EXPLORING QUALITY OF LIFE AT PETRA THROUGH PALEOPATHOLOGY

By

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The ancient city of Petra, Jordan was home to the capital of the Nabataean kingdom from approximately the 3rd or 2nd century B.C. to 106 A.D. During the 1st century B.C. and A.D, Petra prospered as an urban trade center as evident by its massive rock-cut architecture. Although archaeological work at the site has been ongoing since the early 1900s, much of this work has focused on Petra's architecture leaving much to be discovered about people's daily lives, particularly, the lives of the non-elites. This research project aims to uncover the health of a group of non-elites buried along Petra's North Ridge using paleopathology. First excavated in 1994, the North Ridge contains churches, domestic structures, and shaft tombs dated from the 1st-4th century A.D. In 2012 Megan Perry and S. Thomas Parker excavated three 1st century A.D. shaft tombs, two of which contained a minimum number of 28 individuals. During this study, a thorough inventory and pathological analysis was conducted on these remains. Afterwards, the pathology data collected from these 28 individuals was combined with data from previous studies on the North Ridge to bring the sample size up to 64 skeletons. These results were then compared statistically to other contemporaneous samples from varying settlement types using chi-square tests. The North Ridge remains were found to contain a surprisingly low level of chronic diseases and malnutrition in comparison to other urban samples. This may indicate that Petra's inhabitants experienced better nutrition and sanitation than previously associated with

most ancient cities. However, the results of this study are preliminary and require further study, particularly, improved paleodemographic research, before they can be confirmed.

EXPLORING QUALITY OF LIFE AT PETRA THROUGH PALEOPATHOLOGY

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

The ancient city of Petra, located within the southern region of the Hashemite Kingdom of Jordan, has fascinated Western minds since its rediscovery by Johann Ludwig Burckhardt in 1812 (Lewis 2003). Located in a mountainous area east of Wadi Araba, Petra is believed to have served as the capital city of the Nabataean kingdom from roughly the 3rd or 2nd century B.C. to 106 A.D. (see Figure 1). The Nabataeans were a cultural group that inhabited parts of southern Jordan, Israel, and northwest Saudi Arabia (Parr 2003). These individuals shared a distinct language, had their own religious pantheon, and created their own types of pottery, coins and architecture. From the 1st century B.C. through 1st century A.D., Petra flourished due to its involvement in the incense trade, along with agricultural production (Fiema 1996; Graf and Sidebotham 2003). During this time, numerous construction projects were completed within Petra, included monumental tombs, houses, and civil structures (Schmid 2005). In 106 A.D. Nabataean rule came to an end with the annexation of the Kingdom by the Roman Empire.

While archaeological work at Petra has steadily progressed since the early 1900s, there are many remaining questions concerning Petra, one of which is what the quality of life was like for Petra's inhabitants. This research project attempts to explore the quality of life of a group of 1st century A.D. non-elites buried at a section of Petra known as the North Ridge through the use of paleopathology and comparative analysis with regional contemporary sites. For the purpose of this project, quality of life was defined in terms of physical well-being as determined by the presence or absence of disease and diet related pathologies.

Chapter 2 of this work describes what is currently known about Petra from archaeological and historical scholarship as well as discusses how paleopathology can provide additional insight into the health of the city's general population. In addition, Chapter 2 offers a list of predictions expected to be observed within the study sample. In Chapter 3, a description of the skeletal sample used as well as a list of the inventorying and paleopathology procedures followed throughout this study is given. Additionally, descriptions of the 14 comparative samples used during this project are provided. Chapter 4 offers an overview of the pathology frequencies found within the North Ridge sample as well as demonstrates how these disease rates compare to those found within other contemporaneous, regional settlements. Chapter 5 provides a discussion of the various pathology frequencies found within the North Ridge burials and proposes that Petra's non-elite population was healthier than originally predicted. Last, Chapter 6 summarizes the implications of the pathology frequencies found within the North Ridge burials and provides a list of future research endeavors.

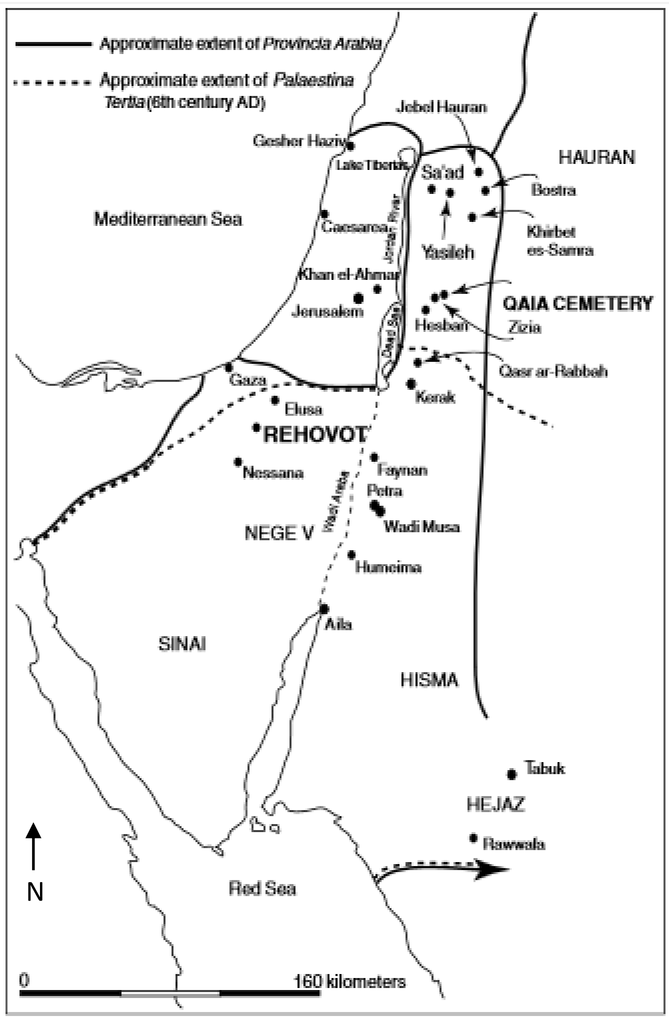

Figure 1. Map of sites mentioned in text. Adapted from Perry (2007)

Background

Although archaeological evidence has helped answer important questions concerning the city of Petra, many aspects of the site remain unknown and a large part of its remains unexcavated. One of the biggest research areas neglected by archaeologists is establishing what daily life was like for Petra's inhabitants, in particular, determining the population's health. The implications of a population's health reach far beyond that of one's exposure to a disease pathogen. Differences in health based on age, sex, subsistence methods, socio-economic status, and daily activities have implications for internal socioeconomic dynamics within a site (Larsen 1997). For this very reason, studies in health and disease provide promising information both to studies of Petra and to the ancient world in general. Determining the disease profile of the remains recovered from Petra's North Ridge helps reveal the range of diseases the population was exposed to as well as help answer questions concerning who in the population was most vulnerable to illness and who suffered the most stress and trauma. Furthermore, regional comparative studies can be informative in how ecology and culture influence health (Larsen 1997). Additionally, whether or not the North Ridge remains exhibit disease markers contributes to the general body of knowledge on life in ancient cities. Through the use of paleopathology, researchers can reveal new insights into what daily life was like for this enigmatic population.

History of the Region

Although Petra served as the capital city of the Nabataeans, most textual sources that reference the Nabataeans are written by the Greeks and Romans (Schmid 2005). The Greek historian Diodorus depicts the Nabataeans of 312 B.C. as nomadic pastoralists located somewhere within central or southern Jordan. Diodorus also mentions a "certain rock," possibly

Petra [*pétra* (πέτρα) means "rock" in ancient Greek], where the women, children, and elderly would stay while the men left for an annual meeting to make trades (*Library of History* 19.94.1; 95.1-97.6). Beyond Diodorus's account and a few inscriptions referencing Nabataean traders, there is little textual evidence linked to the Nabateans before the 1st century B.C. (Wenning 2007).

Given the scarce amount of written data available, archaeology has played an important role in helping fill in the gaps in Petra's history. Establishing the precise date of Nabataean occupation of Petra is a difficult endeavor because there are very few building inscriptions at the site, leaving archaeologists to rely on coins and pottery for chronological information (Parr 2007). Nevertheless, current archaeological evidence suggests that the first permanent settlements within Petra may have developed as early as the 3rd or 2nd century B.C. (Graf et al. 2005; Mouton et al. 2008; Parr 2007). The site additionally may have hosted seasonal dwellers, suggested by a tent settlement at az-Zantur dated by Stucky (1992) to the end of the 2nd century B.C. The 2nd century B.C. also probably marked increased formal interaction with other realms, indicated by an inscription from the city of Priene in Asia Minor identifying a local ambassador named Moschion who visited Petra in 129 B.C. (Bowersock 1983). By the end of the 1st century B.C. there is evidence of several Nabataean houses varying in size and decoration as well as the emergence of large civil and private construction projects such as temples and elaborate tomb façades (Schmid 2005), denoting the presence of a sedentary population.

Throughout the 1st century B.C. and 1st century A.D. Petra prospered as a caravan city (Fiema 1996; Graf and Sidebotham 2003). Several Greek historians, including Diodorus (*Library of History* XIX .94.4-5), comment specifically on Petra's involvement in the incense trade during this period. Located strategically in between southern Arabia and the

Mediterranean, Petra played a primary role in the transport of frankincense and myrrh from Arabia to the rest of the Mediterranean world (Fiema 1996). In addition to Petra's involvement in trade, the city also was an aromatic production center as seen by the various raw plant products used in ancient perfumes found throughout the area (Johnson 1987), the numerous *unguentaria* produced at Petra (Johnson 1990), as well as from written accounts from Strabo (*Geography* 16.4.26) and Pliny (*Natural History* 12.73). Petra's prosperity can be seen in the various construction projects undertaken during this time period, particularly during the reign of Aretas IV (9 B.C.-40 A.D.), such as the Temple of the Winged Lions, the theatre and houses built at el-Katute, (ez-Zantur (Parr 2007)) and on the North Ridge. Existing structures also underwent dramatic changes as seen by the addition of a theater to the Great Temple Complex during the 1st century A.D. (Joukowsky 2009).

Part of Petra's success is attributed to its sophisticated citywide water distribution system. Located favorably in a valley in the western section of the Jordanian plateau, the city is intercut by wadis which create a natural drainage system during heavy rainfall. In addition, the Nabataeans created an innovative water management system which technologically evolved to meet the city's increasing water demands as the city's population grew (Ortloff 2005). What started out as a simple open channel running through the Siq (the deep canyon leading into the site) evolved into a system of pipelines, dams, and cisterns that ensured a year-round water supply. A large portion of this water supply was piped into the city via springs from surrounding areas (Ortloff 2005). Despite their desert environment, the Nabataeans were so successful at water management that they managed to fill up pools and water gardens such as those found attached to the Great Temple complex, earning their nickname "Masters of the Desert" (Bedal 2002).

Although Petra's city center was not suitable for large scale agriculture, the Nabataeans utilized arable lands surrounding the city to provide food for the city's inhabitants. Evidence from areas such as Jabal ash-Sharāh (Tholbecq 2001) and Umm Rattām (Lindner et al. 2000) suggest that terrace cultivation was used to supply food for Petra. Additionally, Lavento et al. (2007) argues that Jabal Hārūn and its surrounding region were cultivated extensively for Petra's use during the 1st century A.D. This assessment is based on the large amount of 1st and early 2nd century A.D. Nabataean pottery and hydraulic installations found at the site. Given that the land surrounding Jabal Hārūn was of poor quality, Lavento et al. (2007) argues that its use indicates Petra's growth during the 1st century A.D. since the city's demand for food called for even the use of second-rate lands. Crops that are known to have been produced throughout Nabataea consisted of cereals, roots, chick peas, various vegetables, and fruits such as grapes and olives (Oleson 2007). Jacqueline Studer (2007) analyzed faunal remains from ez-Zantur, a domestic area of Petra, and found that the faunal assemblage contained a large quantity of domesticated sheep and goats, and only a small proportion of wild animals, indicating that the Nabataeans were relying on herd animals with little hunting of wild game. Additionally, Studer (2007) documented an increase in pig remains and a decrease in camels from the 1st century B.C. to the 1st century A.D. Given camels' traditional association with nomadism and the amount of time and energy required to raise pigs, Studer suggests this is an indication of Petra's increasing urbanization and sedentism. By the 1st century A.D., Petra had come a long way from its humble beginnings as a temporary tent site.

While it is well established that Petra's economy flourished during the 1st century A.D., it is less obvious as to whether or not this prosperity extended to people's personal lives, particularly in reference to their health. One of the biggest questions this project aims to answer is whether or not the urban intensification of Petra resulted in poor health compared with other non-urban Nabataean sites. Additionally, this project seeks to infer what the Nabataeans' daily lives were like at Petra, particularly the types of activities in which people were involved, what their living conditions were like, and upon what their nutrition was based as indicated by the observable pathologies seen within the study sample. Furthermore, it is hoped that the results of this investigation will broaden researchers' perspectives of ancient cities as a whole and reveal whether or not Petra fits the stereotype of the disease-ridden city.

One way archaeologists can measure health within a given population is through the field of paleopathology, which is the study of diseases in ancient populations. Paleopathology is a multidisciplinary approach that provides a valuable means of studying human remains because it views remains within a biocultural context, that is, both biological and cultural considerations should be taken into account to explain the presence or absence of disease within a given population (Buikstra and Cook 1980). Through this biocultural perspective, paleopathology moves away from mere diagnosis into the realm of answering broader questions of anthropological interest concerning social structure and past lifeways. Additionally, paleopathology allows for the study of a broad range of human illnesses by adopting the medical definition of disease (Grauer 2012). For instance, Stedman's Medical Dictionary (1995) defines disease as "an interruption, cessation, or disorder of body functions, systems or organs." Therefore, evidence of infectious disease, physiological stress, nonspecific infections, degenerative diseases, and trauma, which can all leave an impact on the bones, is taken into consideration during paleopathological studies (Larsen 1997).

Current Paleopathological Research in the Near East

Despite paleopathology's potential value to scholars' understanding of Petra's past, there have been few in-depth paleopathological studies of the ancient Near East as a whole; however, this appears to be changing. For instance, Bikai and Perry (2001) excavated two tombs (MNI=40) at Petra's North Ridge during 1998 and 1999 and observed the remains for pathological conditions. Given that they found a lack of indicators of skeletal stress and/or infectious disease, the authors' research indicates an overall picture of good health for their sample. Grauer and Armelagos (1998) conducted similar bioarchaeological research on the Early Roman (198-63 B.C.) to Early Byzantine (365-400 A.D.) midsize city of Tell Hesban, an archaeological site located 9 km north of Madaba, Jordan. Like Bikai and Perry (2001), their research demonstrates that people living in ancient cities may have had better health than what is expected for an agricultural-based sedentary population based on North American studies. Paleopathological work conducted by Perry (2007) provides additional insight into the health status of ancient, non-sedentary populations such as seen at the Queen Alia International Airport (QAIA cemetery), for smaller agricultural villages such as at Rehovot, as well as for the port city of Aila. As scholarship improves and more paleopathological data is collected from Near Eastern samples, researchers stand to gain a new understanding of life in the ancient Southern Levant. In particular, the addition of data from Petra's North Ridge, and its comparison to data from various ancient settlement types, can provide a more thorough picture of quality of life in the Nabataean capital.

The North Ridge Tombs

The North Ridge section of Petra was first excavated in 1994 by the American Center of Oriental Research. Some archaeological evidence, including military inscriptions and figurines, suggest that the North Ridge may have once served a military function (Bikai 2004). The area also contains churches dating to the 4^{th}-5^{th} centuries A.D., including the Ridge Church and the Blue Chapel, domestic structures dating from 1^{st} – 4^{th} centuries as well as various shaft tombs dating to the 1^{st} century A.D. As previously noted, two tombs named North Ridge Tombs 1 and 2 were excavated during 1998 and 1999 by Bikai and Perry (2001). The human skeletal remains from Tomb 1 did not exhibit any pathological conditions; however, those from Tomb 2 showed signs of degenerative conditions as well as fractures. Overall, the individuals in Tomb 2 appear relatively healthy for the time period (Bikai and Perry 2001). In 2012 Megan Perry and S. Thomas Parker excavated three 1^{st} century A.D. shaft tombs (Tombs B.4, B.5, and B.6) and two domestic structures from the 1^{st} – 4^{th} centuries A.D. on the Petra North Ridge (Figure 2). Tombs B.4 and B.5 will comprise the focus of this study.

Figure 2. Map of the Petra North Ridge. Area B, the location of the tombs excavated in 2012, is indicated by the arrow

The remains recovered from the North Ridge provide a unique opportunity to study the health and lifestyles of Petra's inhabitants. Despite the great amount of research focus given to Petra's monumental tomb facades, excavations of these structures have provided very little information about the people interred there due to the fact that the vast majority are devoid of skeletal remains owing to looting and to their usage as shelter and/or storage facilities overtime (Perry 2002). In contrast, the North Ridge Tombs contain at least 28 individuals from a supposedly non-elite context, given their modest architecture. Artifacts found with the burials such as Nabataean fine painted ware, *unguentaria*, complete lamps, and burnt incense provide unique insight into Nabataean funerary customs as well as chronological information linking the remains to the 1st century A.D. Although the North Ridge burials do not appear to represent the wealthiest, elite segment of Petra's population, their classification as non-elites does not imply that these individuals were impoverished. The fact that these individuals were placed within tombs along with a multitude of material objects suggests that while they might not have been from the top echelons of society, they were also most likely not destitute. Thereby, through the analysis of this skeletal sample, this project will allow a broader understanding of Petra's ordinary occupants.

Paleopathology as a Means for Investigating Ancient Life

To provide a complete picture of health at Petra's North Ridge, researchers must think beyond the likelihood of individuals' exposures and genetic immunity to disease pathogens. In addition, a wide number of environmental factors, both physical and cultural, as well as political-economic factors must be taken into consideration (Goodman 1998; Inhorn and Brown 1990). In particular, people's mobility, methods of food production, available natural resources, social status, and population size can have profound impacts on health and disease. Therefore, given what is known about the inhabitants of the North Ridge, certain assumptions can be made as to the type of pathologies likely to be observed in the available sample.

The frequencies of many infectious conditions theoretically are amplified in urban environments such as Petra. For instance, Oxenham and colleagues (2005) demonstrate in their study of northern Vietnam from the Mid-Holocene to Metal periods an increase in infectious disease over time that they hypothesized could have resulted from greater migration, increased population density, changing agricultural practices, and more sedentism. Similarly, Eshed and colleagues (2010) found an increase in inflammatory diseases in the southern Levant during the transition from nomadic, Natufian hunter-gatherers to settled, aggregated Neolithic farmers. Dense, sedentary populations typically accumulate a large amount of human waste which can foster the conditions needed for parasites to flourish. Additionally, certain diseases such as measles, smallpox, and rubella pose a greater problem to urban settlements than to smaller ones because they require a large population to survive (Armelagos 1990; Barrett et al. 1998; Cohen 1989). Therefore, living in an urban environment such as Petra may have caused people to experience diseases they would not have encountered in the hinterlands. These problems could have been exacerbated by the fact that Petra served as a trade center, bringing in traders from populations with different disease profiles. Thus, Petra's inhabitants would have been exposed to a host of diseases traders and migrants brought with them to the city center.

In addition to problems with infectious disease, it is possible that the inhabitants of the North Ridge experienced nutritional deficiencies, particularly given their apparent reliance on agriculture from surrounding settlements. Oftentimes when societies undergo agricultural intensification, this leads to the consumption of less varied diets which lack essential nutrients, especially if they consist primarily of cereal grains that can prevent the absorption of particular vitamins (Armelagos 1990; Barrett et al. 1998; Cohen 1989). Additionally, given the North Ridge's inhabitants' apparent status as non-elites, it is possible that social stratification could have prevented these individuals from experiencing the same access to food resources as those buried in Petra's more prominent tombs. However, assuming that the individuals buried at the North Ridge consumed a diet similar to that of other inhabitants living at Petra, this possibility may be unlikely given the vast amount of domesticated faunal remains found at ez-Zantur (see Studer 2007) indicating that the population was consuming a significant amount of protein.

Nevertheless, given that poor nutrition can negatively impact the human immune system (see McDade 2005), if the inhabitants of the North Ridge experienced inadequate diets, skeletal indicators of both malnutrition and increased infectious disease are expected to be observed. In particular, periostitis, dental enamel hypoplasias, osteoarthritis, vertebral osteophytosis, osteoporosis, and trauma are recorded in this study as indicators of the population's quality of life. For an in depth look at the codes used, during this study, please consult Buikstra and Ubelaker (1994: 114-115).

While certain infectious diseases such as tuberculosis, treponematosis, and leprosy often leave characteristic skeletal lesions found in archaeological samples, many diseases do not produce specific responses (Larsen 1997). Furthermore, disease diagnosis from skeletal remains is typically determined based on lesion type as well as distribution, making it unwise to assign specific diseases to incomplete or commingled remains (Ortner 2003). Often researchers must rely on other indicators to gauge a population's health. Fortunately, nonspecific pathological conditions can shed light on ancient health despite the fact that they cannot be linked to specific diseases. Periostitis is an inflammatory response that most often occurs when a bone is infected or injured. This causes the formation of woven bone at the site of insult or infection. Eventually, as the bone heals, the woven bone may become incorporated into the underlying cortical bone and will appear smooth and dense (Ortner 2003), resulting in a sclerotic appearance. Periostitis not only increases in frequency in situations with increased infectious disease, such as increased sedentism or population density, but also with nutritional deprivation, as this decreases the immune response to infection (Larsen 1997; McDade 2005). The increase in periostitis with increased sedentism and population density has been documented in many archaeological populations. This shift is particularly acute in New World communities who began relying more on maize agriculture as they became more sedentary. For instance, Lallo and Rose (1979) found that the combined rate of periostitis and osteomyelitis (a more severe form of periostitis which affects the bone marrow) increased from 30.8% to 67.4% from the Late Woodland (1050-1200 A.D.) to the Middle Mississippian (1200-1300 A.D.) period (N=572). During this period, individuals at Dickson Mound were involved in/experienced increased maize consumption, increased population density, increased sedentism, and increased trade interactions with neighboring groups from the Late Woodland to Middle Mississippian period. Given that periostitis can be caused by infectious disease as well as by other insults, researchers should be cautious in their interpretations of illness. However, by combining evidence of periostitis with other skeletal indicators of disease, scholars can begin to elucidate the health status of ancient populations.

Another pathology commonly used to interpret the health status of ancient populations is porotic hyperostosis. Porotic hyperostosis is the appearance of porous, periosteal lesions on the surfaces of the skull in particular, the parietals, eye orbits, and occipital due to red blood cell loss and subsequent marrow hypertrophy (Roberts and Manchester 2005). When the eye orbits are affected, this specific lesion is often referred to as cribra orbitalia. Porotic hyperostosis is typically considered to be a sign of chronic anemia due to iron deficiency or parasitic infection (Larsen 1997). Scholarly research suggests that these lesions are indicative of childhood anemia specifically given that active lesions are most often found in subadult remains and the fact that the cranial vault bones serve as a major center of red blood cell production during childhood and adolescence (Larsen 1997; Walker et al. 2009). However, whether or not iron deficiency is truly the cause of this problem has been debated. For instance, Walker and colleagues (2009) argue that porotic hyperostosis is most likely caused by megaloblastic anemia, a condition linked to vitamin B_{12} deficiency rather than iron. Regardless as to its cause, porotic hyperostosis can reveal important information concerning past lifestyles and behaviors since decreases in the bioavailability of both iron and B_{12} have been linked to similar social and environmental causes such as parasitic disease, poor nutrition, lack of sanitation, and increased sedentism (Larsen 1997; Sullivan 2005; Walker et al. 2009). Therefore, studies of porotic hyperostosis frequencies have the potential to reveal important information concerning the lifestyles of past populations.

Dental pathologies comprise a significant portion of paleopathological data. Given that teeth are very durable and generally preserve well in the bioarchaeological record, teeth have played an important role in providing insight into past populations' health and diet (Langsjoen 1998). One area of particular interest to researchers has been the study of dental enamel hypoplasias. Dental enamel hypoplasias are horizontal grooves that form in the crowns of the teeth, usually the incisors and canines, when amelogenesis is disrupted (Goodman et al. 1980). This disruption is generally acknowledged to be caused by some form of systemic metabolic stress that occurred while the individual was undergoing tooth formation; however, in rare instances, dental enamel hypoplasias can also be caused by localized trauma (Goodman and Rose 1990; King et al. 2002).

Because tooth enamel does not remodel, dental enamel hypoplasias are easily observable in individuals throughout their lives as permanent indicators of childhood stress events. By measuring the distance from the cementum-enamel junction (CEJ) to the dental enamel hypoplasias, researchers can calculate the approximate ages that these dental enamel hypoplasias formed (Goodman et al. 1980). While this method has been criticized for its oversimplification of the tooth formation process (Hillson and Bond 1997; King et al. 2002), in lieu of the use of a scanning electron microscope, this macroscopic method still provides a valuable means of distinguishing possible patterns of chronic stress episodes. Using this data combined with that of other nonspecific stress indicators, researchers can begin to infer the health of ancient populations. For instance, many authors have used the presence of dental enamel hypoplasias to infer relationships amongst people's health status and their nutrition (Goodman et al. 1987, Sawyer and Nwoku 1984), social status (Palubeckaitė et al. 2002), as well as their environment and living conditions (King et al. 2005; Zhou and Coruccini 1998).

Another non-specific disease commonly identified in the bioarchaeological record is osteoarthritis. Osteoarthritis is a degenerative condition that affects synovial joints in the body. Osteoarthritis occurs when the joint tissue's system of breakdown and repair becomes imbalanced (Hunter 2011). This can lead to the loss of articular cartilage between joint surfaces causing direct contact between adjacent bones. Subsequently, this may result in osteophyte formation at joint surfaces and margins, sclerosis of subchondral bone, eburnation, grooves, and/or surface porosity (Jurmain 1999).

Most (80%) cases of osteoarthritis are classified as idiopathic, meaning there is no evident cause (Aufderheide and Rodriguez-Martín 1998). While there is ample evidence to suggest that advanced age plays a primary role in osteoarthritis, there are many other etiological factors linked to the condition, in particular, biochemical changes to the articular cartilage, biomechanical stress, age of onset, genetics, sex, and obesity (Hunter 2011; Jurmain 1999). Although there have been many attempts made to directly link patterns of osteoarthritis to physical behavior, such as the application of repetitive, heavy labor, these studies have produced conflicting results (Jurmain 1999). Therefore, researchers should be cautious in their interpretations of past behavior based on patterns of osteoarthritis in archaeologically derived skeletal samples. Nevertheless, looking for patterns of joints affected on a population level and conducting comparisons amongst different groups may reveal unique intergroup differences suggestive of different lifestyles and behaviors (Jurmain 1999).

Another condition similar to osteoarthritis that specifically affects the vertebral bodies is vertebral osteophytosis. Unlike osteoarthritis which involves synovial joints, vertebral osteophytosis is concerned with the synchondroses of the spine (intervertebral disks), less moveable joints made up of fibrocartilage. Like osteoarthritis, vertebral osteophytosis is a degenerative condition that leads to the breakdown of joint cartilage and causes bony changes to occur in adjacent elements. Common changes include the development of osteophytes on the margins of the vertebral body and Schmorl's nodes, depressions found on the superior or inferior surface of the body (Ortner 2003). Studies have shown that patterns of affected vertebrae appear to be related to the curvature of the spine and the biomechanical stress of bipedalism, with the lumbar vertebrae being most affected and the thoracic vertebrae being the least (Jurmain 1999). While age appears to be a factor in the determination of vertebral osteophytosis, as with osteoarthritis, the exact etiology is not easily distinguishable. This means that researchers should be conservative in their interpretations, particularly in trying to link physical behavior to the condition (Jurmain 1999).

Osteoporosis is an observable degenerative condition that can reveal important information concerning ancient populations. Osteoporosis is a disorder in which bone resorption occurs faster than bone deposition leading to bone mass reduction and increased fracture risk. Elements made up primarily of cancellous bone are most severely inflicted, particularly the vertebral bodies. Other common sites affected include the femoral neck, the ribs, the sternum, and the pelvis (Ortner 2003). Osteoporosis may be caused by age and hormone related changes or as a secondary consequence of other conditions e.g. osteogenesis imperfecta or Paget's disease (Ortner 2003; Stini 1990). In modern populations, this condition disproportionally affects postmenopausal women (Stini 1990); however, whether the same is true for ancient populations is debatable. For instance, in their study of a 1st and 2nd century A.D. sample from the Roman port city of Velia, Beauchesne and Agarwal (2011) found that older women and men showed no statistically significant difference in metacarpal cortical bone loss, indicating that postmenopausal women were no more adversely affected by osteoporosis than men. The authors indicate that biocultural factors such as the women's diet, reproductive history, and daily labor could have decreased their chances of contracting the condition. Lee et al. (1993) reported similar results in their study of the remains of 18th and 19th century females buried at Christ Church, Spitalfields, London showing that the women of Spitalfields experienced less bone loss than modern day females. Regardless as to whether or not women in antiquity were more susceptible than men, evidence of osteoporosis within archaeological samples is valuable since senile individuals are most likely to contract the condition (Ortner 2003). Therefore, if osteoporosis is seen to affect younger individuals, this may reveal important information concerning the population's lifestyle that could be associated with the disease.

Trauma, injury inflicted to bone by an extrinsic object or surface, is a common observation in osteoarchaeological samples that can also help reveal biological and cultural information about past populations. Traumatic injuries can mainly be divided into two broad categories: dislocations and fractures. Dislocations occur when adjacent joint surfaces are moved apart from one another, as is commonly seen in injuries of the shoulder and hip joints. Fractures on the other hand occur when the bone is broken either completely (complete fractures) or with part of the bone left intact (incomplete fractures) (Lovell 1997). Observation of fractures will compose a portion of this study.

Evidence of fractures within archaeological skeletal populations has played an important role in scholar's interpretations of past behavior. By considering the types of fractures produced (e.g. sharp force trauma versus blunt force trauma), the skeletal distribution of the fractures, the timing of the injuries (e.g. antemortem versus perimortem), the age and sex distribution of the affected individuals, as well as sociocultural factors (e.g. historical accounts of interpersonal violence, archaeological evidence of weapons, and considerations of the physical environment) bioarchaeologists can begin to make educated inferences about past lifestyles (Lovell 1997). For instance, in their study of two prehistoric populations in the Pacific Islands (Taumako and Nebira), Scott and Buckley (2010) found evidence of accidental injuries and interpersonal violence based upon the observable pathologies as well as on ethnohistoric information. Injuries found in the postcranial elements of the two samples, such as the presence of a distal fibula fracture suggestive of a twisted ankle, indicate both populations experienced roughly the same amounts of accidental trauma. In contrast, the population at Nebira showed a much higher rate of adult cranial fractures that combined with historical information is indicative of warfare. Similarly, Bikai and Perry (2001) found evidence of fractures in the ribs and distal radii of some of their remains from 1st century A.D. Petra which given the location of the fractures as well as a consideration of Petra's rocky environment, they attributed to accidental falls.

Although skeletal trauma can provide important information concerning past populations, there are a number of factors which can impede the interpretation process. For instance, when scholars attempt to determine the timing of an injury without direct evidence of healing, this can be very difficult to distinguish since neither perimortem nor postmortem injuries result in a repair response. Researchers must instead look for more subtle distinctions such as the appearance of the edges of the fracture as well as the angle at which the bone broke (Jordana et al. 2013; Sauer

1998). This process, as well as identifying trauma in general can be complicated by taphonomic processes such as weathering and scavenger activity which can obscure fracture appearance (Calce and Rogers 2007). Additionally, given that juveniles' bones are in the process of growing, antemortem fractures in subadults may heal and eventually be replaced by new bone as part of the natural growth process leaving behind no visible indicators of injury (Ubelaker and Montaperto 2012). Therefore, while trauma analysis can serve as a useful tool of interpreting past behavior, researchers should be cautious in their analyses and remain cognizant of the fact that a lack of evidence of trauma does not imply an evidence of absence.

Limitations of Paleopathology

Although paleopathology can reveal a wealth of information about human health, it does have limitations. In particular, Wood et al. (1992) identified three important problems researchers face when trying to analyze human remains: demographic nonstationarity, selective mortality, and hidden heterogeneity. Demographic nonstationarity refers to the fact that populations are constantly changing either through the migration of people into and out of a site and/or changes in birth rates and death rates. Consequently, if a population experiences changes in fertility, this could cause life expectancy statistics to more adequately reflect the population's fertility rate as opposed to its mortality profile (Wood et al. 1992). Selective mortality means that the dead population under investigation does not accurately represent the living population from which the remains were derived. Therefore, researchers should be cautious in their interpretations of past population's health when they never have a fully representative sample. Hidden heterogeneity refers to the fact that death is selective, meaning that not everyone in a given population has the same chance of contracting a disease and/or surviving (Wood et al.

1992). Therefore, those who are frailest in a population often die quickly before obtaining skeletal pathologies, whereas those who survive the disease often sustain skeletal lesions. This can cause lesion frequency data to become skewed since the remains that are frailest and healthiest will look essentially the same, that is, they will both be lesion-free (Wood et al. 1992). Theoretical issues such as these require thoughtful consideration and make the use of multiple lines of evidence such as data from historical documents as well as data on diet, migration, lifestyle, and political-economic organization more important than ever.

Some researchers such as Goodman (1993) argue that Wood et al. (1992) exaggerate the challenges faced by paleopathologists. Whereas Wood and his coauthors are primarily concerned with the relationship between individual mortality and disease, Goodman claims that much more important information can be inferred from skeletal pathologies, such as how group level indicators of stress and disease relate to people's daily living. For example, if there was a group of adult skeletons who exhibited signs of poor nutrition, this could possibly be connected to lower work capacity, which could have broader social implications. The way to determine this, according to Goodman, is to look at multiple indicators of health rather than single lesions, consider contextual information concerning the study population, and view health on the group as opposed to the individual level. While these techniques may not completely resolve all of the issues concerning paleopathological interpretations, Goodman argues that paleopathologists are more capable of interpreting the health of past populations than Wood and colleagues would have the public believe. Through the careful consideration of ways to mitigate the inherent issues of working with osteoarchaeological samples, paleopathology can provide valuable information concerning past populations.

This project uses paleopathology to explore the health of a sample of non-elites buried on Petra's North Ridge through the careful analysis of multiple indicators of health and through the comparison of health data collected from several contemporary Nabataean sites. Although determining quality of life from skeletal lesions is a challenging endeavor, by combining this information with knowledge from the historic record, archaeological data, as well as a careful consideration of the physical and political environment, great strides can be made in providing an educated interpretation of the North Ridge inhabitants' past lifestyle.

Hypotheses

Given what is known about 1st century A.D. Petra from current archaeological and historical data, several research hypotheses were proposed for this project:

1) It was predicted that the North Ridge remains would have experienced worse health than contemporaneous agricultural village and rural/nomadic comparative samples. In particular, the North Ridge inhabitants were expected to exhibit higher rates of infectious disease and chronic stress. Given that Petra served as a major trade city during the 1st century A.D., it was assumed that the North Ridge inhabitants would have been exposed to a greater variety of disease pathogens caused by the constant movement of peoples into and out of the city center. Additionally, it was expected that the city's inhabitants would have experienced more crowded, unsanitary living conditions than less urban groups. To validate this prediction, the North Ridge sample was expected to contain frequencies of periostitis, porotic hyperostosis/cribra orbitalia, and dental enamel hypoplasias that were significantly higher than the agricultural village and rural/nomadic comparative samples and statistically similar to that of other urban comparative groups.

2) The North Ridge burials were expected to show rates of degenerative disorders similar to those seen within other urban, contemporaneous groups. Given that osteoarthritis is one of the most frequent pathologies observed within archaeologically derived skeletal remains, it was assumed that the North Ridge burials would exhibit a high rate of this condition in comparison to other pathologies. Additionally, given that osteoarthritis and vertebral osteophytosis have sometimes been linked to behavioral patterns, assuming that the North Ridge inhabitants were participating in the same types of physical activities as other urban dwellers from the time period, it was predicted that the two groups would demonstrate similar patterns of affected joints. Specifically, for this prediction to be true, the North Ridge burials and urban comparative samples should show statistically similar rates of osteoarthritis and vertebral osteophytosis as well as statistically similar patterns of affected joints.
3) It was predicted that the majority of osteoporotic elements found within the North Ridge sample would belong to females, since women are typically more affected by the condition than men. For this assumption to hold true, a statistically higher rate of affected elements from the North Ridge would have to belong to females as opposed to males.
4) The North Ridge remains were expected to exhibit low levels of trauma, particularly, violent trauma, similar to that of other comparative samples. Given that there is no archaeological and/or historical evidence suggesting that Petra was heavily involved in violent conflict during the 1st century A.D., it seemed doubtful that the North Ridge remains would display high rates of fractures. Any fractures potentially found in the sample, were predicted to be accidental. For this to be confirmed, the North Ridge

remains were expected to show statistically similar or lower rates of trauma as observed in comparative urban and agricultural village samples. Additionally, it was predicted that the majority of fractures found within the sample would be healed or healing wounds indicative of accidents.

5) The North Ridge remains were expected to display worse health than elite individuals buried at Petra. This prediction was made under the assumption that a person's social status, as indicated by grave goods and tomb structure, is a direct reflection of that person's access to necessary resources during life. For this assumption to be correct, the North Ridge remains would have to show a statistically higher number of pathologies than the elite remains buried at the site.

Alternatively, if the above research hypotheses do not hold true, it could be argued that the health conditions at the North Ridge were not as dire as predicted. Instead of facing problems with poor sanitation, Petra's inhabitants may have been safe guarded against many harmful, pathogens due to their clean water supply. Additionally, as Studer's (2007) research demonstrates, despite their reliance on agriculture, the North Ridge inhabitants may have enjoyed a varied diet with adequate nutritional content that helped bolster their immune systems. Similarly, if the North Ridge remains do not show drastic differences in health than the elites buried at the site, this could indicate that social status had little to no effect on people's access to life's basic resources. Also, if the North Ridge remains show rates of degenerative conditions, osteoporosis, and trauma different from what is predicted above, this could be an indication of behaviors and social practices that have not been revealed by the historical and archaeological data.

Materials and Methods

The skeletal sample used in this study consists of remains excavated under the direction of Megan Perry and S. Thomas Parker during 2012. These remains were recovered from two first century A.D. rock-cut shaft tombs (Tombs B.4 and B.5) from Petra's North Ridge. It is suspected that natural processes such as flooding and anthropogenic processes contributed to the scattering of skeletal remains within the tombs. Tomb B.4 was excavated in its entirety and found to contain a minimum number of 13 individuals. Tomb B.5 was partially excavated and found to contain a minimum number of 15 individuals. The remains from both tombs (MNI=28) were investigated during this study.

All results were recorded using the procedures outlined in *Standards for Data Collection from Human Skeletal Remains* by Buikstra and Ubelaker (1994). First, a thorough inventory of the skeletal elements was conducted using commingled and complete skeletal inventory forms as appropriate in order to determine the minimum number of individuals represented. During this process, age and sex estimations of the remains were performed when possible. Given the fragmentary nature of the skeletal sample and the fact that there are no standard age or sex estimation techniques developed specifically for the population under study, morphological traits rather than metric traits were primarily used to distinguish age and sex (see Cox and Mays 2000 for further explanation on reliability of metric traits). Furthermore, given the insecure nature of sex estimation techniques for subadults (see Cox and Mays 2000), sex estimations were only applied to adult remains.

When feasible, sex estimates were made using the different morphological features of the os pubis (Phenice 1969) and cranium (Buikstra and Ubelaker 1994). Adult age estimates were made using the morphology of the pubic symphysis and the auricular surface in conjunction with the scoring systems devised by Brooks and Suchey (1990) and Lovejoy et al. (1985) respectively. In addition, fusion of the cranial sutures was recorded using the scoring procedure outlined by Buikstra and Ubelaker (1994). Although dental eruption is generally considered to be the most accurate method of subadult age estimation (Lewis and Garn 1960), few subadult dentitions were present in the sample. Therefore, subadult age estimates were primarily performed by examining stages of epiphyseal fusion of the long bones and stages of primary ossification center fusion of irregular bones using Scheuer and Black (2000). Age estimates of juvenile remains were also determined using skeletal measurements originally devised by Fazekas and Kósa (1978) modified by Buikstra and Ubelaker (1994).

Any skeletal elements identified during the initial inventory process as possibly containing pathologies were pulled aside for later macroscopic and microscopic pathological analysis with a light microscope. Each bone was coded individually on the basis of the element's name, what side of the body it came from, and what section/aspect of the bone was affected, using the same general coding procedure developed by Buikstra and Ubelaker (1994:114-115). Further information concerning the specific type and severity of the skeletal response was recorded according to the type of pathology under study. In particular, the remains were examined for seven different pathologies indicative of general health: periostitis, porotic hyperostosis, osteoarthritis, vertebral osteophytosis, osteoporosis, trauma, and dental enamel hypoplasias. For an in depth look at the codes used during this study, please see Buikstra and Ubelaker (1994:114-115).

Periostitis was documented based on the type of bone formation present on the element's outer surface. This included either woven bone (code 4.1.1), sclerotic reaction (code 4.1.2), or a mixed combination of the two (code 4.1.3). Severity was recorded based upon the percentage of the observable element that was affected as either less than one-third (code 4.6.1), between one-third and two-thirds (code 4.6.2), or greater than two-thirds (code 4.6.3) (Buikstra and Ubelaker 1994).

Possible cases of porotic hyperostosis were scored based on the severity of bone porosity present ranging on a scale from whether the bone porosity was barely visible (code 6.1.1) to whether the bone showed coalescing foramina and thickening (code 6.1.4). Additionally, porotic hyperostosis was recorded based on what section of the bone was affected using codes 6.2.1 to 6.2.5, such as whether or not only the eye orbits contained lesions (6.2.1) or both the eye orbits and near the sutures were pathological (6.2.4). Last, whether or not the lesions were active (code 6.3.1), healed (code 6.3.2) or a mixture of the two (code 6.3.2) was documented (Buikstra and Ubelaker 1994).

Several different features of osteoarthritis were coded for during this study. First, the amount of lipping observed on the margins of the joint surfaces was scored on a scale ranging from barely visible (code 8.1.1) to ankylosis (fusion) (code 8.1.4). Next, evidence of porosity on the joint surface was recorded according to whether or not the pores were pinpoint (code 8.3.1), coalesced (code 8.3.2), or a combination of the two (code 8.3.3). Additionally, eburnation was coded based on its expression, that is, whether it was barely visible (code 8.5.1), contained polish (code 8.5.2), or contained both polish and grooves (code 8.5.3) (Buikstra and Ubelaker 1994). Likewise, evidence of periarticular resorptive foci was documented as either barely visible (code 8.7.1) or clearly observable (code 8.7.2). Each of these features was scored based upon its most severe appearance within a given bone. In addition, each trait was coded for severity based upon what percentage of the joint surface (less than one-third, between one-third and two-thirds, or greater than two-thirds) was affected by a given characteristic. Last, any osteophytes present on the joints' surfaces were scored based on their visibility (codes 8.7.1 and 8.7.2) (Buikstra and Ubelaker 1994). Osteoarthritis was only coded for vertebrae if these characteristics affected the diarthrodial joints. If the vertebral bodies exhibited similar characteristics, this was coded as vertebral osteophytosis.

Vertebral osteophytosis was coded primarily using codes 7.2.1 through 7.2.4 by the maximum expression of osteophytes present on the vertebral bodies. Additionally, any evidence of Schmorl's nodes was recorded based upon its most severe appearance as either barely visible (code 7.1.1), moderate (code 7.1.2), or marked (code 7.1.3) (Buikstra and Ubelaker 1994).

Osteoporosis was first documented using codes 3.1.1 through 3.1.6 according to where on the element bone loss occurred e.g. on a bone's periosteal surface or inside bone trabeculae. Then, the percentage of the observable bone that was affected by osteoporosis was coded as either less than one-third (code 3.2.1), between one-third and two-thirds (code 3.2.2), or greater than two-thirds (code 3.2.3). Last, whether a bone showed signs of cortical thinning (code 3.6.1) or not (code 3.6.2) was recorded (Buikstra and Ubelaker 1994).

Trauma was recorded by fracture type e.g. simple versus comminuted using codes 5.1.1 through 5.1.9. Any fractures suspected of occurring around time of death were coded as either clear perimortem trauma (code 5.3.1) or possible perimortem trauma (code 5.3.2). Antemortem fractures were also scored according to how far along in the healing process they appeared using codes 5.4.1 through 5.4.3, such as whether or not callus formation was evident (Buikstra and Ubelaker 1994).

Dental enamel hypoplasias were documented using the enamel defect recording form seen in Buikstra and Ubelaker (1994). Each tooth containing hypoplasias was listed under what side of the skull it was from, whether it was mandibular or maxillary, and its specific tooth type (e.g. incisor versus canine). Defects were scored on a scale from zero to five to describe their specific hypoplasia types, such as whether they consisted of linear horizontal grooves or linear horizontal pits. When possible, the distance from the occlusal portion of the dental enamel hypoplasias to the cementum-enamel junction was measured to approximate age of hypoplasia formation.

Once all pathology data was recorded, frequencies of observable pathological conditions were calculated by element, joint, or by minimum number of individuals as applicable. This information was then combined with data collected by Bikai and Perry (2001) on Tombs 1 and 2 from the North Ridge for comparison with other contemporaneous samples from the region. This comparative data was analyzed using Chi-square tests using JMP 11 software (Cary, NC). A Bonferroni Correction Test was applied to adjust the significance level to minimize the occurrence of a type-I error.

Comparative samples consisted of 13 sites located in Jordan and Israel from the Nabataean, Roman, and Byzantine era. These sites were divided up and analyzed according to their settlement type i.e. whether the sites were considered to be urban, agricultural villages, or rural/nomadic. In general, the comparative sites classified as rural/nomadic had the lowest prevalence of pathologies followed by agricultural villages, and urban sites. After initial comparisons were made amongst varying settlement groups, a second comparative analysis was conducted between the North Ridge and el-Khubtha, an elite group of burials at Petra, to test for any observable differences related to status.

Four urban samples were used in this analysis, including remains from the city of Jerusalem during the Roman era as well as skeletal material from Tell Hesban, Aila, and el-Khubtha. Like Petra, Tell Hesban and Aila were both located in areas favorable for trade. Tell

Hesban was located at the crossroads of two major trade routes the *via nova Trania* and a Roman road stretching from Livias to Esbus. Aila, located near the Gulf of Aqaba, participated in maritime trade and craft production. The remains from el-Khubtha come from monumental tomb façades within Petra likely containing elite populations that were excavated by Lucy Wadeson and analyzed by Megan Perry.

Data from six agricultural village sites were compared to the North Ridge during this study. These sites included one Nabataean era village located east of Petra, Wadi Musa. Also, two Roman era villages, one of which was located in Israel, Gesher Haziv, and another approximately 100 km north of Petra, Qasr ar-Rabbah, were compared. Two villages spanning from the Roman through the Byzantine era, Yasileh and Sa'ad in northern Jordan, were used in addition to the Byzantine era settlements of Rehovot located in southern Israel and Khirbet es-Samra in northern Jordan.

Two sites classified as rural/nomadic were used within the study Khan el-Ahmar and the Queen Alia International Airport (QAIA). Khan el-Ahmar was located near Jerusalem and contained skeletal remains recovered from the Byzantine era monastery of St. Euthymius. The QAIA was located approximately 25 km south of Amman and is thought to have belonged to a group of pastoral nomads who inhabited the site annually during the summer months.

Whether or not living in an urban environment, such as the North Ridge, has a negative impact on disease will be explored within the coming chapters. Understanding the potential role the social and physical environment plays on disease frequencies can help further elucidate whether or not the idea of the dirty city of antiquity is fictitious. Furthermore, this study will provide valuable insight into the lifeway of an unexplored population.

Results

Given Petra's status in the 1st century A.D. as a caravan city, it is reasonable to assume that the individuals buried along the North Ridge came into frequent contact with traders and immigrants. Additionally, current archaeological and historical evidence suggests that these individuals would have eaten a diet consisting primarily of domesticated animals and plants cultivated from the surrounding hinterlands. Whether or not this lifestyle resulted in poor health was determined by examining skeletal pathologies found within the study sample and comparing them to other regional populations.

The remains from tomb B.4 were found to contain a minimum number of 13 individuals including nine adults and four subadults (Table 1). Of the ten adult skeletons identified, three were identified as male, two as female, one as a possible female, and four were indeterminate. The fragmentary conditions of the remains hindered age estimation of all but one of these adult individuals. This individuals was of unknown sex and determined to be between the ages of 18 and 22. Of the three subadults identified from tomb B.4, the first was a newborn or close to term baby, the second was between two and three years old and the third was between four and six years old.

Tomb B.5 contained at least 15 individuals, 14 of which were identified as adults and one that was determined to be a subadult (Table 1). Out of the 14 adults, six were estimated as male, four as female, and five as unknown. Specific adult age estimations was possible for one of the males, three of the females, and for three of indeterminate sex. The male was found to be between 45 and 50 years of age. One of the females was determined to be approximately 18 to 20 years of age, the second between 25 and 45 years of age, and the third between 35 and 45 years of age. Of the three individuals of indeterminate sex the first was estimated to be greater than 50 years old, the second between 25 and 30 years old, and the third between 30 and 35 years old. The single juvenile found buried within tomb B.5 was between 12 and 13 years old.

Table 1. Minimum Number of Individuals (MNI) Buried in Tombs B.4 and B.5

Age	Indeterminate	Male	Female	Total
New Born	1	--	--	1
1-4	1	--	--	1
5-9	1	--	--	1
10-14	1	--	--	1
15-19	--	--	1	1
20-34	3	--	1	4
35-49	--	--	2	2
50+	1	--	--	1
Adult	5	8	3	16
Total	13	8	7	28

Periostitis

Overall, the skeletal fragments from tombs B.4 and B.5 show few incidences of periostitis. Out of 4,284 total fragments, only 29 (0.7%) show evidence of the infection (Table 2; Appendix A). Of these 29, one appears to come from a subadult individual and the rest from adults. Eighty-three percent of these lesions appear to be active at time of death (reactive woven bone), fourteen percent appear to be in the process of healing (sclerotic reaction) and three percent appear to be both active and healing (woven bone and sclerotic reaction evident) .

Given that many of the elements were commingled in situ, results are reported separately for each of the tombs by skeleton type i.e. commingled or articulated as seen in Figure 3. The majority of fragments in the sample affected by periostitis come from the articulated remains found in tomb B.5 (4% of these fragments affected) in particular, from an adult female (B.5:15 Individual 1) mostly found articulated on the tomb floor. This individual showed evidence of periostitis in her arms (right ulna and both radii) and legs (left femur, right fibula, and both tibiae). Other affected elements found in tomb B.5 include two ribs, a skull fragment, and a femur fragment. Tomb B.4 shows evidence of an affected second metacarpal as well as a sacrum. By looking at the distribution of loci containing elements with periostitis (see Appendix A), it is estimated that a minimum number of five individuals (18% of total sample) show evidence of the infection.

Table 2. Percentage of Skeletal Fragments Affected by Periostitis

Tomb	**N**	**%**
B.4 and B.5 combined	4284	.7
B.4	2285	.1
B.5	1999	1

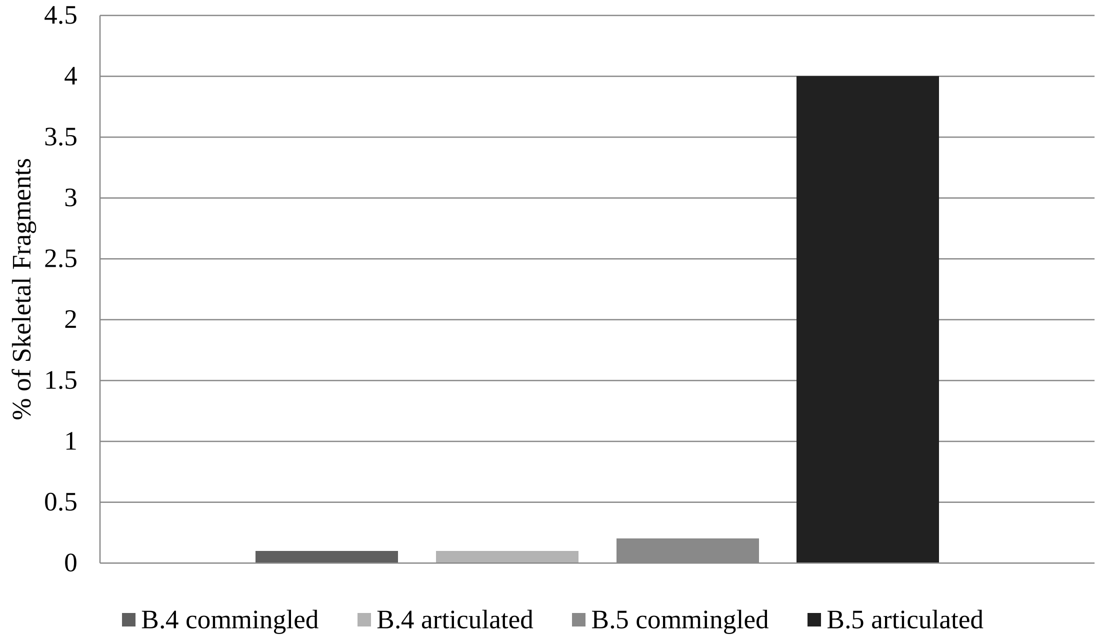

Figure 3. Frequencies of periostitis by subgroup

Porotic Hyperostosis/Cribra Orbitalia

Six-hundred and seventy skull fragments were identified within the study sample. Out of these, none show evidence of porotic hyperostosis or cribra orbitalia. Given that skulls are fairly well represented within tombs B.4 and B.5, this appears to be a reflection of the low amount of acquired anemia within the sample rather than a sampling error.

Osteoarthritis

Osteoarthritis is one of the most commonly observed pathological conditions seen within the North Ridge burials. Fourteen percent of joints within the sample (N=472) show signs of the degenerative disorder (Table 3; Appendix B). All of these joints appear to come from adult individuals. The wrist is the most commonly affected (43%) followed by the foot (22%) and knee (21%).

Table 3. Percentage of Joints Affected by Osteoarthritis from Tombs B.4 and B.5

Joint	**N**	**%**
All	472	14
Shoulder	18	11
Elbow	30	7
Wrist	35	43
Hand	35	17
Hip	21	0
Knee	38	21
Ankle	34	12
Foot	27	22
Cervical	59	15
Thoracic	122	7
Lumbar	49	8
Sacrum	4	0

The remains from tomb B.4 show a higher number of affected joints than the remains from B.5 (Figure 4); however, this difference is insignificant at the 0.0167 significance level (χ^2=2.884, p=.0894). Specifically, the articulated remains from Tomb B.4 show the highest rate of osteoarthritis out of all four subgroups (Figure 5).

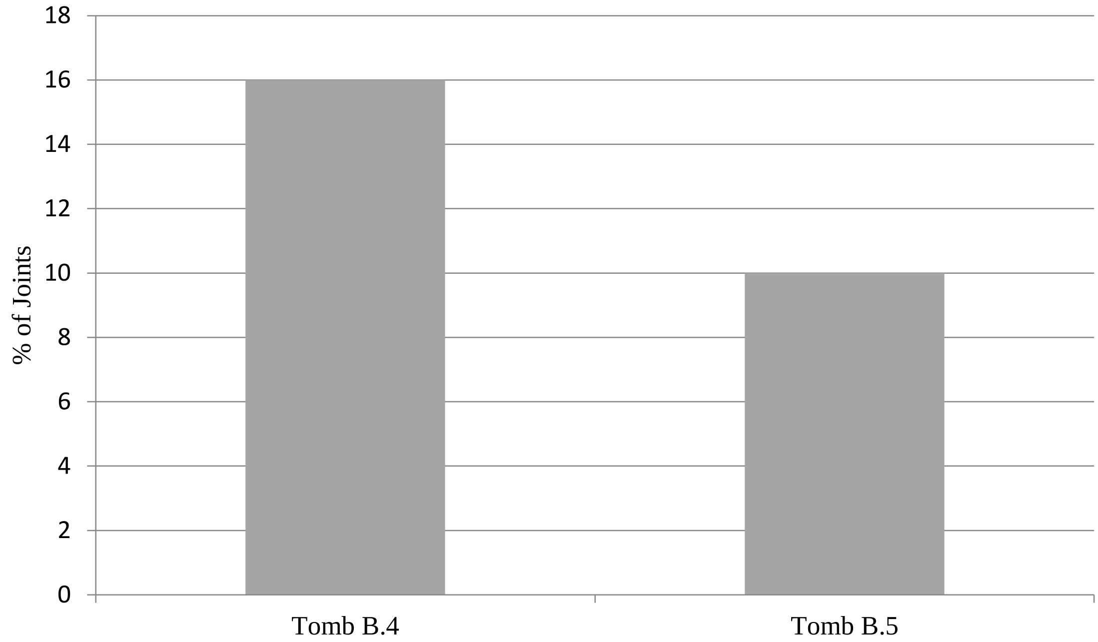

Figure 4. Percentage of joints affected by osteoarthritis in tombs B.4 and B.5

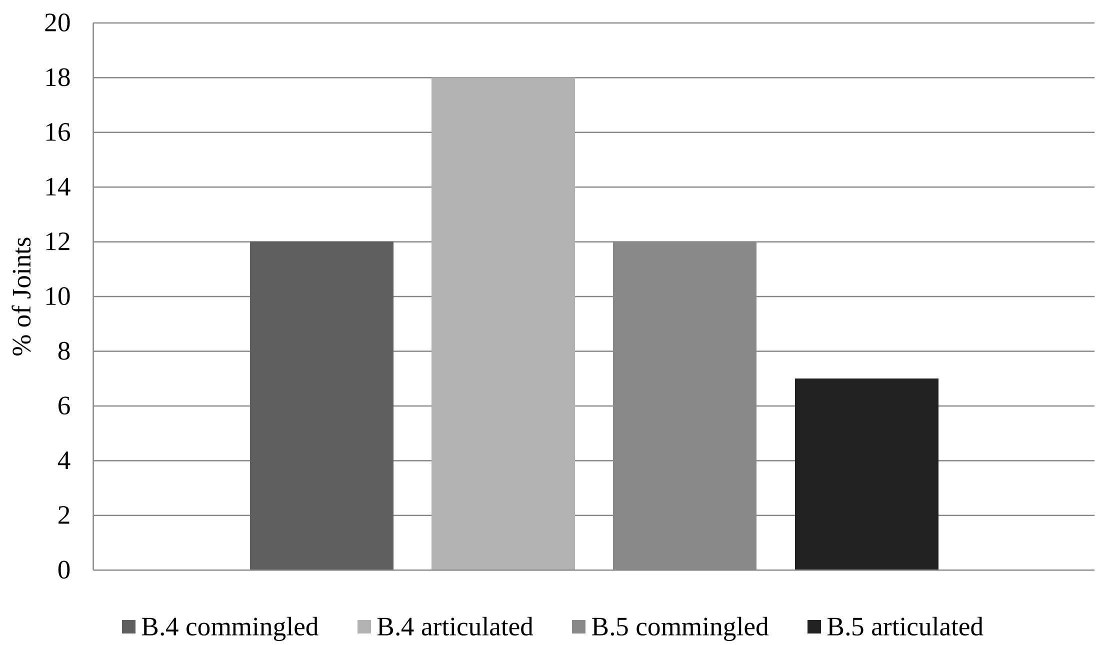

Figure 5. Percentage of joints affected by osteoarthritis in each subgroup

Vertebral Osteophytosis

Vertebral osteophytosis is the most frequent pathology (25%) seen within the sample (Table 4). The majority of affected vertebrae come from tomb B.4 (Figure 6). As with osteoarthritis, all cases come from adult remains. When looking at the rates of vertebral osteophytosis found within each of the sample's subgroups, the articulated remains from tomb B.4 (Figure 7) exhibit a significantly higher amount of cases than any of the other subgroups as reported at the 0.0167 level of significance (χ^2=19.144, p<.0001). The most common expression of vertebral osteophytosis seen within the entire sample is curved spicule formation (52%) indicating that the majority of cases were relatively severe (Figure 8; Appendix C).

Table 4. Percentage of Vertebrae from Tombs B.4 and B.5 with Osteophytosis

Vertebra	**N**	**%**
All	259	25
Cervical	94	27
Thoracic	116	26
Lumbar	49	22

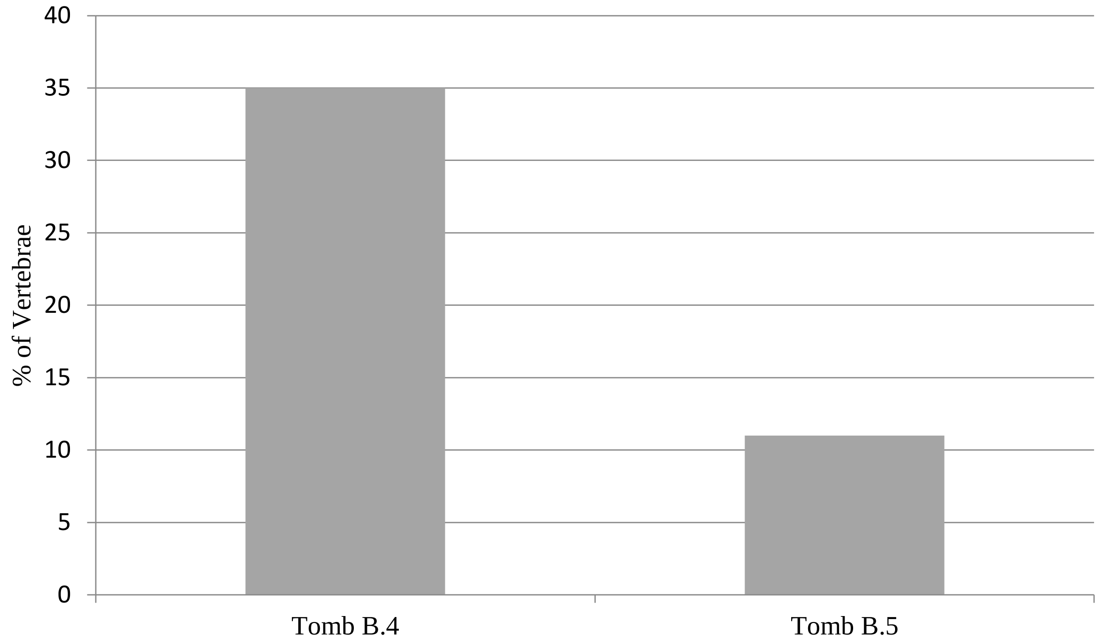

Figure 6. Percentage of vertebrae from tombs B.4 and B.5 with osteophytosis

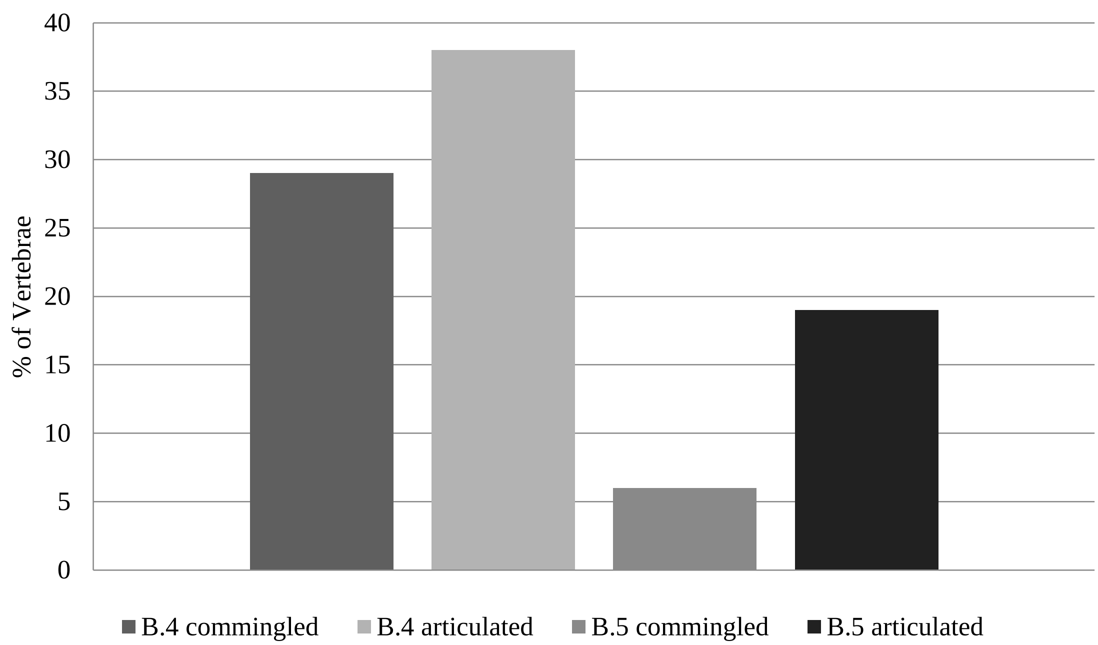

Figure 7. Percentage of vertebrae with osteophytosis in each subgroup

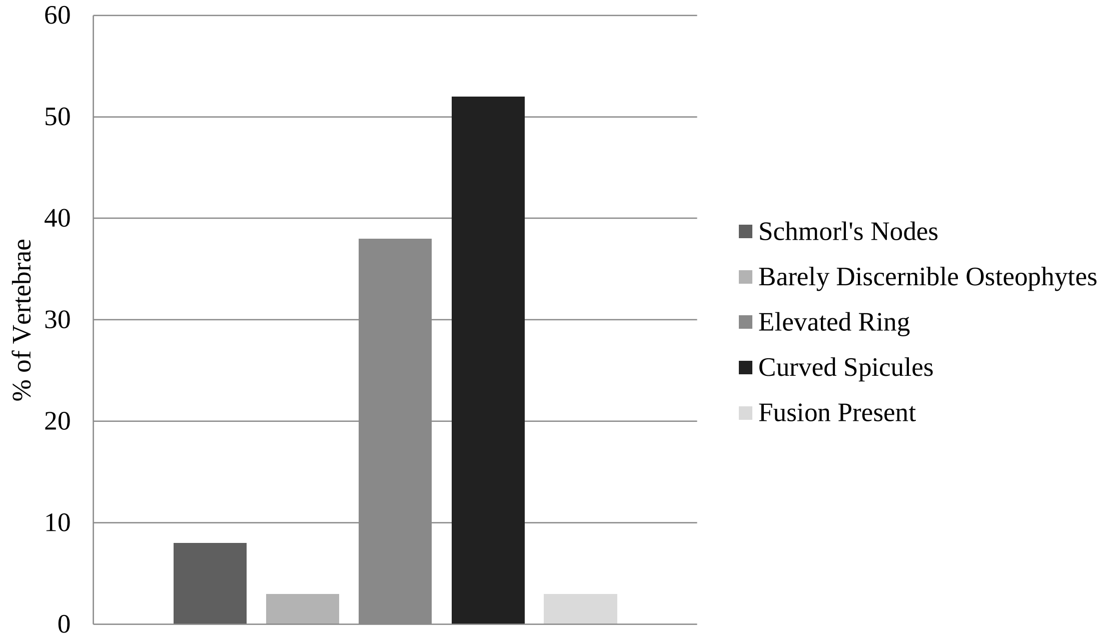

Figure 8. Frequency of characteristics of osteophytosis seen in pathological vertebrae from tombs B.4 and B.5

Osteoporosis

One-hundred and two skeletal fragments from tomb B.5 contain evidence of osteoporosis (Table 5; Appendix D). All but one of these fragments come from a single adult female (B.5:15 Individual 1) found mostly articulated on the tomb floor. These lesions are evident throughout the individual’s entire skeleton. The other osteoporotic element is an adult humeral fragment found among tomb B.5’s commingled remains (B.5:19). Given that locus B.5:19 was located directly underneath B.5:15, it is very possible that this commingled humeral fragment actually comes from B.5:15 Individual 1. Therefore, it is estimated that a minimum number of one individual (4% of individuals from sample) suffered from the disease.

Table 5. Percentage of Skeletal Fragments from Tombs B.4 and B.5 with Osteoporosis

Tomb	**N**	**%**
B.4 and B.5 combined	4284	2
B.4	2285	0
B.5	1999	5

Trauma

Very few incidents of trauma are present within the North Ridge sample. Eight fractures are seen in the remains from tombs B.4 and B.5 (Table 6). Out of the four tomb subgroups, only the articulated remains from tomb B.4 and the commingled remains from tomb B.5 contain fractures (Figure 9). The rib is the most commonly affected element. Sixty-three percent of all identified fractures are complete fractures found on ribs three through ten (see Appendix E). Other affected elements include a cervical vertebrae and a trapezium from tomb B.4, locus B.4:23 individual two. All of these fractures appear to come from adult remains.

Table 6. Percentage of Skeletal Fragments with Fractures

Tomb	**N**	**%**
B.4 and B.5 combined	4284	.19
B.4	2285	.13
B.5	1999	.25

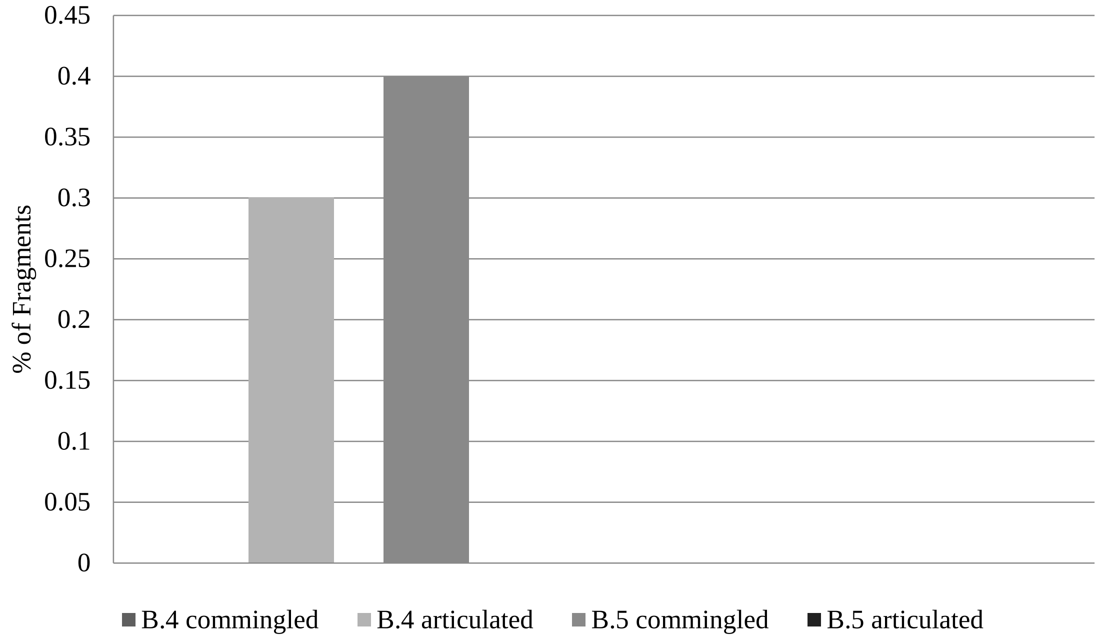

Figure 9. Percentage of fragments from each subgroup with fractures

Dental Enamel Hypoplasias

Thirteen teeth (n=103), the majority of which come from Tomb B.5, contain dental enamel hypoplasias (Table 7). The incisors and canines are the two greatest affected (Table 8). These teeth have between one and six defects, most of which (76%) are characterized as linear horizontal grooves (see Appendix F).

Table 7. Percentage of Teeth from Tombs B.4 and B.5 with Dental Enamel Hypoplasias

Tomb	**N**	**%**
B.4 and B.5 combined	103	13
B.4	28	14
B.5	75	12

Table 8. Percentage of Teeth with Dental Enamel Hypoplasias by Tooth Type

Tooth Type	N	%
Incisor	9	44
Canine	11	36
Premolar	27	11
Molar	57	4

When estimated for age of occurrence, the majority of these teeth show signs of repeated stress events staged less than a year apart. These hypoplasias formed approximately between one and six years of age (see Appendix F). It should be noted that many teeth suffered from extensive wear making hypoplasia formation difficult to discern. While most of the affected teeth were found loose in situ making it hard to link them to specific individuals, given the number of specific tooth types present within the sample (e.g. number of upper left canines) as well as the loci in which these teeth were found (see Appendix F), it is estimated that a minimum number of five individuals (18% of total sample) suffered from dental enamel hypoplasias.

Comparative Analysis between the North Ridge and Contemporaneous Sites

As previously mentioned, pathology frequency data from North Ridge tombs 1, 2, B.4 and B.5 were combined to compare to other contemporaneous settlement types (see Table 9). Urban comparative sites data used in this analysis come from Jerusalem, Tell Hesban, Aila, and el-Khubtha (Table 10).

Table 9. Pathology Frequency Data for North Ridge Samples

Site	**N/ MNI**	**Periostitis (%)**	**Porotic Hyperostosis (%)**	**DEHs (%)**	**Trauma (%)**
Total	**64**	10	0	19	0.1
North Ridge Tombs 1 and 2	**36**	<1	0	19	.17[a]
North Ridge Tombs B.4 and B.5	**28**	18	0	18	.19

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
[a]Only includes data from commingled remains from Tomb 2

Table 10. Pathology Frequency Data for Urban Comparative Sites

Site	**Period**	**N/ MNI**	**Periostitis (%)**	**Porotic Hyperostosis (%)**	**DEHs (%)**	**Trauma (%)**
Total		263	8	29	44	0.14
Jerusalem[a]	Roman	18	-	-	6	-
Tell Hesban[b]	Roman-Byzantine	191	10[d]	50	91[e]	-
Aila[c]	Byzantine	47	15	9	48	0.14
El-Khubtha	Nabataean	7	0	29	29	0

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
[a]Smith et al. (1992)
[b] Grauer and Armelagos (1998)
[c] Perry (2002)
[d]Juveniles only
[e]Canines only

The North Ridge site contains low rates of periostitis and trauma similar to other contemporaneous urban settlements from the region (Table 11). Additionally, both the North Ridge and urban comparative samples exhibit a fair amount of degenerative disorders such as osteoarthritis and vertebral osteophytosis (18% of joints in each sample are affected by the conditions); however, patterns of joints affected vary between the two samples (Table 12). In contrast, skeletons from the North Ridge show statistically lower proportions of childhood stress and chronic anemia as determined by rates of dental enamel hypoplasias and porotic hyperostosis at the 0.0167 level of significance (χ^2=13.893, p=.0002 for dental enamel hypolasias and χ^2=24.094, p<.0001 for porotic hyperstosis as seen in Table 11).

Table 11. χ^2 Test Results between North Ridge and Urban Comparative Sites

	North Ridge Samples	**Urban Comparative Samples**	χ^2	**P**
N/MNI	64	263		
Periostitis	10	8	.131	.7171
Porotic Hyperostosis	0	29	24.094	<.0001*
DEHs	19	44	13.893	.0002*
Trauma	.17	.14	.133	.7150

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
*Significant (α=0.0167)

Table 12. Osteoarthritis and Vertebral Osteophytosis Joint Frequency Data and χ^2 Test Results between North Ridge and Urban Comparative Sites

	North Ridge Tombs		**Urban Comparative Samples**[a]			
Joint	N	%	N	%	χ^2	P
All	727	18	463	18	.006	.9361
Shoulder	18	11	23	30	2.201	.1379
Elbow	30	7	23	22	2.580	.1082
Wrist	35	43	29	10	8.293	.0040*
Hand	35	17	35	11	.467	.4945
Hip	21	0	31	3	.691	.4059
Knee	38	21	35	17	.180	.6716
Ankle	34	12	31	3	1.665	.1969
Foot	27	22	35	0	8.611	.0033*
Cervical	153	22	60	17	.812	.3676
Thoracic	238	16	103	36	17.566	<.0001*
Lumbar	98	15	58	16	.001	.9718

[a]Data only for Aila from Perry (2002)
*Significant (α=0.0167)

Agricultural village samples used in this study consist of data collected from Wadi Musa, Qasr ar-Rabbah, Gesher Haziv, Yasileh, Sa' ad, Rehovot, and Khirbet es-Samra (Table 13).

Table 13. Pathology Frequency Data for Agricultural Village Comparative Sites

Site	Period	N/ MNI	Periostitis (%)	Porotic Hyperostosis (%)	DEHs (%)	Trauma (%)
Total		682	7	7	38	0.52
Wadi Musa[a]	Nabataean	34	0	0	64[h]	<0.01
Qasr ar-Rabbah[b]	Roman	15	13	0	0	-
Gesher Haziv[c]	Roman	24	-	-	45[i]	-
Yasileh[d]	Roman-Byzantine	47	-	-	50	-
Sa' ad[e]	Roman-Byzantine	338	1	-	40	-
Rehovot[f]	Byzantine	96	15	22[j]	68[k]	0.52
Khirbet es-Samra[g]	Byzantine	128	-	6	0	-

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
[a]Perry (1998)
[b]Perry and Al-Shiyab (2005)
[c]Faerman et al. (1994)
[d]Khwaileh (1999)
[e]al-Awad (1998); Williams et al. 2004
[f]Perry (2002)
[g]Nabulsi (1998)
[h]All of dentition except for 3rd molar
[i]By individual, not by tooth
[j]Individuals with observable cranial elements in the sample only
[k]Maxillary central incisors and/or mandibular canines only

Agricultural villages and the North Ridge show similar rates of chronic infection, chronic anemia, childhood stress, and degenerative disorders as seen by rates of periostitis, porotic hyperostosis, dental enamel hypoplasias, osteoarthritis and vertebral osteophytosis observed within each of the sample types (Tables 14 and 15). However, the types of joints most affected by osteoarthritis varied between the North Ridge and comparative samples (Tables 15). Additionally, the agricultural village sample shows statistically higher rates of trauma than the North Ridge sample (Table 14). Once again, all results are reported at the 0.0167 level of significance.

Table 14. χ^2 Test Results between North Ridge and Contemporaneous Agricultural Villages

Site	North Ridge Samples	Agricultural Village Samples	χ^2	P
N/MNI	64	682		
Periostitis	10	7	.476	.4903
Porotic Hyperostosis	0	7	4.814	.0282
DEHs	19	38	9.351	.0022
Trauma	.17	.52	14.508	.0001*

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
*Significant (α=0.0167)

Table 15. Osteoarthritis and Vertebral Osteophytosis Joint Frequency Data and χ^2 Test Results between North Ridge and Agricultural Village Sites

	North Ridge Tombs		**Agricultural Village Samples**[a]			
Joint	N	%	N	%	χ^2	P
All	727	18	2360	38	103.641	<.0001*
Shoulder	18	11	121	58	4.303	.0380
Elbow	30	7	124	55	22.609	<.0001*
Wrist	35	43	125	35	.689	.4066
Hand	35	17	123	11	.818	.3658
Hip	21	0	127	23	4.503	.0338
Knee	38	21	124	58	15.940	<.0001*
Ankle	34	12	117	34	6.415	.0113*
Foot	27	22	117	15	.738	.3902
Cervical	153	22	385	23	.050	.8236
Thoracic	238	16	686	40	47.095	<.0001*
Lumbar	98	15	311	63	67.936	<.0001*

[a]Data only for Rehovot from Perry (2002)
*Significant (α=0.0167)

Rural/nomadic samples consist of data collected from Khan el-Ahmar and the Queen Alia International Airport Cemetery (Table 16).

Table 16. Rural/Nomadic Comparative Site Data

Site	**Period**	**N/ MNI**	**Periostitis (%)**	**Porotic Hyperostosis (%)**	**DEHs (%)**	**Trauma (%)**
Total		164	13	24	27	0.96
Khan el-Ahmar[a]	Byzantine	36	-	-	39	-
QAIA[b]	Roman	128	13	24[c]	14[d]	0.96

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
[a]Hershkovitz et al. (1993)
[b]Al-Sa'oud (2003); Perry (2002)
[c]Individuals with observable cranial elements in the sample only
[d]Maxillary central incisors and/or canines only

Skeletal remains from the North Ridge as well as those from rural/nomadic comparative sites show similar low rates of childhood stress and general infection as seen by amounts of dental enamel hypoplasias and periostitis respectively (Figure 17). Both site types also show relatively frequent amounts of osteoarthritis and vertebral osteophytosis (18% of joints from North Ridge, 22% from rural/nomadic sample affected by the two conditions); however, patterns of affected joints vary slightly between the two (Tables 18) . In contrast, rural/nomadic samples show significantly higher rates of chronic anemia (i.e. porotic hyperostosis) as well as trauma than remains analyzed from the North Ridge (Figure 17).

Table 17. χ^2 Test Results between North Ridge and Contemporaneous Rural/Nomadic Sites

Site	North Ridge Sample	Rural/Nomadic Samples	χ^2	P
N/MNI	64	164		
Periostitis	10	13	.519	.4714
Porotic Hyperostosis	0	24	18.360	<.0001*
DEHs	19	27	1.622	.2028
Trauma	.17	.96	35.001	<.0001*

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
*Significant (α=0.0167)

Table 18. Osteoarthritis and Vertebral Osteophytosis Joint Frequency Data and χ^2 Test Results between North Ridge and Rural/Nomadic Sites

	North Ridge Sample		**Rural/Nomadic Samples**[a]			
Joint	N	%	N	%	χ^2	P
All	727	18	1083	22	5.231	.0222
Shoulder	18	11	70	6	.656	.4178
Elbow	30	7	75	20	3.243	.0717
Wrist	35	43	33	18	4.845	.0277
Hand	35	17	48	8	1.482	.2234
Hip	21	0	82	6	1.346	.2460
Knee	38	21	67	7	4.128	.0422
Ankle	34	12	48	0	.514	.4733
Foot	27	22	36	3	5.906	.0151*
Cervical	153	22	143	16	1.791	.1808
Thoracic	238	16	318	38	33.076	<.0001*
Lumbar	98	15	163	34	10.599	.0011*

[a]Data only for Queen Alia International Airport Cemetery from Perry (2002)
*Significant (α=0.0167)

Comparative Analysis between the North Ridge and el-Khubtha

Both the North Ridge and el-Khubtha samples show similar rates of periostitis and trauma (Table 19). The remains from el-Khubtha exhibit a significantly higher amount of chronic anemia as displayed by porotic hyperostosis/cribra orbitalia as well as a significantly higher amount of childhood stress as indicated by dental enamel hypoplasias (Table 19). It should be noted that no comparison was made between the rates of degenerative disorders observed given that osteoarthritis/vertebral osteophytosis frequencies were calculated differently at the two sites (by joint type at the North Ridge and by minimum number of individuals at el-Khubtha).

Table 19. χ^2 Test Results between North Ridge and el-Khubtha Samples

Site	North Ridge sample	el-Khubtha sample	χ^2	P
N/MNI	64	7		
Periostitis	10	0	.717	.3972
Porotic Hyperostosis	0	29	71.000	<.0001*
DEHs	19	29	9.409	.0091*
Trauma	.17	0	1.891	.1691

Note: MNI refers to minimum number of individuals. All results are reported by MNI except for trauma which is reported by total number of fragments. DEHs stand for dental enamel hypoplasias
*Significant (α=0.0167)

In general, the remains from the North Ridge tombs contain low levels of disease. In fact, most of the pathological frequencies determined for the North Ridge sample during this study most closely resemble frequencies seen in contemporaneous rural/nomadic samples and agricultural villages, rather than urban cities. Possible reasons as to why certain similarities and differences exist between the North Ridge and comparative groups are explored within the next chapter.

Discussion

As summarized in hypothesis 1, the paleopathological data on those buried on the Petra North Ridge was expected to demonstrate that these non-elite urbanites had suffered from poorer health than residents of regional agricultural villages and rural/nomadic settlements from the same time period. Various studies of prehistoric New World populations (see Lallo and Rose 1979; Powell 2000; Reinhard 1988 for examples) as well as Old World populations (see Eshed et al. 2010; Oxenham et al. 2005) indicate an increase in infectious disease after the transition from foraging to agriculture. This change was most often accompanied by population growth and increased sedentism typical of urban habitats. Archaeological and historical evidence indicates that 1st century A.D. Petra shared many similarities with sedentary, agriculturally-based populations. In addition, the city was a trade center, likely characterized by high population mobility of humans and their disease pathogens. Due to these factors, it was expected that the North Ridge inhabitants would have poorer health than individuals from less densely settled, less sedentary, and/or more homogenous populations. In particular, it was originally thought that the North Ridge remains would exhibit high frequencies of pathologies indicative of chronic disease and stress. However, the picture presented at the North Ridge is more complex.

Interpretations of Health at Petra in Comparison with Other Contemporaneous Settlements

Contrary to predictions made in hypothesis 1, the North Ridge inhabitants appear to have suffered from low levels of chronic infection and/or malnutrition as indicated by periostitis. While the frequency of periostitis seen within the entire North Ridge sample closely resembles that found within other urban settlements, neither group shows a high rate of occurrence (10% and 8% of individuals in each sample respectively). In fact, it should be noted that contrary to expectations, the rural/nomadic sample used within this study exhibits the highest rate of the pathology (13% of individuals in sample). Regardless, periostitis does not appear to be a prevalent problem in all three settlement types (urban, agricultural village, and rural/nomadic). Additionally, it was found that the majority of fragments containing periostitis from North Ridge tombs B.4 and B.5 were active, indicating that the unfortunate minority who did suffer from the condition may have been frail at time of death.

Given that so few cases of periostitis were seen within the North Ridge sample and comparative groups suggests that conditions resulting in periostitis may not have been prevalent problems in Classical-period Jordan and Israel. This could serve as an indication of low levels of infectious disease and malnutrition seen throughout the region, or alternatively, it could indicate that many groups throughout the ancient Near East were dying from acute infections that did not have time to form bony responses. Issues of bone preservation, particularly given the fragmentary nature of the North Ridge remains, and sampling error could also play a role in observing the pathology. For instance, research suggests that the tibia is the element most commonly affected by periostitis (Milner 1991; Roberts and Manchester 2005). Of the 29 affected fragments from the North Ridge tombs B.4 and B.5 sample, 11 of those fragments (38%) were from tibiae. Therefore, it is possible that the rate of periostitis seen within the North Ridge burials is underestimated given the relatively low percentage of tibiae preserved within the sample. However, whether or not this could be the sole contributing factor to lower periostitis rates and/or whether or not the same can be said for the other comparative groups requires further research.

Given that the North Ridge burials contain no evidence of porotic hyperostosis and/or cribra orbitalia further implies that hypothesis 1 was incorrect. Instead, this suggests that Petra’s non-elite inhabitants experienced relatively good health devoid of malnutrition and/or chronic infections leading to this condition. As previously noted, porotic hyperostosis/cribra orbitalia is commonly thought to result from chronic anemia due to iron deficiency or parasitic infections (Larsen 1997). Lack of sanitation has been recognized as a possible contributing factor that exacerbates an individual's chances of becoming anemic (for examples see Lambert and Walker 1991; Larsen and Sering 2000). For instance, improper disposal of waste products and the consumption of dirty, contaminated water may increase individuals' chances of attaining harmful blood-loss- and diarrhea-causing parasites that can lead to anemia. The fact that the North Ridge remains have a significantly lower percentage of porotic hyperostosis/cribra orbitalia than any of the comparative groups may be a consequence of Petra's sophisticated, clean water system. This could have possibly prevented the spread of harmful waterborne pathogens. Furthermore, the North Ridge inhabitants could have had less exposure to harmful bacteria and/or parasites than their neighbors through less contact with animals and their waste. For instance, given that Petra's inhabitants relied primarily on agricultural products from the surrounding settlements could have meant that these individuals were less likely to come into contact with manure than residents of agricultural villages.

Another oft cited contributing factor to chronic anemia is diet. In particular, many New World agricultural groups that relied primarily on maize, an iron-poor food source, have been cited as having high rates of chronic anemia (for examples see Cook 1984; Goodman et al. 1984; Milner 1991). Despite their apparent reliance on agriculture, given the variety of plants known to have existed throughout Nabataea (Oleson 2007), it is possible that the North Ridge inhabitants ate a well-balanced, diet high in iron and/or vitamin B_{12} that lowered their chances of becoming anemic. For instance, work conducted by Studer (2007) at a domestic section of Petra, ez-

Zantur, indicates that Petra's residents consumed a variety of animals including sheep, goats, birds, and fish. While Studer's research does indicate a difference in diets between elites and non-elites, namely that the elites were consuming more birds, overall, her research demonstrates that Petra's inhabitants received adequate protein. Therefore, assuming that the North Ridge inhabitants ate a relatively healthy diet and had low contact with harmful pathogens supports the notion that these individuals would have experienced low rates of anemia.

Hypothesis 1 predicted that the frequency of dental enamel hypoplasias present within the sample would be statistically higher than rates observed in comparative agricultural villages and rural/nomadic samples. Surprisingly, only 19% of individuals buried at the North Ridge show evidence of dental enamel hypoplasias indicative of periodic stress episodes during childhood. This rate is most similar to that seen within contemporaneous rural/nomadic settlements and agricultural villages and is significantly lower than rates seen within other urban sites, indicating that hypothesis 1 is incorrect. However, this assessment is somewhat tentative given that very little teeth were found within tombs B.4 and B.5 (n=103) as well as the fact that extreme dental wear often reduced tooth crowns down to the cementum-enamel junction, obliterating any hypoplasias that could have existed. Even if the frequency of dental enamel hypoplasias seen within the sample is unbiased and represents a true reflection of the paucity of the condition experienced at the North Ridge, this does not necessarily suggest that the majority of the population was healthy. As Wood and colleagues (1992) have pointed out and King and coworkers (2005) have expanded upon, populations which exhibit higher rates of dental enamel hypoplasias may be healthier than those that do not since a lack of hypoplasia formation may indicate higher childhood mortality. However, given that all of the affected teeth from tombs B.4 and B.5 are permanent, and the vast majority contains multiple hypoplasias, indicates that many of those who suffered from childhood stress managed to survive into adulthood. This information combined with periostitis and porotic hyperostosis/cribra orbitalia data further supports the notion that the North Ridge inhabitants experienced relatively good health most likely due in part to adequate nutrition and a clean water supply.

Hypothesis 2 suggested that the North Ridge sample would contain frequent amounts of pathologies indicative of osteoarthritis and/or vertebral osteophytosis. As predicted, some of the most common pathologies observed within the North Ridge sample are degenerative disorders, specifically osteoarthritis and vertebral osteophytosis (18% of total joints from the sample affected by osteoarthritis and/or verterbral osteophytosis). This frequency closely matches that seen within other contemporaneous urban sites and is also fairly similar to that seen within rural/nomadic samples. In contrast, agricultural villages show a significantly higher amount of degenerative disorders than any of the other site types.

Patterns of osteoarthritis have sometimes been used to assess activity patterns of past populations. Hypothesis 2 also postulated that the North Ridge remains would show degenerative pathology frequencies and joint distributions statistically similar to that of other contemporaneous, urban sites. Although the North Ridge tombs do not differ significantly from contemporaneous urban sites in terms of degenerative disorders, contrary to hypothesis 2, they do exhibit a larger amount of osteoarthritis in the hands and feet than the other urban samples. In addition, the agricultural villages used in this study show much more osteoarthritis in the elbows, knees, and ankles, and the rural/nomadic sites contain much more osteoarthritis in the feet than the North Ridge sample.

The dissimilarities seen in affected joints within the three settlement types may indicate a difference in activity patterns performed amongst these varying sites; however, given the insecure nature of behavioral assessment from osteoarthritis (see Jurmain 1999), this interpretation should be approached with caution, especially since these changes may not necessarily be caused by biomechanical stress. Additionally, the commingled, fragmentary nature of the North Ridge remains makes it very difficult to assess whether or not affected individuals experienced single or multiple joint involvement as well as whether these individuals were young or old adults. Therefore, one could interpret the lower frequency of osteoarthritis observed at the North Ridge site in comparison to agricultural villages as an indication that the North Ridge inhabitants participated in less physically demanding activities. However, given that osteoarthritis is frequently related to old age, it could also be argued that the agricultural village sample consisted of older individuals more likely to show signs of the condition. Additionally, the agricultural villagers could have had a higher genetic predisposition to osteoarthritis. Therefore, the information provided by osteoarthritis and vertebral osteophytosis is somewhat limited. Nevertheless, given that these two conditions were the most commonly observed pathologies within the North Ridge sample suggests that the majority of health problems experienced at the site were probably not related to infectious disease and/or malnutrition.

Hypothesis 3 suggested that the majority of individuals affected by osteoporosis would be female. Given that evidence of osteoporosis is only definitively found in one adult individual from North Ridge tombs B.4 and B.5, makes testing of this hypothesis unwise. Typically, osteoporosis is thought to be caused by hormonal and age related changes, particularly seen in postmenopausal women; however, other causes such as inadequate diet, immobility, genetics, as well as extended periods of lactation in women, have all been linked to the condition (Stini 1990). As already discussed, current evidence suggests that the North Ridge inhabitants experienced relatively low amounts of chronic stress and received sufficient nutrition. This information combined with the fact that the affected individual was an adult female could suggest that the osteoporotic changes were age and/or sex related. Even if this individual suffered from osteoporosis due to social and/or environmental factors, given that only one individual from the North Ridge tombs was identified as having this disease suggests that osteoporosis was probably not a significant problem for the population. Unfortunately, due to the small sample size of affected individuals makes further analysis concerning sex and age related differences impossible.

Hypothesis 4 predicted that the North Ridge remains would contain few fractures, similar to that observed in other contemporaneous samples, and that the majority of these fractures would be accidental. This hypothesis was supported by the fact that overall, the North Ridge sample has very little evidence of trauma (0.17% of fragments), the majority of which consists of healing/healed fractures in the ribs. These fractures, as well as two Colle's fractures found within the remains from tomb 2, may have resulted from falls, especially given Petra's rocky environment (Bikai and Perry 2001). Furthermore, although interpreting violent behavior from archaeological remains is a difficult and imprecise endeavor, certain indicators such as perimortem wounds, cranial trauma, as well as sharp force/projectile trauma can be used to assess the likelihood of violence (Jurmain 1999). Given that the fractures seen in the North Ridge sample do not satisfy any of these criteria, it appears that these incidents were most likely accidental in nature.

Further support for hypothesis 4 can be found when looking at the comparative data. The amount of trauma seen at the North Ridge most closely resembles that seen at other contemporaneous urban sites and is significantly lower than what is seen in agricultural villages and rural/nomadic samples. Additionally, unlike the North Ridge site, both the agricultural village and rural/nomadic samples show some examples of skeletal trauma patterns indicative of interpersonal violence (Perry 2007). Moreover, archaeological and historic evidence for the rural/nomadic comparative site known as the Queen Alia International Airport cemetery suggests that some of the individuals buried here may have served as military auxiliaries for the Roman army (Perry 2007). This suggests that varying trauma levels seen amongst the different settlement types could be a direct reflection of the different activities people performed during their daily lives. For instance, it is possible that the inhabitants of the North Ridge as well as other regional, contemporaneous urban settlements experienced less interpersonal violence and accidents than those individuals from agricultural villages and rural/nomadic sites. However, given the relatively small amounts of fractures observed within the samples, this interpretation is tentative.

Inter-site Comparison of Health Status between Elite and Non-elite Inhabitants of Petra

The recent excavation of skeletal remains from two monumental façade tombs at el-Khubtha provides the opportunity to compare these health indicators in elite and non-elite populations. Hypothesis 5 predicated that the North Ridge burials would contain considerably more pathologies than the remains from el-Khubtha; however, this did not prove to be the case. Both sites appear to exhibit relatively low rates of infectious disease, malnutrition, and trauma. This data seems to suggest that that the living conditions at Petra were of a high enough caliber that regardless of social standing, all individuals led relatively healthy lives. For instance, given Petra’s clean water system, all individuals, regardless of status, may have been protected from the harmful effects of waterborne diseases. Alternatively, the similarities viewed between the

North Ridge and el-Khubtha samples could be due to a sampling error or a misinterpretation of social status. As Robb and colleagues (2001) have pointed out, interpreting social status from tomb construction and grave goods is not a straightforward matter. As previously discussed, despite perceived differences in social status from the material remains, such as the monumental tomb facades at el-Khubtha and the simple shaft tombs at the North Ridge, it cannot be said with complete certainty that these two samples represent the wealthiest and the poorest of Petra's inhabitants or that symbolic status directly translates to economic status. This could mean that the reason the two samples appear so similar is not because there were no dramatic health differences amongst Petra's populace, but rather that Petra's absolute wealthiest and/or poorest citizens are not represented within the data. Additionally, given the relatively small number of individuals analyzed from el-Khubtha (MNI=7), there could have been a sampling bias. Regardless, of these potential caveats, given Petra's apparent status in the 1st century A.D. as a prosperous city, it is still very plausible that even Petra's least successful inhabitants received an adequate enough diet and sanitation to ward off many significant health problems.

Two statistically significant differences are observed between the samples. Unlike the North Ridge, el-Khubtha has a much higher rate of porotic hyperostosis/cribra orbitalia (29% of sample) indicative of chronic anemia as well as a much higher rate of childhood stress as exhibited by dental enamel hypoplasias (29% of sample). These disparities could be a direct reflection of varying diets and habits between the two groups. For instance, as Studer's (2007) study of ez-Zantur demonstrates, there were some differences in meat consumption of at least some non-elite and elite inhabitants of Petra. If the elites buried at el-Khubtha were consuming meats lower in protein content which prevent iron absorption, this could possibly lead to higher anemia. Similarly, studies have shown that certain cuts of meat as well as methods of food preparation impact meat's iron content (Cross et al. 2012; Pourkhalili et al. 2013). Additionally, there could have been different childrearing practices observed between the elites and non-elites, such as type of childhood diet, that would have influenced the amount of dental enamel hypoplasias seen within the two samples. Therefore, differences between elite and non-elite pathology rates could reflect dissimilar eating habits and/or cultural practices. Nevertheless, considering that the samples showed very similar rates of other diseases indicates that the entire populace probably enjoyed relatively healthy lifestyles.

Overall, the majority of hypotheses in this study were unsubstantiated, indicating that the North Ridge inhabitants were healthier than originally predicted. In particular, the North Ridge tombs appear to contain low levels of chronic disease, malnutrition, stress, anemia, and trauma. In fact, in many ways the North Ridge sample more closely resembles contemporaneous rural/nomadic sites and agricultural villages than other urban cities. Reasons for this are somewhat speculative given the difficulties of linking many of the fragmentary, commingled pathological remains from the North Ridge tombs to specific individuals. However, it is possible that given Petra's status as a wealthy, urban trade center and what is known of the city's water system, that the North Ridge inhabitants enjoyed a well-rounded diet and fresh, clean water decreasing their chances of malnutrition and disease. Additionally, as predicted, it appears that the North Ridge inhabitants may have experienced less conflict than many of their contemporaries, resulting in fewer incidents of violent trauma. It should be noted that the results from this study do not preclude the fact that the North Ridge inhabitants could have suffered from acute, virulent epidemics such as smallpox and the bubonic plague that kill off their hosts before skeletal pathologies can form. Therefore, while this study provides a good outlook on long-term, chronic health problems at Petra, to get a complete picture of disease would require additional research.

Conclusions

Contrary to expectations, the skeletal remains from the North Ridge contained only a moderate number of pathologies compared with contemporary regional sites. This indicates that Petra's general population suffered from few cases of chronic diseases and/or malnutrition leading to these non-specific indicators of stress. In fact, in many ways, disease rates calculated for the North Ridge remains more closely resembled pathology frequencies from contemporaneous rural/nomadic samples than other urban populations. This result was particularly surprising considering that urban, sedentary populations typically show more indicators of poor health than smaller, mobile groups (Larsen 1997). Additionally, few significant differences in health were observed between the North Ridge and el-Khubtha samples. These similarities seem to indicate that the majority of Petra's inhabitants, regardless of status, received a clean water supply, sufficient sanitation, and/or an adequate diet that helped lower the chances of acquiring harmful pathogens. Whether or not this was true, given the current data, it appears that the idea of the "dirty" city of antiquity is a myth, at least in the case of Petra. While certain urban populations may conform to the general stereotype that ancient cities were unhealthy, this is clearly not true for all. Additionally, given the important role cultural practices and the physical environment can have on disease frequencies, makes it necessary to view each population's health status within its own context.

The results from this study provide a new understanding of chronic health problems amongst Petra's non-elite inhabitants; however, whether or not individuals could have died from acute epidemics is yet to be resolved. As Wood and colleagues (1992) have pointed out, it is incorrect to assume that skeletons without bone pathologies are healthy, since these individuals could have died or recovered from virulent diseases before a bony response could form. To eliminate this possibility, it is helpful to have a clear understanding of the past via the archaeological and historic records as well as paleodemographic data from the sample under study (Margerison and Knüsel 2002). Using survivorship curves can help researchers identify mortality differences typically seen in attritional and epidemic ridden samples. Given the fragmentary condition of the remains under study and current methods of skeletal age and sex techniques, the creation of survivorship curves is not yet possible for Petra. However, hopefully in the future with the creation of better skeletal techniques for the analysis of fragmentary, commingled remains as well as the addition of more skeletons to the current sample, this issue will be resolved. Therefore, as of now, the possibility of epidemics cannot be ignored, particularly given that Petra was a trade city that probably experienced an influx of immigrants with different disease ecologies. Nevertheless, it appears that the inhabitants probably did not suffer from many of the chronic health problems typically associated with city living.

In addition to helping determine whether a burial sample died from acute epidemics, future analyses concerning age and sex distributions may reveal sociocultural and biological factors that contribute to disease rates at the North Ridge. Age and sex disparities in disease distributions are typically not random. Instead, they reflect important differences in the practices and biology of specific groups of people. For instance, Sullivan (2005) has suggested that pregnant and lactating women may have an increased susceptibility to iron deficiency anemia. Therefore, if all of the anemic individuals within a sample are female, this could have little or nothing to do with the bioavailability of iron at the particular site. Discovering discrepancies such as this can provide important insight not gained by population level disease frequencies alone and may help account for health factors not necessarily related to the physical environment.

Another area of research that may contribute greatly to the understanding of health and disease at Petra's North Ridge is stable isotope analysis. Isotopes are varying forms of a single element that have different numbers of neutrons. Analysis of isotope ratios in bone collagen and tooth enamel apatite, in particular carbon and nitrogen isotopes, can provide useful information about past diets (see Larsen 1997). For instance, plants can generally be divided into three different types based on their photosynthetic pathways: C_3, C_4, and CAM. These three plant types vary in the amount of stable isotopes ^{13}C and ^{12}C they take up. Therefore, by observing the ratio of stable isotopes $^{13}C/^{12}C$ in human bone collagen, researchers can determine what types of foods the individual consumed. Similarly, ratios of stable isotopes $^{15}N/^{14}N$ differ in plants according to whether or not the plants acquired nitrogen from the soil or the air in addition to many climatic factors such as temperature and humidity. By discerning the ratio of stable isotopes $^{15}N/^{14}N$ seen within human bone, researchers can determine whether or not individuals consumed mostly marine or terrestrial foods (Larsen 1997). Understanding diet via stable isotope analysis can provide broader insight into the health of a given population since different nutritional deficiencies have been linked to immunosuppression (see McDade 2005). Therefore, through diet analysis, researchers can provide a more nuanced interpretation as to why the North Ridge population exhibited certain pathologies.

Another useful application of stable isotope analysis to the North Ridge remains is to determine mobility. Strontium isotopes (^{87}Sr and ^{86}Sr), in particular, have commonly been used to track the mobility of archaeologically derived skeletal material (see Bentley 2006). Separate geologic areas have distinct strontium isotope ratios. These isotopes can erode into the soils, and as individuals eat various plants and animals from a particular geographic area, these foods leave isotopic signatures within human bones. By matching up these signatures to local levels of strontium isotopes, researchers can determine whether or not a skeleton originated within the environment it was buried. For instance, by analyzing the strontium signature of an individual's tooth pulp, which forms in childhood, researchers can determine whether or not that person's childhood was spent in the place that he or she was buried. Given the influx of traders believed to have visited Petra during the 1st century A.D., this type of analysis would be particularly beneficial in testing the possibility that some of the North Ridge burials contained traders as opposed to permanent inhabitants.

In addition to conducting multiple types of analyses to the North Ridge remains, increasing the current sample size and that of the comparative groups may help eliminate the inherit problems of sampling biases as well as provide a bigger picture of life among Petra's non-elite population. In particular, given that the el-Khubtha sample only contained a minimum number of seven individuals, it would be useful in the future to have a greater number of comparative burials from the elite segment of Petra's population to better explore the effects of social status on health and disease. Given that many of Petra's monumental tombs no longer contain skeletal material, this task may prove difficult. Nevertheless, there are still many more burials to be explored at the North Ridge. Additionally, it may prove useful in the future to separate out the el-Khubtha sample completely from the other urban comparative sites when performing statistical analyses so that overall comparisons can be made amongst the North Ridge, el-Khubtha, and other urban samples separately. Through future analyses of these remains it is hoped that the work of this project will continue on and will provide insight into the lives of Petra's inhabitants.

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Appendix A: Cases of Periostitis from Tombs B.4 and B.5

Locus	Element	Side	Section/Aspect	Observations		
B.4:16	4.1.5	1	5	4.1.2	4.6.1	Remodeling of head resulting in misshapen appearance
B.4:23 Individual 2	3.4.0	1	1	4.1.2	4.6.2	
B.5.9 Commingled	4.3.1	2	2	4.1.3	4.6.2	subadult
B.5:15 Individual 1	4.1.2	2	2 (radial tuberosity)	4.1.1	4.6.2	
B.5:15 Individual 1	4.1.2	2	1 and 2	4.1.3	4.6.2	
B.5:15 Individual 1	4.1.2	1	2 (radial tuberosity)	4.1.1	4.6.3	
B.5:15 Individual 1	4.1.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.1.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.1.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.1.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	1	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	2	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	2	shaft frag	4.1.1	4.6.3	
B.5:15 Individual 1	4.3.3	2	shaft frag	4.1.1	4.6.2	
B.5:15 Individual 1	4.3.3	2	shaft frag	4.1.1	4.6.2	
B.5:15 Individual 1	4.3.1	2	shaft frag	4.1.1	4.6.3	

B.5:15 Individual 1	4.3.1	2	shaft frag	4.1.1	4.6.3
B.5:15 Individual 1	4.3.4	1	shaft frag	4.1.1	4.6.3
B.5:15 Individual 1	4.3.4	1	shaft frag	4.1.1	4.6.3
B.5:15 Individual 1	4.3.4	1	shaft frag	4.1.1	4.6.3
B.5:15 Skull #4 and other	2.0.0	?	?	4.1.2	4.6.2
B.5:27	3.6.3	1	shaft frag	4.1.2	4.6.1
B.5:31	3.6.3	?	shaft frag	4.1.1	4.6.1

Appendix B: Cases of Osteoarthritis from Tombs B.4 and B.5

Locus	Element	Side	Section/Aspect	Observations			
B.4:10	4.1.4	2	9	8.1.2	8.2.2		
B.4:10	4.1.3	1	5	8.1.2	8.2.2		
B.4:10	4.1.2	1	5	8.1.1	8.2.1		
B.4:10	3.1.3	1	3	8.1.2	8.2.3		
B.4:10	3.1.3	2	3	8.1.3	8.2.3		
B.4:10	3.1.3	2	1	8.1.2	8.2.2		
B.4:10	3.1.2	2	1	8.1.1	8.2.3		
B.4:10	3.1.2	1	1	8.1.1	8.2.3		
B.4:10	3.1.0	1	1	8.1.3	8.2.3		
B.4:10	3.1.0	2	1	8.1.3	8.2.3	8.5.2	8.6.2
B.4:10	3.2.2 or 3.2.3	1	1	8.1.2	8.2.2		
B.4:10	3.2.0	?	1	8.1.2	8.2.2	8.3.1	8.4.2
B.4:10	3.2.0	2	2	8.1.2	8.2.2		
B.4:10	4.3.1	1	5	8.1.1	8.2.1		
B.4:16	4.3.1	?	5	8.1.3	8.2.1		
B.4:16	4.3.2	1	7	8.1.2	8.2.1		

B.4:16	4.3.2	2	7	8.1.2	8.2.2	8.5.3	8.6.2	8.7.2
B.4:16	4.1.5	1	9	8.1.2	8.2.2			
B.4:16	4.1.5	1	9	8.1.2	8.2.2	misshapen		
B.4:16	4.1.4	1	5	8.1.2	8.2.2			
B.4:16	4.1.4	1	9	8.1.2	8.2.2			
B.4:16	4.1.4	2	5	8.1.2	8.2.2			
B.4:16	4.1.4	2	1	8.1.2	8.2.2			
B.4:16	4.1.4	2	5	8.1.3	8.2.2	8.5.2	8.6.2	
B.4:16	4.1.4	2	5	8.1.3	8.2.1			
B.4:16	4.3.7	?	9	8.1.3	8.2.2			
B.4:16	4.3.7	?	1	8.1.2	8.2.3			
B.4:16	4.3.7	?	5	8.1.3	8.4.3	severely misshapen with extensive spicule formation; proximal ephiphysis looks blocky in shape		
B.4:16	3.1.2	1	1	8.1.2	8.2.2			
B.4:16	3.3.0	1	1	8.1.3	8.2.1			
B.4:16	3.3.0	3	3	8.1.3	8.2.2			
B.4:18	3.1.3	2	1	8.1.3	8.2.3	8.3.1	8.4.2	misshapen and perforated showing signs of resorption and bone formation

B.4:18	3.1.3	2	1	8.1.2	8.2.1		
B.4:17/22	4.3.2	1	7	8.1.2	8.2.3	8.7.2	8.9.2
		1	2	8.3.1	8.4.2		
B.4:22	4.1.2	1	1	8.1.2	8.2.1		
B.4:22	4.1.3	1	1	8.1.2	8.2.1		
B.4:22	4.1.3	2	5	8.1.2	8.2.1		
B.4:22	3.2.1	2	2	8.1.2	8.2.2		
B.4:22	3.2.1	2	1	8.1.2	8.2.2		
B.4:22	3.2.1	1	1	8.1.2	8.2.2		
B.4:22	3.2.1	1	1	8.1.2	8.2.2		
B.4:22	4.3.6	1	5	8.1.2	8.2.2	8.5.2	8.6.1
B.4:22	4.3.5	2	8	8.1.1	8.2.1		
B.4:22	4.1.6	?	1	8.1.2	8.2.3		
B.4:22	4.1.6	?	1	8.1.2	8.2.3		
B.4:22	4.1.6	?	1	8.1.2	8.2.3		
B.4:22	4.1.6	?	1	8.1.2	8.2.3		
B.4:22	4.1.6	?	1	8.1.2	8.2.3		
B.4:22	4.1.6	?	1	8.1.2	8.2.3		
B.4:22	4.1.6	?	1	8.1.2	8.2.3		

B.4:22	4.1.6	?	1	8.1.2	8.2.3
B.4:22	4.1.6	?	1	8.1.2	8.2.3
B.4:22	4.1.5	?	5	8.1.2	8.2.3
B.4:22	4.1.5	2	5	8.1.2	8.2.3
B.4:22	4.1.4	2	1	8.1.2	8.2.2
B.4:22	4.1.5	2	1	8.1.2	8.2.2
B.4:22	4.1.5	2	1	8.1.2	8.2.2
B.4:22	4.1.5	2	1	8.1.2	8.2.2
B.4:22	4.1.5	2	1	8.1.2	8.2.2
B.4:22	4.1.5	2	1	8.1.2	8.2.2
B.4:22	4.1.5	2	1	8.1.2	8.2.2
B.4:22	4.1.5	2	1	8.1.2	8.2.2
B.4:22 commingled	4.3.5	2	9	8.1.1	8.2.1
B.4:22 commingled	4.3.7	?	1	8.1.3	8.2.2
B.4:22 commingled	4.3.7	?	1	8.1.2	8.2.2
B.4:23	3.2.0	1	3	8.1.1	8.2.2

B.4:23	2.0.7	1	Mandibular condyle	8.3.1	8.4.2
B.4:23	4.1.2	1	1	8.1.2	8.2.2
B.4:23	4.1.5	1	1	8.1.2	8.2.2
B.4:23	4.1.4	1	3	8.1.2	8.2.3
		1	1	8.5.1	8.6.3
B.4:23	4.1.4	1	2	8.5.2	8.6.2
		1	9	8.1.2	8.2.3
B.4:23	4.1.4	1	2	8.1.2	8.2.1
B.4:23	4.3.7	?	9	8.1.2	8.2.2
B.4:23	4.3.7	?	2	8.1.3	8.2.3
B.4:23 Individual 1	4.3.6	2	5	8.1.2	8.2.2
B.4:23 Individual 1	4.3.6	2	5	8.1.2	8.2.2
B.4:23 Individual 1	4.1.5	1	1	8.1.2	8.2.2
B.4:23 Individual 1	4.1.5	1	6	8.1.2	8.2.1
B.4:23 Individual 1	4.3.7	?	1	8.1.2	8.2.1

B.4:23 Individual 1	4.3.7	?	1	8.1.3	8.2.2	8.5.3	8.6.2			
B.4:23 Individual 1	4.3.7	?	1	8.1.3	8.2.2					
B.4:23 Individual 1	4.3.7	?	5	8.1.3	8.2.2					
B.4:23 Individual 1	4.3.2	1	6	8.7.2						
B.4:23 Individual 1	4.0.2	1	7 & 8	8.7.2						
B.4:23 Individual 2	4.3.6	1	5	8.1.2	8.2.3	8.5.2	8.6.1	8.7.2	8.8.2	8.9.2
B.4:23 Individual 2	4.3.6	1	1	8.5.1	8.6.1					
B.4:23 Individual 2	4.3.6	1	1	8.1.2	8.2.2					
B.4:23 Individual 2	4.3.6	1	1	8.1.2	8.2.2					
B.4:23 Individual 2	4.3.6	1	1	8.1.3	8.2.2					
B.4:23 Individual 2	4.3.7	?	1	8.1.2	8.2.2					
B.4:23 Individual 2	4.3.7	?	1	8.1.2	8.2.2					

B.4:23 Individual 2	4.3.7	?	2	8.1.2	8.2.1		
B.4:23 Individual 2	4.1.4	2	1	8.1.2	8.2.1		
B.4:23 Individual 2	4.3.7	?	9	8.1.2	8.2.2		
B.4:23 Individual 2	3.3.0	1	3	8.1.2	8.2.2		
B.4:23 Individual 2	4.3.7	?	9	8.1.2	8.2.3		
B.4:23 Individual 2	4.1.6	?	1	8.1.2	8.2.3		
B.4:23 Individual 2	4.1.6	?	9	8.1.2	8.2.3		
B.4:23 Individual 2	4.1.4	1	1	8.5.3	8.9.3		
B.4:23 Individual 2	3.3.0	1	2	8.1.2	8.2.3	8.5.2	8.6.1
B.4:23 Individual 2	3.3.0	2	2	8.1.2	8.2.2		
B.5:4	4.3.2	1	7	8.1.2	8.2.2	8.7.2	
		1	1 & 8	8.3.3	8.4.2		
B.5:9 commingled	3.1.2	3	Dens/9	8.1.2	8.2.2	8.3.2	8.4.2

		3	Dens/8	8.5.2	8.6.2		
B.5:12	4.1.5	1	3	8.1.2	8.2.3	8.5.2	8.6.1
B.5:12	4.1.5	1	9	8.1.2	8.2.2		
B.5:12	4.1.5	?	Hamulus	8.1.2	8.2.2		
B.5:15	T12	1	1	8.1.2	8.2.3		
B.5:15 commingled	4.0.2	1	Acromion process	8.1.3	8.2.2		
B.5:15 commingled	4.3.7	?	1	8.1.2	8.2.1		
B.5:19	4.3.2	1	7	8.5.3	8.6.3		
B.5:19	4.3.2	?	7	8.5.3	8.6.2		
B.5:19	3.1.3	1	2	8.1.3	8.2.3		
B.5:27	4.1.5	2	9	8.1.2	8.2.2		
B.5:27	4.1.5	1	9	8.1.1	8.2.3		
B.5:27	4.1.5	?	1	8.1.2	8.2.2		
B.5:27	4.1.5	?	1	8.1.2	8.2.2		
B.5:27	4.1.4	2	9	8.1.2	8.2.1		
B.5:27	4.1.4	2	9	8.1.2	8.2.1		
B.5:27	4.1.4	1	9	8.1.2	8.2.1		
B.5:27	4.1.4	2	9	8.1.2	8.2.1		

B.5:27	4.1.4	1	9	8.1.2	8.2.1	
B.5:27	4.1.4	1	9	8.1.2	8.2.1	
B.5:27	4.1.5	?	1	8.1.2	8.2.2	
B.5:27	4.1.5	?	1	8.1.2	8.2.2	
B.5:27	4.1.5	?	1	8.1.2	8.2.2	
B.5:27	4.1.5	?	1	8.1.2	8.2.2	
B.5:27	4.1.5	?	1	8.1.2	8.2.2	
B.5:27	4.1.5	?	1	8.1.2	8.2.2	
B.5:27	4.1.5	?	1	8.1.2	8.2.3	
B.5:27	4.1.3	1	5	8.1.2	8.2.2	
B.5:31	4.3.7	?	1	8.1.2	8.2.2	
B.5:31	4.3.7	?	1	8.1.2	8.2.2	
B.5:31	4.3.7	?	5	8.1.2	8.2.2	
B.5:31	4.3.7	?	5	8.1.2	8.2.2	
B.5:31	4.1.4	1	9	8.1.3	8.2.3	misshapen

Appendix C: Cases of Vertebral Osteophytosis from Tombs B.4 and B.5

Locus	Element	Side	Section/Aspect	Observations
B.4:10	3.1.3	3	3	7.2.3
B.4:10	3.1.3	3	3	7.2.3
B.4:10	3.1.3	2	1	7.2.3
B.4:10	3.1.3	2	1	7.2.3
B.4:10	3.1.3	3	1	7.2.2
B.4:10	3.1.3	3	3	7.2.2
B.4:10	3.1.3	3	2	7.2.3
B.4:10	3.1.3	3	3	7.2.3
B.4:10	3.1.3	3	2	7.2.1
B.4:10	3.2.1	3	3	7.2.2
B.4:10	3.2.1	3	3	7.2.2
B.4:10	3.2.1	3	2	7.2.2
B.4:10	3.2.1	2	1	7.2.2
B.4:10	3.1.0	?	1	7.2.3
B.4:16	3.3.0	3	3	7.2.3
B.4:16	3.3.0	3	3	7.2.3
B.4:16	3.3.0	?	3	7.2.3

B.4:16	3.3.0	1	1	7.2.3
B.4:16	3.3.0	2	3	7.2.3
B.4:16	3.1.0	3	2	7.2.3
B.4:16	3.3.0	3	1	7.2.2
B.4:16	3.1.0	3	3	7.2.3
B.4:16	3.1.0	3	3	7.2.3
B.4:17/22	3.2.1	3	1	7.2.3
B.4:22	3.2.1	2	3	7.2.2
B.4:22	3.2.1	3	1	7.2.2
B.4:22	3.2.1	3	2	7.2.4
B.4:22	3.2.1	3	1	7.2.4
B.4:22	3.2.1	3	2	7.2.2
B.4:22	3.2.1	3	2	7.2.2
B.4:22	3.2.1	3	2	7.2.2
B.4:22	3.2.1	3	2	7.2.2
B.4:22	3.2.1	2	1	7.2.3
B.4:22	3.2.1	2	2	7.2.3
B.4:22	3.2.4	1	2	7.2.2
B.4:22	3.2.2	3	1	7.2.2

B.4:22	3.2.3	1	2	7.2.2
B.4:22	3.2.4	3	1	7.1.2
B.4:23	3.1.4	3	1	7.2.2
B.4:23	3.1.3	3		7.2.3
B.4:23	3.1.3	3	3	7.2.3
B.4:23	3.2.0	3	1	7.2.2
B.4:23	3.2.0	1	1	7.2.3
B.4:23 Individual 1	3.2.1	3	1	7.2.3
B.4:23 Individual 1	3.2.1	2	1	7.2.3
B.4:23 Individual 1	3.2.1	3	1	7.2.3
B.4:23 Individual 1	3.2.1	2	2	7.2.2
B.4:23 Individual 1	3.2.1	1	2	7.2.2
B.4:23 Individual 1	3.3.0	?	?	7.2.3
B.4:23 Individual 2	3.1.0	3	3	7.3.3
B.4:23 Individual 2	3.1.0	3	3	7.3.3

B.4:23 Individual 2	3.2.1	3	2	7.2.2	
B.4:23 Individual 2	3.2.1	3	1	7.2.2	
B.4:23 Individual 2	3.2.0	3	3	7.2.2	
B.4:23 Individual 2	3.2.0	3	3	7.2.2	
B.4:23 Individual 2	3.3.0	3	1	7.1.2	
B.4:23 Individual 2	3.3.0	3	3	7.2.3	
B.5:11	3.1.0	2	1	7.1.3	7.2.2
B.5:11	3.1.0	3	1	7.1.3	
B.5:11	3.1.0	3	3	7.2.3	
B.5:11	3.1.0	3	3	7.2.3	Slightly wedged with extensive spicule formation. All cervical vertebrae bodies from B.5:11 have surface porosity and some lipping
B.5:12	3.3.0	2	1	7.2.3	
B.5:12	3.3.0	1	2	7.2.3	

B.5:15	3.1.3	3	2	7.2.1	
B.5:15	3.1.3	2	1	7.2.2	
B.5:15	3.2.0	3	1	7.2.3	
B.5:15	3.3.0	3	3	7.2.3	
		2	1	7.1.2	
B.5:15	3.3.0	2	3	7.2.3	
B.5:15	3.0.0	?	3	7.2.3	
B.5:15 person under L9 W of skull 10	3.1.2	3	2	7.3.4	C2 fused with part of C3; the disk space is compromised

Appendix D: Cases of Osteoporosis from Tombs B.4 and B.5

Locus	Element	Side	Section/Aspect	Observations		
B.5:15	3.6.3	1	shaft	3.1.2	3.2.3	3.6.1
B.5:15	3.6.3	1	shaft	3.1.2	3.2.3	3.6.1
B.5:15	3.6.3	1	4	3.1.2	3.2.2	3.6.1
B.5:15	4.2.3	2	4	3.1.2	3.2.3	3.6.1
B.5:15	4.2.3	2	4	3.1.2	3.2.3	3.6.1
B.5:15	4.2.3	1	7	3.1.2	3.2.2	3.6.1
B.5:15	4.2.3	1	7	3.1.2	3.2.2	3.6.1
B.5:15	4.2.2	2	5	3.1.2	3.2.3	3.6.1
B.5:15	4.2.1	1	4	3.1.2	3.2.2	3.6.1
B.5:15	4.0.2	2	scapular spine	3.1.2	3.2.3	3.6.1
B.5:15	4.3.5	1	1	3.1.2	3.2.2	3.6.1
B.5:15	3.6.3	2	4	3.1.2	3.2.2	3.6.1
B.5:15	3.6.3	2	4	3.1.2	3.2.2	3.6.1
B.5:15	3.6.3	2	4	3.1.2	3.2.2	3.6.1

B.5:15	3.6.3	2	4	3.1.2	3.2.2	3.6.1
B.5:15	3.6.3	2	4	3.1.2	3.2.2	3.6.1
B.5:15	3.6.3	2	4	3.1.2	3.2.2	3.6.1
B.5:15	3.6.2	2	4	3.1.2	3.2.3	3.6.1
B.5:15	3.6.3	2	shaft	3.1.2	3.2.3	3.6.1
B.5:15	3.6.3	2	4	3.1.2	3.2.2	3.6.1
B.5:15	3.6.3	1	4	3.1.2	3.2.2	3.6.1
B.5:15	4.2.1	2	frag	3.1.2	3.2.3	3.6.1
B.5:15	4.2.1	2	frag	3.1.2	3.2.3	3.6.1
B.5:15	4.2.1	2	frag	3.1.2	3.2.3	3.6.1
B.5:15	4.2.1	2	frag	3.1.2	3.2.3	3.6.1
B.5:15	4.2.1	2	frag	3.1.2	3.2.3	3.6.1
B.5:15	4.2.1	2	frag	3.1.2	3.2.3	3.6.1
B.5:15	4.2.1	2	frag	3.1.2	3.2.3	3.6.1
B.5:15	3.7.0	3	9	3.1.2	3.2.3	3.6.1
B.5:15	3.7.0	3	9	3.1.2	3.2.3	3.6.1
B.5:15	4.3.2	2	9	3.1.2	3.2.3	3.6.1

B.5:15	4.3.5	?	1 &6	3.1.2	3.2.3	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	shaft frag	3.1.4	3.2.2	3.6.1
B.5:15	4.3.1	2	1 or 9	3.6.1		
B.5:15	4.3.4	1	1 or 9	3.1.2	3.2.3	3.6.1

B.5:15	4.3.3	1	shaft frag	3.1.2	3.2.3	3.6.1
B.5:15	4.3.3	1	shaft frag	3.1.2	3.2.3	3.6.1
B.5:15	4.3.3	1	shaft frag	3.1.2	3.2.3	3.6.1
B.5:15	4.3.3	1	shaft frag	3.1.2	3.2.3	3.6.1
B.5:15	4.3.3	1	shaft frag	3.1.2	3.2.3	3.6.1
B.5:15	4.3.3	1	shaft frag	3.1.2	3.2.3	3.6.1
B.5:15	4.3.3	1	shaft frag	3.1.2	3.2.3	3.6.1
B.5:15	4.3.3	2	shaft frag	3.1.5	3.2.3	3.6.1
B.5:15	4.3.3	2	shaft frag	3.1.5	3.2.3	3.6.1
B.5:15	4.3.3	2	shaft frag	3.1.5	3.2.3	3.6.1
B.5:15	4.3.3	2	shaft frag	3.1.5	3.2.3	3.6.1
B.5:15	4.3.3	2	shaft frag	3.1.5	3.2.3	3.6.1
B.5:15	4.3.3	2	shaft frag	3.1.5	3.2.3	3.6.1
B.5:15	4.3.3	2	shaft frag	3.1.5	3.2.3	3.6.1
B.5:15	4.3.3	2	5	3.1.2	3.2.3	3.6.1
B.5:15	4.0.2	2	2	3.1.2	3.2.2	3.6.1
B.5:15	4.1.2	1	1 & 2	3.1.4	3.2.3	3.6.1

B.5:15	4.1.1	2	1	3.1.4	3.6.1	
B.5:15	4.1.1	2	4 & 5	3.1.4	3.6.1	
B.5:15	4.1.3	2	1 & 2	3.1.4	3.2.3	3.6.1
B.5:15	4.1.3	2	3	3.1.4	3.2.3	3.6.1
B.5:15	4.1.3	2	4 & 5	3.1.4	3.2.3	3.6.1
B.5:15	4.1.2	2	2 & 3	3.1.2	3.2.3	3.6.1
B.5:15	4.1.2	2	1	3.1.4	3.2.3	3.6.1
B.5:15	3.3.0	2	3	3.1.2	3.2.3	3.6.2
B.5:15	3.3.0	?	3	3.1.2	3.2.3	3.6.2
B.5:15	3.3.0	3	3	3.1.2	3.2.3	3.6.2
B.5:15	3.3.0	3	3	3.1.2	3.2.3	3.6.2
B.5:15	3.3.0	3	3	3.1.2	3.2.3	3.6.2
B.5:15	3.2.4	3	3	3.1.2	3.2.3	3.6.2
B.5:15	3.2.0	3	3	3.1.2	3.2.3	3.6.2
B.5:15	3.2.0	3	3	3.1.2	3.2.3	3.6.2
B.5:15	3.2.0	1	3	3.1.2	3.2.3	3.6.2
B.5:15	3.2.0	1	2	3.1.2	3.2.3	3.6.2

B.5:15	3.2.0	2	2 & 5	3.1.2	3.2.2	3.6.2
B.5:15	3.2.0	2	2 & 5	3.1.2	3.2.2	3.6.2
B.5:15	3.2.0	2	5	3.1.2	3.2.3	3.6.1
B.5:15	3.2.0	2	3	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	3	3	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	3	3	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	3	3	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	3	3	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	3	3	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	3	3	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	2	2	3.1.2	3.2.2	3.6.2
B.5:15	3.1.0	2	2	3.1.2	3.2.2	3.6.2
B.5:15	4.1.5	1	3	3.1.2	3.2.2	3.6.1
B.5:15	4.1.5	2	1	3.1.2	3.2.2	3.6.1
B.5:15	4.1.4	1	9	3.1.2	3.2.3	3.6.1
B.5:15	4.1.4	1	9	3.1.2	3.2.3	3.6.1
B.5:15	4.1.5	2	3	3.1.2	3.2.2	3.6.1

B.5:15	4.1.5	2	3	3.1.2	3.2.2	3.6.1
B.5:15	4.1.5	2	3	3.1.2	3.2.2	3.6.1
B.5:19	4.1.1	?	1	3.1.1	3.2.2	3.6.2

Appendix E: Cases of Trauma from Tombs B.4 and B.5

Locus	Element	Side	Part of bone involved	Observations	
B.4:22	3.6.3	2	7 & 8	5.1.2	5.4.3
B.4:23 Individual 2	3.1.0	3	3	5.1.6	
B.4:23 Individual 2	4.1.4	1		5.1.1	5.4.8
B.5:9 commingled	3.6.3	?	4	5.1.1	5.4.2
B.5:15 commingled	3.6.3	?	shaft	5.1.1	5.4.2
B.5:27	3.6.3	2	4	5.1.1	5.4.2
		2	4	5.1.1	5.4.2
B.5:27	3.6.3	2	4	5.1.1	5.4.2

Appendix F: Cases of Dental Enamel Hypoplasias in Tombs B.4 and B.5

Locus	**Tooth**	**Position**	**Distance from DEH to CEJ (mm)**	**Estimated Age of Occurrence in Years**
B.4:17	Canine	Maxillary, Right	9.9	1.0
			8	1.3
			7.5	1.6
			7	2.25
			6	
B.4:22 commingled	2nd Incisor	Maxilla, Left	1.9	3.7
B.4:22 commingled	Canine	Maxilla, Left	5.6	2.5
			4.2	3.4
			3.1	4.1
			2.1	4.7
			1.3	5.2
B.4:22 commingled	2nd Premolar	Mandible, Left	2.1	5.7
B.5:4	Canine	Mandible, Left	5.5	3.3
			5.0	3.6
			4.0	4.1
B.5:4	2nd Premolar	Mandible, Right	4.0	5.4
			2.5	2.4
B.5:9 Individual 1	1st Premolar	Maxilla, Right	3.5	4.3
B.5:9	1st Incisor	Mandible, Left	3.5	2.4

Individual 1				
			3.0	2.6
B.5:9 Individual 1	2nd Incisor	Mandible, Left	4.0	2.3
			3.3	2.6
B.5:13	1st Molar	Maxilla, Left	--	--
B.5:13	1st Molar	Mandible, Left	1.2	3.0
B.5:15 Skull #8	2nd Incisor	Maxilla, Left	--	--
B.5:31	Canine	Mandible, Right	4.0	4.1
			3.5	4.4
			2.0	5.3

Note: DEH=Dental Enamel Hypoplasia, CEJ=Cementum-Enamel Junction