NEOPLASTIC DISEASES IN PRE-HISPANIC ANDEANS: A COMPARATIVE ANALYSIS ON THE EFFECTS OF ALTITUDE BETWEEN THE HIGHLANDS AND COASTAL REGIONS

by

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ABSTRACT

CARITA KAY WESTBROOK. Neoplastic Diseases in Pre-Hispanic Andeans: A Comparative Analysis of the Effects of Altitude Between the Highlands and Coastal Regions. (Under the direction of DR. SARA JUENGST)

This thesis is a comparative review of skeletal elements from coastal and highland regions of Peru to determine if altitude effects the incidence of skeletal cancer formations. Pathological analysis was completed on 372 skeletal elements: 299 elements from coastal regions, and 73 from the highlands. The rate of malignant neoplastic diseases in the highlands is 5.48%, compared to 0.67% within the coastal region, suggesting that incidence of cancer is greater within regions of high altitudes.

Based on the sociocultural lifestyle factors and environment exposure between the coastal and highland areas, it is evident that both regions of the Andes were exposed to the same types of carcinogens. However, amounts of exposure occurred at different levels. Therefore, as exposure to environmental carcinogens occurred at both the coastal and highland regions, with the exception of altitude, this study further supports evidence that altitude is likely the causal factor of the incidence and prevalence of cancer in the Andes.

Further research is suggested to continue gathering data to better define the significance of cancer in the Central Andes and the health and disease load of the Andean populations of the past. In particular, there is a need for highland excavations in search of neoplastic diseases, in an environment free of looting, if possible.

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LIST OF ABBREVIATIONS

NMNH	National Museum of Natural History
MSC	Museum Support Center
WHO	World Health Organization
GLOBOCAN	Global Cancer Observatory
EIP	Early Intermediate Period
LIP	Late Intermediate Period
ENSO	El Niño Southern Oscillation
NPC	Nasopharyngeal Carcinoma

CHAPTER 1: INTRODUCTION

In recent decades, cancer has become a more central focus of paleopathological research, underscoring the idea that the formation of cancer is determined by a multitude of factors: primarily genetics and environment. To determine how environment affects incidence of cancer, analysis among a group with similar genetics would provide the strongest argument for a particular environmental concern. The Andean population provides an excellent opportunity to study the impact of altitude on cancer risk due to the limited genetic variation between groups living at varied altitudes (Valverde et al., 2016; Torres et al., 2018). Even comparing "Andean regions versus Amazonian regions, when data for these regions are combined to form two separate macro data sets, the percentage of genetic variation between these two regions is negligible" (Lewis et al., 2017:172). Accordingly, the Andean population provides an ideal population to determine how altitude affects the incidence and prevalence of neoplastic diseases.

There are different types of neoplastic diseases depending on the type of neoplasm that develops. A neoplasm, often referred to as a tumor, is defined as an abnormal mass of tissue with excessive and uncontrolled growth after cessation of a cellular change (Pérez-Losada, 2010; Roberts and Manchester, 2010; White et al., 2012). A diagnosis of cancer exists in cases of the existence of a malignant neoplasm.

Approximately 80% to 90% of human cancers are due to environmental factors, based on epidemiological evidence (Micozzi, 1991). Similarly, research by Pérez-Losada (2010) indicate that, "[t]he environmental component may play a more essential role in sporadic tumors than in hereditary cancer, and in some cases may over-ride the genetics" (317). High altitude is the most common environmental characteristic in the Andes which may impact the risk of cancer. Areas of high altitude are defined as elevations at 2,000 meters and above, as this is when a body at rest begins to experience hypoxic stress from lack of oxygen (Little, 1981; Weinstein, 2007; Valverde et al., 2015). Although there are an increasing number of paleopathological articles regarding cancer in antiquity, there is a shortage in archaeological comparative studies to determine how the environment effects incidence of cancer in the past (Micozzi, 1991; Klaus, 2016).

Saldana et al., (1973) investigated whether altitude in the Andean region was a causal factor in the incidence of cancer and concluded that altitude induced hypoxia results in the initiation and increased growth of chemodectoma tumors, which are tumors of the carotid body. In addition, recent Ecuadorian population health studies argued that there is risk of developing and dying from cancer as a result of living at high altitudes based on the health and mortality rates in the country (Garrido and Garrido, 2018). However, these studies are biomedical and based on modern human in the present time. To date, there are no known bioarchaeological investigations of how altitude effects the incidence and prevalence of cancer in peoples of the past.

The purpose of this thesis is to provide evidence on how altitude affects the incidence and prevalence of neoplastic diseases in pre-Hispanic peoples living in the highlands and coastal regions of the Andes. Although the Andes are spread across Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela, the focus of this research is on the central Andean region, specifically Peru and Northern Bolivia. To obtain this objective, first I will explain the biological and metabolic responses experienced by the body due to high altitudes, in addition to how cancer can result. Next, I will provide the archaeological setting of the regions and common carcinogenic exposures across the Andes. Then, I will provide analysis of seven case studies, including descriptive interpretation of the osteolytic and osteoblastic reactions on the skeletal elements, including differential diagnosis. Last, I will discuss the likely impact of altitude on the occurrence of cancer for these groups.

CHAPTER 2: BACKGROUND

In this section, I will provide an overview of the biological and metabolic responses of the body when introduced to a hypoxic environment. These bodily responses to hypoxia, more common at higher altitudes, correlate to processes which promote cancer-creating conditions.

High altitude impacts the body in specific ways, mostly due to reduced barometric pressure. The reduction of barometric pressure limits the amount of available oxygen for intake, placing the body into hypoxic stress resulting in a decrease in physical and mental activity (Clegg, 1970; Weinstein, 2007; Pawson and Huicho 2010). The carotid bodies in the neck are responsible for keeping the body's oxygen supply equalized and, as a result, send signals to the brain to increase respiration to reach acclimatization to the environment; this is the premise of The Developmental Adaptation Hypothesis (Beall, 2013). The increase of respiration will provide additional oxygen the body needs, but also increases CO_2. This increase of CO_2 causes an increase of acid in the body, which favors an alkaline state. As a result, the kidneys try to remove the increase of acid, placing additional stress on the renal system. Both of these increased stresses of the carotid and renal system can directly correlate to the instances of chemodectomas and prostate cancer in Andeans (Saldana et al., 1973).

Thus, the physiological changes which result from hypoxia are closely related to instances of cancer. Hypobaric hypoxia is "defined as the decrease in oxygen intake for metabolic processes due to reduced barometric pressure" (Valverde et al., 2015:2). To help the body adapt to hypoxic conditions, hypoxia-inducible factors (HIF) mediate the transcription of genes to allow the body to adapt to the low oxygen environment (Jain et al., 2014). There are three hypoxia inducible factors: HIF-1α, HIF-2α, and HIF-3α. During this process, the heat shock response is activated which is a primary response when the body is under stress. The initiation of the heat shock response activates the nitric oxide production pathway and increases production of nitric oxide. Nitric oxide supports HIF-1α and vice versa which helps to regulate myocardial inflammation while increasing the heart's output. This cyclical production and additional pathway are a cellular response to survive environmental stresses due to hypoxic conditions.

The downfall of this symbiotic relationship, is that HIF-1α is directly correlated with production of cancer cells and metastases via angiogenesis, which enables vascular development from the tumor to other areas of the body, and encourages malignant progression (Höckel and Vaupel, 2001; Calzada and del Peso, 2007; Sahlgren et al., 2008; Jain et al., 2013; Jun et al., 2017). This is based on the conversion of epithelial transitions by genetic notch signaling which is essentially changing the genetic code for tumors to become migratory, instead of non-mobile (Sahlgren, 2008). Importantly, HIF-1α also initiates changes in metabolism, specifically with anaerobic glucose metabolism, which has been suggested to directly correlate to tumor survival. This provides further complications to Andean people, considering during the LIP they already consumed an excessive carbohydrate diet. Thus, making hypoxia the causal factor of cancer in individuals exposed to high altitudes in the Andes.

CHAPTER 3: ARCHAEOLOGICAL SETTING

This chapter will discuss the cultural settings and the risk factors for the varied cultures within the Andean regions of Ancash, Arequipa, Cuzco, El Alto, El Beni, Huancavelica, Ica, Junín, La Libertad, La Paz, and Lima during the Late Intermediate Period (LIP), and the beginning of the Late Horizon. Essentially, the data I analyzed came from the north, central, and southern coastal and highland regions. The purpose is not to provide an in-depth review of each of the cultures within these regions, but to compare and contrast the lifestyle factors and environmental exposures between the coastal regions and highlands. To accomplish this, I will provide general background of the cultural setting of the Central Andes. Then, I will discuss the risk factors associated with the cultural lifestyles and environment exposures, followed by more cultural specifics based on the coastal and highland regions. This will allow for comparison of risk factors and environmental exposures between the coastal and highland regions. If groups of varied altitude ranges have the same types of lifestyle factors and environmental exposures (other than altitude), then altitude can be inferred as the causal of cancer in the Andes.

3.1 Background

The Late Intermediate Period (AD 1000-1479) was known as time of regionalization, meaning there was cultural division amongst the people of the Andes (Quilter, 2014). Arkush (2017) suggests this was due to the failure of old social, political, and economic systems, such as the Wari and Tiwanaku cultural groups, resulting in a change from political centralization to smaller scale communities. Vogel (2017) infers this occurred based on evidence of environmental changes such as flooding and drought on the coastline due to the El Niño Southern Oscillation (ENSO) phenomenon and Jennings (2008) theorized the potential for political collapse because of the lack of ability to prevent or account for the devastating events. Importantly, although the larger polities of the area collapsed, an expansive socioeconomic organization was in place resulting in extensive trade networks known as the vertical archipelago (Quilter, 2014; Marsteller, Zolotova, and Knudson, 2016). Furthermore, the LIP was a time of substantial increase in the production of agricultural foods, goods, materials, and metallurgy at near industrial levels with regional labor specializations (ibid). Fisherman on the coast traded their fish, shellfish, and spondylus for cotton, maize, and other items from the valleys; while people from the highlands went to the coastal regions to trade dried meat, wool, and dried tubers (Pezo-Lanfranco, et. al., 2017). This economic model of trading intersects with associated risk factors of developing cancer as it pertains to the cultural lifestyle factors of food intake and interaction with carcinogens in the Andean environment.

3.2 Risk Factors

Known cancer causing agents exist within the Andes associated with sustenance, cooking methods, sanitation, and environmental carcinogens. The intent is to discuss some of the basic known cancer-causing agents within the Andes that contribute to incidence of cancer, before delving into the specifics of the coastal regions versus the highlands.

An Andean diet consisted of a wide array of agricultural produce, marine resources, and hunted/pastoral meats from the highlands. However, the majority of the diet of Andean societies are based on foods high in carbohydrates (Keatinge, 1988; Gagnon, 2011; Lambert et al., 2012). An increased carbohydrate intake produces an excess of glucose (sugar) providing an ideal environment for neoplastic diseases as sugar molecules are used as a fuel source by abnormal cells, attributing to rapid cancerous cell proliferation. In addition to carbohydrates, most of the agricultural diet consists of starchy foods. Although some starchy foods do have carbohydrates, the importance of this distinction is that starches can increase propensity of cancer. Sugar and starches are part of what is considered an inflammatory diet (Garrido and Garrido, 2018), as they increase the production of pro-inflammatory and inflammatory biomarkers, which are associated with an increased risk for colorectal cancer (ibid). Furthermore, diets highly saturated in meat are known to increase risk of cancer (Nerlich, 2017). Most of the foods consumed require heating, and the cooking methods used to heat food would occur by fire.

Cooking meat via fire either outdoors or indoor hearths provides exposure to carcinogens (Verano, 1997; Nerlich, 2017). Notably, indoor hearth usage provides greater carcinogenic exposure due to the increased smoke inhalation in a confined space (Nerlich, 2017). Firing of pottery during the LIP increased as pottery production increased significantly (Quilter, 2014), which would have resulted in further smoke inhalation. Another method of smoke inhalation occurred from smoking, while uncommon during pre-Hispanic times, evidence in Chile indicates possibility and an additional exposure to carcinogens (Echeverría, 2014; Nerlich, 2017). The adapted diet and associated open fire cooking methods, are not the only afflictions experienced that would attribute to a neoplastic risk factor; sanitation also plays a role in the chronic stress placed on Andeans.

A sedentary lifestyle can be detrimental to the health of the community as unsanitary living conditions and contaminated water resources can occur from increased population growth (Verano 1997) and concentrations of natural occurring metals (Nerlich, 2017). The close proximity of a population increases sewage, which if not properly managed can contaminate water sources, and become a vector for exposure to additional diseases and pathogens. Andean settlements were associated with bacterial and protozoan diseases such as Carrion's disease and Chagas disease (Verano 1997; Blom et al. 2005). In addition, unsanitary conditions combined with a damp climate, exacerbated pathogens such as pinworms, hookworms, tapeworms, and many others (ibid). Although these factors may not be indicative of cancer-causing agents, the increased biotic stress placed on the body by varied diseases can provide an environment more suitable for the incidence of neoplasms to occur (Höckel and Vaupel 2001; Liu et al. 2008; Klaus 2009; Sahlgren et al. 2008; Valverde et al. 2015; Jun et al. 2017; Ewald 2018). Instead, these should be considered contributing factors, which could make the body more susceptible to the development of neoplastic diseases. Additionally, contaminated water sources, resulting from human behaviors, such as increased mining for metals, or local environmental variation, can be a direct or indirect cause of carcinogen exposure, such as arsenic and lead (Verano 1997). Heavy metal concentrations such as mercury, arsenic, and lead in the past may have existed at levels greater than current concentrations, further increasing contact with carcinogens and the likelihood of tumor development (Nerlich 2017). The associated risk factors as described above all contribute to the incidence and prevalence of neoplastic diseases in Andeans.

3.3 Coastal Regions

The north, central, and southern coasts were included in the data population. From the north coast, skeletal elements originated from Chicama in the La Libertad region. The culture in Chicama was known as the Chimú or the Chimor State (Quilter, 2014). The Chimú had an expansive polity control on the north coast and controlled trade of spondylus shells, which were a commodity of prestige. As this was a coastal location, the diet was heavy in marine resources (Covey, 2008), and agricultural products such as maize. In addition, consumption of *chicha* (maize beer) was prevalent (Vogel, 2017). Evidence of textiles, silver plates, production of adobe bricks, shell beads, spondylus, silverwork, with gold and other metals existed, reflecting the types of exposures to environmental materials (Quilter 2014; Vogel, 2017). Furthermore, the north coast was known for the melting of metals for metallurgy, known as smelting, which would have increased carcinogen exposure, which was not common as most of smelting occurred in the highland regions (Lechtman, 1991).

The central coast cities of Pachacamac, Anchicaya, Chillón, Huacho, and Pasamayo within the Lima region were included in the data population; the majority coming from Pachacamac. Pachacamac was home to the Ychsma, during the LIP, while the other settlement areas were home to the Chancay. As they resided on the coast, their main source of sustenance was marine based, and their dried fish was traded for agricultural goods from the inland valleys (Marsteller, Zolotova, and Knudson, 2006). Agricultural foods such as legumes, corn, sugar cane, sorghum, amaranth, saltbush, and a wide variety of meats were consumed (ibid). In addition, fruits, peppers, and various tubers were eaten and *chicha* was consumed (Pezo-Lanfranco, 2016). Specialization of the central coast consisted of fishing, utilitarian ceramics, textile production, shell working, and metallurgy (Marsteller, Zolotova, and Knudson, 2006; Covey, 2008; Quilter, 2014).

The southern coast (valley) data samples were from Nazca in the Ica region in addition to Chaviña and Huarato from Arequipa, belonging to the Tisa culture. Agriculture and farming were the central economic activity in the southern valleys, in addition to the fishing on the coast (Quilter, 2014). The southern coast experienced an increase in number and size of settlements as the population was at its highest during the LIP (Conlee, 2005, Quilter, 2014). Labor specializations consisted of pottery, weaving, farming, and fishing (ibid). Additionally, materials found in the south coast consisted of obsidian from highlands, spondylus, ground stone, and ceramics. Although, the quality of ceramics decreased from previous fine polychrome to allow for an increase in production (Conlee, 2005). Due to intense trading along the coastline, agricultural and faunal foods would have been similar on the coastal ad highland regions (ibid).

3.4 Highland Regions

The northern highland region of Ancash included samples from Huari, Macato (near Huaras), and Copa Chica. Maize agriculture was prominent in the north and central highlands in addition to pastoral duties (Covey, 2008). Sustenance consisted of maize, legumes, tubers, along with *chicha* consumption and coca and lime chewing (Pezo-Lafranco, 2017).

Of the central highlands, data samples came from the region of Junín to include the cities of Caudiville, Chulec-Oroya, Tarmatambo, and cities near and east of La Oroya. The Wanka culture controlled an expansive area of the central highlands. Foods consisted of camelid meat, maize, coca chewing, hot peppers, coca, and other agricultural tubers (Quilter, 2014; Pezo-Lanfrano, 2017). During the LIP, in the Wanka II period, they experienced a large population increase which would have presented additional sanitation concerns. Evidence of obsidian, textiles, and varied metals existed (Quilter, 2014) and known mining and smelting occurred in all areas of the highlands within the Central Andes (Lechtman, 1991).

The southern highland regions included El Alto (Altiplano), El Beni (Magdalena), La Paz (Cachilaya, Takaua Chulpa, Kupa-Pukia Chulpa, Lacaya, and Lake Titicaca), and Cuzco (Cuzco, Pikillaqta, Cusco near San Pedro, and just outside of Cusco). The southern highlands experienced a large amount of agricultural and pastoral diets. Food consumption consisted of maize, excessive amounts of camelids and deer, salt, chili peppers, maize, plus marine resources such as dried fish traded for dried camelid meats. (Dearborn, et al. 1998; Covey, 2008; Arkush, 2017). Coca chewing and *chicha* consumption was prevalent in the southern highlands as well (ibid). A variety of artifacts such as jewelry, metal artifacts. Agricultural tools, needles, and clothing pins were discovered in the southern highlands that determined increased metallurgy in the area (McEwan, 1996; Arkush, 2017).

3.5 Discussion

Based on the sociocultural lifestyle factors and environment exposure between the coastal and highland areas, it is evident that both regions of the Andes were exposed to the same types of carcinogens. However, amounts of exposure may have occurred at different levels.

In general, all Andeans had a carbohydrate dense diet, which consisted of starchy foods, and sugars. In addition, marine resources, and hunted or pastoral meats were consumed. Due to extensive trading, Andeans maintained a diet of variety of foods from all regions, although quantity would vary depending on an individual’s location. For example, Marsteller, et al. (2016), used stable isotopes to show that groups from coastal and valley areas ate the same foods, just in different quantities; higher amounts came from the local region.

The cooking methods for the regions did vary slightly. Coastal regions used open fires, but mainly to heat stones for cooking and drying fish as opposed to the highlands which used indoor hearths (Pezo-Lanfranco 2017). Highlanders using indoor hearths would have a greater exposure to smoke inhalation, however coastal regions would have exposures as well for cooking and firing pottery.

Sanitation concerns existed in both the highland and coastal regions as the LIP was a time of high population density. Increased populations in the highlands and coastal regions would have brought introduction to additional diseases and pathogens providing increased stress. Most importantly, carcinogenic metal exposure would have occurred heavily due to mining labor, environmental exposure, and within water sources. Metals in the highlands included gold, silver, arsenic, bronze, mercury, copper, lead, and tin (Lechtman, 1991; Schultze, et. al., 2016). Exposure to metals would have affected all areas of the Andes, but at varied levels. Applying Marsteller, Zolotova, and Knudson's (2016) theory of levels of consumption depending on locale, you can infer the amount of exposure to metallic carcinogens would have occurred at varied rates depending on the locale. Most importantly, metal carcinogenic exposure occurred in all areas. Although mining occurred in the highlands, it was evidenced that smelting and metallurgy occurred in the coastal regions. Furthermore, metallic seepage into water supplies would have affected highlands and lower valleys and coastal regions due to water run-off.

In summary, although exposure of carcinogens occurred at varied levels, the types of metals they were exposed to were similar. Meaning, Andeans of the coastal and highland regions would have been exposed to the same types of carcinogens. However, the amounts of exposure were at varied concentrations, which provides an excellent population control to determine altitude as a causal factor among people of the Andes.

CHAPTER 4: BIOARCHAEOLOGY OF CANCER

Skeletal cancers can take many forms. Here, I present a differential diagnosis of cancer that originates from bone to contextualize my findings. Tumors can start from tissue within the body and metastasize to bone, such as cases of melanoma, and multiple myeloma.

4.1 Differential Diagnosis

The most common benign neoplastic diseases arising from bone are osteochondromas, osteomas, and osteoid osteomas (Ortner, 2001; Waldron, 2009; Roberts and Manchester, 2010). In addition, the most common malignant neoplastic diseases are osteosarcoma, chondrosarcoma, and Ewing's sarcoma (ibid). Differential diagnosis is used to correctly classify the types of neoplastic diseases in the data set. This section will discuss differential diagnosis of the most common tumors originating from the bone and those covered within this research.

Osteochondroma is the most common benign bone tumor. However, they are not actually tumors, but an incorrect ossification of bone cells in the growth plates from trauma to the muscle (Roberts and Manchester, 2010). As a result, this typically occurs in children during periods of growth, and development stops with the cessation of growth (Ortner, 2003; Roberts and Manchester, 2010). Osteochondroma most commonly occurs in the femur, humerus, and tibia, but can also be located on the foot, hand, and pelvis (Waldron, 2009). These neoplasms present as swelling of the bone and an outward localized expansion of the cancellous bone (cartilage). This occurs because of a reduced or diminished cortex layer, generally towards the end of the bone as this area is closer to the growth plates (Ortner, 2003; Roberts and Manchester, 2010). The swelling occurs due to new bone formation on the outside of the affected skeletal element in a response of the localized outward growth of the osteochondroma.

Osteomas are another common benign bone tumor, often referred to as ivory osteomas or button osteomas. The common discovery of these in the archaeological record are a result of mineral density making the tumor suitable for preservation (Ortner, 2003). These tumors are almost exclusively located on the frontal and parietal bones of the skull and frontal sinus, but can also develop on the mandible, maxilla, and the external auditory meatus of the temporal (Waldron, 2009). There are three varieties of these tumors. The first variety of osteoma is the most common, the button osteoma, and protrudes from the periosteum (outer covering of bone) in a smooth, circular, button like appearance (ibid). The second variety of osteoma is an overgrowth of cortical bone in the bony auditory canal (Ortner, 2003). The last variety of osteoma, occurs in the frontal and paranasal sinuses. The growth is initiated with a mixture of fibrous tissue and woven bone and eventually becomes solid (ibid). Depending on the severity of size, these tumors can severely disfigure the host but otherwise do not usually cause problems.

Osteoid osteomas present as localized swelling of the bone in an outward expansion due to tumor growth within the bone (Roberts and Manchester, 2010). These tumors are most commonly found in the femur and tibia, but also appear on the foot, hand, and humerus (Waldron, 2009). Osteoid osteomas are small, however if the lesion involves the cortex, the bone responds by thickening the inner or outer cortical layer of bone; providing a greater surface response. They can be easily confused with the malignant cancers osteochondroma or chondrosarcoma, depending on the location of the growth expansion.

Chondrosarcomas are another common malignant bone tumor. They are most commonly found in the pelvis and femur but can also occur in the humerus, tibia, ribs, and scapula (Waldron 2009). Typically, these tumors develop in the intra-medullary cavity, but can also arise from the surface of the bone (ibid). These sarcomas are large, bulky tumors that are aggressive and locally invasive. These tumors present as swelling of the bone when development occurs in the medullary cavity. As the tumor enlarges and expands it thins the cortical bone, periosteal reactions occur on the outside of the bone, thickening the bone. When the tumor begins on the surface of the bone the growth presents as clouds or cauliflower in appearance.

Osteosarcoma is the most common primary malignant tumor occurring in bones (Waldron, 2009; Calvert et al., 2012). Growth of this tumor initiates in the bone, protrudes outwards, appearing as either a Codman triangle (elevated bone growth in the shape of a triangle) or a sunburst appearance depending on the location of the tumor (Aufderheide, 1997; Capasso, 2005; Waldron, 2009; Calvert et al., 2012; de Boer and Maat, 2016). These sarcomas are most commonly found in the femur, tibia, and humerus (Waldron, 2009). An example of osteosarcoma is provided by Capasso (2005); as a Peruvian femur dated to 800 BP displayed an osteoblastic response in an outward starburst pattern, similar to the spreading of a thin coral reef. Location sites of this type differ from above, presenting in the pelvis, proximal femur, proximal humerus, and skull (Waldron, 2009).

Ewing’s Sarcoma is the third most common malignant bone tumor. These tumors most commonly occur in the femur, pelvis, and tibia, but also appear in the humerus, fibula, ribs, vertebra, and scapula (Waldron 2009). However, according to (Arrieta et al.

2016), they indicate Ewing's sarcoma occurs in the pelvis most frequently. While osteosarcoma begins from the cortex of the bone, Ewing's sarcoma is initiated at within the bone (DeWitte 2015). It presents as a small round cell tumor, which can grow to produce bony spicules in a sunburst appearance (Ortner 2003). In addition, these outward growths of the tumor can also appear like onion skin (Arrieta et al. 2016). Origination can occur in either the medullary cavity or in the cortical bone (ibid).

Metastatic carcinomas are cancers that originate within the tissue and metastases to the bone. They can be osteolytic, osteoblastic, or a combination of both. (Baraybar and Shimada, 1993; Waldron, 2009). These lesions typically have scalloped edges and occluded diploe, and are frequently located on the cranium (Baraybar and Shimada, 1993; Marks and Hamilton, 2007).

Nasopharyngeal carcinoma (NPC) is common among ancestral communities due to the usage of fires within poorly ventilated areas (Ortner, 2003), or due to toxic fumes from metalworking (Roberts and Manchester, 2010). This is common in children due to primary malignant bone tumors occur during bone growth periods (Ortner, 2003). This squamous cell carcinoma originates within the lateral wall of the nasopharynx, and frequently provides secondary deposits within the facial bones (Mark, 2007). Although Mark disagrees with Ortner in reference to diagnosis of NPC as he indicates that this pathological analysis is highly over referenced and there is not enough evidence to support the theory of occurrences due to usage of cooking fires or exacerbation due to high altitude. Capasso (2005) agrees that a higher occurrence can correlate to a high presence of Epstein-Barr viruses and other chemical compositions that increased cariogenic factors; which is further supported by Kirkpatrick (2018). Typically, examples of NPC display severe destruction of the bone (Capasso, 2005).

Rhabdomyosarcoma occurs in children under 20 (Gerszten and Allison, 2012; Fornaciari, 2017). This rare tumor primarily occurs in the head and the neck and as such there are minimal evidence paleopathological records; in fact, only one example was located in literary research (Capasso, 2004; Halperin, 2004; David and Zimmerman, 2010l Gerszten and Allison, 2012; Fornaciari, 2017). This tumor is typically localized, and surrounding areas are non-destructive (Halperin, 2004; Gerszten and Allison, 2012; Fornaciari, 2017). Furthermore, David and Zimmerman (2010) detail diagnosis as based primarily on age, location of tumor, and the histological picture of the tumor as pleomorphic cells in a loose stroma. In summary, the tumor is made of varied sized cells in the connective tissues and vascular system.

Myelomatosis is also known as multiple myeloma or Kahler's disease is defined as a malignant cancer of the bone marrow plasma cells; consisting of osteoclastic activity with rapid reproduction (Riccomi, et.al., 2019; Roberts and Manchester, 2010). This metastatic plasma cell cancer causes periosteal reactions in bones. It most commonly occurs in the skull, pelvis, and ribs (Waldron, 2009). The lytic reaction eats away holes into the skull or bones without periosteal reaction, and provides a distinct moth-eaten appearance (Waldron, 2009; Riccomi et. al., 2019). Rothschild, Hershkovitz, and Dutour (1998), also describe the appearance of the lesions as space occupying as if something was occupying the cavity of the lesion or as having a punched-out appearance. Risk factors for development include, but are not limited to, metal working, chemical exposure, and ionizing radiation, which would be consistent within the Andean region.

4.2 Archaeology of Andean Cancer

Archaeological cases of cancer in the Andes are relatively rare, most often discussed as a footnote to larger investigations of health in the past. Here I will discuss seven previously identified cases of cancer excavated from coastal regions of Peru, as a comparison for my data. One individual originated from the southern coast near Ilo Peru, while the other six came from different locations within the Lambayeque Valley in the Northern Coast.

An interesting case of osteosarcoma was excavated on the southern coast near the modern city of Ilo, Peru (15 masl). This afflicted person was a female of approximately 30-35 years of age at the time of death and dated to the Chiribaya period (A.D. 1150-1300) (Aufderheide et al. 1997). Due to the cultural burial process of wrapping and tying the remains, the body was well preserved. The right humerus, still partially covered in skin, displayed exposed bony spicules in a starburst pattern, similar to a mini, thinned version of a coral reef, averaging 1.2cm in length (ibid). Measurements taken of the diaphyseal diameter showed an expansion from 2.2cm at the proximal end, to 5cm at the max width of the tumor, narrowing to 3cm at the distal end (ibid). Diagnosis was made based on visual and radiographic inspections of the sunburst pattern of the tumor; in addition to CT scans of the intramedullary cavity, which reflected the common feature of “puffy clouds” of the diaphyseal cortex (ibid). Macroscopic views revealed deep and widened lytic lesions, with a rough spongy texture. Although it was noted that sunburst and onion skin patterns can occur in other cancers, this instance was diagnosed as osteosarcoma based on the limited margins and organized growth (ibid).

The remaining examples are all from the Lambayeque Valley on the northern coast of Peru. During an archaeological project at the eastern perimeter of the temple of Huaca Las Ventanas in Sican, Peru (89 masl), a young to middle-aged adult male presented cavernous lesions on the fifth lumbar vertebrae (Baraybar and Shimada 1993). The lesion is described as a patchwork of bony spicules or flakes/sheets, similar to the pockets you would find in a sponge. The authors argued that this tumor could not have been a primary tumor, benign or malignant, as this tumor produced an osteoblastic response, meaning the spicules were spreading cells that created bone and it moved into the axial skeleton instead of the appendicular skeleton (ibid). Thus, they concluded that the tumor fit the description of a secondary tumor, such as metastatic carcinoma, most likely prostate carcinoma due to the location of the tumor (ibid). Although this is not a common diagnosis for someone of that age in modern times, as high altitude severely affects the carotid bodies and subsequently the renal system, occurrence at a younger age is plausible.

Four cases of possible prostate cancer were discovered in different areas of the Lambayeque Valley. Pathological abnormalities were viewed microscopically, scored, and described based on three characteristics: (1) bone growth or resorption, extend of inward and outer growth, size, and shape; (2) the location of the tumor on the skeleton, and; (3) which skeletal elements are affected by the lesions. These cases were determined to be metastatic prostate cancer based on several factors including: clinical and bioarcheological comparisons, molecular mechanisms of osteoblastic activity, and lesion distribution and progression, which occurs in the disease (ibid). In other words, diagnosis was made based on a holistic visual comparison, where the cancer originates, and where it can spread based on the circulatory system.

The first case was described as a robust male adult, aged between 35-45 years old at time of death, with significant abnormal growth of the lower lumbar region. This individual was recovered from a tomb in El Triunfo (518masl) and dated to the Middle Sicán period (A.D. 900-1050/1100) (Klaus 2016). The lytic lesions are ubiquitous in nature with large anterior bony growths extending laterally from the L3, L4, and L5 vertebrae.

The second case originates from Zarpán (88masl) and also dated in the Middle Sicán period (A.D. 900-1100). This individual was an adult male aged 40- 45+ years at time of death (Klaus 2016). The lesions presented here were a combination of new bone formation and resorption on the anterior and lateral L5 vertebra and the first sacral vertebra (S1). However, the bone resorption completely destroyed the margins between the L5 and S1. The lytic lesions present are deep and wide, easily confused with the nutrient foramen. This individual also showed evidence of (healed) pathological processes including cribra orbitalia and porotic hyperostosis, in addition to active periodontal disease. Although these conditions may not be related to the neoplasm, they can help explain the stress load and immune function of an individual from birth to death, which is important as overall health correlates to the impact of environmental stresses and the possibility of developing cancer.

The third case of prostate cancer from the Lambayeque valley came from an adult male individual excavated from the fishing village of La Caleta de San José (8masl) and dated to the Chimú and Chimú-Inka era (A.D. 1375-1532). The pathology was an amalgamation of new bone formation, bone loss, and osteophytes (bone spurs) growing in the margins of the L2, L3, and L4 vertebrae (ibid). The L5 vertebra also showed mild bone spurs on the superior margin. The external abnormal bone growth on the lumbar vertebrae were placed similar to tightly folded ribbon, portraying curls and pits of bone growth. In addition to the lesions affecting the lumbar vertebrae, this individual showed evidence of severe osteoarthritis, healed rib fractures, and a probable case of tuberculosis.

The fourth case originated from Eten (14masl). This adult male was 35-45 years old at the time of death, and dated to the Early/Middle Colonial period (A.D. 1533-1620). Large osteophytic bone growth was documented on the right superior and left anteroinferior margins of the vertebrae. Furthermore, abnormal bone formation was also present on the anterior surface of the L4 vertebra. In addition to the metastatic cancers present, post-mortem bone degradation occurred from salt, which complicated the diagnosis (although this was a common problem at Eten).

The final case of cancer within the Lambayeque Valley was also excavated from the city of Eten,. This individual was a child, approximately five or six years old, based on the fusion sequence in the vertebral column (Klaus, 2014). Sex was not estimated due to the young age of the child. This child was excavated from a burial in front of an altar at the Chapel of the Divino Niño de Eten, in a secondary burial over existing burials. This is an important distinction in considering how a community felt about the child's death and that this child was part of the community. The skeletal elements for the individual consisted of the right clavicle, right humerus, right and left ulnae, four right ribs, three left ribs, left and right scapulae (Klaus, 2014). In addition, vertebral column elements consisted of T5 thru T11 and L1 thru L5. All elements have evidence of osteoblastic and osteolytic activity of the anterior and posterior metaphyses, combined with extreme porosity and trabecular bone exposure on the borders of the scapulae and neural arches of the vertebrae (ibid). The final diagnosis of probable acute leukemia was based on the locations of the lytic and bone building activities, the age of the child, and the normal pathways of leukemia within the cortex.

All of these instances of malignant cancer in the Andes are located in coastal or valley regions at areas of low altitude. Most of the individuals were adults: with six of the individuals were adults and one was a child. The majority of individuals were estimated to be male: five estimated to be male, one female, and one indeterminate child. This sex ratio may be impacted by the fact that four of the cases were probable prostate cancer, which can only occur in males. Six of the seven came from the north coastal area of Peru. In considering previous discussions about the differences of environmental factors among the coastal areas, the north coast was the only coastal area known for smelting (melting of metals), which many of them are known for their cancerous properties. This increased carcinogenic exposure could possibly be the reason for increased instances of cancer on the northern coast of Peru.

CHAPTER 5: METHODS AND MATERIALS

This section will cover specifics regarding the methods and materials used to complete the research. The topics include data collection, background of the collection, and the methods of analysis used for pathological diagnosis, sex estimation, and age estimation of the individual skeletal elements.

5.1 Data Collection

I collected data February 4-15, 2019 from skeletal remains stored at the National Museum of Natural History, Smithsonian Institution (Washington, D.C.). Using the Peruvian Human Remains Collection, I analyzed 299 bones from the coastal regions and 73 bones from the highlands, totaling 372 skeletal elements. The bones analyzed consisted of crania with and without mandible (N= 196), mandible without associated crania (N= 5), femur (N= 127), humerus (N= 21), fibula, (N= 2) and tibia (N= 21). The majority of elements were crania and femora (Table 1). The focus of skeletal elements consisted of the crania and long bones as they were the most common bones where tumors would occur.

The collection of these elements is the result of looting that occurred in Peru at various archaeological sites and burials. After looting occurred, skeletal element surface collections were recovered by Dr. Aleš Hrdlička during the early 20th century (Ortner, 1999). The archaeological dates for majority of the collection are estimated at AD 1100-1500, but are imprecise as the cultural context was lost because the burials were looted for gold and other valuable objects, and the skeletal remains were tossed aside (ibid). In either case, the collection remains viable for this research as I am looking for evidence of cancer among coastal and highland regions, and singular bones can still tell a story of the health of an individual. The collection I reviewed originated from 31 total sites (Table 2); the majority of sites were located in coastal regions.

5.2 Data Analysis

Method for analysis was based on presence or absence of neoplastic diseases, founded on methods used by Ortner (1999). This was accomplished by: 1). Observing the cortical bone morphology, of all elements, for periosteal reactions consistent with neoplastic lesions per standards established by Ragsdale, Campbell, and Kirkpatrick (2017), as opposed to changes due to taphonomic processes per the standards in place by Buikstra and Ubelaker (1994). Diagnoses were further supported based on bone morphology images and descriptions established by Ortner (2003), Waldron (2009), and Roberts and Manchester (2005). 2) Observing incidences of localized inflammation of bone shafts, resulting in the expansion of the cortical bone per margin guidelines established by Ragsdale, et al. (2017). 3) Lesions were recorded as either absent or present.

Sex was estimated based on the cranial morphology of the nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge/glabella, and mental eminence per the scoring system standards in Buikstra and Ubelaker (1994), developed by Acsadi and Nemeskeri (1970). The sex of the post crania elements was recorded based on sexual dimorphism, and compared against NMNH’s records. This method was necessary because a complete skeletal set was uncommon for the collection, as a result only the skeletal elements most likely to reflect neoplastic diseases were reviewed. Sex was recorded as either male or female, or unknown when a determination could not be made.

Estimates of age were determined by rating cranial suture fusion, epiphyseal union, and dental eruption. Cranial suture fusion was rated following stages established by Meindl and Lovejoy (1985), where adulthood begins as a young adult with the closure of the incisive suture and start of closure in the transverse palatine, and posterior median palatine (Buikstra and Ubelaker, 1994). Epiphyseal union was determined based on ratings developed by Ubelaker (1989) per the following fusions: fusion of the femoral head and greater trochanter to the shaft in addition to the distal femur; fusion of the distal humerus including the medial epicondyle; fusion of the proximal tibia; fusion of the proximal fibula. Dental eruption was rated based on the stages developed by Ubelaker (1989). Age groups of interest were simplified to be adult (20+) or sub-adult (under age 20) due to incomplete skeletal records. The estimated adult age range starts at age 20, as this is the classification of young adult following endocranial and palate sutures listed in Buikstra and Ubelaker and established by Meindl and Lovejoy (1985).

As my sample set was not enormous, a Fisher's Exact test was used to determine if significant patterns of data existed within the coastal and highland regions. Significance was recognized for comparison when $p > 0.05$. The importance of using this test was to provide qualitative statistical data to determine data significance in addition to quantitative calculations of data comparison.

CHAPTER 6: RESULTS

Out of 372 skeletal elements, 299 are from the coastal regions, and 73 are from the highlands (Table 3, 4). Thirteen benign neoplasms were recorded, nine were from the coastal area and four originated from the highlands. The coastal region had one example of osteochondroma on a femur, three examples of button osteomas of the crania, and five individuals with extoses of the external auditory meatus. In the highland region, all four individuals had extoses of the external auditory meatus.

The coastal region contained 11 elements out of 299 total observed elements (3.68%) (ten crania and one femur) with neoplastic disease. This included ten crania and one femur (Table 4). Of the 11 elements in the coastal area, eight crania and one femur have benign neoplasms, while two crania present with malignant cancer. The incidence of malignant cancers of the coastal region was 0.67% (Table 5). Of those with malignant cancer, one was estimated to be an adult male and one was estimated to be an adult female.

From the highland sample, eight crania out of 73 total observed elements (10.96%) displayed evidence of neoplastic diseases (Table 4). All impacted individuals were estimated to be female, one sub-adult and seven adults. Of the eight crania with neoplastic disease, four are benign, and four are malignant. The incidence of malignant cancers of the highland sample at 5.48% (Table 5). Based on a Fisher's Exact t-test, the significance of the percent of malignancy comparison of coastal versus highlands was statistically significant at $p = 0.015$ (Table 6), with significance valued as $p<.05$.

CHAPTER 7: DISCUSSION

In this chapter, I will discuss the benign and malignant cancers diagnosed in the collection. First, I will discuss why benign cancers, such as auditory exostoses and button osteomas, were documented but ultimately not considered cancerous, as they likely did not impact people's daily lives. Next, I will present a differential diagnosis and in-depth description of each example of malignant cancers identified in the collection. I will describe why these seven skeletal elements were most likely to have cancer.

Instances of neoplastic diseases occurred in both the coastal and highland regions. However, in truly considering altitude as a causal factor of cancer, focus should be on the comparison of malignant neoplastic diseases, as only malignant neoplasms are cancerous. Furthermore, the majority of benign growths documented are debatable as to whether they are considered a neoplasm at all.

According to Frayer (1988) extoses of the external auditory meatus is an abnormal bone growth likely caused by diving in cold waters, or excessive wind exposure while fishing, while Ortner believes the growths are bone reactions as a result of ear infections (Ortner, 2004). Stewart (1979) suggests extoses are a result of a bony response to cholesteatoma, which is a soft tissue tumor. However, this seems highly unlikely as these growths do not seem to occur as the result of metastases and there is no indication of any osteolytic or osteoblastic activity. Frayer's suggestion makes the most sense considering the sociocultural and environmental context in the areas of the Central Andes. In the coastal areas, fishing was common, and diving for spondylus shells was frequent during the LIP and previous periods as it was a highly traded commodity (Quilter, 2014). Within the highland region, occurrence of these extoses are likely because of heavy winds in the mountains, which would have the same types of effects as winds during fishing. Whether these are to be truly considered benign tumors or not, as they are common in both the coastal and highland areas, factoring these types of tumors would not provide any significant data.

Button osteomas are known as benign tumors; however, their presence would not affect quality of life, and they are not malignant tumors. The only benign tumor identified within this research that could have had a dramatic effect on lifestyle would be the osteochondroma. Although this type of tumor is not life threatening, it likely contributed to a life of pain and uncomfortable walking. The addition of this one benign tumor from the coastal region would not have provided a significant difference in the results. Most importantly, benign tumors are not cancerous and determination should not be based on tumors that are not cancerous.

NMNH 21269 (Uncatalogued) is a right femur of a probable adult female from the coastal region of either Chicama or Pachacamac. Age was based on complete fusion on the metaphyses. Slight macro porosity exists at both the proximal distal ends of the femur. In addition, the femoral head has macro porosity, which is not necrotic. A tumor like growth is present on the posterior femoral neck, in between the femoral head and lesser trochanter (Figure 1.1). Cancellous bone in present in the lesion, which is apparent by the bone exposure (Figure 1.2). The femoral neck appears to be lengthened, but is not similar to a femoral neck slippage. Minimal femoral head lippage has occurred on one area, but is not arthritic or diseased (Figure 1.3). As a result of the growth on the femoral neck, the gluteal tuberosity has thickened and lengthened down the shaft. Although this is a common location for metastasis to occur, osteochondroma is likely due to location, cancellous bone in the lesion, and a lack of lytic activity. In addition, comparing this lesion to the bone chart provided by Ragsdale (2017), this lesion exists with the most common location for osteosarcoma, suggesting this is likely a benign osteochondroma. A paleopathological diagnosis was not on record at the Smithsonian for this element.

NMNH 379280 is an adult male from the coastal region of Pasamayo, Peru presents with an area of osteolytic activity on the frontal bone of the cranium. Taphonomic processes are evident on the cranium, yet only this one area on the front bone seems to be affected. The hole in this frontal bone has lytic activity surrounding the hole (Figure 2), which is not common in multiple myeloma. If taphonomic processes were completely to blame, the internal flaking occurring within this hole would most likely not occur. In addition, the lytic activity surrounding the area is darkened which is consistent with other malignant metastatic carcinomas. Paleopathological diagnosis is not on record at the Smithsonian for this element.

NMNH 379293, an adult female originated from the coastal area of Huacho. This individual has several massive holes present with both osteoblastic and osteolytic activity on all areas of the cranium (Figure 3.1-3.8). As these holes contain both osteoblastic and osteolytic activity and not in the typical moth-eaten pattern, and the holes are larger than 1mm this is not likely multiple myeloma. Instead, probable diagnosis is malignant metastatic carcinoma. The Smithsonian has diagnosed this cranium as metastatic carcinoma.

NNMH 226069 is an adult female from the highland region of Tiahuanaco. The cranium present with several osteolytic lesions on all areas of the cranium (Figure 4.1-4.6). Taphonomic processes are present, which possible could explain the exposed areas on the frontal bone. However, the right parietal bone was preserved in soil, and a small lytic lesion could be observed (Figure 4.3). This lesion does appear to be moth-eaten, a typical description of multiple myeloma, however osteoblastic activity is not common in multiple myeloma and this appears heavily on the occipital bone (Figure 4.4, Figure 4.6). Based on the combination of these activities, I suggest diagnosis of malignant metastatic carcinoma. The Smithsonian did not have a diagnosis for this cranium.

NMNH 242535 is an indeterminate child from the highland area of Caudiville, approximately four to five years in age based on dentition (Figure 5.2). The nasal cavity of this child contains a large mass measuring 11.89mm X 6.14 on the right side, and 13.72mm X 6.55mm on the left side (Figure 5.1). The mass is fibrous in nature and interconnected. The continuation of the mass further in the nasal cavity is not evident due to the small size of the foramen magnum. Diagnosis of NPC is unlikely due to the tumor seems to be the primary location, not a secondary deposit, and typically NPC typically causes severe destruction of the surrounding facial structures. Although, the paleopathology of this type of cancer has only documented once, rhabdomyosarcoma meets criteria. The tumor is localized without surrounding destruction (Halperin, 2004; Gerszten and Allison, 2012; Fornaciari, 2017), presented as a mass of connected tissues in the cranium of a child (David and Zimmerman, 2010). Based on a combination of these factors, likely diagnosis is rhabdomyosarcoma, a malignant cancer. The Smithsonian listed diagnosis for this child as myeloma. I disagree with the record, based on my observations, as there were no holes in the cranium, and the combination of factors discussed all meet the criteria for rhabdomyosarcoma. Without access to radiology of this cranium, myeloma could not be supported.

NMNH 242559, is an adult female from the highland region of Caudiville. This cranium presents with several moth-eaten, punched-out lesions over the entire cranium (Figures 6.1-6.7). Trepanation is found on the right parietal bone, and presents the question of how the community would have cared for someone, and medically treat someone with this condition. Based on the appearance of the holes in the cranium, malignant multiple myeloma is probably. The Smithsonian has diagnosed this cranium as having multiple myeloma.

NMNH 242578 is an adult female from the highland region of Cuzco. This cranium has smaller, more defined holes all over the cranium (Figures 7.1-7.6). These holes are also moth-eaten in appearance, and appear to be punched-out. In addition, there is not type of lytic activity occurring. The combination of these factors lends to a probably diagnosis of multiple myeloma. The Smithsonian has diagnosed this cranium as having multiple myeloma.

In summary, out of the seven example discussed above, only six have cancer. From the coastal area, there are two individuals, one adult male and one adult female. In the highland area, there are four individuals, three adult females, and one indeterminate child. In comparing with the existing bioarchaeological records discussed in my literature review, all seven individuals originated from the coastal area, consisting of five adult males, one adult female, and one indeterminate child. Based on comparing these results, it appears that males are more likely to develop cancer in coastal areas, and females are more likely to develop cancer in highland areas, while incidence in children can occur in either altitude level.

CHAPTER 8: CONCLUSIONS

The rate of malignant neoplastic diseases in the highlands is 5.48%, compared to 0.67% within the coastal region, suggesting that incidence of cancer is greater within regions of high altitudes. Based on a Fisher Exact Test the significance of the percent of malignancy comparison of coastal versus highlands was statistically significant at $P = 0.015$, where significance exists when $p < 0.05$. Notably, five out six malignant cancers were female, and all of these cancers were observed in the crania.

Due to the socio-economic cultural model of trading during the Late Intermediate Period, Andeans maintained a diet of a variety of foods high in carbohydrates, sugars, and meat from all regions, although quantity would vary depending on an individual's location. These food types are associated with increased risk of cancer, or fuel for metastases of existing cancers. Associated carcinogenic exposure to smoke inhalation from cooking, smoking, and firing of ceramics, was evident in both coastal and highland regions. In addition, increased populations during the Late Intermediate Period brought concerns of sanitation across the Andes, which would have increased the stress load of the communities. In addition, exposure to metallic carcinogens existed in coastal and highland regions whether by mining, metallurgy, smelting, or water contamination. As access to environmental carcinogens occurred at both the coastal and highland regions, with the exception of altitude, this study further supports evidence that altitude is likely a causal factor of the incidence and prevalence of cancer in the Andes.

Further research is suggested to continue gathering data to better define the significance of cancer in the Central Andes and the health and disease load of the Andean populations of the past. In particular, the need for highland excavations in search of neoplastic diseases, in an environment free of looting, if possible. This will help to determine further archaeological context, and assigned sociocultural gender roles, which may contribute to a shift in the modern-day guidelines of likelihood of cancer type by sex. In addition, it would be interesting to understand the location of these burials compared to others in the community to determine how they treated and cared for within the community.

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APPENDIX A: TABLES

Table 1: Distinct counts of skeletal elements reviewed within varied regions.

Region	Crania	Femur	Fibula	Humerus	Mandible	Tibia	Total
Coastal							**299**
Arequipa	53	46		8	5	1	113
Ica						1	1
La Libertad	2	73	1	9		17	102
Lima	72	7	1	3			83
Highland							**73**
Ancash	3			1			4
Cuzco	5						5
El Alto	4						4
El Beni	1						1
Huancavelica	10	1					11
Junin	32					2	34
La Paz	13						13
Lima	1						1
Total	**196**	**127**	**2**	**21**	**5**	**21**	**372**

Table 2: Table of distinct locations of skeletal elements analyzed.

Burial Location	Total Elements
Acobamba, Huancavelica	11
Altiplano, El Alto	4
Anchicaya, Lima	1
Cachilaya	2
Carhuaz/Copa Chica	2
Caudiville, Junín	20
Chaviña	107
Chicama	102
Chillon, Lima	2
Chulec-Oroya	3
Cuzco	4
Huacho	3
Huarato, Peru	6
Huari	1
Kupa-Pukia Chulpa, La Paz	1
La Oroya	7
Lacaya, La Paz	1
Lake Titicaca	3
Macato/Huaras	1
Magdalena, El Beni	1
Nazca	1
Pachacamac	72
Pasamayo	6
Pikillaqta, Quispicanchi Prc	1
Quiterada, Junin	1
Takaua Culpa, La Paz	2
Tarmatambo, Peru	3
Tiahuanaco	4
Total	**372**

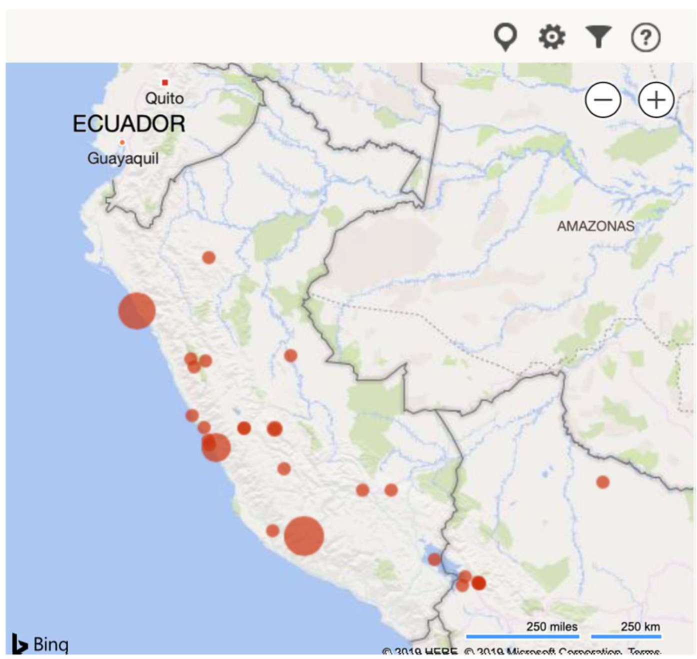

Table 3: Table of geographic locations with presence of benign and malignant neoplastic diseases.

Burial Location	Benign	Malignant
Acobamba	1	
Caudiville, Junín	2	2
Chaviña	1	
Chicama	2	
Cuzco		1
Huacho		1
Lake Titicaca	1	
Pachacamac	6	
Pasamayo		1
Tiahuanaco		1
Total	**13**	**6**

Table 4: Results of geographic comparison of absence versus presence of benign and malignant neoplastic diseases.

Region	Absence	Benign	Malignant
Coastal	96.32%	3.01%	0.67%
Highland	89.04%	5.48%	5.48%

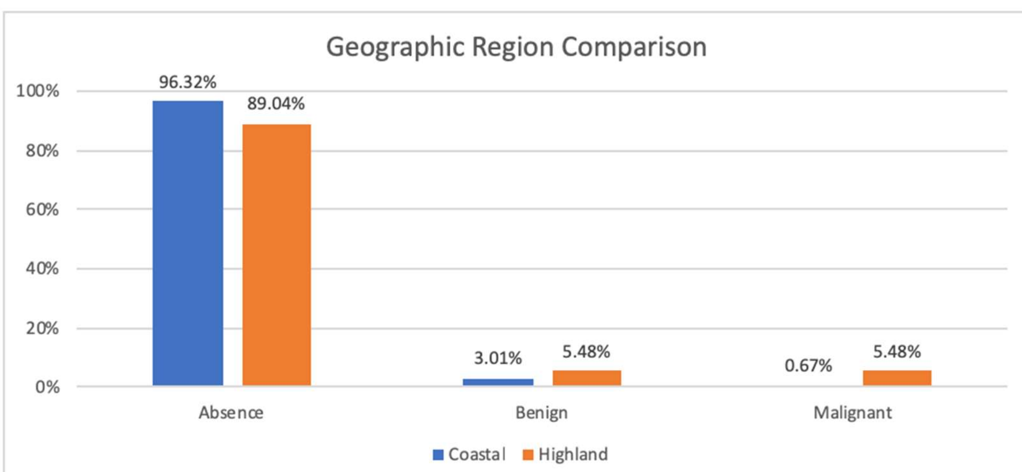

Table 5: Total counts of data reviewed within the Andean regions and incidences of neoplastic diseases.

Geographic Region	Total Elements Reviewed	Total Incidents Found	Total Incidents Benign	Total Incidents Malignant	Percent of Malignancy Within Region
Coastal	299	11	9	2	0.67%
Highland	73	8	4	4	5.48%
Total	**372**	**19**	**13**	**6**	

Table 6: Total of absence and presence of neoplastic diseases per sex.

Sex	Absent	Benign	Malignant	Total
Coastal				**299**
Female	83	3	1	87
Male	139	6	1	146
Unknown	66			66
Highland				**73**
Female	20		4	24
Male	36	4		40
Unknown	9			9
Total	**353**	**13**	**6**	**372**

APPENDIX B: FIGURES

Figure 1.1. NMNH 21269. Chicama or Pachacamac, Peru. Right femur. Proximal posterior view.

Figure 1.2. NMNH 21269. Chicama or Pachacamac, Peru. Right femur. Medial posterior view.


Figure 1.3. NMNH 21269. Chicama or Pachacamac, Peru. R femur. Lateral anterior view.


Figure 2. NMNH 379280. Pasamayo, Peru. Superior cranial view.

Figure 3.1. NMNH 379293. Huacho, Peru. Anterior view.

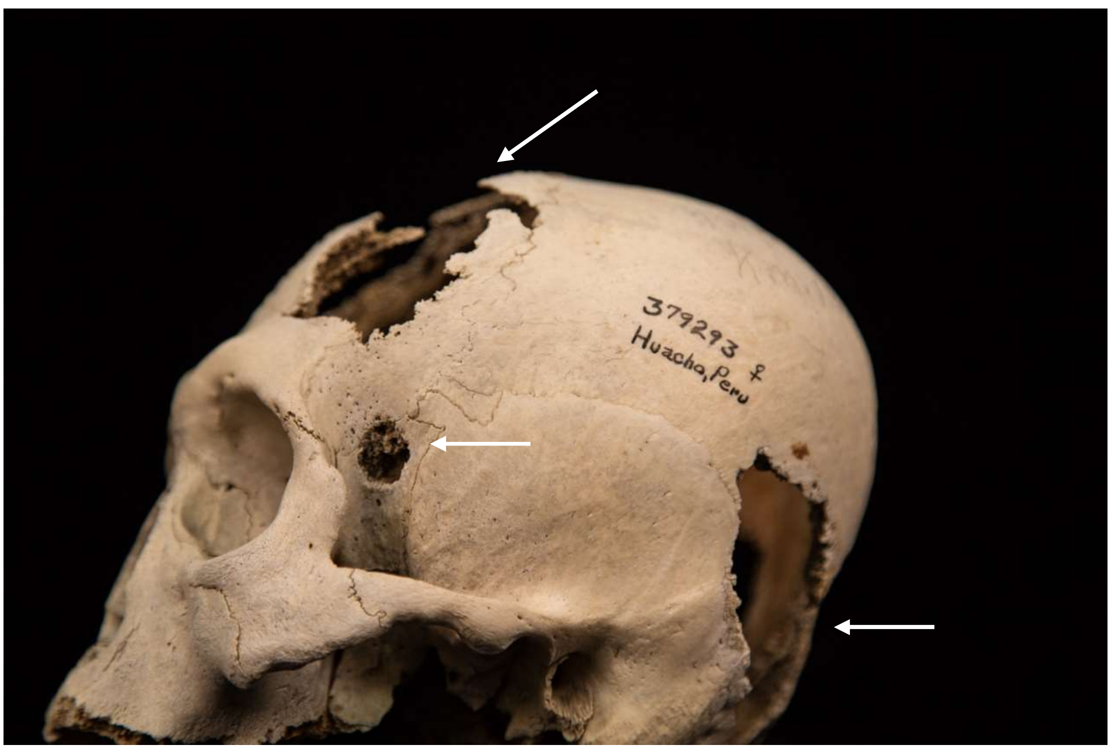

Figure 3.2. NMNH 379293. Huacho, Peru. Left lateral view.

Figure 3.3. NMNH 379293. Huacho, Peru. Left and posterior view.

Figure 3.4. NMNH 379293. Huacho, Peru. Right lateral view.

Figure 3.5. NMNH 379293. Huacho, Peru. Right and posterior view.

Figure 3.6. NMNH 379293. Huacho, Peru. Inferior view.

Figure 3.7. NMNH 379293. Huacho, Peru. Superior cranial view.

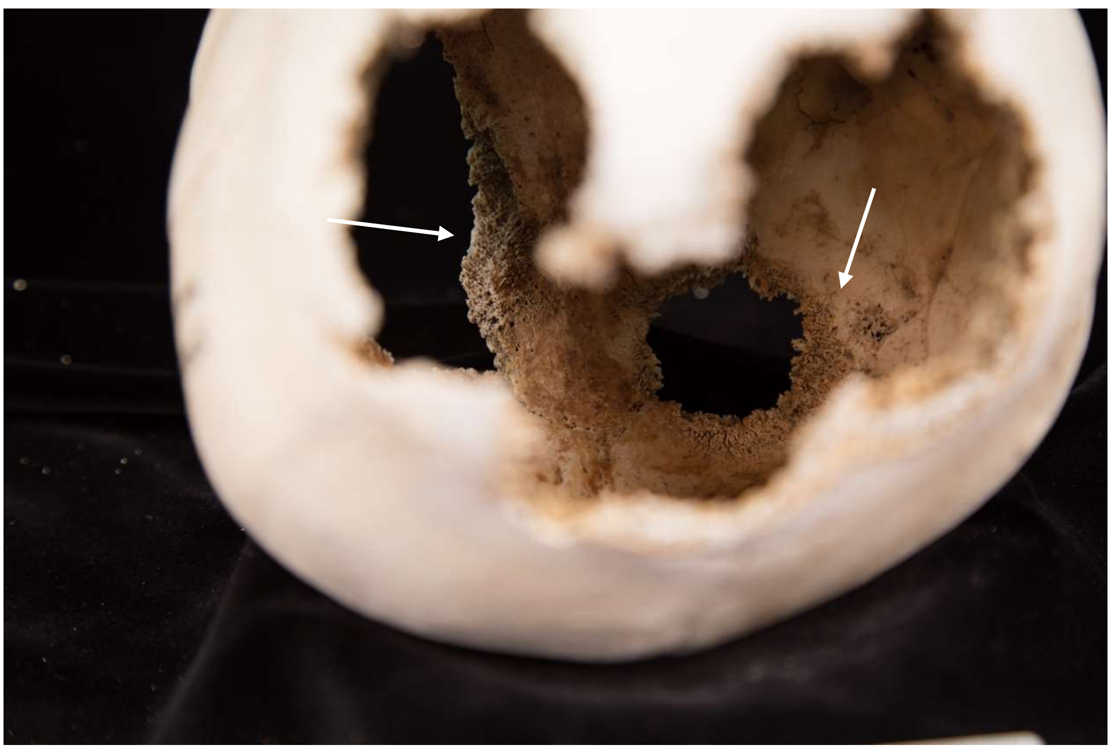

Figure 3.8. NMNH 379293. Huacho, Peru. Internal cranium view.

Figure 4.1. NMNH 226069. Tiahuanaco, Bolivia. Anterior view.

Figure 4.2. NMNH 226069. Tiahuanaco, Bolivia. Anterior view (close).

Figure 4.3. NMNH 226069. Tiahuanaco, Bolivia. Right lateral view.

Figure 4.4. NMNH 226069. Tiahuanaco, Bolivia. Right lateral posterior view.

Figure 4.5. NMNH 226069. Tiahuanaco, Bolivia. Left lateral view.

Figure 4.6. NMNH 226069. Tiahuanaco, Bolivia. Posterior view.

Figure 5.1 NMNH 242535. Caudiville, Peru. Anterior view.

Figure 5.2 NMNH 242535. Caudiville, Peru. Inferior view.

Figure 6.1. NMNH 242559. Caudiville, Peru. Anterior view.

Figure 6.2 NMNH 242559. Caudiville, Peru. Right lateral view.

Figure 6.3. NMNH 242559. Caudiville, Peru. Right lateral posterior view.

Figure 6.4 NMNH 242559. Caudiville, Peru. Left lateral view.

Figure 6.5. NMNH 242559. Caudiville, Peru. Posterior view.

Figure 6.6. NMNH 242559. Caudiville, Peru. Superior cranial view.

Figure 6.7. NMNH 242559. Caudiville, Peru. Inferior view.

Figure 7.1. NMNH 242578. Cuzco, Peru. Anterior view.

Figure 7.2. NMNH 242578. Cuzco, Peru. Left lateral view.

Figure 7.3. NMNH 242578. Cuzco, Peru. Right lateral view.

Figure 7.4. NMNH 242578. Cuzco, Peru. Posterior view.

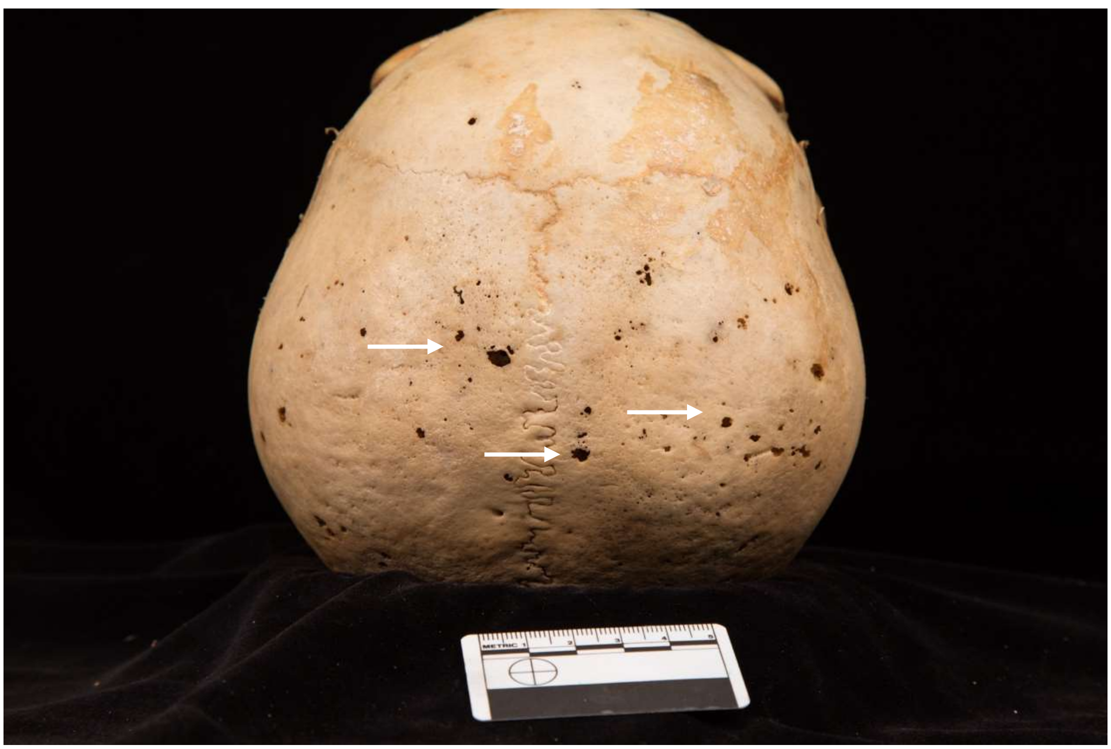

Figure 7.5. NMNH 242578. Cuzco, Peru. Superior view.

Figure 7.6. NMNH 242578. Cuzco, Peru. Inferior view.