranial Modification: A Case Study of Cranial Porosity and Cranial Modification Intensity in Late Intermediate Period (AD 1000 - AD 1400) Andahuaylas, Peru

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EXTRINSIC EFFECTS OF CRANIAL MODIFICATION: A CASE STUDY OF CRANIAL POROSITY AND CRANIAL MODIFICATION INTENSITY IN LATE INTERMEDIATE PERIOD (AD 1000 – AD 1400) ANDAHUAYLAS, PERU

by

DAVETTE NICOLE GADISON

Under the Direction of Bethany L. Turner-Livermore, PhD

ABSTRACT

Body alterations such as artificial cranial modification are permanent irreversible changes to the body that become a powerful, constant visual “salient” indicator (Torres-Rouff 2002) or life-long affiliation or demarcation of social identity (Kurin 2014). Most studies have focused on the social implications as well as typology and classification methods. Very few studies have investigated the extrinsic pathological consequences of external compression caused by the boards, pads, and bands used to create pressure at various points on the skull in order to achieve the desired modified shape. This study investigates the relationship between porotic lesions on the external cranial vault and the degree of modification intensity of the predominant cranial modification forms in the Chanka and Quechua societies from the Late Intermediate Period (AD 1000 to AD 1400) in Andahuaylas, Peru.

INDEX WORDS: artificial cranial modification, porotic hyperostosis, cribra orbitalia, Andahuaylas
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by

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DEDICATION

To my family: Rosalind, David, and Dathan. Thank you for your support.
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1 INTRODUCTION

This study utilizes a bioarchaeological approach to investigate the physiological responses of the human cranium to artificial cranial modification processes. Cranial modification was practiced in prehistoric and historic populations throughout the world, including Iraq (Trinkaus 1982), the Americas (Kohn et al 1990; White 1996; Papa and Perez 2007; Cocilovo et al 2011; Tiesler 2012, 2014), as well as throughout Europe (Dingwall 1931 see chapters 1 and 2), and has been extensively studied by numerous scholars (i.e. Broca 1878; Morton 1839; Dingwall 1931; Blom 1999; Tiesler 2014; Clark 2007; Deams and Croucher 2007; Frieß and Baylac 2003; O’Brien and Stanley 2013; Okumura 2014; Perez 2007; Pomeroy et al. 2010; Torres-Rouff 2002; Tubbs et al. 2006). Many early studies were primarily descriptive and focused on cranial modification as a biological oddity; more recent studies primarily focus on typology, modification devices and classification methods, as well as cultural affiliation. Very few studies investigated the physiological effects of the human cranium in response to cranial modification. Many existing cranial modification studies do not focus on the compensatory responses of the skull to external compression from cranial shaping. Thus, this study aims to add to current literature regarding the effects of cranial modification on cranial bones by assessing the relationship between cranial porosity and cranial modification intensity.

1.1 Research Objective

This study employs metric and non-metric osteological methods of analyses in order to test hypotheses regarding the extrinsic compensatory responses of the human cranium to external forces of compression. More specifically, the current study investigates the relationship between cranial porosity and artificial cranial modification on crania from Chanka and Quichua societies.
that coalesced during the Late Intermediate Period (AD 1000 - AD 1400) in the Andahuaylas, Peru. The study aims to elucidate whether cranial porosity is a product of the modification process itself or health related stress.

1.1.1 Research Questions and Hypotheses

Research questions involved in this study include the following:

*Is artificial cranial modification intensity correlated with increased severity of cranial porosity?* If cranial porosity is a result of cranial modification processes, then individuals with increased cranial modification intensity (elongation) will display increased amounts of cranial porosity. Increased presence of porosity and cranial modification intensity may also indicate that individuals with elevated amounts of porosity and extreme cranial elongation could have been under greater stress than individuals or groups with less cranial elongation. Alternatively, lack of significance between the relationship of cranial porosity and cranial modification would indicate that cranial modification intensity is not a likely etiology for cranial porosity in the Chanka and Quichua groups in Andahuaylas.

*Is there a correlation between artificial cranial modification and the intensity of cranial porosity within or between population groups?* Variability in the association of cranial modification with increased severity of cranial porosity could suggest unequal access to food resources or clean water, which could in turn suggest inequality within or between the population groups. If a specific modification type is associated more significantly with higher levels of cranial porosity then 1) individuals may have experienced elevated levels of stress as a result of political and economic instability during the Late Intermediate Period (AD 1000 – AD 1400) and therefore, porosity could be a form of anemia or other health related stressors or 2) cranial
porosity may be a result of differences in the way in which the amount, location, or duration of external pressure was applied to crania between ethnic groups.

1.2 Expected Results

The Late Intermediate Period was a tumultuous period of time in which populations experienced increased rates of conflict, crowded living conditions, resource scarcity, and poorer health. Considering the decline in political and economic stability, as well as increased violence during the Late Intermediate Period, cranial porosity from the research collection in Andahuaylas, Peru are not expected to correlate significantly with cranial modification practices; instead, cranial porosity is expected to correlate with stressors such as anemia or parasitic infections as oppose to compression from external pressure. Clearer interpretations of etiologies of cranial porosity, such as porotic hyperostosis, and effects of cranial modification can provide better understandings of the Late Intermediate Period and life experiences of pre-Columbian cultures from Andahuaylas. This study seeks to add to the current literature on effects of cranial modification and the etiologies of cranial lesions.
2 CRANIAL MODIFICATION

2.1 Introduction

Alterations and adornments of the human body are physical transformations through which individuals can display identity and convey social information (Torres-Rouff 2002). Permanent modifications, particularly artificial cranial modification, are of great interest to archaeologists for their usefulness in the reconstruction of past social systems (Clark 2013). More specifically, scholars regard body modifications and ornamentation as demarcations of boundaries between individuals and societies, as well as fundamental elements in the construction of identities (Torres-Rouff 2002, Pomeroy et al. 2010).

Artificial cranial modification primarily results from cultural practices involving the application of apparatuses to infant crania in order to alter the shape of the skull (Okumura 2014). As adopted by Tiesler (2012) here and throughout this thesis, the terms “intentional cranial modification”, “head shaping”, and “artificial cranial modification” are used synonymously to refer to the result of artificial forces of compression or constriction to the malleable skull of infants and toddlers during their first few months and years of life. The practice of intentional cranial alteration by shaping the cranial vault was a widespread tradition in ancient and modern time periods employed by various cultures throughout the world.

Various methods of compression and constriction appear to have been culturally specific and were employed throughout the ancient world to alter the shape of infant crania. Many populations have displayed evidence of unintentional cranial modification resulting from various cultural practices that include swaddling or the continuous use of constrictive headgear (Torres-Rouff 2003). Artificial modification may also occur unintentionally as in instances in which a child’s head may be bound to a cradleboard, as the case in some Native North American groups.
(Kohn et al 1995; Piper 2002). However, the most dramatic forms of artificial cranial alterations result from intentional cultural practices (O’Brien and Stanley 2013). The most prominent examples are documented in ancient South American groups. Apparatuses used for cranial alteration range from massages to hard compression devices such as boards, constricting wraps, hats, and bandages (Tiesler 2012; O’Brien and Stanley 2013).

![Figure 1 Example of a Chinook child being carried in a cradle board (From Mason 1889).](image)

Alterations such as artificial cranial modification are permanent irreversible changes to the body that become a powerful, constant visual indicator (Torres-Rouff 2002) of life-long group affiliation to, or demarcation of, a social identity (Sharpova and Razhev 2011; Kurin 2014; Torres-Rouff and Yoblansky 2005). Therefore, studying patterns of body alterations can lead to better understandings of group identity ties, aspects of aesthetics and beauty, culture, gender, and social structures (Tiesler 2012; Blom 2005). As Tiesler (2014:13) eloquently states:
“The human body, with its physical and psychological properties, figures both as a basis and mediator in all cultural interactions and, as such, is also affected by the social life it supports. Thus, its anthropological study, and that of its cultural modifications, does not only inform on morphological adaptation and plasticity but equally grants glimpses on society itself.”

The cultural practice of cranial alteration predates written history (Tubbs et al. 2005) and has been widely recognized throughout many regions of the world. Cranial shaping has been considered one of the most ubiquitous ancient biocultural practices that have been noted to occur on every inhabitable continent (Gerstzen 1993; Clark et al. 2007) and was not exclusive to modern Homo sapiens (Trinkaus 1982). Since archaic Homo sapiens in Australia (Anton and Weinstein 1999) to modern periods, cranial modification had some presence in almost every inhabitable region (Schijman 2005). It was a familiar practice in ancient Phoenicia by 4,000 BC (Imbelloni 1938 as translated by Schijman 2005) and common practice in places such as Indonesia, Sumatra, Bomeo, the Philippines, Afghanistan, Turkmenistan, and Beluchistan (Schijman 2005). However, its occurrence was predominant in the Americas, more specifically, in Mesoamerica and the Andes (Tiesler 2014).

Cranial modification practices range in motives, as well as styles, throughout the world. For instance, some reasons for such practices are attributed to aesthetic beauty, political and ideological ideals, gender and identity, and status (Tiesler 2014). Examples of scholarly research, such as that of Blackwood and Danby (1955), highlight numerous cultural groups from the Songish of British Columbia to the Arawe of Melanesia. These groups appear to have practiced artificial cranial modification for aesthetic reasons and attributed it as a mark of beauty (Clark
2013). Beyond aesthetic beauty, the work of Tiesler (2011) delves into the processes of infant and childhood cranial shaping and suggests that such processes in population groups of ancient Mesoamerica express elements of ancient cosmology and ideology. The implementation of cranial modification as an ethnic marker has been addressed by many scholars as the use of the cultural practice in regions such as the in pre-Columbian South America, particularly the Andes (Torres-Rouff 2002; Kurin 2014).

2.2 Artificial Cranial Modification in the Prehistoric Andes

In the ancient Peruvian Andes, cranial modification served as a marker of social identity and has been considered one of the most salient corporeal markers of social identity in this region (Kurin 2012). Most Spanish chroniclers considered cranial modification to be a cultural atrocity; however, chroniclers, such as Cobo (1979) [1653], Betanzos (2004) [1557], Cieza de Leon (1984) [1553], and Garcilaso de la Vega (1966) [1609-1613], described the practice of cranial modification as a social identifier that distinguished regional, ethnic, and/or kin group affiliation (see Blom 2005; Kurin 2012). More recent research in the Andes has demonstrated that cranial modification was practiced in order to segment populations into social or ethnic groups (Torres-Rouff 2002).

Although numerous styles of cranial modification exist globally, two basic types of modification were primarily practiced in the Andes. The first type of modification is known as the annular form, which consists of circumferential binding, and the second is tabular, which involves pressure applied to both the frontal and occipital regions of the cranium to create a lateral expansion of the parietal bones (as described by Dembo and Imbelloni 1938, see Blom 2005). Annular modification type is achieved by the application of bandages bound tightly to the head after birth producing a “cone-shaped cap” (Dingwall 1931:13). The tabular form, also
called fronto-occipital or fronto-lambdoidal, is achieved by boards and pads as material apparatuses. Each of these two types of artificial modification have considerable variability that is mostly due to variability in the degree and/or angle of pressure applied to the occipital region of the cranium (erect or oblique) (Torres-Rouff 2003).

Unintentional cranial modification is another general form of modification that occurs primarily from various child rearing practices. For instance, practices such as cradle boarding can cause flattening of the parietals and occipital bones. Additionally, swaddling can also cause unintentional modification. Regardless of the intentionality that results in modified crania, social or cultural aspects of societies can still be interpreted from the resulting modified crania. For instance, the practice of swaddling or using cradleboards, which are typically considered unintentional ways of achieving cranial modification, are cultural practices that can provide valuable information to scholars in their reconstructions of past societies.

Artificially modified crania are also used as proxies to convey social information that was revealed by garments worn as head ornamentation (Kurin 2012). Such information is useful when limited details are available regarding the possible hairstyles, hats, and other accessories that may have been worn as headgear by ancient populations such as the Andahuaylans, as cranial shape “likely conformed to the headgear used to modify the skull,” (Kurin 2012:210). Generally, variation in hat form and design are broadly used as a regionally specific identifier of affiliation to a specific region or community (see Cook 1992). To this day, head gear in Andahuaylas populations continues to serve as an identifier of affiliation to regional or ethnic communities. Therefore, artificial cranial modification can be used indirectly as an identifier of deeply rooted social identity (Kurin 2012).
Body alterations, particularly cranial modification, appear to have been an ancient practice that was not exclusive to modern humans (Trinkaus 1982). Evidence of artificial cranial flattening in two Neanderthal skulls (Shanidar 1 and 5) from Shanidar, Iraq, date back to 45,000 years B.P. (Trinkaus 1982).

Many scholars have focused on their research on cranial modification because cranial modification is an irreversible identifier that signifies life-long affiliation or demarcation of social identity (Sharpova and Razhev 2011; Kurin 2014). The practice of cranial modification can range in purpose from markers of social status, as in the Sargat, to social identifiers, such as the pre-Inca Chiribaya in Peru (Sharpova and Razhev 2011; 202-203).

2.3 Artificial Cranial Modification in Andahuaylas

Cranial modification practices were not common practice in Andahuaylas during the Middle Horizon Period according to mortuary contexts (Kurin 2012). An emergence of cranial modification in this region appears to occur during the Late Intermediate Period following the fragmentation of the Wari state. During Late Intermediate Period in Andahuaylas, cranial modification increased significantly to 76% (208/273) and persisted at high levels throughout the remainder of this time period (Kurin 2014). Of a total of 36 crania excavated, all of which date to the Middle Horizon period (AD 600- AD 1000), none exhibited cranial modification (Kurin 2014: 239). Reasons for such stark increase in artificial modification practice have been attributed to the ethnogenesis of Chanka and Quichua societies that coalesced after Wari state fragmentation around AD 1000 - AD 1400.

The most prominent forms of artificial cranial modification in this region are the annular or circumferential forms in which the cranial vault expands superior and posteriorly (Kurin 2012). There is great diversity in the amount of styles that exist within the broad annular
classification category. Therefore, to be more specific, the annular forms of modification that are predominantly displayed in the Andahuaylas region are annular erect and annular oblique (Kurin 2012). Practitioners utilized circumferential bindings and pads against the frontal bone as well as on the occipitomastoid suture (Kurin 2012). The placements of modification devices were positioned at different angles on the skull in order to achieve annular erect and oblique styles.

![Figure 2 Common styles of annular modification in Andahuaylas with corresponding band orientation (adapted from Kurin 2012).](image)

Research on artificial cranial deformation in Andahuaylas indicates that band placement was primarily above or below the frontal bosses. Locations of pressure were often applied posteriorly to the coronal suture, on the posterior portion of the cranium centered on lambda, the squamous portion of the occipital bone, and/or below inion (Kurin 2012:215). Variation in band placement may be the result of unstandardized modification techniques; however the majority of
the population (84.4%) employed one of seven major styles (Kurin 2012). The most common are among those illustrated above.

Distinguishing the motivation of artificial cranial modification in this region proved to be a difficult as variability by sex, burial caves, or historically documented *ayllus* (Kurin 2014). Scholarly consensus, regarding artificial cranial modification practices in ancient Andahuaylas, confirms that artificial cranial modification was an identifier of social group affiliation that may have been organized by lineage, kinship, or ethnic, or “ethnic-like identity” (Kurin 2014).

2.4 Consequences of Artificial Cranial Modification

The physiological consequences of cranial modification have not been discussed as in-depth a manner as have typology and classification methods and techniques (Aufderheide and Rodriguez-Martin 1998). However, there are several physiological side effects that arise as a result of head shaping processes. Consequences range from internal bone restructuring, external infections, to social violence. Although scholars posit that as a result of neural plasticity, even in the most extreme forms of cranial modification generally do not affect the normal functions of the brain (White 1996).

2.4.1 Changes to Bone Structure

A few current research studies have suggested that the structure of cranial bones can be altered due to force from compression (Mendonça de Souza et al. 2008). Changes to the bone structure include a reduction in spaces in diploe, increased thickness of the outer table in areas that experienced compression, and premature suture closure causing cranial hypertension (Mendonça de Sousa et al. 2008). Depressed suture abnormalities and necrosis (Holliday 1993), periosteal reactions (Aufderheide and Rodriguez 1998), and even death may occur as a result of cranial modification practices.
Studies have also suggested that the frequency of occurrence of wormian bones, although somewhat subject to genetic determinants, are influenced by cranial modification practices as well (O’Loughlin 2004:146). A result of cranial modification there is a shift in cranial and brain shape from a spherical to non-spherical shape causing an increase in surface area (Moss 1958). This increase in surface area may occur at the sutures, such as the masto-occipital suture, or wherever it is necessary for the skull to increase cranial capacity. Therefore, intercalary bones, or wormian bones, have been suggested to increase in rates of occurrence as the brain grows in order to fill space between sutures and aid in increasing cranial surface area (McGibbon 1912). Research on modified crania has supported the notion that there is an elevated presence of wormian bones observable in sutures of modified crania versus non-modified crania (Gottlieb 1978).

In addition, Blom et al. (2005) and Mandonça de Sousa et al. (2008) suggest that in Peruvian populations, porotic hyperostosis can be misdiagnosed as porosity resulting from cranial modification. Conversely, recent research in Andahuaylas, Peru, Kurin (2012) found that megaloblastic anemia was the likely cause of porotic hyperostosis, and cranial modification was ruled out as the cause of the porosity.

Although somewhat controversial, artificial cranial modification has been argued to not only change the shape of the calavera but also influence the shape of facial bones and cranial base morphology (Cheverud et al 1992; Anton 1989). In annular modification styles, there appear to be associated with increased facial height and decreased facial breadth (Kohn et al 1993). The primary influenced regions are suggested to be the upper facial bones and eye orbits (Kohn et al. 1993:148). Research by Cheverud et al. (1992) suggests that fronto-occipital cranial modification in the Peruvian Ancon and Songish Indian populations had significant indirect
effects on craniofacial and cranial base morphology. Many additional studies have also pointed
to significant changes in cranial vault and facial proportions (see Cocilovo et al 2011). However,
many of these studies have analyzed small population sample sizes and often use the same
collections in their research (Pomeroy et al. 2010). Therefore, variation in indirect effects of
facial and cranial base morphological changes resulting from cranial modification may be due to
differences between sample sizes, methods used, or variation between population groups studied
(Pomeroy et al. 2008).

2.4.2 External Reactions

Placement and pressure of various implements on the head for purposes regarding
shaping the head can create a host of issues. Throughout various regions of the world, the
process of modification involved placing apparatuses on the head and applying pressure for
several consecutive days. Improper care or replacement of bandages, pads, or other devices used
in this process can create microenvironments suitable for microorganisms to thrive. For instance,
in France, a form of conical head shaping was practiced primarily by elites who would wrap
bandeaus (tight headdresses) around their heads to achieve the desired conical shape (Tubbs et
al. 2005). In doing so, the headdress would seldom be removed and become inhabited by lice
that would contribute to skin infections and ulcers (Tubbs et al. 2005). In 1913, Dingwall
associated this use of French tight bands with some diseases that occurred in the scalp (Holliday
1993). Stewart (1976) provided descriptions of types of active inflammatory lesions in children,
one of which was a child from Peru (Mendonça et al 2008). He attributed the reactions to have
occurred in association with external compression. Necrosis of bone is also occasionally found
associated with the use of cranial modification apparatuses (Gerstzen 1993) and is the result of
restriction of blood flow to growing bone.
2.4.3 Social Violence

Additional, indirect consequences of cranial modification resulted from acts of structural and social violence. Different styles of cranial modification served as demarcations of social boundaries in some populations and therefore these differences in styles fostered environments of structural inequality and made some population groups targets of acts of violence (Kurin 2012). Increased lethal violence was sometimes experienced by some groups within societies displaying a specific type or more pronounced form of modification, whereas other groups with different styles and more subtle degrees of modification experienced less lethal traumatic wounds. For instance, in the Andahuaylas region of Peru, Kurin (2014) concludes that Chanka groups experienced lethal violence more frequently than the neighboring Quichua group. Even though the Chanka sustained considerably more violent and lethal forms of trauma, they continued to practice cranial modification for centuries. Therefore, demarcating social boundaries and sustaining group solidarity appear to have been worth the risk of potentially being targets of violence and victims of ethnocide.

2.5 Summary

Modifications and ornamentation of the human body demarcate boundaries between individuals and society and are fundamental in the construction of identities (Lee 2009:154). Body alterations provide an additional avenue of inquiry for bioarchaeologists that compliment other aspects of research on reconstruction of group dynamics and individual agency (Lozada 2011; Torres-Rouff 2011). Alterations may include temporary or permanent transformations of the skin, teeth, and muscular or skeletal system (Lee 2009). For example, less permanent forms of body modifications include tattooing, scarification, and piercings, while more permanent forms of alterations include foot binding and cranial modification.
Practices of body modifications, for various motives and motifs (Tiesler 2014), have spanned back through centuries of historic and prehistory periods of time. In some instances body modifications, particularly cranial modification, have been a result of unintended alterations, for instance unintentional cradle boarding, which prompts some researchers to categorize cranial modification as an unintentional result of cultural practice (Mendonça de Souza et al. 2008:43). However, abundant research exists in the literature regarding intentional and unintentional modification of the skull (Mendonça de Souza et al. 2008:43) and many of these studies elucidate that intentional modification is a result of purposeful cultural practices (Kurin 2012). Regardless of intentionality, alterations to the skull are associated with some form of cultural practice performed during child infancy (Perez 2007:1649). Both intentional and unintentional cranial alterations, as well as their consequences, are of great interests to bioarchaeologists as they try reconstructing important aspects of past populations such as identity and social interactions within and between different populations.

Although there were numerous physiological and social risks involved with cranial modification, societies continued to implement the practice, therefore, the risks were worth undertaking in order to visually display group affiliation or identity. This also suggests that people were aware of ways to take care of and mitigate some of these risks, particularly the potential physiological risks. Populations in Peru have evidenced their skill of cranial surgery through surgical procedures such as trepanation (Verano 2003) and therefore, people perhaps were very knowledgeable in regards to providing and taking care during the process of modifying crania of their children.
3 CRANIAL GROWTH AND DEVELOPMENT

3.1 Introduction

Intricate mechanical and spatial growth processes, between components of the human cranium during ontogeny, follow sequential developmental stages in which different components achieve morphological adulthood at different times (Bastir et al 2006). Working together as one functional unit, the bones of the cranium have the ability to perform dynamic adjustments during growth and development in order to respond to intrinsic and extrinsic pressures (Cheverud et al. 1992; Moss 1958). Therefore, the manipulation of infant crania found in the archaeological record was not a passive product of random variation during development; the process of shaping crania involves dynamic relationships between culturally extrinsic stress from compression forces and intrinsic compensatory forces that alter and redirect cranial expansion (Tiesler 2014:34).

External pressures cause the internal neurological and connective tissues to redirect growth toward uncompressed areas of the skull (Tiesler 2014:43). This type of response is possible during the postnatal stage of development, due to the level of plasticity of cephalic tissues (Tiesler 2014:43). Artificial cranial modification in humans is only possible during the first 3 years of life and at an even lesser extent up to 6 years of age; active cranial cerebral and cranial expansion nears completion around the third year of life (Kuffel 2004). To form a clearer basis of understanding of the elements involved in artificially restricted cranial growth, it is first necessary to understand the ontological, physiological, and pathological concepts of the cranium and cranial growth.
3.2 Developmental Anatomy

Cranial growth is driven by neuro tissue expansion and begins as early as twelve weeks into the gestation period and involves intramembranous and endochondral ossification (Lewis 2004). More specifically, the bones that form the cranial vault are generated by intramembranous (within membrane) ossification while the bones at the base of the skull are formed by endochondral (within cartilage) ossification (Lewis 2004). Although the bones that form the cranium are already formed at birth, they remain unfused. Sutures, which are connected by fibrous tissues, separate the bones that form the cranial vault in order to allow for flexibility when the skull passes through the birth canal and during continuous postnatal growth of the brain (Morriss-Kay and Wilkie 2005). Suture growth and maintenance are essential for cranial vault expansion in order to accommodate brain growth during childhood development (Morriss-Kay and Wilkie 2005).

During the early stages of cranial growth and development, the skull is highly sensitive to physiological defects, such as craniosynostosis, or premature suture closure (Morriss-Kay and Wilkie 2005), as well as environmental or cultural practices such as cranial modification (O’Brien and Stanley 2013; Torres-Rouff 2002). Due to the malleable and fragile nature of the infant skull, the process of artificial cranial modification is often implemented soon after birth (Dingwall 1931; Tubbs et al. 2005).

A significant difference in human cranial anatomy exists between neonatal and early postnatal stages than that of adolescent and early adulthood. The neonatal and early postnatal stages of cranial growth and anatomy are critical because it is during these stages when the cranium is most malleable and susceptible to cranial shaping, which is the focus of this thesis.
The neonatal cranium can be sectioned into two portions: the neurocranium, which encapsulates the brain, and the viscerocranium, which includes the mandible and facial bones. Facial bones undergo continuous growth into adulthood (Kiesler 2014). This section will primarily focus on neurocranial growth, as this region of the cranium is directly affected by external compression. Neurocranium growth and development is also of interest because intentional and unintentional modification of the skull primarily occurs in these regions and the compensatory responses of these regions to external forces are useful in addressing the research questions proposed in this study.

Similarly to that of other tissues in the body, the formation of the human cranium is subject to genetic, and to a lesser extent, environmental factors (Kohn 1991). The bones of the neurocranium that surround the soft tissue in the skull respond to neural growth in a relatively passive manner, and expand as the neural tissues grow (Tiesler 2014:40). The neurocranium may be further sub-divided into the cranial vault and cranial base. Components included in the neurocranium are the paired parietal, temporal, frontal, sphenoid, and ethmoid bones, and the unpaired occipital bone (Kuffel 2004). The tissues that are sheltered by the neural cranial bones are the dura mater, which are the external layer of the protective tissues that play an important role in growth and development of the neurocranium (Gagan et al. 2007; Opperman et al. 1993). The dura mater, as well as the brain, influence and constitute the primary driving forces of growth, to include the size and shape of neurocranial bones and sutural patency (non-fusion) (Barbeito-Andres et al 2015; Podda et al. 2003).

During the first years of life, six fontanels serve as areas of growth and connections between the bones that comprise the cranial vault and have an important role in cranial expansion (Tiesler 2014:36). Fontanels are fibrous membrane-covered openings (gaps) that are
formed when more than two flat bones of the cranial vault meet (Podda et al. 2003). These fibrous tissue articulations unite the adjacent flat bones of the skull through sutures (Tiesler 2014; Kuffel 2004). Their presence allows for compression and overlap during the birth process. The developing cranium has a total of six fontanels; a single posterior, the paired sphenoidal, the paired mastoidal, and the single frontal fontanel (Kiesler and Ricer 2003). The juxtaposition of the two parietals and occipital bone creates the posterior fontanel (Kuffel 2004) and is the first fontanel to close (Kiesler and Ricer 2003). The paired sphenoid fontanels are created at the juxtaposition of the parietal bones and the occipital bone (Kuffel 2004) and become obliterated by around 3 months of age (Podda et al. 2003). Both mastoidal fontanels form at the juncture of the occipital, parietal, and temporal bones (Kuffel 2004). The mastoidal fontanels close at around twelve months of age (Podda et al. 2003). The anterior fontanel forms at the point where the two frontal and parietal bones meet (Kuffel 2004) and is the most prominent fontanel that is the last to close at the median age 13.8 months (Kiesler and Ricer2003).

Figure 3 Anterior view of a fetal cranium (Schaefer et al. 2009 with permission).
Externally applied pressures from the birthing process, as well as internally applied pressures from the processes of rapid brain growth within the first year of life, are possible because of the ability of the cranial vault bones to overlap and expand (Kuffel 2004). The
elastia provided by the fontanels is necessary during the child birth process, allowing for passage of the cranium through the birth canal (Tiesler 2014:36). After birth, the cranial bones remain malleable and susceptible to changes in shape (Tiesler 2014).

Cranial sutures are the major sites of bone growth and expansion (Morriss-Kay et al. 2005). The sutures of the cranial vault include the metopic, also known as the frontal suture, which divides the frontal bone into two halves. It is the first suture to ossify, a process that typically occurs about the age of two years old (Kiesler and Ricer 2003; Ohman 1994). The sagittal suture runs from the anterior fontanel to the posterior fontanel separating the parietal bones into two halves. The coronal sutures separate the paired parietal bones and will typically remain patent during infancy (Kuffel 2004). The lambdoid suture divides the two parietal bones and occipital bone and maintains sutural patency throughout infancy (Kuffel 2004). Lastly, the squamosal sutures form a fibrous band at the superior border of the squamous part of the temporal bone. They articulate anteriorly with the greater wing of the sphenoid bone, superiorly to the parietal bone and posteriorly to the occipital bone. The orientation of the cranial sutures provides flexibility for expansion of the cranium in various directions in reaction to rapid brain growth (Kuffel 2004). Rapid volumetric increase of the brain during the early postnatal period causes displacement of the flat bones of the neurocranium (Kuffel 2004). Sutures, which are sites of intramembranous bone growth activity (Kuffel 2004), respond with osseous formation along the sutural edge (Friede 1981). Timing of expansion and closure of sutures and fontanels during cranial development allow for symmetric formation of cranial bones during adolescence and into adulthood (Kuffel 2004).
3.3 The Ossification Process

The process of ossification of the cranium during the developmental stage is possible through intramembranous and endochondral ossification processes (Jiang et al. 2002). Intramembranous ossification is the process defined as direct bone formation, which differs from endochondral ossification which the ossification process begins with cartilage formation before bone development (Kuffel 2004). The neurocranium undergoes intramembranous ossification while the viscerocranium (facial bones) and basicranium (cranial base) are formed primarily by endochondral ossification (Ohman 1994).

Formation of the neurocranium occurs from five primary ossification centers that are located in the paired frontal and parietals, and the occipital bone (Kiesler and Ricer 2003). Growth from these ossification centers occurs in a radial pattern expanding outward with osteoblastic activity (formation of new bone) at the edges while, osteoclastic (resorption of old bone) activity occurs towards the center (Kiesler and Ricer 2003). An increase in brain volume triggers a response in these five ossification centers causing them to expand (Kiesler and Ricer 2003; Opperman 2000). Thickening of the trabeculae bone occurs as the bones become more compact and less porous as trabecular bone thickens. The continuous formation of compact bone begins to oppose the flat bones of the developing cranium, this is how a suture is formed (Kuffel 2004). As mentioned previously, the sutures are the primary location of skull growth as they respond to stimulation from intracranial pressure caused by volumetric change (Jaing et al. 2002; Opperman 2000; Kuffel 2004).

Cartilaginous bone growth sites respond to intracranial pressure from brain growth with expansion and by laying down additional cancellous bone at the edges of cranial bones (Kuffel 2004). In order to maintain the gap between opposing flat bones, sutures will form additional
bone (Kuffel 2004). It is important that sutures remain unossified or in a patent state during development in order for the proper formation of the neurocranium to occur (Kuffel 2004).

Ossification and fontanel closure occurs upon the cessation of intracranial expansion pressure at the primary ossification centers (Kuffel 2004). As brain growth slows, cartilaginous bone growth sites at the sutural fronts continue to lay down cancellous bone, which eventually overlap opposing bones, thereby creating continuous flat plates (Podda et al 2003, Opperman 2000). Termination of suture patency at this point is important because it becomes non-effective after this period (Kuffel 2004). If the rate of new bone formation is too rapid, there can be premature fusion of one or more sutures; this can cause cranial asymmetry, or craniosynostosis (Kuffel 2004). Premature ossification of sutures appears to contribute to increased brain volume and internally applied pressures (Fok et al 1992). Permanent asymmetric “deformation” of the cranium can result (Kuffel 2004). In contrast, if sutures fail to ossify in a timely manner, fontanels may remain abnormally large (Opperman 2000).

3.4 Postnatal Growth

Within the first year of life, the majority of cranial expansion is experienced in the frontal region (Tiesler 2014:39). Between the ages of two and six, although growth is largely reduced at this time (Kräußel 1979), cranial expansion tends to direct dorsally (Tiesler 2014:39). As Tiesler (2014:39) suggests, “this aspect could be important to the head-modeling process and holds implications for the change in vectors of bone mass expansion during head shaping.”

During the first four years of child development, the cranial base experiences proportionately less expansion than the neurocranium (Tiesler 2014:39). In comparison to cerebral development, facial bone expansion tends to occur relatively late (Enlow and Roger 1990; Tiesler 2014:39) and remains continuous up until adulthood (Kräußel 1979 in Tiesler 2014). Sufficient cranial and
neurological expansion and development during this stage of development can provide indications of the “integrity of the central nervous system” (Tiesler 2014:39). For instance, in the first few months of life motor skill abilities such as grasping and head and neck movement control, as well as auditory and visual precision are typically learned (Tiesler 2014:39).

3.5 Brain Expansion, Cranial Growth, and Cultural Compression

An intricate relationship exists between brain expansion and cranial bone growth (Moss 1958). The bones that encapsulate and protect the soft tissues (such as the brain, periosteum, and dura mater) undergo relatively passive expansion in response to neural growth (Tiesler 2014:37). The dura mater, cranial vault bones, and periosteum comprise the embryonic neurocranial vault (Tiesler 2014:37) and later, during the developmental process, form a functional system (Tiesler 2014). Unbalanced relationships between cranial bone expansion and brain growth during the infancy period typically result in irregular cranial shape (Kuffel 2004). Research on the different forms of artificial cranial deformation must be based on “normal” neurocranial growth because the magnitude and direction, or vectors, of endocranial and neural growth are very similar processes (Moss 1958:275). Therefore, it is important to consider conditions that restrict normal cranial growth to better assess the dynamics of induced compression from cultural practices (Kiesler 2014).

The tightly linked relationship between brain growth and development and morphogenesis of the endocranium is predominant during the pre- and perinatal stages (Neubauer et al. 2009). The embryonic brain is enveloped by mesenchyme that is composed of two layers: the inner endomeninx and outer ectomeninx (Sperber et al 2010). The endomeninx forms the pia mater and the arachnoid which are the two leptomeningeal tissues that cover the brain (Neubauer 2009; Sperber et al. 2010). The internal layer of the ectomeninx differentiates to
form the dura mater of the brain, which remains unossified (Sperber et al. 2010). The external layer is composed of chondrogenic and osteogenic properties which contribute bone growth (Neubauer 2009; Sperber et al. 2010). “Osteogenesis of the ectomeninx occurs as intramembranous bone formation over the expanding dome of the brain, forming the skull vault, whereas the ectomeninx forming the floor of the brain chondrifies as the chondrocranium, which later ossifies endochondrally (Sperber et al. 2010:97). Therefore, the form of the brain is directly reflected by the size and shape of the endocranial bones. “Analysis of phenotypic integration of the neurocranium and the brain in craniofacial pathologies support the notion that brain, meninges, and skull interact in highly coordinated way (e.g. anencephaly, microcephaly, and craniosynostosis; Neubauer et al. 2009:240-241).

As discussed previously, expansion of the brain creates tension “along the endocranial surface of the braincase, especially via the falx cerebri and the tentorium cerebelli, which activates osteoblast deposition within sutures, and drift and endochondral growth in synchondroses (Neubauer et al. 2009:241). The close knit relationship between brain growth and cranial expansion are of great interests when investigating potential intrinsic and extrinsic alterations of the head in response to external forces of compression. Such tension can redirect brain growth to areas not under compression and can also potentially cause structural or functional damage to endocranial tissues in addition to altering the shape of the cranial bones.

3.6 Intrinsic and Extrinsic Cranial Expansion

During the maturation process, cranial bones function together as one unit and do not necessarily constitute individual anatomical elements. Therefore, this relationship is important to consider when investigating the dynamics between extrinsic and intrinsic induced restraints (Tiesler 2014:40). The biological compensatory processes that become adapted to externally
localized pressures are contingent upon the type of artificial cranial shaping (Tiesler 2014:41). It is also important to note that devices or apparatuses used during the process of shaping the cranium cannot change the magnitude of intrinsic growth, but will alter the direction of growth (Moss and Young 1960; Nichter et al. 1986). Most literature regarding the morphological implications of artificial cranial modification does not differentiate between annular and tabular modeling or between tabular oblique and erect head shapes. However, few scholars have explored this relationship.

The cranial growth model by Moss (Moss 1958, Moss and Young 1960) provides support to the theory that neurocranial bone compensation is highly interconnected with encephalic tissue restructuring. In 1960, Moss and Young investigated the nature of intrinsic functional interactions that occur between the neurocranial components (dura mater, brain, cranial bones) as they adjust to external pressure. Moss and Young (1960) consider the pathogenesis of cranial modification in regards to growth alterations in one component stimulates growth vector changes in each of the other components. They further explored the intrinsic neural responses to external compression forces used to achieve various styles of cranial modification.

Despite the high amount of diversity in regards to modification techniques and intentionality and part of the practitioner, Moss and Young (1960:279) used two broad classification schemes, erect and oblique; as these are the two main forms of modification that result from the various techniques.

In “vertical” (erect) forms of modification, which result from externally applied force on the posterior portion of the occipital bone in a fashion roughly parallel to the “eye-ear plane”, intrinsic growth is restricted posteriorly and therefore redirected in lateral, superior, and anterior directions (Moss 1959; Moss and Young 1960). The restriction in neuro expansion with erect
modification styles limit the amount of room needed for the rapid growth of the superior posterior cerebral tissues (Moss and Young 1960:280). It is important to keep in mind that the occipital bone undergoes endochondral ossification and reaches its growth potential earlier than the remaining cranial vault bones and is more rigid during cranial ontogenic processes. This provides a clearer understanding as to why posterior expansion of the cerebellum is nearly impossible and therefore is directed anteriorly against the anterior basioccipital region of the skull, creating what is known as basal kyphosis, as well as an additional kyphosis in the brain stem (Moss and Young 1960:280). An elevation in the neural tissues in the cerebral fossa, created by kyphosis, offsets the growth vectors and can stimulate osseous elevation in the eye orbits (Moss and Young 1960).

Figure 6 Occipital Bone is highlighted to visualize the anterior and posterior regions of the occipital bone as they are anatomically situated in the human skull. Images are generated by Life Science Databases (LSDB).

Oblique modification styles are different than the erect forms in that there are two vectors of external forces causing intrinsic growth vectors to redirect growth in superior and posterior
directions (Tiesler 2014). This upward and backward movement of endocranial expansion may create flattening of the occipital bone which can result in bulging, or (pseudo) platybasia, of the dorsal portion of the base of the cranium (Moss and Young 1960; Kohn et al 1993; Tiesler, 2014:42). The superior-posterior angle in oblique modification styles allow greater “formational change than the erect types because they [oblique styles] allow a backward and upward expansion of the neural tissues encapsulated by the occipital bone” (Tiesler 2014:46).

Figure 7 Example of oblique cranial modification style on RCC.01.01.23 (photo by Gadison 2014).

Research involving the investigation of intrinsic and extrinsic cranial development provides clearer understandings of the processes of cultural cranial shaping practices. Such studies also inform about the alterations that compression forces can stimulate in the neural
growth vectors, which in turn alter bone expansion (Tiesler 2014:41). In artificially modified crania, internal pressure can occur when a skull cap is extrinsically conditioned by compression (Moss 1958; also see Tiesler 2014:41-42) and thus, stimulate cranial expansion; similarly as in cases of stenosis. The external stimulation from tension is then transmitted through the dura mater and sutures (Sgouros 2005). The dura mater and sutures make up the adherence zones between the dura mater and the vault bones (Tiesler 2014:43). The following sections in this chapter will further explore specific intrinsic and extrinsic alterations of the skull in response to external pressure.

3.6.1 Intrinsic Adjustments of Cranial Growth

Aside from the redirection of brain growth, which is stimulated by external compression forces, it is important to address some of the pathological conditions that restrict cranial growth in order to carefully construct hypotheses about cranial growth dynamics prompted in response to external cultural compression forces. Comparisons between pathological alterations and culturally induced cranial pressure can potentially be useful in exploring the “functional and dysfunctional” compensatory adjustments that result from artificial cranial modification (Tiesler 2014:41).

Premature suture closure or suture obliteration, such as in craniosynostoses, results in abnormal cranial shape as a response to an imbalance between cranial growth and brain expansion during the infancy (Connolly et al. 2004). Craniosynostosis is the most prolific craniofacial malformation in humans and may occur as sporadic or in conjunction with over 120 plurismalformative syndromes (Bernardini et al. 2012). However, in recent years, it has become evident that affected individuals may have normal suture opening and cranial shape during infancy but later develop postnatal craniosynostosis (Connolly et al. 2004; Bernardini, et al.
In either case, one or more sutures prematurely ossify during the growth process causing conditions such as craniosynostosis or craniostenoses.

Conditions involving the obliteration of sutures prematurely alter cranial growth causing cranial expansion to occur parallel to ossified sutures versus perpendicular due to the fact that the cranium is unable to expand in the direction of fused sutures (Virchow 1851; Tiesler 2014; Connolly et al. 2004). The restriction of cranial growth as a consequence of premature suture closure is associated with hydrocephalus (an increase in cerebralspinal fluid) (Thompson et al. 1997), elevated intracranial pressure (Gault et al. 1992; Baird et al. 2012; Connolly et al. 2004), and impairment of neurological and developmental functions (Baird et al. 2012). Increased intracranial pressure may also stimulate osteological growth. Increases in risks of intracranial hypertension generally rise with the age of the individual and the number of suture closures that are prematurely obliterated (Tiesler 2014:41). Localized hypertension at the base of the cranial cavity becomes problematic because it can disrupt the flow of blood and cerebrospinal fluid (Tiesler 2014:41). Chronic occurrence of hypertension may lead to damage in the functional tissues of the brain, as well as optical atrophy if left unattended (Tiesler 2014:41). Some researchers suggest that multiple suture closures are not associated with heightened levels of restricted cranial growth when compared to single suture closures (Sgouros 2005). Individuals with Apert’s syndrome (development of above normal cranial volume after six months of age) and complex multiple suture synostosis (lower than normal cranial volume) are exceptions (Sgouros 2005). In regards to modified crania, research suggests that cranial capacities in modified crania are similar to non-modified crania (Nichter et al 1986).
3.7 Extrinsic Alterations of Cranial Vault Expansion

The dynamic relationship between cranial tissues respond in the same manner to extrinsic culturally applied forces to the skull. The process of shaping the skull by external compression is only feasible just after birth when the cranial tissues are highly maleable. Once the perinatal stage passes, pressure on the calavera becomes isometric and limits active cranial expansion by shifting tension forces (Tiesler 2014:43). External cranial compression does not reduce growth. Instead, growth vectors redirect tension to unrestricted areas of the skull. The tension stimuli in this process are diffused through the dura matter to connective tissues of the fontelles and then to the sutures. The intrinsic compensatory response occurs perpendicularly to the areas of extrinsic compression (Tiesler 2014:43). For example, in oblique anteriorposterior compression, the central occipital and frontal bones are compressed which causes expansion to be redirected laterally and upward.

Tension distribution becomes more complex when margins of compression forces are near fontanels or sutures, such as with annular forms of artificial modification and most tabular anteriorposterior modifications (Tiesler 2014:43). When compression is severe and sustained past the period of fontanel closure, sutural growth compensates and creates a bulge on the compressed side and a concave furrow on the unrestricted side of the suture (Tiesler 2014:43). Stewart 1948 described the potential for extremely modified crania to exhibit a groove that may entirely surround compressed frontal surface behind the coronary suture while other crania may display bilateral depressions behind bregma (Tiesler 2014:43). Studies by Tiesler (1999; 2006) indicate that there is a linear relationship between the intensity of cranial modification and the manifestation of post coronal grooving. This grooving may be due to the increased capacity of adaptive response during the developmental stage prior to fontanel closure. It is interesting to
note that Dingwell (1931) described a transverse groove or depression above the temples that was common in certain parts of the world and associated with young children carrying heavy, bulky items with a head support. Such grooves were mentioned as results of unintentional modification (Dingwell 1931). Similar grooves, in this instance, also may appear just above lambda where the sagittal and lambdoidal sutures converge. When the compression plane does not meet lambda a furrow or groove is created (see Figure 7). Furthermore, these grooves may also be visible depending on the ways in which bands or wraps are oriented on the skull.

Figure 8 Post coronary grooving and depression above lambda, as indicated by white arrows, in infant cranium (photo by author).

The basicranium portion of the cranium is more rigid than the calaverial bones due its endochondral and advanced ossification process and poses greater resistance to external compression. This is important to consider because the basicranium supports the important
nerves and vessels, such as the optical nerve, in the skull (Tiesler 2014:45). It is also important to note that during infancy, the foramen through which the fifth cranial nerve passes, is not completely ossified (Tiesler 2014:45). Therefore, with a lack of ossification in the occiput, craniofacial nerves remain vulnerable to exposure in some regions of the skull and these areas of vulnerability could lead to complications during artificial cranial modification processes that are implemented soon after birth (Tiesler 2014:45). Hard modification implements would need to be secured tightly on the occipital bun in order to achieve morphological change, specifically when perpendicularly applied to the basicranium (Tiesler 2014:45) as in tabular-erect forms of modification. In contrast to the calvarium, depending upon the amount and the location of pressure, the lower portion of the occipital bone reacts by either flattening or compensating by creating a bulge of kyphosis as mentioned above (Tiesler 2014:45-46).

3.8 Summary

Cranial modification is achieved through dynamic relationships between the normal vectors of infantile neurocranial growth and responses to externally applied forces. This chapter has provided an overview of human cranial growth during pre and postnatal stages and highlighted and described key principles that are important factors in cultural head shaping practices (Tiesler 2014). Implements used to shape the skull do not alter the “magnitude of intrinsic growth,” but can alter the direction of cranial growth (Moss and Young 1960:275). Ultimately, the anatomical elements of the head develop as a functional unit, as oppose to individual components, and respond to intrinsic and extrinsic pressures. This is important to note because intrinsic and extrinsic forces that act on one region of the skull during development will cause stimuli to transmit through the dura mater and to each of the other cranial components. Each element of the skull will then adjust growth and expansion in response to the stimuli.
4 CRANIAL LESIONS

4.1 Introduction

Skeletal growth rate has been identified as a highly sensitive indicator of stress, health, and well-being of past populations (Larsen 1997:9). In early stages of life, growth and development are “sensitive indicators of the quality of the social, economic, and political environment” in which individuals live (Lewis 2006:60). During the initial stages of the bone developmental process, rates at which bone remodeling occurs involves a “perfect” balance between the amounts of the apposition and resorption of bone (Lewis 2006). Disruption in equilibrium can lead to abnormalities indicative of bone pathologies (Lewis 2006). These abnormalities, or measures of health, are of great interest to bioarchaeologists because they provide insight into the experiences of deprivation, degeneration from habitual activity, and both specific and non-specific disease in ancient populations (Larsen 1997).

Spanning back to early prehistory, health has had a central role in indicating quality of life (Steckel and Rose 2002). Inequality in the royal cemetery complex at Abydos, Upper Egypt was correlated with the frequency and severity of porotic hyperostosis based on factors such as occupational and social class (Keita and Boyce 2006). Klaus and Tam (2009) found that there was an increase in systemic stress, to include porotic hyperostosis, during post-contact Spanish colonialism in Mórrope, Peru. Similarly, Larsen and Sering (200:131) found an increase in the presence of anemia and other stressors, to include infection, after European arrival to Georgia Bright. Poor living conditions resulting from sedentism, nucleation, and water contamination resulted in increased levels of anemia in the Georgia Bright population. In Villa El Salvador, Peru, Prechenkia and Delgado (2006) suggest that there is a pattern in the presence of skeletal stress markers that indicate a social divide in the skeletal population. The skeletal remains
exhibited differences in degenerative joint disease and post cranial trauma which was associated with wealth and burial goods which suggests that social status potentially contributed to unequal distribution of labor, particularly in males (Prechenkia and Delgado 2006).

4.2 Porotic Hyperostosis and Cribra Orbitalia

Porotic hyperostosis and cribra orbitalia are among the most common physiological indicators of deprivation generally associated with early childhood development. Porotic hyperostosis and cribra orbitalia have been documented in historic and prehistoric populations throughout the world and are commonly used by bioarchaeologists to assess health and nutrition in past populations. Porotic hyperostosis is a result of porous lesions that typically occur on the outer table of the skull (Walker et al. 2009). These lesions form as a result of expansion of the diploe, or spongy bone, resulting in thinning and porosity of the cortex (Ortner 2003; Blom et al. 2005; Walker et al. 2009). However, most scholars conclude that porotic hyperostosis is “osseous evidence of marrow hyperplasia,” despite ongoing debate regarding its causes (Blom et al. 2005:153).

Marrow hyperplasia is the a compensatory condition in which the body reacts to decreased levels of oxygen by producing an elevated amount of red blood cells and immature cell precursors (Blom et al. 2005). Significant increases in this production stimulate expansion of marrow cavities (Blom 2005:153). In the early stages of life, children have considerable plasticity; therefore, the pressure created from red marrow hyperplasia, in these instances, may cause degradation of the cortex, in turn leading to porotic hyperostosis. Marrow hypoplasia can eventually manifest in osseous tissues giving a hair-on-end appearance, and serve as indicators of childhood health when observed in adult crania.
Diploe expansion occurs in response to marrow hypertrophy and other pathological conditions in response to iron-deficiency or hemolytic (Rostchchild 2002) anemia, as well as chronic scalp infections (Blom et al. 2005; Walker et al. 2009). Other arguable causes of diploe expansion include osteitis or diagnostically alteration (Walper et al 2004), lead poisoning (Glen-Haduch et al. 1997), pressure from binding or carrying heavy objects during childhood, as well as external compression forces from modifying cranial shape in cranial modification processes (Blom et al. 2005; Mendonça de Souza et al. 2008). Due to similar observable etiologies, cribra orbitalia has been suggested to be a form of porotic hyperostosis that manifests on the superior portion of the eye orbits (Walker et al. 2009:139).

Figure 9 Example of porosity on the occipital bone from PCU.01.01.24 from the Andahuaylas collection. (photo by author).
Dating back to the 1950’s, iron deficiency anemia has been associated, almost synonymously, with the marrow hypertrophy which leads to the manifestation of porotic hyperostosis and cribra orbitalia. Prior inferences and theories, such as these, were based upon modern epidemiological data, as well as clinical cases in which radiographic images of marrow hypertrophy and iron-deficiency anemia existed simultaneously (see Walker et al. 2009).

The etiologies of both conditions have been hotly debated for many years (Walker et al. 2009; see Holland and O’Brien 1997), and the variability in the suggested etiologies of porotic hyperostosis and cribra orbitalia is observable in research across various regions of the world. For example, porotic hyperostosis is associated with infectious disease, iron or B-vitamin deficiencies and parasitism in indigenous North American groups, while sickle-cell anemia or thalassemia may contribute to porotic hyperostosis in African-American and Mediterranean populations (Angel 1966; Walker et al. 2009:110). In Cuzco, Peru, Turner and Armelagos (2012)}
found that porotic hyperostosis was linked to coastal environments, which suggests that, in this region, the condition was correlated with anemia stemming from environmental stressors.

Klaus and Tam (2009) suggest that porotic hyperostosis is often incorrectly diagnosed. There are numerous contrasting proposed etiologies for porotic hyperostosis and cribra orbitalia. Researchers suggest that nutritional diseases such as scurvy and rickets, nonspecific osteitis, tumors, and hemorrhagic or inflammatory processes can yield similar appearance as porotic hyperostosis, without the presence of postcranial abnormal activity and periosteal inflammation and therefore, these conditions should be dismissed as etiologies for porotic hyperostosis (Ortner 2003; Klaus and Tam 2009).

Klaus and Tam (2009) and Walker et al. (2009) dismiss iron deficiency anemia as a causal agent of porotic hyperostosis, although iron deficiency anemia has long been considered a prominent cause of the porosity (Larsen 1997; Keita and Boyce 2004:65; Laloo et al. 1977:473-474). Walker et al. (2009) propose that megaloblastic anemia stemming from B-vitamin deficiency, intestinal parasites, and unsanitary conditions are likelier culprits of cranial porosity. Likewise, Holland and O’Brien (1997) and Larsen (1997) suggest that factors such as increased blood loss, parasitic infections, and chronic diarrhea are non-dietary factors that can contribute to the presence of porotic cranial lesions. Some studies have also shown that porosity also may be a result of inflammatory processes, infection, and other diseases (see Schultz et al. 2001).

4.3 Parasites

Parasitic activity is an additional factor to consider in the discussion of the etiologies of porotic hyperostosis because parasites can be causal agents of anemia. Populations that were often exposed to contaminated water and food sources (Blom et al. 2005; Klaus and Tam 2009), high-altitude hypoxia (Rothschild 2000), and crowded unsanitary living conditions (Kurin 2012)
were often at risk of being infected with parasites. Parasites vary in species and climatic regions, yet mostly thrive in dry arid environments such as coastal regions. Kent et al. (1994) posit that porotic lesions should be interpreted as the body’s adaptive response to parasitic infection through sequestering of circulating iron for the reproduction and growth of pathogens.

Bioarchaeological research indicates that the level of anemia in coastal and marine dependent populations can be explained by the contaminated water and food sources (Walker 1986). Individuals who ingested contaminated resources, such as uncooked or improperly cooked fish foods, would also have experienced chronic diarrhea and intestinal bleeding. These symptoms are often attributed to gastrointestinal disorders and increased susceptibility to anemia, due to the fact that increased blood loss and “gastric mobility” occur more rapidly than the appropriate amount of time needed for adequate iron absorption (Blom et al. 2005).

4.4 Infection

The placement of modification devices on the infant skull with pressure can cause inflammation, bleeding, scalp scarring, as well as necrosis of bone. If the head is not properly attended to regularly during the modification process, and if the bandages are not changed or cleaned regularly, periosteal reactions or even gangrenous infections can occur. Such pathological responses can lead to periosteal reactions, manifestation of cranial porosity, and in extreme cases, necrosis of bone (although a separate mechanism than marrow hypertrophy, necrosis has been suggested to cause similar porotic lesions) potentially leading to death (Mendonça de Souza et al. 2008; Nichter et al. 1986).

4.5 Cranial Porosity and Modification

The debate over the etiologies of porotic hyperostosis becomes further complicated with the consideration of cranial modification as an additional cause of cranial porosity. Confusion
stems from instances in which compression forces applied to bone stimulate structural alterations within the inner bone matrix (Mendonça et al. 2008), typically at the region between inon and lambda (Manriquez et al. 2006). Stewart (1976) and Hrdlicka (1908) provided descriptions of large occipital scarring in children from a North American population that utilized cradleboards to immobilize their children, which resulted in flattening of the occipital bone. Hrdlicka did not make an association between the cradle boarding and the scarring; instead he attributed the scarring to poor hygiene. According to Blom (2005) the porosity associated with modified crania can easily be misinterpreted as porotic hyperostosis, particularly in regions of the world where both commonly occur together, such as in prehistoric Peruvian populations. As mentioned previously, there is difficulty in discerning etiologies of cranial porosity. There is much debate regarding not only the etiologies of cranial porosity but also whether or not one can visually differentiate the way in which porosity manifests depending on the specific types of causal agents (Walker et al. 2009, Klaus and Tam 2009; Kent et al 1994).

4.6 Case Study

Research by Kurin (2012) investigates the role of post-imperial Wari state collapse during the Late Intermediate Period (AD 1000-1400) and its impacts on heterogeneity in diet, as well as long-term effects on health and frailty of subsequent populations in Andahuaylas, Peru. She analyzed cranial lesions, including porotic hyperostosis, as indicators of compromised health. In Andean sierra populations, porotic cranial lesions may result from megaloblastic anemia, which is caused by malabsorption of vitamin B12 and/or B9 and chronic dietary deficiencies (Walker et al. 2009). According to El Najjar et al. (1976), megaloblastic anemia can occur from consumption of primarily vegetarian products that lack adequate levels of iron, and/or as a consequence of gastrointestinal parasites and infectious diseases that may lead to
nutrient malabsorption and diarrhea (Stuart-Macadam 1992). The other likely etiologies of cranial porosity in the study populations included maize consumption and compression from cranial modification binding pressure. Due to multifactorial etiologies that can cause cranial lesions, it is important to tease out the most likely indicator to understand the conditions that helped foster compromised health (Kurin 2012).

Kurin’s 2012 analysis demonstrated that an overall increase in porotic hyperostosis occurred during the post-imperial era. Although there were shifts in the pattern of maize consumption, as indicated by the carbon isotope data, these patterns did not account for the rates of porotic hyperostosis (Kurin 2012).

Populations in Andahuaylas illustrate different frequencies of cranial porosity; over 54% of individuals with cranial modification displayed cranial porosity (116/214), while 25% (10/40) individuals without cranial modification exhibited cranial porosity (Kurin 2015). Osteological data suggest that there was an overall decline in health during the LIP after Wari collapse and that individuals with artificially modified crania exhibited more frequent signs of dietary deficiencies (Kurin 2015). Data from a recent carbon and oxygen isotopic analysis from tooth enamel apatite, which provides insight into past diet and mobility, also suggest that there was an overall dietary shift from the Wari imperial period into the early LIP (Kurin 2015). Although the \( \delta^{13}C \) mean values do not change over time, the ranges do change. The \( \delta^{13}C \) values during Wari imperialism range from -4.9‰ to -3.7‰ (mean = -4.2‰, s.d. = 0.6‰) and \( \delta^{18}O \) values from teeth showed ranges from -12.7‰ to -9.0‰ (mean = -10.5‰, s.d. = 1.2‰). After the fragmentation of the Wari state, \( \delta^{13}C \) values range from -1.5‰ to -8.5‰ (mean = -4.9‰, s.d. = 1.6‰), while \( \delta^{18}O \) values range between -11.3‰ and -8.5‰ (mean = -9.5‰, s.d. = 0.7‰) (Kurin 2015). Variables were further explored by Kurin (2015) to elucidate the basis for disparity. Her
assessment of cranial modification suggested that modification was not significantly correlated with dietary consumption patterns, with results showing ranges for unmodified individuals of δ\(^{13}\)C at ranges of -1.5‰ to -8.1‰, mean = -4.9‰ (N =13) and modified individuals at ranges between -2.5‰ to -8.5‰, mean = -4.6‰ (N=11) (Kurin 2015). When lesion frequencies were compared to isotopic data, individuals with enriched δ\(^{18}\)O illustrated a strong association with cranial lesions with values of δ\(^{18}\)O at -1.5‰ to -8.1‰, mean -4.9‰ (N = 13) for individuals with cranial lesions and ranges of δ\(^{18}\)O ranges from -2.5‰ to -8.5‰, mean = -4.6‰. However, cranial lesions were not strongly associated with δ\(^{13}\)C values. Isotopic data from Kurin’s (2015:25) research indicates that availability of food did not change significantly during Wari state collapse, but “socially-structured food accessibility” does change overtime in this Andahuaylas region.

In order to determine whether cranial binding was the cause of the cranial lesions, Kurin (2012) mapped the locations of porosity on the cranial vault of each cranium. In total, 92% (63/68) of the individuals with porotic hyperostosis displayed porosity on the occipital and posterior parietal regions of the skull (Kurin 2012). Areas of the cranial vault that would have been impacted by binding (just posterior to bregma), did not appear to have a significant increase of porosity compared to areas that were unaffected by binding pressures. According to Kurin 2012, this would indicate that cranial binding was more than likely, not the etiology of porotic hyperostosis in the Andahuaylas populations.

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Due to the fact that the two prior causes were ruled out, the most fitting etiology of porotic hyperostosis in the post-imperial era of Andahuaylas is nutrient malabsorption caused by parasitic or bacterial infections (Kurin 2012). Because of the near significant increase in porotic hyperostosis from the Middle Horizon Period to the Late Intermediate Period, it is possible that the dynamic changes in settlement patterning and increased population densities were the underlying factors of pathological cranial lesions (Kurin 2012). As seen in later civilizations, an increase in population density coupled with unsanitary living situations can provide an optimal environment conducive to bacterial and other microbial infectious diseases which spread throughout human populations causing illness and death.

As previously discussed, there is an abundance of potential causes of porotic hyperostosis, as it is a non-specific condition, resulting from marrow hyperplasia into surrounding osseous tissues. In order to form a better understanding of porotic lesions and their etiologies, this thesis investigates the extrinsic relationship between cranial porosity and cranial modification. More specifically, the present study seeks to detect whether or not the observed porosity localized on the occipital and parietal bones are correlated with the varying degrees of cranial modification intensity, elongation.
Proposed hypotheses for the present study are as follows:

(1) If cranial porosity is an extrinsic biological response to compression from cranial modification practices, then the intensity of porotic activity will correlate with the degree of intensity (elongation) of cranial modification (i.e. non-modified crania will have no porosity, slightly modified crania will exhibit some porosity, and extremely modified crania will have high porotic activity).

(2) Alternatively, if presence of porosity does not correlate with variance in modification intensity, then equal frequencies of porosity will be expressed in individuals with non-modified crania and those with cranial modification regardless of levels of intensity.

4.7 Summary

The scholarly debate regarding the etiologies of porotic hyperostosis and cribra orbitalia have prompted innovating new approaches to investigating the various questions surrounding the matter. Included in the debate is compression from cranial modification and its potential for causing porous lesions on the occipital and parietal bones.

Research by Kurin (2012) suggests that cranial vault lesions observed in post-imperial Late Intermediate Period societies were results of megaloblastic anemia. The current study further investigates and builds upon the relationship of porotic activity and intensity of cranial modification from Chanka and Quichua ethnic groups from the Late Intermediate Period in Andahuaylas. This study further investigates the relationship of porotic activity and external compensatory cranial responses to artificial cranial modification. More specifically, the current research seeks to discern whether intensity of porotic activity corresponds with intensity, or elongatedness, of non-modified and modified crania.
5 BACKGROUND

5.1 Geography

The Andean cordillera, chain of mountain ranges, in western South America runs north to south along the coast of the continent. They are among the highest and longest mountain ranges in the world. The proximity of the Andean cordillera to the coastline results in a series of various distinct ecozones that “enhance or limit human occupation and development “(Schreiber 2001:76). The mountains, in conjunction with the cool offshore air, create a rain shadow effect which results in dry desert on the northern coast of Chile and Peru. The coastal line, as well as the valley floors of rivers that flow through the Andes, have been the primary extent of human occupation until the last half-century (Schreiber 2001:76).

The Andahuaylas province is situated in the southern portion of the Andean sierra central. The north and west portion of the region is bordered by the Pampas River, while the valley is transected by the Chamboa River that runs east and west through the valley. Similar to other parts of the sierra central, Andahuaylas cycles between a wet season, which is rainy and warmer from November through April, and dry season, which is cooler and ranges from May through October (Kurin 2012; Kellett 2010).

Despite the extreme altitudes in the Andean highlands, populations have still managed to acclimate to the vertically arranged ecozones and implement subsistence strategies (Schreiber 2001). The Apurimac department, which is situated between Ayacucho and Cusco departments, consists of two provinces: the Andahuaylas and Chincheros provinces. The western portion of Apurimac, which is the Andahuaylas region, is comprised of a rugged landscape with high mountain peaks and deep canyons with peaks that reach heights above 5,000 meters above sea level (masl) and valley floors as low as 1,800 masl (Kurin 2012, Kellett 2010). Such rugged
terrain has presented challenges to both the past and present populations in the area. Populations have adapted to the region by implementing effective subsistence and land use strategies in order to take advantage of the vertical landscape, which can be subdivided into various “contiguous ecological zones” (Kellett 2010). Geographically, much of the Andahuaylas region is well suited for high-altitude subsistence, such as pastoralism (Kurin 2012).

The Andahuaylas region is unique because it has one of “the few broad mid elevation valleys with moderate cultivable slopes and excellent soils, making it very well suited for agriculture” (Kellett 2010:22). Between 2,700 masl to 3,500 masl is the Kickwa ecotone where major indigenous crops such as maize, is predominantly cultivated, as well as the production of

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**Figure 11** Sites included in the present research study. The study area is encircled by the blue outline. The green squares are the Chanka sites and the pink area is the Quichua site (adapted from Kurin 2012).
additional minor crops such as oats, beans, and barley (Kurin 2012; Kellett 2010:30). At a length of about 25 km, the Andahuaylas valley is among the largest areas of maize production in the department (Bauer et al 2010).

The suni, zone ranging in elevation between 3,500 masl to 3,800 masl, is located above areas suitable for maize agriculture. This ecotone consists of high valleys and slopes, as well as cooler temperatures and rain fed agriculture due to low “amount of spring fed irrigation water on these high elevation slopes” (Kellett 2010; Kurin 2012). The climate in the suni zone is best suitable for the cultivation of tubers and is a serves as “the heart of modern day potato production and is of the most intensive potato producing areas in Peru” (Kellett 2010:26).

The puna zone is situated between 3,800 and 4,000 masl is a cold and windy grassland with billowing topography at the lower levels and rugged peaks at the highest regions of the zone (Kellett 2010). This zone also has accessible surface water from lakes and springs and is therefore, “suitable” for camelids (Kellett 2010); although camelid husbandry in modern day Andahuaylas is not largely practiced in the region (Kellett 2010). In Andahuaylas, cultivation ceases above 4,000 masl, as low temperatures and frost prevent the ability for agriculture (Kellett 2010:27). Given the agricultural ecozones, populations subsisting off of the high altitude have been suggested to have set up trades and organized in ayllu structured groups.

5.2 Culture History

In order to best contextualize the historical background of the Andahuaylas region, it is important to discuss the significance of the Wari state, which predates the emergence of societies, such as the Chanka and Quichua societies, in the Andahuaylas region. The Wari state, also referred to as an empire, was among the first most expansive civilizations in the Andes, that coalesced around AD 600 (Isbell 2008; Tribbett and Tung 2010; Kellner and Schoeninger 2008).
and endured until about AD 1000-1100 (Isbell and McEwan 1991; Covey et al 2013; Bauer and Kellett 2010). This period, known as the Middle Horizon, dates from AD 600-1000 (Knudson and Tung 2011).

The Wari state was among the first most expansive civilizations in the Andes during the Middle Horizon (AD 600 to AD 1000). The Wari state expanded from its capital in the Ayacucho basin to incorporate extensive areas of the south and central, including large portions of fertile agricultural areas in the highlands and areas along the coastal region (Schreiber 2001; Isbell 2008; Tung 2013). The Wari also controlled diverse populations from various geographical regions including a range of ethnic groups and resources (Valdez 2006; Tung 2008; Tribbett and Tung 2010).

The Wari capital city, Huari, was located in the Wari heartland in the central Peruvian highlands near the modern day city of Ayacucho, which is about a two day walk from Andahuaylas (Isbell 2004; Kurin 2012). The Wari are associated with having one of the most distinctive and expansive architectural styles in the prehistory of the New World (Isbell and McEwan 1991). Wari expansion was accompanied with Wari-style artifacts and architecture (Jennings 2006; Isbell 2008; Valdez 2006). Wari architectural styles included D-shaped temples, orthogonal cellular patio groups, and buildings made of stone that were typically covered with clay and often coated with white plaster (in some instances, potentially on ceremonial buildings, red paint was applied) (Isbell 2004, 2006).

They appeared to have enacted dominance through differential levels of control throughout their domain (Tung 2008). As evidenced through the remains of material culture at Wari-affiliated sites, Wari imperialism spread throughout the Andes by the use of military force and ideological indoctrination. Among the most successful strategies employed by the Wari was
the use of violence (Kurin 2013). These were, arguably, the major factors in maintaining and expanding their imperial authority (Knudson and Tung 2011).

According to the literature, Wari political leaders used varied approaches to obtain political control; which were potentially dependent upon the state goals, the local infrastructure, and the local elites (Knudson and Tung 2011). Some researchers argue that Wari imperial investment and expansion was dependent upon the distance that a region was located from the heartland, as well as potential for wealth, local political organization, and local tolerance to outside rule (Schreiber 1987). In any case, a mixed mosaic of military force and ideological indoctrination can be seen in the archaeological record. Remains of administrative and religious centers that were established throughout the Peruvian Andes by the Wari legacy are still in existence (Tung 2008; Knudson and Tung 2011). Wari administrative centers ranged across the highlands in places such as Viracochapampa, Azangaro, and Pikillacta, and reflected planned architecture and structure that mirrored the distinctive Wari style (Isbell 2004; McEwan 1991).

Wari investment in Andahuaylas may have been due to several reasons; 1) its strategic location for travel to other affiliated sites; 2) abundance of mineral resources such as salt and copper and 3) investment in camelids for wool, meat, and trade (Kurin 2012). A lack of lethal skeletal trauma, defensive architecture, and warrior iconography suggests that Wari interest in Andahuaylas may have strictly been centered on economic reorganization and extraction of material goods (Kurin 2012). The assimilation of Andahuaylas under Wari governance during Middle Horizon may have thus been a peaceful experience, although it did not last in the midst of Wari state fragmentation.
Figure 12 Proposed boundaries of the Wari Empire (adapted from Kellett 2010).

Approximately 1000 AD the two most prominent states in the region, the Wari and Tiwanaku states, simultaneously experienced fragmentation. Periods of sociopolitical instability can impact social and structural organizations of affected populations, as well as lead to emergence of new polities. In instances of complex societal collapse or degeneration, regeneration of new societies depend upon principles and structures of government that were in place prior to collapse (Kolata 2006:209; Yoffee 2006). It is important to note that collapse is a
process associated with swift considerable fragmentation or reorganization of established complex polities, such as states or empires, into smaller, less complex entities (Tainter 1990). Collapse does not solely imply the abandonment of regions or local resettlement of outside populations, although these events may occur in the process (Railey and Reycraft 2008). Collapse involves significant social and political reorganization and therefore, it does not necessarily mean that when a society collapses that all of its territories will as also be subject to the same fate (Railey and Reycraft 2008). Often accompanied with the coalescence of new polities are increased rates of endemic conflict, which may arise during times of transformations such as in state fragmentation or collapse (Tainter 1988). Coalescence of new polities, population resettlements, and elevated rates of endemic warfare were experienced during the Late Intermediate Period in Andahuaylas. The emergence of cranial modification practices as a marker for identity began with the ethnogenesis of new population groups in this region. Individuals with specific cranial modification styles may have been more frequent targets of violence (Kurin 2012).

The Late Intermediate Period, dating between AD 1000 and AD 1400, was a turbulent period in which many populations experienced sociopolitical transformations, settlement relocation, and increased conflict (Kurin 2014). In fact, this period was marked with the formation of hundreds of small polities (Rowe 1945; Covey 2008) and the highest levels of warfare in Andean prehistory (Arkush and Tung 2013). Widespread major transformations have been attributed to a long-term drought (Bauer et al. 2010) and the collapse of the Wari state around AD 1000 at the end of the Middle Horizon (AD 600-1000) (Tainter 1988).
5.3 Wari in Andahuaylas

The Late Intermediate Period was a time of profound shifts in demographic and settlement patterning and has been characterized as a period of tremendous instability, particularly in the highlands (Tung 2008:101; Bauer and Covey 2002). The increase in tension and social instability has been attributed to the Wari and Tiwanaku societal fragmentation. Many regions experienced abandonment of lower valley settlements and an increase in settlement establishments on hill-tops and ridges (Bauer et al. 2010). In addition to shifts in settlement patterning, there appears to have been shifts in agricultural practices, from predominantly maize production to agro-pastoralism and camelid herding (Bauer et al. 2010).

The “political vacuum” created by the period of collapse affected the vast majority of settlements. Particularly in Wari-affiliated sites, during their influence in the Middle Horizon, the Wari did little to stabilize the environment and instead created a political atmosphere conducive to violence in the southern portion of the hinterland (Tung 2007). During the Middle Horizon, the Wari style of rule was inconsistent and ranged from direct to indirect styles of authority. It is thought that the variability in Wari presence contributed to the result of massive population movements that shifted to highlands, constructed defensive structures, increased violence, and subsistence shifts after the Wari state decline (Kurin 2012, Bauer et al. 2010).

In Andahuaylas, Wari governance appears to have involved the management of local populations. Local leaders may have been co-opted to aide in the restructuring and management of local economic systems (Kurin 2012:37) and potentially coerced or enticed through various techniques employed by Wari officials.

Due to the mosaic of political influence that the Wari exerted over the Andean populations, after its collapse, some communities may have chosen to retain the social,
economic, and political practices and ideologies that were in place during the Wari rule. Other communities may have chosen to completely abandon all associated practices. In order to investigate such possibilities, bioarchaeologists have assessed the human skeletal remains by the use of various methods in order to understand changes that populations may have undergone. For example, Tribbett and Tung (2010) analyzed the skeletal remains of a population of post-Wari citizens that lived in the former Wari capital of Huari in order to reconstruct their diet and to interpret any potential changes in social structural norms. Their research results reflected a high frequency of dental caries. The percent of dental caries in this population, to include caries in the cemento-enamel junction, was much higher than that of the baseline for agriculturalists (Tribbett and Tung 2010). Their results indicated that the post-Wari community continued to practice agricultural and consume large amounts of carbohydrate-rich foods during Wari rule. However, in Andahuaylas, the archaeological material remains point to a swift decline in Wari style ceramics and sudden shifts in settlement patterns (Schreiber 1992; see Bauer et al 2010).

5.4 After Collapse

Uncertainty currently surrounds the reasons as to what caused the Wari and Tiwanaku states to fragment and decline. What is certain is that there was a ripple effect that was created from the degradation of both complex states. Most regions throughout Peru experienced increased hostility, political, and economic competition. The Wari collapse has been described as “a seismic phenomenon that emanated from the core and rippled out” causing regional fragmentation and abandonment of settlements (Kurin 2012:28). Following the fragmentation of the Wari state in the near-hinterland region of Andahuaylas, came the emergence of new polities such as the Chanka and Quichua ethnic groups (Kurin 2012, 2014; Bauer et al 2010).
5.4.1 Ethnogenesis in Andahuaylas

Following the fragmentation of the Wari state in Andahuaylas, came the emergence of new polities, including the Chanka groups (Kurin 2012, 2014; Bauer et al 2010). Scholars have demonstrated through bio-affinity research using non-metric cranial data that the Chanka are likely descended from previous populations that existed during the Wari-era in Andahuaylas (Pink and Kurin 2011). The distinct presence of the Chanka society has been considered by scholars to likely have been an ayllu structured society (Kurin 2014), a social group that has communal resources, ranking in terms of kinship, and a common founding ancestor (Isbell 2010). Ethno historic texts have also characterized Chanka as consisting of small ayllus that united only for purposes of defense and conquest (Kurin 2012). For example, Garcilaso de la Vega (1968:299-300; as translated by Kurin 2012:36) states, “The denomination ‘Chanka’ encapsulates many other nations like the Huancohuyllu, Utunslla, Vilcas, Yquichancos, Morochucos, Tacmanas, Quinuallas and Pocras; they who boast ascendance from various parents, some from springs, some from lakes, others from the heights of the mountains.” This interpretation by Garcilaso suggests that the Chanka society was delineated into smaller ethnic lineages or groups (Kurin 2012).

Controversy surrounds the meaning of the term Chanka, as some scholars have used this term to define a cultural area, as well as to generalize and refer to any archaeological remains in the Apurimac Department (Bauer and Kellett 2010). In order to grasp a more complete and better understanding of the polities that were established in the region, more clarity and regionally specific terms are critical (Bauer and Kellett 2010). Therefore, following Bauer and Kellett (2010), throughout this thesis the term Chanka refers to specific groups of individuals who lived
in the modern day province of Andahuaylas during the Late Intermediate Period and early prehistory.

There was no writing system in place during this period; therefore, it was not until Spanish colonialism that accounts of Chanka and Quichua groups in Andahuaylas were documented by chroniclers. Although caution must be heeded when referring to chronicles, due to bias and gaps in time from when events occurred and when chroniclers documented events, important information still may be gleaned from such documents.

According to chroniclers, the emergence of the Chanka society began shortly after the Wari fragmentation in the Andahuaylas region, during a period called the Age of Auca Runa or warlike men (Garcilaso de la Vega (1968) [1613]; see Kurin 2012; Bauer et al. 2010). It was a time defined by conflict, conquest for land, and political subjugation. This era is also characterized by population growth, conflicts over resource procurement, and societal relocations to hilltop fortresses (pukaras) overseen by señores (hereditary lords) and sinchis (military leaders) (Felipe Guaman Poma de Ayala (1980 [1615] see Kurin 2012).

The Chanka society has been depicted as aggressive and hostile. Historical documents illustrate the violent nature of Chanka encounters with rival groups. Monzon ([1583] 1881:222 see Kurin 2012:38) reports that the protohistoric and early historic periods in Andahuaylas where characterized by inter-ethnic group violence in which Ayacucho tribes frequently fought with the neighboring Chanka groups. It has also been suggested that endemic violence typically did not occur between “an Indian and another of the same village, but between one village and another” (Ondegardo de Polo 1873:163 see Kurin 2012:38).
5.4.2 Cranial Modification and Ethnogenesis in Andahuaylas

Transformations in response to Wari collapse stimulated changes in ways in which societies perceived, as well as conceived, identities (Kurin 2012). The demise of Wari economic and ideological influence, including hierarchical status differences, created a new environment in which neighboring groups could reorganize and negotiate relationships (Kurin 2012). This process of negotiations was the driving force of ethnogenesis in Andahuaylas and was “reified through cranial modification” Kurin (2012:226).

As discussed previously, the analysis of permanent body alterations can provide a wealth of social information about past populations. Permanent alterations such as cranial modification can inform researchers about identity, culture, gender, group affiliation and social structures (Kurin 2014). Teasing out the meaning(s) of cranial modification in Andahuaylas was a challenge because head shapes were not significantly correlated with various factors such as sex, residential origin, bio-affinity, status, burial cave, or historically documented ayllus (Kurin 2012).

Research in Andahuaylas suggests that there is no substantial evidence of cranial modification as a practice during the Middle Horizon and it was not practiced by the Wari (Kurin 2012; Tung 2003). Post-imperial mortuary contexts suggest that cranial modification had only became a common practice in Andahuaylas after Wari state fragmentation (Kurin 2012). Cranial modification significantly increases among Andahuaylas population groups (both Chanka and non-Chanka (Quichua) groups) during the early Late Intermediate Period (Kurin 2012). Variability in cranial modification types within groups, as well as both modified and unmodified head forms, was contemporaneous in Chanka and Quichua societies (Kurin 2012).
As previously discussed, many anthropologists regard cranial modification as an indicator of social identity, as well as group affiliation, and not just simply a cultural practice of childrearing (Kurin 2014). The rapid introduction of cranial modification to Andahuaylas groups in the Late Intermediate Period (LIP) perhaps played a role in the process of ethnogenesis, whereby pre-existing or newly-created societies coalesce and become prominent markers of social boundaries that then intertwine with other surviving groups or integrated with lingering components of previous societies and become woven together in such that new boundaries are drastically redefined between groups (Kurin 2014). Ethnogenesis may commonly occur as a result of major societal reorganization (Kurin 2014). At the end of the Middle Horizon, tightly knit social, political, as well as economic ties were largely broken, most likely necessitating new social bonds or ties between groups (Kurin 2014). During the LIP, cranial modification may have promoted solidarity between groups, who would occasionally join together in order to legitimate claims to resources and social networks (Kurin 2014).

In Andahuaylas, the Chanka societies incorporated cranial modification as a tradition, potentially, in order to delineate intergroup differences (Kurin 2014:254). Cranial modification was possibly “structured by historically and politically contingent and embedded conventions” as opposed to biological reasons, in which “groups became socially relevant as distinctions were acknowledged” (Kurin 2014:254). Furthermore, cranial modification perhaps created a platform for establishing coalitions from a tradition of “boundary-marking” that would persist for hundreds of years regardless of the potential risks of violence that may have been ascribed to modified crania (Kurin 2014:254).

Cranial modification may not only have promoted group solidarity or a basis for establishing coalitions (Kurin 2014:254), but it may have also caused increased balkanization
with individuals that remained outside of the group (Torres-Rouff 2002). This could have created tension and violence (check Taylor 2010), as evidenced by significant increase in frequency and lethality of trauma, specifically in Andahuaylas. Particularly in the Chanka groups, males and females displayed similar patterns of trauma, such as distribution, frequency, and lethality of wounds (Kurin 2014:254), indicating that violence was experienced in similar ways across all members of the subpopulation groups. However, individuals with modified crania experienced significantly (or nearly significantly) higher rates of trauma than non-modified contemporaneous adjacent groups (Kurin 2014:255), which suggests that they may have been targeted for genocide.

The reorganization and coalescence of new social and ethnic groups and the sudden emergence of cranial modification swiftly after Wari state fragmentation in Andahuaylas, suggest that local societies underwent profound transformations following Wari collapse. The relationship between cranial modification and cranial trauma “point to the creation of new social boundaries as well as the intentional, physical destruction of the very individuals who employed those boundary-marking practices in this region of the Andes” (Kurin 2014:255).

5.5 Summary

The Late Intermediate Period was a tumultuous period in which major state collapse occurred, creating a political vacuum from which ethnogenesis of numerous micro societies occurred. Along with ethnogenesis, groups set out to differentiate themselves from others and often employed the use of cranial modification to do so. As a permanent form of bodily modification, cranial modification has become a salient scalar identifier for social information conveyed by various societies throughout the Andes. However, along with the conspicuous
distinction of cranial modification as a social identifier, came the influx of targeted violence and killing of members of modified groups.
6 RESEARCH DESIGN

6.1 Overview

Consequences of cranial modification, such as premature suture closure and morphological changes have been a topic of research since the 1930s but very few studies address the association between boney pathological conditions and cranial modification (Mendonça de Souza et al. 2008; Cocilovo et al. 2011). There is current debate among scholars as to whether or not cranial porosity, specifically porotic hyperostosis, is inappropriately diagnosed on human crania that display cranial modification. Scholars, such as Blom et al. (2005), Tiesler (2014) and Mendonça de Souza et al. (2008), have provided insights into the relationship between physiological reactions from cranial modification apparatuses and the appearance of porosity from external cranial compression.

The primary research objective of this thesis is to utilize bioarchaeological methods and techniques to investigate the extrinsic physiological changes induced by cranial modification. More specifically, this research investigates cranial porosity, porotic hyperostosis and cribra orbitalia, and their relationship with cranial modification in the Chanka and Quichua ethnic groups from Andahuaylas, Peru during the Late Intermediate Period (1000-1400 AD). Working within the parameters of this preliminary study, I seek solely to examine the relationship between porosity and cranial modification. Therefore, differential diagnoses of porotic lesions observed on crania were not the focus of this study and thus, were not undertaken at this time. The process of assessing the correlation between the two variables at hand will allow for future possibilities to address more fine-tuned questions about cranial porosity, such as whether or not it is possible to tease out etiologies or differentially diagnose cranial porosity. This research serves to help narrow the focus of the broader scope of the debate.
6.2 Research Question

The objective of this research is to assess the presence of non-specific pathological conditions and identity in order to elucidate whether or not the observable porosity likely ensued from nutritional or microbial infection as a result of unsanitary living conditions and limited access to essential resources, or if porosity was caused from the compression from apparatuses used during the cultural practice of intentional cranial modification. The central research questions are: (1) is artificial cranial modification intensity significantly associated with increased severity of observed cranial porosity in prehistoric Andahuaylas populations? (2) Is there significant association between severity of cranial porosity and cranial modification intensity between Chanka and Quichua groups? If the manifestation of cranial porosity is a physiological result of mechanisms from the process of modifying the cranium, then porosity should correlate with the increasing intensification of modified crania. Lack of correlation between the two variables would imply that other stressors or confounding factors may be at play.

6.3 Methodology

In order to examine the relationship between porotic hyperostosis and intentional cranial modification, several methods are employed. This study assesses the presence, absence, and typological details of cranial modification in a total sample of 33 crania. Methods for estimations of age and sex were conducted on each adult cranium following Buikstra and Ubelaker (1994). Cranial modification, age and sex estimations, and porotic lesions were examined using scoring criteria from Buikstra and Ubelaker (1994). All 33 adult crania date to the Late Intermediate Period. Cross tabulations with chi-square significance and linear regression statistical analyses
were run on IBM SPSS Statistics 20 in order to assess the correlation between the observed cranial porosity and cranial modification styles and intensity.

6.3.1 Assessing Cranial Modification

The current literature regarding research on cranial modification lacks consensus on standardized methodology and approaches to identifying variation of modification styles and intensity (described as elongatedness) of skulls (Mendonça de Souza et al. 2005; Blom 1999). This research incorporates an approach combining methods from Kurin (2012) and Blom (1999) as well as cranial vault maximum length measurements to investigate intensity and variation in cranial modification.

Each skull was observed for the presence, style, intensity, and modification type (annular or tabular) and subtype (erect or oblique). Modified and non-modified crania were then given a numerical score based on style and subtype. Modified crania were scored with either “1” for erect or “2” for oblique styles. Any crania that did not display cranial modification were scored with a 0 for not present and removed from the analysis. Next, modified crania were visually grouped into categories by the overall shape of the skull and the modification technique (placement of padding or modification tools at the location of compression on the skull).

Once a skull was identified as erect or oblique, it was further examined to establish the location of placement of the cranial shaping devices that were used to alter the skull shape (Blom 1999:146). This step was part of a scoring process used by Kurin (2012) from Buikstra and Ubelaker (1994). A numerical identification code was established, as in Kurin (2012:112-113), based on the planes of pressure.
As Kurin (2012:113) stated in her example, adding pressure to “6” (lambda) and “7” (above inion) in Figure 3.1 would cause the cranium to form an erect shape, while pressured applied at position “8” (inion) would shape the skull to look oblique. Each code was recorded after visual assessment.

Maximum cranial length, measured using criteria from Buikstra and Ubelaker (1994), was altered for the modified cranial. Maximum length was measured with spreading calipers beginning at glabella and moving posteriorly across the sagittal plane, or where the sagittal plane would be located (some cranial sutures were obliterated), to the most posterior point of the skull.

6.3.2 Age Estimation

Teeth are an important aspect of bioarchaeological research because teeth reflect diet, health, disease, and age-at-death (Buikstra and Ubelaker 1994). They are often the only tissues
available for research due to the structural integrity of dentition, whereas bones are not as
durable and may not be well-preserved in the archaeological record (Buikstra and Ubelaker
1994). Because this study only involves the analysis of crania, a macroscopic method utilizing
dentition for age estimation was adapted from Buikstra and Ubelaker (1994:51). This study is
restricted to included only individuals in post-adolescents with age estimations of 15 or older, as
estimation of sex juveniles (younger than 15 years of age) is undeterminable.

<table>
<thead>
<tr>
<th>Age Code</th>
<th>Age Category</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>YA</td>
<td>Young Adult</td>
<td>15-34 years</td>
</tr>
<tr>
<td>MA</td>
<td>Middle Adult</td>
<td>35-49 years</td>
</tr>
<tr>
<td>OA</td>
<td>Old Adult</td>
<td>50+ years</td>
</tr>
</tbody>
</table>

### 6.3.3 Sex Estimation

Cranial modification practices do not affect sexually dimorphic characteristics on crania
(Torres Rouff 2003). Males and females can display considerable variation in sexually dimorphic
indicators and thus, sexually dimorphic characteristics were used in this study to discern between
male and female individuals (Buikstra and Ubelaker 1994). Typically a mixed method approach
for sex estimation utilizing postcranial skeletal elements, such as the os coxae, would be ideal;
however, due to the disassociation of postcranial elements from commingled excavation
contexts, only cranial features were examined for sex and age determination here.

Cranial morphological scoring system by Acasdi and Nemeskeri (1970) were used to
estimate the sex of each skull (Buikstra and Ubelaker 1994). Indicators for assessing sexually
dimorphic cranial features included the mastoid process, nuchal crest, supra-orbital margin, and
supra-orbital ridge/glabella. Each feature was assigned a score from “1” (very gracile) to “5”
(very robust). When the mandible was present and complete, the gonial angle and mental
eminence were scored using the same system.
Sexually dimorphic features that were damaged from trauma or taphonomic processes were not used in the assessment, only the indicators that were present and complete were used for sex estimation. Coding for sex estimations followed the nomenclature used by Kurin (2012): females were coded (F), probable females (F?) or males (M?), males (M?), and unknown (U).

<table>
<thead>
<tr>
<th>Sex Code</th>
<th>Sex Category</th>
</tr>
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<td>F</td>
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</tr>
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<td>Probable Female</td>
</tr>
<tr>
<td>M</td>
<td>Male</td>
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<tr>
<td>M?</td>
<td>Probable Male</td>
</tr>
<tr>
<td>U</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

6.3.4 Cranial Porosity

Cranial lesions are often used and a pathophysiological indicator of frailty experienced in early childhood (Kieta and Boyce, 2006). As previously discussed, diploe expansion in bone occurs in response to marrow hypertrophy and other pathological conditions such as scurvy, chronic scalp infections, and arguably by pressure from binding or carrying heavy objects during childhood development (Blom et al. 2005; Walker et al. 2009). Methods for assessing cranial porosity in this study were modified from Buikstra and Ubelaker (1994). This approach encompasses location of porosity, degree of porosity, healing, and severity (which indicates observable amount of porosity) on each cranium.
7 RESULTS

7.1 Frequency Results

A total of 34 modified cranial with complete data were analyzed in order to interpret frequency and statistical information. The following table (Table 3) and figure (Figure 14) display the frequency data regarding the percentages of modified cranial intensity as they related to increasing severity of cranial porosity.

Table 3 Chanka and Quichua porosity and modification intensity data (n=34).

<table>
<thead>
<tr>
<th>Porosity Levels</th>
<th>Slight Modification</th>
<th>Moderate Modification</th>
<th>Extreme Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>No porosity</td>
<td>0</td>
<td>0</td>
<td>3%</td>
</tr>
<tr>
<td>Slight porosity</td>
<td>9%</td>
<td>17.6%</td>
<td>11.8%</td>
</tr>
<tr>
<td>Moderate porosity</td>
<td>9%</td>
<td>9%</td>
<td>23.5%</td>
</tr>
<tr>
<td>Severe porosity</td>
<td>0</td>
<td>9%</td>
<td>5.88%</td>
</tr>
</tbody>
</table>

Figure 14 Percentages of levels of modification intensity as they are associated to porosity severity.
Both the Chanka and Quichua modified cranial were sectioned into groups based on the severity of porosity score; Table 4 displays the division of cranial modification intensity and the association with severity of porosity scores.

<table>
<thead>
<tr>
<th>Porosity Scores</th>
<th>Slight Modification</th>
<th>Moderate Modification</th>
<th>Severe Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 15 illustrates a graph of the data from Table 4 which shows that there is not a tight correlation between the increase in severity of cranial porosity and the increase in cranial modification intensity, although there does appear to be an increase in prevalence of porosity beginning at from slight to moderate levels and then there is a steep decline from moderate to severe levels of porosity. Severe forms on cranial modification appear to exhibit all levels of cranial porosity from 0 (no porosity) to 3 (severe porosity). The cranial with moderate modification intensity appear to have more instances of slight porosity (1) than moderate and severe presence of porosity. Crania with the slight form of modification intensity present both slight (1) and moderate (2) cranial porosity. This data suggests that there is not a strong association between increasing severity and cranial modification intensity.
7.1.1 Results for Chanka Groups

The Chanka groups seem to display a very similar pattern to the total Andahuaylas group above when analyzing the relationship between cranial porosity severity and modification intensity, as seen in Table 5 and Figure 16 below. Similar to the combined population sample above, the Chanka groups do not appear to show a significant correlation between porosity and modification intensity however, as the severity levels of porosity increase, more individuals with severe modification appear to be affected by heightened levels of porosity with a steep decline at the severe (3) porosity severity level.

**Figure 15** Cranial porosity severity and modification intensity in Chanka and Quechua groups during the Late Intermediate Period in Andahuaylas, Peru.
### Table 5
Chanka groups cranial porosity and modification intensity data (n=26).

<table>
<thead>
<tr>
<th>Porosity Scores</th>
<th>Slight Modification (1)</th>
<th>Moderate Modification (2)</th>
<th>Severe Modification (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>6</td>
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<td>1</td>
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</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

**Figure 16** Severity of porosity and cranial modification intensity in Chanka groups.

When further analyzing the Chanka data by cranial modification type (oblique and erect), it appears that there is a steady decline in severity of cranial porosity in the oblique style crania, although, overall, there remains to be more oblique style crania with severe porosity than the number of individuals with the erect modification style (Figure 17). Analysis of cranial modification intensity by modification styles suggests that individuals with the oblique style modification exhibit more intense modification than the erect style (Figure 18). This could potentially be the reason why there are more oblique style crania with more severe cranial porosity, or these individuals or their population as a whole may have been under more stress.
Figure 17 Severity of cranial porosity in the Chanka groups.

Figure 18 Intensity of cranial modification in the Chanka groups.
7.1.2 *Quichua Results*

There are no significant patterns that emerge with the Quichua group results. In fact, modification intensity and cranial porosity severity show equal amounts of cranial porosity in the slight, moderate, and severe modification intensity levels. These results are most likely due to the fact that the Quichua group sample size is extremely low and lacks a representative sample group of individuals for this population (Table 6 and Figure 19).

<table>
<thead>
<tr>
<th>Porosity Scores</th>
<th>Slight Modification (1)</th>
<th>Moderate Modification (2)</th>
<th>Severe Modification (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 6** Quichua group n=8.

**Figure 19** Porosity severity scores compared to cranial modification intensity in the Quichua group.
A closer look at the breakdown of the results by cranial modification style for the Quichua population illustrates that porosity severity does not increase as modification intensifies. The data actually suggest that there are an equal number of individuals with oblique and erect styles of modification at each intensity level (slight intensity = 2, moderate intensity = 2, severe intensity = 3). Increasing levels cranial modification intensity consists of an equal number of individuals that are affected with the increases in cranial porosity severity as shown in Figure 20 and Figure 21 below.

![Severity of Porosity for the Quichua Group by Modification Type](image)

*Figure 20* Porosity severity compared to cranial modification type
7.2 Cross Tabulations with Chi Square Significance

In this study, cross tabulations with chi square significance tests were used to statistically elucidate whether or not there is a significant correlation between severity of porosity and intensity of cranial modification. The hypothesis for this study is as follows, there is no correlation between intensity of cranial modification and severity of cranial porosity. Therefore, if the results suggest no significance between the two variables, it would be an indication that the porosity is more likely caused by stress such as the megaloblastic anemia as research by Kurin (2012) suggests. Alternatively, if increased levels of cranial porosity are associated significantly with increased cranial length then: 1) there is a possibility that either individuals with more extreme modified crania suffered from more stress; 2) more pressure or extended processing periods for achieving longer or more extreme modification styles instigates more cranial porosity; 3) the structure of bone becomes compromised under simultaneous stress from health
and cranial compression during the post-natal developmental stages or; 4) binding pressure from deforming apparatuses creates enough pressure to constrict blood flow causing necrosis of bone.

The combined sample of Chanka and Quichua groups displayed no significance between severity of cranial porosity and intensity of cranial modification. However, the level of severity of cranial porosity significantly associate with the intensification (increasing elongation) of cranial modification in the Chanka group sample (Pearson Chi-Square = 40.007, df = 21, p = .007). Therefore, in the Chanka groups in Andahuaylas, chi-square results indicate that the amount of cranial porosity present on crania may actually be associated with the variability in cranial vault elongation from modification practices.

Although the Quichua group is extremely small for statistical analysis, a cross tabulation with chi-square significance was still conducted on this sample and resulted with non-significant (Pearson chi-square =3.450, df = 6, p = .751) associations between cranial modification intensity and severity of cranial porosity. There also appeared to be no significant difference with age or sex in relation to severity or degree of cranial porosity and cranial modification intensity within the populations. Therefore, cranial porosity and cranial modification appear to have equally affected different sex and age group in these populations.

7.3 Linear Regression

A linear regression was used to test the amount of variation accounted for cranial porosity and cranial intensity. The linear regression results indicate that there is no significance relationship between the two variables. There is less than a 1% chance that severity of cranial porosity correlates with cranial modification intensity. Therefore, the linear regression supports the chi-square results for the total population sample. The linear regression results further suggest that the two variables (porosity and modification intensity) are likely not influence by
each other. However, the sample size in this study is very small and may not be representative of
the populations analyzed for this research. There may also be other confounding factors
involved.
8 DISCUSION

8.1 Interpretation of Results

The goal of this research was to elucidate whether observed cranial porosity was a result of health related stress or mechanisms of cranial modification in Chanka and Quichua groups in Andahuaylas, Peru. In order to investigate the possible relationship between the two variables, a cross tabulation with chi square significance test was conducted. The hypothesis of the study, which states that severity of cranial porosity will not significantly correlate with intensity of cranial modification, was supported by the lack of significance from the chi-square results. In addition, the lack of significant results from the linear regression analysis further supports the hypothesis. However, it is important to note the small collective sample size of both the Chanka and Quichua groups used in this study.

The lack of significance from the analyses indicate that: 1) stress was more of a driving force of cranial porosity in the prehistoric groups in Andahuaylas versus the actual process of molding and elongating cranial form to achieve various shapes or styles; 2) external pressure from compression forces applied to crania during the head shaping process may not actually cause diploe expansion in this population as proposed by some scholars or; 3) there are other confounding factors that are affecting the relationship between the two variables, perhaps cranial height and breadth or other variables that influence cranial porosity.

Given the results from this study, the most likely etiology of the cranial porosity is that it occurred as a consequence of stress related factors, whether from disease, unsanitary conditions, structural violence, or stress from increased levels of violence experienced during and after the fragmentation of the Wari state in the Late Intermediate Period. Near significant increases in rates of porotic hyperostosis from the Middle Horizon to the Late Intermediate Period (Kurin
2012), as well as increases in population density and major population shifts in settlement patterns are potentially the factors responsible for increased levels of stress that subsequently resulted in higher rates of porotic cranial lesions.

Aggregation and shifts in population settlements are supported by archaeological material remains in Andahuaylas. Survey work by Kellett (2010) suggests that during the Late Intermediate Period there were transitions in settlements into higher elevation on defensible hilltops and ridges. Archaeological evidence also suggests the presence of protective defense structures that ancient groups constructed through architecture and through the use of the topography in order to surround and protect their communities (Kellett 2010). Significant shifts towards defensive style settlements could be indications of increased conflict. As indicated by Arkush and Tung (2013), nucleation, fortification, and settlement pattern have all been identified as indicators of the result of conflict and threats of attack in the archaeological record. Elevated levels of conflict and violence as demonstrated in research by Kurin 2012, 2014 would heighten population stress levels, as access to essential recourses may be restricted.

These defensive hill-top settlements are presumed to have been crowded with the living and dead, as well as animals and their excrement, all within close proximity of each other (Kurin 2012). With no immediate water sources accessible on hill-top sites in Andahuaylas (Kellett 2010), individuals would have had to travel outside of their protected settlements to retrieve water which would then be stored for prolonged periods of time within the settlement community (Kurin 2012). Stored stagnant water could have become contaminated with various particles, such as human and/or animal waste, which would have also created an environment for various microbial organisms, such as parasites, protozoa, bacteria, and viruses, to thrive (Kurin 2012). Disease and illness would be able to quickly and easily spread through crowded unsanitary living
conditions and infect many individuals. As mentioned previously, hypothesis posited by Kurin 2012, suggests that megaloblastic anemia is the cause of porotic hyperostosis within the Chanka and Quichua groups in Andahuaylas and that cranial modification was ruled out as a result of the cranial porosity observed on the crania. The results of this study support the notion that cranial modification may not be the etiology for the porosity however, this study has limitations. There was no control in place for distinguishing markers for porosity from health related factors versus porosity from non-health related stress.

As discussed previously, some scholars argue that causes of diploe expansion include various forms of anemia, parasitic activity, and disease while others argue that porosity results from osteitis or diagentic alteration (Walker et al 2004) as well as pressure from binding or carrying heavy objects during childhood, and external compression forces from modifying cranial shape (Blom et al. 2005; Mendonça de Souza et al. 2008). Distinguishing between the types of porosity may alter the outcome of the results. Some also argue that size of the pores from diploe expansion, macroporosity as appose to microporosity, is a way to differentiate types of cranial porosity from porotic hyperostosis (microporosity) from macroporosity caused by cranial modification. Yet another debate exists over whether the etiology of cranial porosity can be expressed through morphological differences in the appearance of porosity; whether porosity looks different if caused by scurvy as appose to anemia (Walker et al. 2009; Oxenham 2010).

Another limitation in this study was the sample size of individuals from the Chanka and Quichua groups. The small sample size could potentially affect the statistical results. The two groups were pooled into one for analyses due to the limited number of each sample, particularly with the Quichua group. However, when the cross tabulation with chi-significance was tested on Chanka and Quichua groups independently to investigate whether severity of cranial porosity
was correlated with increased cranial elongation, the Chanka population showed significant correlation (Pearson Chi-Square = 40.007, df = 21, p = .007, N = 28) while the Quichua group showed lack of significance. As mentioned above, perhaps there is some confounding factor/s at play, if not cranial height and breadth perhaps amount of force and duration of compression to achieve more pronounced and extreme cranial shapes. Research by Mendonça et al. 2008 showed periosteal reaction on the outer table of an infant skull that displayed clear signs of cranial flattening from undergoing cranial modification processing and died during the process. It may be possible that periosteal reactions from bandages, boards, and pads being placed on the skull for extended periods of time could cause the porosity on the external table of the skull and remain through adulthood.

Bioarchaeological and archaeological data indicate that Chanka communities were under greater stress than some of their neighbors such as the Quichua. Chanka individuals, according to the bioarchaeological data, experience high rates of cranial injuries particularly lethal injuries. They also appear to exhibit higher rates of severe cranial porosity as observed in this study and more extreme cranial modification. Increased stress and the external force of compression from cranial modification processes may have a synergistic affect causing increases in amount of porosity. Stress could potentially exacerbate the propagation of cranial porosity during the head shaping process.
9 CONCLUSION

9.1 Concluding Remarks

The variability in Wari rule (indirect versus direct rule) throughout regions of Peru created interesting dynamics during and after the fragmentation of the Wari state. The inconsistency in state authoritative presence, in some ways, contributed to the different ways in which populations reacted to or experienced the aftermath of Wari collapse. Archaeological evidence in Andahuaylas, where Wari employed variable style of authority, show a sharp decline in Wari style ceramics which suggests that there was a swift withdrawal of Wari from the Andahuaylas region shortly after state fragmentation. This was a time period marked by increased conflict as well as the ethnogenesis of Chanka and Quichua groups, the coalescence of numerous of small populations, and implementation of cranial modification as a visible social marker of identity. Shifts in settlement patterning toward aggregated hilltops and high mountain ridges, as well as the use of topography for defensive barriers to protect communities, indicates increased concern for conflict. Bioarchaeological data coincides with the archaeological material remains in that there were increased levels in lethal trauma increasing mortality, particularly in the Chanka communities, as well as increased amounts of surgical procedures in the way of trepanations. In addition to settlement shifts toward higher defensive positions and increased warfare and conflict, there were also changes to subsistence patterns, from agriculture to agropastoralism and a narrowing of dietary diversity.

This study centered on cranial modification intensity and its external effects on cranial bones in populations from Andahuaylas, Peru indicating that the relationship between cranial modification intensity and severity of cranial porosity in this region are not correlated. Findings of this research suggest that cranial porosity is not a consequence of increased intensity of cranial
Modification in prehistoric Chanka and Quichua groups in Andahuaylas. If cranial porosity was a result of the processes of cranial modification, then one would expect that both the Chanka and the Quichua groups would reflect similar patterns of correlation between cranial porosity and cranial modification intensity; therefore both groups should reflect significant results regarding porosity and modification intensity if modification does indeed cause or exacerbate inflammatory processes leading to cranial porosity. Instead, the data suggest alternative patterns in that inflammatory responses stemming ultimately from political and environmental factors as well as crowded, unsanitary living conditions are likelier causes of cranial porosity observed in the sample population.

9.2 Contributions of Research

In the past, researchers focused analysis on cranial modification as an “oddity” but over time the compilation of studies began to reveal a distribution of modification types (Blom 2005:5). As researchers began to link cranial modification to cultural practices, a pattern emerged that showed a range in culturally, geographically, and/or temporally variable styles (Blom 2005). Although studies have continuously and increasingly evolved, few researchers are currently exploring other dimensions of understanding indirect biological consequences of intentional cranial modification cultural practices Mendonça et al. (2008). This study further builds upon current models of cranial modification as well as provides more insight in the current debate over whether porosity observed on modified cranial result from compression forces, nutritional deficiencies, or pathological mechanisms. This research also serves to further contribute to current interpretations of porotic hyperostosis and its etiologies in south-central Andes.
Future goals for this research are: (1) to assess the entire Andahuaylas cranial collection to obtain a much larger sample size which would also provide better representative samples from each population group to better observe any trends or significance between the relationships of the variables; (2) include additional health markers, such as linear enamel hyperplasias, as additional controls for stress related variables to better distinguish between porosity associated with stress, cranial modification, or other factors; (3) attempt to address micro versus macro porosity concerns that are argued to be associated with stress and cranial porosity; (4) integrate innovative technological tools to achieve a more fine-grained differentially diagnoses of the various types of etiologies from observable cranial porosity and; (5) employ alternate statistical tests and categorical groups to interpret data.
REFERENCES


APPENDICES

Appendix A

Appendix A.1 Chanka Chi-square Results

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
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<tbody>
<tr>
<td>Pearson Chi-Square</td>
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<td>.007</td>
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<tr>
<td>Likelihood Ratio</td>
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<tr>
<td>Linear-by-Linear</td>
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<td>.507</td>
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<tr>
<td>Association</td>
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<tr>
<td>N of Valid Cases</td>
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Appendix A.2 Quichua Chi-square Results

<table>
<thead>
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<th>Value</th>
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<tbody>
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<td>Pearson Chi-Square</td>
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Appendix B

Appendix B.1 Linear Regression Output Results

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<th>Std. Deviation</th>
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<tr>
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<tr>
<td>Cranial Mod. Intensity</td>
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### Correlations

<table>
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<td>1.000</td>
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### Model Summary

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<tr>
<td>1</td>
<td>.095&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.009</td>
<td>-.018</td>
<td>.8540</td>
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</tbody>
</table>

<sup>a</sup> Predictors: (Constant), Cranial Modification Intensity  

<sup>b</sup> Dependent Variable: Severity of Porosity