SOCIAL IDENTITY AND LIFE COURSE STRESS IN NABATAEAN JORDAN

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The population of Nabataean and Early/Middle Roman Jordan consisted of agricultural and pastoral nomadic communities. Archaeological research in Jordan supports a symbiotic relationship between these different subsistence communities. A bioarchaeological examination of the agricultural population at Khirbet Qazone (1st – 3rd century C.E.) and the pastoral community at Zabayir (2nd – 3rd century C.E.) revealed evidence for the effects of stress, diet, and activity over the life course for different subsistence communities in Nabataea and the post-annexation Province of Arabia.

Non-specific stress indicators (linear enamel hypoplasia, cribra orbitalia, and porotic hyperostosis) were evaluated by individual age-at-death and growth using vertebral neural canal (VNC) diameters and long bone lengths, which revealed plasticity and adaptability for both communities. However, cribra orbitalia was significantly related to age-at-death and some VNC measurements for the agricultural group.

Like other sites in the region, comparison of $\delta^{13}C$ and $\delta^{15}N$ from dentine collagen and $\delta^{13}C$ from bone apatite revealed that those buried at both sites relied heavily on C_3 plant resources and C_3 grazing animals, although C_4 dietary contributions were greater at Zabayir. Incremental analysis of $\delta^{13}C$ and $\delta^{18}O$ from dental enamel demonstrated that while weaning patterns were more variable at Khirbet Qazone, both communities completed weaning by 3 to 3.5 years of age. Evidence for activity as indicated by musculoskeletal markers was also similar between the two communities. The data further illuminate the complex nature of subsistence economies and regional community

identity and support existing archaeological research suggesting mutualism and cooperation between agricultural and nomadic pastoral communities in the Near East based on these two populations.

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1.0 INTRODUCTION

Bioarchaeology focuses on uniting the physical remnants of human lives within their archaeological or social context to envision the cultural, biological, and environmental influences on individuals in the past (e.g., Buikstra 1977, Larsen 2002). This biocultural perspective considers mortuary contexts inclusive of their spatial, material cultural, and human components to deconstruct the past in a way that communicates its reality for those who lived it. As a result, the human skeleton has been increasingly recognized as a form of material culture imprinted with evidence for the biological, environmental, and cultural components of an individual's lifestyle and their role within a community (Sofaer 2006, Larsen 2002, Zvelebil and Weber 2013). In Nabatean and Early/Middle Roman Jordan, a growing body of bioarchaeological research has begun to reveal more about the lifeways of the region's inhabitants. Several studies compare the incidence of non-specific stress indicators, such as linear enamel hypoplasia (LEH), porotic hyperostosis, cribra orbitalia, and osteoperiostitis, along with evidence for dental health, pathology, and trauma to reveal differences and discuss similarities between populations in the region (Perry 2002a, Canipe 2014, Delhopital 2010, 2011, Lieurance 2018). Furthermore, studies examining diet and mobility have begun to create a more dynamic view of the region's Nabataean and later Roman inhabitants (Appleton 2015, Perry, Coleman, and Delhopital 2008, Perry et al. 2020, Perry, Jennings, and Coleman 2017).

However, bioarchaeology in Jordan, and elsewhere, has struggled to depict the longitudinal depth of identity from cross-sectional cemetery contexts. Many approaches focus on typological comparisons between categorical identities viewed as biological or social constants such as chronological age, sex, and status. Advancements in human biology and social theory examining the metaphysical aspects of the human experience have informed meaningful interpretations of identity and continue to afford more integrated approaches for examining identity in the past (Agarwal 2016, Sofaer 2006, Sofaer 2011). The modern biomedical focus on life course assessments of stress may provide an additional avenue to improve understandings of identity for ancient individuals through time (Agarwal 2016).

This project builds upon earlier studies to better define the life experience of individuals outside major urban centers in Nabatean and Early/Middle Roman Jordan and examines whether different subsistence life styles produced significant health outcomes over the life course for two rural populations—Khirbet Qazone (1st – 3rd centuries C.E.) and Zabayir (2nd – 3rd centuries C.E.); or, whether social interaction between agricultural and pastoral groups mitigated some of the more traditionally documented consequences of each lifestyle (Cohen and Armelagos 1984, Lukacs and Walimbe 1998, Larsen 1981, 1995, Driscoll and Weaver 2000, Munoz 2017). Human skeletons from these sites provide a cross-section of rural Nabataean society during and immediately following Roman annexation of the region that affords the opportunity to examine the relationship between the experience of stress, diet, activity, and identity during this socio-politically dynamic period.

1.1 THOERETICAL FRAMEWORK: RECONSTRUCTING IDENTITY IN NABATAEAN AND EARLY/MIDDLE ROMAN JORDAN

The Nabataean kingdom emerged in the 3rd century B.C.E. and ultimately claimed political control over the Jordan Valley and Transjordan plateau, as well as portions of southern Syria, the Negev, and Arabian Peninsula, placing it at the geographic intersection of historically documented political powers in the Mediterranean, Egypt, and Mesopotamia until the kingdom's annexation by Rome in 106 C.E. (LaBianca 2007, Schmid 2008). Occupying a significant portion of the land bridge between these imperial powers has customarily precipitated research attempting to understand Nabataean culture as a function of these more studied societies and generally minimized the local perspective (LaBianca 2007).

For the Nabataean period (300 B.C.E. — 106 C.E.), archaeological research focused at recognizable urban centers contributes to a relatively homogenous view of Nabataean identity, culture, and social organization (Schmid 2008). A research paradigm and excavation program heavily focused on the Nabataean capital city, Petra, has produced few research projects examining the sociopolitical relationships *between* Nabataean cities and towns before or after Roman annexation. Indeed, most research acknowledges the Nabataeans as a people, but not explicitly as a society comprised of communities and individuals, although there are notable exceptions (e.g., Nehmé 2013, Anderson 2005). Consequently, few detailed regional comparisons examine diversity within the Nabataean kingdom and later province of Arabia at the inter-community level or the identity of individuals within communities, outside the kingdom's capital at Petra.

While elsewhere the importance of bioarchaeology for understanding the representation of group and individual identity in ancient populations has been established, Jordanian archaeology is only beginning to recognize the true potential of this field (Zvelebil and Weber 2013, Knudson and Stojanowski 2009, Perry 2012, Judd 2009). Until the 21st century, human skeletal remains were not afforded the same detailed analysis as other types of material culture and many were discarded or simply not recorded (Judd 2009, Perry 2002a, 2007a, 2012, Sheridan 2017). Jordanian archaeology has not typically regarded the body as a source of material culture. Indeed, culture has been defined as "…the non-biological characteristics that are special to a particular society" (LaBianca 2007:4). Consequently, for Nabataean and post-annexation Jordan, identity in mortuary contexts has been referenced primarily in relation to the material and labor investment evident in tomb construction to define social status (Perry 2017, Mare 2001, Wadeson 2011, 2013). Identity is generally discussed collectively, in terms of a distinct material culture, or sometimes in relation to socioreligious corporate or family units in mortuary contexts (Nehmé 2013, Perry 2017, Wadeson 2012). On an intra-community level, some analyses provide disparate sources for evidence of life as reflected by sex and age categories, but these are not employed in detailed discussions of identity or personhood; for example, examination of burial inscriptions, tomb architecture, and body location within tombs have been used to address the role of women in Nabataean and Roman Jordan (Anderson 2005, Mare 2001). While these studies use the body's presence to define a burial place and ascribe meaning to burial accoutrements, identity reconstruction also requires integrated consideration of the body itself since the elements of culture leave a biological impression (Agarwal and Glencross 2011, Knudson and Stojanowski 2008, Sofaer 2006).

1.1.1 Mortuary Ritual and Life Course Modeling as Reflections of Social Identity

Understanding the body and the material record of personhood it recounts can be used to facilitate more detailed perceptions of the metaphysical aspects of life, including identity and social interaction, in past societies (Croucher 2012). Mortuary ritual is a complex dialectic behavioral response to the liminality of death signifying the transition of members from the living community to that of the dead (Croucher 2012, Laneri and Morris 2007). Therefore, to fully understand mortuary ritual, we must also be able to envision the roles of social actors in life.

In life, individuals fulfill various positions defined by the perception of their “rights and duties” in relation to other members of a society (Goodenough 1965:2-3). These roles describe an individual’s personhood or identity within a community, which is comprised of both individual and dividual aspects (Jones 2005, Croucher 2012, Fowler 2004). Unlike individual aspects inherent to the body, dividual components can be removed from the person, including personal adornments like jewelry, clothing, and tomb architecture. Ultimately, together these elements relay physical characteristics of personhood on the body as well as those that are ascribed to the individual through their relationships and interactions with others (Croucher 2012, Fowler 2004) “along lines of age, gender, and kinship” (Sheridan et al. 2014:135).

Moreover, identity is a pluralistic concept in which individuals may hold numerous identities, synchronically or diachronically, which are not immutable, but may change throughout the course of an individual’s life exposing a myriad of social roles that comprise and define them (Casella and Fowler 2005, Sofaer 2006). Sofaer (2006) stresses the importance of integrating the body itself into the analysis of mortuary contexts as a form of material culture to affect more meaningful discussions of identity. Since a person’s experience *throughout life* contributes to the individual and dividual components found in mortuary contexts, consideration of individuals within mortuary contexts following a life course analysis of stress, diet, and cultural context may provide more penetrating constructions of identity for ancient populations.

1.2 SETTLEMENT PATTERNS, SOCIOPOLITICAL ORGANIZATION & SUBSISTENCE ECONOMIES

Life course studies of stress and identity may be particularly revealing for complex cultural interactions, including the relationships between different subsistence communities. A growing corpus of research in Jordan suggests that the Nabataean kingdom comprised a cosmopolitan populous consisting of both semi-nomadic and sedentary populations that worked symbiotically throughout its existence, even after Roman annexation in 106 C.E. (Pearson 2011, Rosen 2007, Oleson 2010, Erickson-Gini and Israel 2013, de Vries 1998). Bioarchaeological studies for the region have demonstrated differences in health between agricultural (urban and rural) and nomadic communities (Canipe 2014, Perry 2002a, Rosen 2007). The theoretical discourse considering relationships between sedentary and pastoral nomadic populations typically espouses a dialectical view of cultural hierarchy, pitting *civilized* sedentary societies against *barbaric* or *troublesome* nomads (Pijl 2007, Pearson 2011, Parker 2013). Inevitably, these discussions envision unequal power relationships between sedentary *states* and more mobile societies that imply directional influence or control (Stein 2002, Hall, Kardulias, and Chase-Dunn 2011, Parker 2013). However, research focused on pastoral nomadic communities increasingly highlights the agency of and flexibility inherent in pastoral nomadic lifestyles and that mobility, as much as sedentism, may be an effective sociopolitical strategy (Honeychurch and Makarewicz 2016, Honeychurch 2014, Stein 2002, LaBianca 1990).

While sedentary communities are easily identified by architectural and material cultural remains, pastoral nomadism is ill-defined and encompasses a broad range of sociocultural lifeways that embody varying levels of mobility and animal husbandry (Honeychurch and Makarewicz 2016). However, these patterns are generally not a focal concern for many archaeological projects due in part to the scarcity of material cultural evidence left by mobile groups and the dispersed, multisite nature of nomadic community landscapes. This means that for many sites it is difficult to determine the number of different semi-nomadic groups or communities that used a site within a given temporal period. It is also difficult to discern the amount of time that any one group spent at a specific location or how frequently the location was used and re-used. In Jordan, during the Nabataean and Early/Middle Roman periods, semi-nomadic or temporary sites are defined primarily by the absence of more substantial architectural remains and material cultural elements such as pottery as well as the presence of rock lines and other small rock features (Rosen 2007). Cemetery contexts associated with semi-nomadic communities can help clarify some of these questions since inter- and intra-group relationships can be explored in greater detail using human skeletal remains and biochemical analyses.

The hypothesis of cooperation between sedentary and pastoral nomadic communities has garnered archaeological support from a survey of Nabataean and Early/Middle Roman pastoral nomadic encampments in the Negev (Rosen 2007). Instead of traditional architectural remains, these encampments exhibit transient remnants of human habitation which are indicative of more mobile communities, such as hearths, stone lines and piles, and cleared areas that likely served as tent pads. None of the encampments identified pre-date the majority of sedentary Nabataean cities (c. 1st century B.C.E.) suggesting that pastoral nomads may have moved into the Negev after more settled populations and lived in close proximity to low-intensity agricultural sites (Rosen 2007). Proximate semi-nomadic and sedentary sites identified in the Wadi el-Hasa have been viewed as part of a symbiotic system in which sedentary populations supplied cereal grains, post-harvest grazing, water, and other resources for nomadic pastoralists (Banning 1986). In exchange, pastoralist communities may have provided animal products such as wool, milk, and even meat.

Although sedentary populations can accommodate domesticated food animals, the increased occurrence of zoonotic diseases, limited space/grazing/water resources, and the potential for crop destruction make large-scale animal husbandry less attractive (Banning 1986, Barth 1956). These limitations create an opportunity for interdependent relationships with local tribes of nomadic pastoralists or a type of specialized pastoralism in which a portion of the population is largely semi-nomadic for animal husbandry management (Levy 1983).

Even larger urban centers in the Nabataean kingdom may have practiced a similar interdependent subsistence relationship with nomadic or semi-nomadic populations. A survey of archaeobotanical remains and agricultural practices at Bosra, Khirbet edh-Dharih, Mada'in Salih, and the residence of Ez-Zantur at Petra also support close association between pastoralists and agriculturalists (Bouchaud 2015). Excavations at Humayma produced an open field with a 1st century C.E. cistern, which was interpreted as a temporary or seasonal occupation for caravans or transhumant nomads existing alongside the sedentary population of the city (Oleson and Brown 2010). Other caravanserai documented around Petra, and in the Negev and Wadi Arabah at Khirbet Sufaysif indicate that nomadism, at least for trade, was an integral part of Nabataean social and economic life (Erickson-Gini and Israel 2013, David 2012, Zayadine 1992). Excessive water stores, such as those at Humayma, likely provided access to water and campsites for caravans traveling along the King's Highway, a major transport route, and thus would have served an important role in the economic stability of the kingdom (Reeves 2004). During the Roman period, transhumant individuals buried at Zabayir (Queen Aila International Airport [QAIA] Cemetery) were buried with Roman style sandals and imported objects demonstrating continued interaction and exchange between semi-nomadic and sedentary populations (Ibrahim and Gordon 1987).

Conversely, Nabataean burials throughout the kingdom contained leather burial shrouds which may have been produced by nomadic pastoralist communities such as the one at Zabayir.

It is generally assumed that the pastoral nomadic Nabataean populous engaged in an agropastoral subsistence economy, perhaps with some small-scale cultivation and agricultural supplementation obtained through trade as well as wild game supplementation. While some reliance on wild game hunting and the copious consumption of pastoral staples like sheep/goat continued in settled Nabataean communities, the utilization of olives, cereal grains, dates, and wine are also associated with these sedentary communities (Schmid 2001, Dolinka 2003, Politis 2004, Ramsay and Smith 2013, Ramsay and Parker 2016, Ramsay and Bedal 2015, Perry et al. 2013). Regional dietary studies rely primarily on the varying quantities of animal bones and seeds recovered from archaeological contexts, along with the availability of material cultural artifacts related to food production and the identification of agricultural fields and water management features (Kouki 2013, Perry et al. 2013, Retzleff 2003, Studer 2007, Ramsay and Smith 2013, Ramsay and Parker 2016, Ramsay and Bedal 2015, Bouchaud, Jacquat, and Martinoli 2017).

While subsistence *products* are well-documented in the form of olive presses, mortars, seeds, and faunal remains, the subsistence *structure* for these population centers has received less attention (Perry et al. 2013). How intensely were the hinterlands of these communities being exploited and by whom? To what extent did they support the urban center? This topic has not been well addressed for either the Hellenistic or later Roman periods at many Nabataean sites. However, it is better documented in surveys in the vicinity of Roman provincial centers such as Jerash which show the presence of an agriculturally-active hinterland (Kennedy 2004, Baker and Kennedy 2011). Surveys in the vicinity of Nabataean Aila and archaeobotanical evidence have demonstrated that the surrounding communities likely relied heavily on imports and products from Aila, suggesting an inverse of the expected model implied in core-periphery relationships (Dolinka 2003, Ramsay and Parker 2016). Conversely, surveys around Petra attest to a diverse agricultural economy along its perimeter, although it is unclear whether these resources were produced primarily for trade, wider distribution, or local and regional consumption (Kouki 2013, Alcock and Knodell 2012, Kouki 2012, Beckers and Schütt 2013, Knodell et al. 2017, Tholbecq 2013, Ramsay and Bedal 2015). Fiema (2003) asserts that a concerted focus on increased caravan trade, sedentism, and agriculture allowed the Nabataean economy to flourish despite the introduction of competition from Red Sea maritime trade from Roman Egypt. On the Madaba Plateau, With increased sedentism and centralization of the Nabataean state some rural groups may have elected greater autonomy by retaining or returning to a more mobile subsistence economy resulting in the symbiotic mixed-subsistence system in evidence for Nabataea (LaBianca 1990). Research examining the relationship between the lifeways of a sedentary, agricultural society and pastoral nomadic community may contribute to a more nuanced depiction of life in Nabataea and the Roman province of Arabia following annexation, particularly in areas outside larger urban centers since less is known about the diversity of health experiences among individuals in these populations.

1.3 THEORETICAL FRAMEWORK: LIFE COURSE STRESS

1.3.1 What's in a Name: Stress and Health in Bioarchaeology

Beginning with a letter to *Nature* in 1936 Han Selye pioneered the use of the term "stress" to define a non-specific physiological response or adaptation to any demand on the body (Selye 1978, 1936, 1976). These demands or stress inducing agents, including physical, environmental, and biological pressures, were identified as stressors and protracted exposure to stress stimuli was shown by Selye to produce a patterned General Adaptive Syndrome, which would ideally strike a biological balance between tissue damage and defense in response to stressors (Selye 1951, 1976, 1950, 1978). Although his ideas did not gain widespread acceptance until the 1970s, subsequent research affirmed Selye's hypothesis and demonstrated that physiological responses to environmental stressors can produce impacts on bone growth in laboratory experiments on mammals, producing osteological indications of stress (Siegel, Doyle, and Kelley 1977, Benderlioglu, Dow, and Ebensperger 2017, Gonzalez, Lotto, and Hallgrímsson 2014, Siegel and Doyle 1975, Viner 1999.).

As early as the 1970s, paleoepidemiological models were used to assess skeletal indicators of stress and disease, and to explore their broader implications for past communities (Temple and Goodman 2014, Goodman et al. 1984, Huss-Ashmore, Goodman, and Armelagos 1982). These models focused on homeostasis and imbalance through the interaction of environmental, physiological, and cultural factors to discuss growth disruption, disease, and death. However, nearly two decades later a broader sociocultural and biological implications for generalized health were added to this original framework and over time "health" and "stress" became synonymous in the paleoepidemiological literature (Goodman and Armelagos 1989, Temple and Goodman 2014). The modern engagement with health and increased incorporation of biomedical research in bioarchaeological studies have contributed to the conflation of the term "health" in relation to ancient contexts. Many bioarchaeological studies focus on health as measured through stress indicator and disease prevalence, but this focus on indicator occurrence means that depictions of health are necessarily portrayed at the individual level as static states of existence (i.e., "healthy" or "unhealthy"), which can be measured within and between populations. In these types of studies, stressor persistence is assumed, and the role of plasticity embodied in the biomedical conceptualization of stress is unacknowledged.

In 1992, Wood and colleagues challenged the extrapolation of population health from the prevalence of stress indicators since at any given point in time the dead cannot be interpreted as a direct representation of living populations due to selective mortality and hidden heterogeneity (i.e., how individuals vary in terms of relative susceptibility or risk of death) (Wood et al. 1992). Death is the result of the body's inability to continue functioning either due to disease, stress, or age-related cessation of function. While the oldest individuals in a burial context may represent the effects of senescence within the population, other burials inevitably represent the individuals within a population that succumbed to a stress or disease event. Therefore, demographic reconstructions, including disease incidence, are not strictly representative of the living population, or individual experiences throughout life. Paradoxically, individuals who survived a health or disease event may demonstrate the most pronounced bone lesions since survivorship can allow for increased skeletal involvement. Additionally, it is worth considering what dimension of stress is being addressed in any study, population or individual, and how these components contributed to the overall health of individuals and communities in life. Finally, the population-based statistical approach employed in many studies depicts stress as a generational state-of-being rather than a condition that continually evolves over an individual's life course, as well as within and between generations based upon environmental and social conditions.

More recently, the validity of assessing health bioarchaeologically has received criticism. Reitsema and McIlvaine (2014) employ the World Health Organization's (1999) definition of "health" as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" to demonstrate the incongruity between bioarchaeological and biomedical interpretations of "health". Social and mental well-being, which are not reflected in the physical indicators of stress identifiable on human skeletal remains, are largely inaccessible aspects of health for bioarchaeologists. This recognition does not preclude meaningful interpretations from archaeological skeletons, but in fact argues for a more rigorous interpretive framework discussing manifestations of stress in the appropriate context. Research emphasizing the relationship between stress indicators and age-at-death, growth potential, and additional stress events over the life course can contribute to deeper understandings of life in the past as well as the relationship between developmental constraints and plasticity and their impact throughout an individual's life (Wood et al. 1992, Temple and Goodman 2014, Reitsema and McIlvaine 2014). Moreover, some aspects of social consciousness can be accessed through identity studies bringing researchers closer to their goal of conceptualizing a comprehensive depiction of health for archaeological populations.

1.3.2 Life Course Stress

To understand life including stress and health from an individual perspective, bioarchaeological studies have focused on individualized portraits of life or osteobiographies developed from evidence over the skeletal life course (Saul and Saul 1989, Zvelebil and Weber 2013, Stodder and Palkovich 2012). Osteobiographies have enriched studies of identity and the experience of stress and disease over the life course by moving away from typological categorizations (Zvelebil and Weber 2013). Instead, life history studies favor the description of individual experiences to create more developed discussions for whole communities. Identity studies have further benefited from methodological advancements in paleodemography, biochemical analyses, and the application of social theory (Knudson and Stojanowski 2008). The increasing use of stable isotopes on archaeological skeletal populations and recognition of life course data from biomedical research have also expanded discussions of human health and stress allowing researchers to look at static events more longitudinally through an individual's life history (Agarwal 2016, Gowland 2015).

As a physiological system with extended development and a relatively slow rate of modification, the skeleton provides a unique cumulative record of an individual's life (Larsen 2002). Advancements in the study of epigenetics have clarified and informed deeper interpretations of the human skeleton as a record of events occurring throughout development, and even before birth, to affect an individual's physiological reality over the life course (Hales and Barker 2001, Lumey, Stein, and Susser 2011, Lumey and Stein 2009). The complex relationship between genetic and environmental events in early life is embodied in the Developmental Origins of Health and Disease (DOHaD) hypothesis, which applies a nuanced understanding of developmental processes to interpret later life events reflecting health and disease (Low, Gluckman, and Hanson 2012, Gluckman and Hanson 2006). Accordingly, the expression of disease and stress recorded on human skeletal remains may be deconstructed to discuss their developmental influences (Goodman 1996, Temple, Nakatsukasa, and McGroarty 2012, Temple 2008, Watts 2013, 2011, Floyd and Littleton 2006). For example, when a growth inhibitor is corrected the body may undergo "catch-up" growth or a rapid increase in growth velocity that reestablishes the individual along the normal growth curve representing plasticity associated with environmental disruptions (Prader, Tanner, and von Harnack 1963, Eveleth and Tanner 1976). Understanding the factors impacting development can afford a more holistic view of the environmental and biocultural influences for individuals and communities in antiquity that may also be key elements in the formation of early identities within society.

The "Barker Hypothesis" or thrifty phenotype model posits that fetal programming may be altered through nutritional insufficiency resulting in detrimental effects later in life (Barker et al.

1989, Hales and Barker 2001). The environmental alteration of an individual's genetic potential has been interpreted as a fetal adaptive or predictive adaptive response to more adequately accommodate the conditions of the perceived postnatal environment (Low, Gluckman, and Hanson 2012, Hales and Barker 2001, Gluckman, Hanson, and Beedle 2007, Gluckman et al. 2005, Gluckman, Hanson, and Spencer 2005). Therefore, environmentally induced changes to the genome, or epigenetics, enable fundamental changes in an individual's development and growth that may extend throughout the life span. However, the perceived postnatal environment more precisely reflects maternal health and may not correlate with the actual postnatal environmental conditions producing an incongruous epigenetic response that can prove problematic for postnatal function. For example, epigenetic changes related to prenatal malnutrition may increase risk for Type 2 diabetes when confronted with optimal nourishment postnatally (Hales and Barker 2001).

Growth retardation has also been linked to maternal health and nutritional insults. Several studies associate reduced height and an increased height-to-weight ratio with prenatal famine experienced during the first two trimesters (Lumey, Stein, and Susser 2011). One study found that adults over 50 years of age who experienced prenatal famine demonstrated reduced methylation of insulin-like growth factor–2 (IGF-2) compared to their unaffected siblings of the same sex evidencing long-term effects related to environmental gene modifications (Heijmans et al. 2008). Ultimately, epigenetic alterations in response to developmental stress may increase risk of death though gene modifications increasing risk for cardiovascular disease, respiratory disorders, and other factors (Barker et al. 1989, Barker, Osmond, and Law 1989). This increased risk of death can be seen archaeologically by examining whether individuals who experienced early life stress, as evidenced by the presence of skeletal stress indicators, also experienced decreased longevity compared to their peers which have no stress indicators or less pronounced lesions.

1.4 RESEARCH QUESTIONS AND HYPOTHESES

The current project will employ evidence for stress and later life health outcomes, diet, and activity to construct a comparative dialogue about identity formation in terms of what it means to be a rural agriculturalist or pastoral nomad in the Nabatean and Early/Middle Roman Near East. The current study will address the following research questions related to the health and lifeways of individuals at Khirbet Qazone and Zabayir during the 1st – 3rd century C.E. in Jordan:

1. How did stress affect the experience of health over the life course and does subsistence practice effect an individual's ability to respond to stress?
2. How did dietary practices, including weaning, influence the experience of stress for individuals based upon their subsistence economy?
3. Are differences in activity patterns evident on the skeletons from the different subsistence groups?

1.4.1 Research Question 1

How did stress affect the experience of health over the life course and does subsistence practice effect an individual's ability to respond to stress in Nabatean and Early/Middle Roman period Jordan?

Based upon previous bioarchaeological research (see Chapter 0), a variety of hypotheses will be explored to examine the experience of health over the life course. In general, communities heavily invested in agriculture experience a high level of environmental stress demonstrated by the prevalence of skeletal indicators of stress, including cribra orbitalia, porotic hyperostosis, and LEH compared to nomadic pastoralist or hunter-gatherer communities (Cohen and Armelagos

1984, Lukacs and Walimbe 1998, Larsen 1995, Driscoll and Weaver 2000, Larsen 1981). Additionally, marginalized communities and groups in state-level societies may experience reduced access to resources and increased environmental stress (Goodman 1998, Zuckerman, Kamnikar, and Mathena 2014).

Given previous research which suggests that agricultural populations generally experience an increased incidence of LEH, cribra orbitalia (CO), and porotic hyperostosis (PH) (Cohen and Armelagos 1984, Lukacs and Walimbe 1998, Driscoll and Weaver 2000, Larsen 1995, 1981), it is expected that if symbiosis with nomadic groups was significantly beneficial for agricultural populations it would have mitigated the detrimental effects of agricultural diets and reduced the occurrence of zoonotic diseases. However, if relationships with pastoral nomadic groups did not play a significant role in metabolic procurement, then the rural population at Khirbet Qazone is projected to have a higher prevalence of LEH, cribra orbitalia, and porotic hyperostosis compared to the semi-nomadic Zabayir group. Therefore, it is expected that:

1.1) The individuals who experienced LEH, cribra orbitalia, and porotic hyperostosis will have an earlier age-at-death than those individuals who do not show skeletal evidence of LEH, cribra orbitalia, or porotic hyperostosis, suggesting that these conditions may be correlated with increased mortality and greater stress over the life course.

1.2) LEH, CO, and PH will occur in association with decreased growth more frequently for the agricultural Khirbet Qazone population compared to the semi-nomadic Zabayir community. Growth will be assessed using vertebral neural canal (VNC) size as well as femoral bicondylar (FBL) and total tibia length (TTL).

1.4.2 Research Question 2

How did dietary practices, including weaning, influence the experience of stress for individuals based upon their subsistence economy?

In addition to understanding the relationship between environmental stress, longevity, and growth for individuals within each population, several aspects of diet will be evaluated to determine if differences in dietary composition played a role in the incidence or severity of stress for individuals between the two populations. Archaeobotanical and faunal studies suggest varied dietary resources at different sites throughout the Nabataean kingdom (Bouchaud 2015, Ramsay and Bedal 2015, Studer 2007, Perry et al. 2013, Ramsay and Parker 2016, Ramsay and Smith 2013, Tholbecq, Durand, and Bouchaud 2008, Jacquat and Martinoli 1999, Bouchaud, Jacquat, and Martinoli 2017). While few isotopic dietary studies have been undertaken for individuals from Nabatean sites, studies from Petra supported a diet comprised predominately of C_3 food resources (Appleton 2015, Perry et al. 2020).

2.1) Based on dietary studies at Petra and historical evidence for widespread trade within the region, isotopic and dental health are expected to demonstrate similar dietary conditions for Khirbet Qazone and Zabayir despite their differing subsistence economies. The study sites are expected to exhibit relatively comparable dental health and $\delta^{13}C$ levels associated with a primarily C_3 diet.

Since the timing of normal tooth growth is relatively consistent between individuals, enamel growth defects, such as LEH, can be measured and tied to specific periods of growth (Goodman and Rose 1990, Goodman and Song 1999, Reid and Dean 2000, Reid and Dean 2006). Inter- and intra-tooth isotopic sampling strategies also use the consistency of normal tooth development to examine dietary patterns, like weaning, over measurable spans of childhood, since different teeth and enamel sections represent different periods of growth (Wright and Schwarcz 1998, 1999, Beaumont et al. 2013, Eerkens, Berget, and Bartelink 2011, Sandberg et al. 2014, King et al. 2018). Many agricultural populations exhibit a higher prevalence of LEHs, along with a greater number of defects for effected individuals (Cohen and Armelagos 1984, Lukacs and Walimbe 1998, Munoz 2017). The shift from breast milk to a comparatively nutrient poor and possibly bacteria rich supplement of crop-based foods may contribute to poorer subadult health (Bourbou and Garvie-Lok 2009). Previous studies have posited that the availability of adequate foods generally contributed to earlier weaning in agricultural populations, which could produce greater stress during earlier growth periods and increased physiological response skeletally to weaning (Sellen and Smay 2001, Cohen and Armelagos 1984). This would produce isotopically measurable trophic level changes that begin earlier in childhood or infancy for agricultural populations. Therefore, it is expected that:

2.2) LEH age of occurrence, as estimated using the Goodman and Song (1999) regression equation, will occur more frequently during weaning within the sedentary population as measured by $\delta^{13}C$ and $\delta^{18}O$ values from incremental tooth enamel samples.

2.3) Individuals with LEHs experienced prior to the cessation of weaning will have a greater number of overall LEH occurrences, other stress indicators, as well as a younger age-at-death along with decreased long bone lengths and VNC diameters.

1.4.3 Research Question 3

Are differences in activity patterns evident on skeletons from the different subsistence groups?

In response to mechanical loading from muscular movement, bone may undergo osteoblastic or osteolytic alteration at muscle, ligament, and tendon attachment sites (Kennedy

1989, Hawkey and Merbs 1995). These musculoskeletal markers (MSMs) are relative indicators of activity that cannot be tied directly to specific behaviors (Meyers et al. 2011). However, previous bioarchaeological research has examined MSMs to discuss relative workloads associated with large scale changes such as the transition to agricultural production (Shuler, Zeng, and Danforth 2012, Eshed et al. 2004, Cohen and Armelagos 1984). Additionally, the social organization of labor has been examined by looking at activity within certain groups or between males and females within populations (Shuler, Zeng, and Danforth 2012, Eshed et al. 2004, Weiss 2017). Since MSMs may reveal something about the activities individuals within a society pursued, they have been included in this study to better define the differences and similarities between different subsistence populations in Nabataea and the Roman province of Arabia. MSMs will be examined for Zabayir and Khirbet Qazone and compared to address the role of stress in each community under the following hypothesis:

3.1) Based on previous bioarchaeological studies evidencing more robust upper limb musculoskeletal insertion development with agriculture (Eshed et al. 2004), it is expected that MSMs will indicate greater activity levels for the Khirbet Qazone population in all adult age categories.

1.5 DISSERTATION CONTENTS

This dissertation is organized around three primary research questions regarding the lives of individuals from two archaeological sites—Khirbet Qazone and Zabayir. Chapter 2 contains a brief culture history of the Nabataeans with theoretical and archaeological information surrounding the development of the Nabataean kingdom, Roman annexation, and the subsequent effects of political change for the former Nabataean territories. Chapter 3 explores bioarchaeological evidence for stress and the integration with other data types to discuss stress experiences over the life course. Chapter 4 details previous bioarchaeological work in the region and other studies of Nabataean and Roman populations, including mortuary and burial practices as well as the exploration of health, mobility, and diet. The application of bioarchaeological methods and the skeletal materials used in pursuit of the project goals are discussed in Chapter 5. The results of the specified analyses are organized by research question and presented in Chapters 6-10 with a discussion for each. Chapter 11 summarizes the results and their contextual integration as signifiers of identity for populations in Nabataea and Roman Jordan; conclusions and future considerations are also presented in Chapter 11. The appendix contains supplemental documents with skeletal recording information as well as figures not included in the main text of the document. Temporal periods throughout this document will adhere to the chronology defined in Table 1-1. Since local events and material cultural changes are often referenced in relation to Nabataean rulers, a chronology of Nabataean kings is also provided (Table 1-2).

Table 1-1. Chronology of archaeological periods in Jordan[1].

Temporal Period	Sub-designation	Chronological Date Range
Paleolithic	Upper Paleolithic	43,000–18,000 B.C.E
Epipaleolithic		18,000–8,500 B.C.E
Neolithic	Pre-Pottery Neolithic A	8,500–7,200 B.C.E
	Pre-Pottery Neolithic B	7,200–6,000 B.C.E
	Pottery Neolithic A	6,000–5,000 B.C.E
	Pottery Neolithic B	5,000–4,500 B.C.E
Chalcolithic	Early Chalcolithic	4,500—3,800 B.C.E.
	Late Chalcolithic	3,800—3,400 B.C.E.
Early Bronze Age	EB IA–B	3,400—3,100 B.C.E.
	EB II	3,100—2,650 B.C.E.
	EB III	2,650—2,300 B.C.E.
	EB IVA–C	2,300—2,000 B.C.E.
Middle Bronze Age	MB I	2,000—1,800 B.C.E.
	MB II	1,800—1,650 B.C.E.
	MBIII	1,650—1,500 B.C.E.
Late Bronze Age	LB IA	1,500—1,450 B.C.E.
	LB IB	1,450—1,400 B.C.E.
	LB IIA	1,400—1,300 B.C.E.
	LB IIB	1,300—1,200 B.C.E.
Iron Age	Iron IA	1,200—1,125 B.C.E.
	Iron IB	1,125—1,000 B.C.E.
	Iron IC	1,000—925 B.C.E.
	Iron IIA	925—722 B.C.E.
	Iron IIB	722—586 B.C.E.
	Iron III	586—520 B.C.E.
Persian Period[2]	Early	539—450 B.C.E.
	Late	450—332 B.C.E.
Hellenistic	Early Hellenistic	332—200 B.C.E.
	Late Hellenistic	200—64 B.C.E.
Nabataean[3]		300 B.C.E. — 106 C.E.
Roman	Early Roman	64 B.C.E. —C.E. 135
	Middle Roman	135—250 C.E.
	Late Roman	250—363 C.E.
Byzantine	Early Byzantine	363—460 C.E.
	Late Byzantine	460—638 C.E.
Early Islamic	Umayyad	640—750 C.E.
	Abbasid	750—969 C.E.
	Fatimid	969—1071 C.E.
	Seljuk-Zenjid	1071—1174 C.E.
Late Islamic	Ayyubid	1174—1263 C.E.
	Mamluk	1263—1516 C.E.
	Early Ottoman	B.C. 1516—1703
	Late Ottoman	B.C. 1703—1918
Modern		B.C. 1918—present

[1]Kennedy (2000), Meyers (1997), Bienkowski (2008)

[2]Meyers (1997) and Bienkowski (2008) conflict regarding the beginning of the Persian Period; Bienkowski's (2008) assessment based upon historical textual evidence is employed here.

[3]Note that the Nabataean period overlaps with both the Hellenistic and Early and Middle Roman periods.

Table 1-2. Chronology of Nabataean kings after Kennedy (2000).

King	Rein
Aretas I	c. 168 B.C.E.
Aretas II	c. 120/110─96 B.C.E.
Obodas I	96─85 B.C.E.
Rabbel I	85/84 B.C.E.
Aretas III	84─62/61 B.C.E.
Obodas II	62/61─59 B.C.E.
Malichus I	59─30 B.C.E.
Obodas III	30─9 B.C.E.
Aretas IV	9 B.C.E. ─ B.C. 40
Malichus II	B.C. 40─70
Rabbel II	B.C. 70─106

2.0 REGIONAL CONTEXT: NABATAEAN AND EARLY/MIDDLE ROMAN JORDAN

This section will provide a brief discussion of the Nabataeans, including their origins, distinct material cultural elements, and insight into community structures and relationships. In 106 C.E. the Nabataean kingdom was annexed by the Roman Empire, which had already expanded its imperial borders to include many kingdoms surrounding Nabataea, including Judea, Egypt, and the Decapolis[1] cities to the north. The impact of this sociopolitical change is also reviewed.

2.1 HISTORICAL CONTEXT IN THE NEAR EAST

Archaeological research in Transjordan and the Jordan Valley have held a disproportionate role in shaping the regional narrative. Temporal periods in the Near East are defined by international historical reference points with the period of the Nabataean kingdom (300 B.C.E. – 106 C.E.) occasionally subsumed, depending upon the region, under the broader Hellenistic (332 – 64 B.C.E.) and Early Roman (64 B.C.E. – 135 C.E.) periods (Table 1-1). Emphasis on historical textual sources have oriented discussions around imperial themes and archaeological research tends to reflect tangible elements within the extant historical sources (e.g., battles, Roman

[1] The Decapolis meaning "ten cities" in Greek was a league of up to 18 city-states that maintained relative independence throughout the Nabataean period in Jordan as relatively small urban centers. The original ten Decapolis cities included Khirbet Tabaqā Fāhil, Umm Qais, Jerash, Amman, al-Rāfa, Qal'at al-Husn, and Dion in Jordan; Beth-Shean in Israel; as well as Damascus and al-Qanawāt in Syria. After 106 C.E., Rome divided the Decapolis cities between the province of Arabia and the Syrian province, *Palestina secunda*, perhaps as an effort to reduce their collective power. In any case, the Decapolis cities flourished and expanded under Roman rule and up to 18 cities are eventually mentioned in association with the Decapolis including Abila in northern Jordan (Applebaum 2007).

annexation, Roman military expansion, etc.), generally minimizing the local perspective and precluding the utilization of other scientific, anthropological, or ethnographic evidence—including social theory, comparative analyses, and human skeletal remains—to create larger frameworks for understanding sociopolitical interactions (Kennedy 2004, Freeman 2008, Meyers 2003, Perry 2012, Perry et al. 2012, Perry 2007a, Judd 2009, Wenning 2013, Graf 2006, Wenning 2007, Bowersock 1983, LaBianca 2007). Similarly, Roman period research has focused largely on infrastructural changes imposed by the Romans and the business of empire building rather than impacts on local social systems and political and economic structures, although a few examples stand out (e.g., Perry 2002a, Oleson 2004, Reeves 2004).

During the Nabataean and Early/Middle Roman periods a few Latin and Greek texts by Strabo, Zenon, Diodorous, and Josephus describe the region and the Nabataeans (Graf 2013, Graf and Said 2006, Schmid 2008). However, these texts and historical records invariably reflect the motives and agendas of their writers and subsequent editors (Bienkowski 1992, Pearson 2011). These documents cannot not effectively define the pattern and process constituting the social complexity of daily life in the region (Perry 2007a, Pearson 2011, Anderson 2005, Graf 2004, Sofaer 2006). Instead, much of our understanding about the local Nabatean population and Early/Middle Roman periods is derived from archaeological excavation and survey.

Dating sites and their sequences of cultural occupation in the Nabataean and Roman periods generally relies on pottery typologies and coins to provide a temporal context for cultural occupations. During the Nabataean period, most Nabataean sites are dated using the local Nabatean pottery, which follows a well-defined chronology with resolutions of 25-50 years between the 1st century B.C.E and early 2nd century C.E. (Schmid 2000), along with imported and locally minted coins. However, in other periods chronologies are more wide-ranging or contested, making short-term changes difficult to evaluate (Freeman 2008). In the absence of pottery or other diagnostic artifacts, radiocarbon dating has established the temporal relationship between archaeological contexts (Higham 2007, Saliège et al. 2013), including the earliest architectural installations at Petra (Renel and Mouton 2013b) and the dates of the earliest monumental Nabataean tombs (Mouton and Renel 2013).

Only a few locally produced historical records provide direct impressions of the region. The Petra papyri, found in the Petra Church, comprise a series of 6th century documents that have been used to assess patterns of land use, legal disputes over space and resources (such as water or dung/fuel), and connections between central Jordan and Palestine, descriptions that have sometimes been extended to discussions of earlier Nabataean contexts (Frösén 2013). The Babatha archive (94 – 132 C.E.) and the letters of Salome Komaise (125 – 131 C.E.) constitute a unique collection of legal documents recovered from the Dead Sea region that provide contextual information about the freedoms, limitations, processes, and social norms that governed the lives of individuals (Esler 2019, Cotton 1995, Isaac 1992). Additionally, epigraphic data, including local inscriptions and graffiti, provide an emic perspective, but may not represent actual or truthful reflections of events; however, they may offer useful insight into local politics as well as the opinions and identity of individuals (Graf 2004, Nehmé 2013, Bienkowski 1992).

While the words and thoughts of a few individuals have been recorded and transmitted through a handful of historical resources, the experiences that influence an individual's health and behavior have left lasting impressions on human skeletons throughout the region. Like other archaeological evidence, the human skeleton can be viewed as a form of material culture to access these experiences (Sofaer 2006), which makes bioarchaeology uniquely positioned to contribute to a discussion of the social and cultural realities in past communities within Nabataea and the later Roman Province of Arabia.

2.2 A BRIEF HISTORY OF NABATAEAN ORIGINS, EMERGENCE, & SOCIOPOLITICAL ORGANIZATION

The historical and archaeological evidence indicate that the Nabataeans, which controlled significant trade routes from South Arabia, across Transjordan and through the Negev, transformed relatively quickly from a nomadic society to a large kingdom. Historical reports of the Nabataean people appear in the 1st century B.C.E. writings of Diodorus Siculus, who describes them as nomadic traders occupying Transjordan and the Dead Sea littoral during the 4th century B.C.E. (Geer 1954). The writings of Diodorus indicate that the Nabataeans gathered at a naturally defensible area many researchers interpret as the location of their kingdom's later capital, Petra, and excavations have identified installations at Petra as early as the late 4th – early 3rd century B.C.E. (Renel and Mouton 2013a, b, Graf 2013, Geer 1954). However, by the 1st century B.C.E., the Nabataeans emerged as a distinct, archaeologically identifiable political entity exemplified by a prolific phase of construction at the capital city, Petra (Figure 2-1) (Al-Bashaireh and Hodgins 2011, Hammond 1973). The specific extent of the Nabataean kingdom's expansive boundaries at any given time are not well-detailed in the historical record.

Many Nabataean sites are affiliated with the kingdom simply based upon the presence of significant Nabataean material culture and assumptions regarding the kingdom's extent. The southern Ghor, the location of Khirbet Qazone, likely was part of the kingdom by the 1st century C.E. based on the filing of papers by Babatha in the kingdom's capital at Petra (2002, Esler 2019, Isaac 1992). Within the Nabataean territory, large urban centers like Humayma and Aila, and smaller sites like Khirbet edh-Dharih demonstrate Nabataean cultural influence through their use of Nabataean coinage, pottery, and religious, architectural, and artistic elements (Delhopital 2010, Lenoble, Al-Muheisen, and Villeneuve 2001, Villeneuve and Al-Mucheisen 2008).

The Nabataean pottery tradition is defined broadly by two categories, Nabataean Painted Fine Ware, which includes an assortment of decorated cups and bowls, and coarse ware, which served a more utilitarian function in food storage, preparation, and cooking (Schmid 2004). Short-lived trends in pottery style allow for relatively precise chorological dating using ceramic typologies following the 1st century B.C.E. (Gerber 1997, Schmid 1995, 2008, 2000). The Nabataeans also developed a state coinage minted at Petra that employed a version of Aramaic, a language used widely across the Near East (Bowsher 2007). Nabataean religion is largely defined by an aniconic tradition that utilizes idol blocks, betyls, and niches for free-standing betyls as physical representations of divinity (Healey 2001, Alpass 2011, Erickson-Gini 2015). The perpetuation of Nabataean cultural elements even after the kingdom's decline would suggest that these features comprised a community sociocultural identity beyond the political level (Politis 2007). Nabataean identity and political affiliation are less clear for sites along the kingdom's eastern desert fringe. For example, the cemetery containing pastoral nomads buried near the Queen Alia Airport (the site of Zabayir) contained artifacts identified as "Greco-Roman" (Ibrahim and Gordon 1987). In addition, the only inscription found at the site was written in Thamudic, a Semitic language closely related to Nabataean that was utilized by primarily nomadic inhabitants of the Nabataean kingdom and its desert environs (MacDonald 1993, Graf 1992).

Figure 2-1. Map of selected Nabataean and Early Roman period sites in Jordan and the Negev (courtesy of Google Earth).

Mesopotamian, Aramaean (Syrian), north Arabian, and former Iron Age populations, including the Idumaeans[2], have been posited by researchers as possible Nabataean predecessors (Graf 1998, Wenning 2013, Healey 1989, Bienkowski 2013). The quest for the "ethnicity" of Nabataean society fails to account for the possibility that *Nabataean* did not initially represent a discrete ethnic identity, but rather a sociopolitical self-categorization of several nomadic Arab tribes into a larger corporate group (Graf 2004, Anderson 2005). An examination of epigraphic inscriptions attributed to the early Nabataeans supports a heritage of plurality with individuals from numerous linguistic, socioreligious, and geographic backgrounds espousing a common identity (Graf 2004). Cultural elements evidenced in these inscriptions crop up throughout

[2] Former inhabitants of Edom who were banished to southern Judaea based on the writings of Strabo (Graf 2004).

traditional Nabataean culture including local deities later subsumed under the royally recognized Nabataean pantheon.

The relative monopoly held by the Nabataeans on the north-south incense trade from southern Arabia to Gaza and Bosra is traditionally viewed as the foundation of the Nabataean economy, facilitating sedentism and the growth of their kingdom (Durand 2004). The roots of the Nabataean trade economy were probably already well-established in the late Iron Age and, it is thought, were so entwined with Nabataean identity that the Nabataeans consolidated their resources with a sedentary community at Petra to better facilitate and defend their trade interests (Durand 2004, Pearson 2011, Schmid 2001, Al-Abduljabbar 1995). Later territorial expansions into southern Syria, the Hauran, Levant, and Saudia Arabia have been viewed as political moves to facilitate greater autonomy over their trade network (Pearson 2011). During their early development, a corporate identity may have been politically functional, allowing the Nabataeans greater authority in negotiations and more effective interaction with regional powers.

Historical records and archaeological data have been utilized to provide some insight into the movement of goods that formed the backbone of the Nabataean economy (Young 2001, Durand 2004). The most widely referenced Nabataean commodity is incense and perfumed oils although, historical sources also report the distribution of precious stones, textiles, and pepper from southern Arabia and India, probably via eastern Arabia (Durand 2004). Frankincense and myrrh produced from the gum resin of plants grown in southern Arabia were specifically referenced by Diodorus and would have been available along the main north-south trade route passing through Transjordan (Durand 2004). During the 1st century B.C.E., the Nabataean response to maritime competition was to expand overland trade routes through the introduction of new routes and greater investment in sedentism, agriculture, and trade infrastructure (Fiema 2003). By the 1st century C.E. Petra had also transitioned from an aromatic raw materials supply station into a manufacturing center of secondary products, such as oils and perfumes. New trade routes were built across the Negev, including a roadway connecting Moyat ʻAwad in the Wadi Arabah desert and Oboda in the Negev, possibly in response to the Hasmonean capture of Gaza (Erickson-Gini and Israel 2013). Petra's enduring status as an influential regional city and the continuation of the caravan trade after Roman annexation would also suggest that overland trade was still a valuable economic venture, even given Rome's access to maritime routes through Egyptian ports (Fiema 2003, 1988).

Archaeological interpretations for most of the excavated communities in Nabataea have focused on their role as facilitators in this trade network including Humayma, Aila, and of course, Petra, leaving alternative economic avenues and potential trade resources relatively undiscussed (Oleson and Schick 2010, Oleson 2010, Oleson and Brown 2010, Dolinka 2003, Schmid 2008). The Dead Sea region was, and remains, an agriculturally productive area (Politis 2004). Ancient crops including balsam, indigo, date palms, and sugar cane (evidenced in Islamic periods) were produced alongside the economic exploitation of bitumen, salt, and sulfur from the Dead Sea (Politis 2004, 1999, 1998). In his writings Diodorus specifically identifies "asphalt"[3] and basalm as valuable trade goods from the Dead Sea region (Geer 1954). Given that a substantial subset of the Nabataean population was devoted to mercantile pursuits, agricultural production was also likely a focal and well-organized industry to support the non-agricultural sections of the populous (Fiema 2003).

[3] Diodorus of Siculus's *The Library of History*, Book 19 Chapter 98

2.2.1 Nabataean Communities

An array of archaeological sites has illuminated aspects of urban, religious, and agricultural aspects of Nabataean society. Many Nabataean population centers such as Humayma, Aila, and Dhiban were founded during the 1st century B.C.E. (Porter et al. 2007, Oleson and Schick 2010, Oleson and Somogyi-Csizmazia 2010, Oleson 1992, Oleson and Brown 2010, Dolinka 2003). The most prolific phase of Nabataean economic growth and expansion followed in the 1st century C.E. and additional communities were founded throughout the kingdom (Graf 1992). The central role of trade is evident at many sites, including Petra, Humayma, Aila, and sites across the Negev that created a large-scale network enabling the widespread movement of goods which fed the kingdom's growth (Durand 2004, Erickson-Gini and Israel 2013, Young 2001). These networks and cities also required significant attention to water access, storage, and distribution, including reservoirs, cisterns, irrigation features, and aqueducts that allowed them to thrive in the sometimes-harsh deserts throughout Arabia and the Levant. A large-scale water-works project at Humayma, including a gravity flow aqueduct fed by springs 27 km to the north near Wadi Ramm, and significant public reservoirs confirm a long-distance network within the region. Moreover, the scale of these projects at Humayma implies support and patronage from the governing body at Petra suggesting a relatively centralized sociopolitical structure (Oleson and Brown 2010).

Some sites encompass the religious or ritual significance of *place* within the kingdom, such as Khirbet edh-Dharih, located approximately 100 km from Petra. The site included a prominent sanctuary dating from the 1st century C.E. and a small village established in the 2nd century C.E. (Lenoble, Al-Muheisen, and Villeneuve 2001, Villeneuve and Al-Muheisen 1988, Villeneuve and Al-Mucheisen 2008). Occupation of the site continued into the 4th century C.E. until the city was destroyed by the 363 C.E. earthquake, which caused destruction across the region evident at other urban centers including Petra and Aila (Lenoble, Al-Muheisen, and Villeneuve 2001, Thomas, Parker, and Niemi 2007, Ward 2016, Kolb 2002b, 1998, Joukowsky 2004, Kolb 2002a, Villeneuve and Al-Muheisen 1988, Villeneuve and Al-Mucheisen 2008). Although described as a provincial city compared to Petra, the disproportionate size of the settlement's temple, first constructed during the Nabataean period and later rebuilt and expanded, suggests that the town may have served as a site of regional religious importance (Villeneuve and Al-Mucheisen 2008). One building with numerous storage rooms and a large banquet hall has been proposed as a facility catering to religious pilgrims.

While Nabatean communities were united by a similar material culture, the examination of individual sites and regions allow for a more integrated understanding of the diversity that existed within the Nabatean kingdom. The Dead Sea region provides an interesting microcosm of the larger Nabataean kingdom. Archaeological and textual evidence depicts the Dead Sea environ as a vibrant region for trade and social interaction between Judean and Nabataean communities, both before and after Roman annexation (Politis 2004). Agricultural products, including balsam and dates, along with minerals, such as bitumen, salt, and sulphur were traded from the Dead Sea region and the mild winter climate also provided a favorable environment for the seasonal residences of the wealthy and influential, including the Judean King Herod (Politis 2004). The Babatha archive (94 – 132 C.E.) provides the most direct evidence for the close relationship between Jewish and Nabataean residents along the Dead Sea (Bowersock 1983, Isaac 1992, Esler 2019). The documents include a series of legal exchanges written in Greek, Aramaic, Hebrew, and Nabataean, between a Jewish widow, from the Nabataean village of Mahoza and Nabataean/Roman officials delineating, among other things, her inheritance of property along the Dead Sea in Nabataea providing evidence for the diverse population along the Judean-Nabataean border. Another set of letters (dated 125 – 131 C.E.), presumably recovered from Nahal Hever near the hiding place of the Babatha archive, documents the legal disposition of Salome Komaise who was also a Jewish woman from Mahoza (Cotton 1995, Esler 2019). Like the Babatha archive, the documents of Salome Komaise were written in Greek, Aramaic, and Nabataean. Although the exact location of Mahoza is not known, it was located close to Zoar, which has been identified as modern Safi (Bowersock 1983), approximately 28 km to the south of the Khirbet Qazone cemetery and within the western periphery of the Nabataean kingdom.

These settled regions within Nabataea had largely symbiotic relationships with pastoral nomads living in their midst as well as along the desert eastern fringe of the kingdom (Rosen 2007, Graf 1992). These mutualistic relationships are emphasized for later periods as well by Banning (1986). However, some researchers have suggested that Thamudic tribes were responsible for the destruction of caravan stations along the Petra-Gaza route during the 1st century C.E. and that tense relations with nomadic tribes also contributed to the later Roman fortification along the eastern desert fringe of the kingdom (Graf 1998, Parker 1987a). However, Thamudic epigraphy also documents association with the Nabataean religious pantheon, suggesting that many tribes may have identified as Nabataean (Graf 1992). Parker (1987a) concedes that Banning's (1986) assertion of mutualism between sedentary and pastoral nomadic communities is evidenced by the archaeological and historical record; however, in his view this is only possible due to a strong centralized policing of frontiers. Sedentism and nomadism may also be viewed as social mechanisms to navigate larger sociopolitical changes (LaBianca 1991). In this view, mobility is one way in which groups can maintain autonomy or resist unfavorable social changes. Pastoral nomadism does not represent a homogenous sociocultural worldview; while some groups may have embraced or welcomed certain changes others may have viewed them as limiting or disadvantageous and resisted. Therefore, subsistence relationships were likely situation dependent and varied based upon relationships between communities as well as the larger sociopolitical ethos.

2.3 ROMAN ANNEXATION AND NABATAEA AS PART OF ROMAN ARABIA

The Nabataean political economy faced a fundamental shift in 106 C.E. when the Roman Empire, which had already expanded to include Egypt and the Levant, annexed Nabataea and the kingdom became a Roman province. Following annexation, Petra was named a metropolis[4] and remained an influential city within the new Roman province of Arabia (Freeman 2008, Bowersock 1983, Fiema 1988, 2001). The catalyst for annexation has been debated with arguments citing Roman commercial trade interests, Roman military and political tension with the Parthians east of Nabataea, or issues within the Nabataean government, possibly following the death of Rabbel II (Young 2001). While each of these reasons likely influenced the ultimate decision to annex the kingdom, the timing of the event during an ongoing campaign against Dacia and the *ad hoc* force deployed by the Syrian governor support something more sudden, such as an issue in Nabataean succession (Young 2001, Freeman 1996).

While Roman annexation is largely thought to have been relatively peaceful, new research is demonstrating support for possible Nabataean resistance and destruction at Petra and Aila. Although several collapsed Nabataean homes were destroyed around this time, the temporal proximity between the c. 113 earthquake and Roman annexation makes it difficult to directly connect the evidence from Aila with Nabataean resistance. At Petra, however, ballista balls

[4] Greek for "mother city", this designation was bestowed upon important or influential cities in the Roman Empire.

associated with destruction at the Great Temple have been used to posit Nabataean opposition to annexation (Joukowsky 2004). A city wall was also hastily constructed along the northern boundary of Petra's urban center either immediately before or after annexation (Parker and Perry 2013), suggesting either Nabataean defense or Roman control was considered necessary.

The Roman military presence in Nabataea made use of some earlier Nabataean forts and watchtowers, but it was not until the Diocletian reforms of the 3rd and 4th centuries C.E. that Rome's military presence was reinforced with widespread regional fortification. Soon after the Nabataean annexation, Bostra and Aila were connected via a garrisoned roadway, the *Via Nova Triana*, which was completed c. 111-114 C.E. Many of the stations along the *Via Nova Triana* were pre-existing Nabataean fortified settlements or caravanserai (Graf 1992, 1979). The initial framework for the Roman *limes Arabicus* or fortified eastern frontier, which followed the *Via Nova Triana* incorporated existing Nabataean fortifications and garrisons, which were added to by the Romans (Parker 1987b, Parker and Betlyon 2006, Parker 1976). The number of these fortified settlements along the eastern frontier increased slightly in the 2nd century C.E. but doubled under the Diocletian reforms in the 3rd and 4th centuries C.E. (Parker 1976).

Following annexation, relations between the Roman military and the pastoral nomadic tribes in the area appears to be relatively peaceful and Musil (1926) even speculated that these tribes may have served as *foederati* for the Roman military along the *limes Arabicus* eliminating the need for extensive fortifications. Archaeological research provides no evidence for localized domestic fortification and supports a largely symbiotic relationship between the region's sedentary and more transient populations (de Vries 1998, Rosen 2007, Freeman 2008, Young 2001, Banning 1986). Furthermore, the presence of temporally overlapping pastoral nomadic and sedentary subsistence communities, suggests that the Roman period did not significantly differ from previous periods (Banning 1986). Traditional attempts to explain the fortification of the frontier and trade areas, particularly along the *Via Nova Traiana* in the 3rd century C.E. have focused on the possibility of hostile interactions with the region's nomadic and semi-nomadic inhabitants (Parker and Betlyon 2006, Parker 1987b, 2000, 1987a). Proponents believe that the location of forts, garrisons, and watchtowers along the roadway may have facilitated quick communication and troop movement (Parker 2000, 1987a, Leadbetter 2004). If true, deteriorating relations with the Roman military along the *limes* could be one reason that the Zabayir cemetery was abandoned in the 3rd century C.E. Other researchers doubt that conflicts with the pastoral nomadic communities were severe or frequent enough to require such a large military presence (Young 2001). Instead, militarization may have been a general demonstration of Roman authority *within* the region quieting unrest among both settled and mobile populations[5] and providing greater protection for the highly profitable caravan trade (Young 2001). This latter proposal also accords with the region's restructuring, which divided the province into northern and southern regions, perhaps as an attempt to reduce power by dividing the northern cities of the Jordan Valley and the powers within the region's southern trade corridor. In any case, the dynamics in the region shifted resulting in increased militarization and political restructuring.

Following annexation, Nabataean military investment along the Petra-Gaza trade route was continued by Roman garrisons until the Severan period, suggesting continued economic stability for traditional trade industries (Cohen 1982). Trade throughout the region appears to have continued unabated and former Nabataean outposts were re-garrisoned by Roman troops, presumably to maintain protection and taxation over traditional trade corridors (Bowersock 1983). However, as provincial Roman citizens, Nabataeans were conscripted into the Roman army

[5] Particularly given the unrest in other parts of the empire like Palmyra.

beginning in c. 113 C.E., suggesting disruption in the lives of at least some individuals within Nabataea (Freeman 2008). Outside Roman military development, the historical accounts report that the administrative functions of most Nabataean cities remained the same under their appointed Roman governors and Nabataean city centers such as Petra, Humayma, and Aila continued to flourish.

2.3.1 Roman Annexation and Social Change

With few exceptions, the question of how Nabataean cities (and citizens) were affected by annexation remains unaddressed. Given the visibility and pervasiveness of the new Roman presence, it would not be unreasonable to expect associated cultural changes; however, continued use of the Nabataean language, burial practices, and pottery at numerous sites, including Humayma, Khirbet Qazone, and Khirbet edh-Dharih, suggest the annexation had little effect on culture and livelihood of many individuals within the new province (see Politis 2007 for a more complete treatment) (Reeves and Bevan 2010, Oleson 2004, Politis 1998, Politis, Kelly, and Usman 2005, Lenoble, Al-Muheisen, and Villeneuve 2001, Freeman 2008, 'Amr 2004). The persistence of Nabataean cultural elements may indicate that the local populace continued to perceive their own identity as Nabataean (Reeves 2004, Oleson 2004, Politis 2007, Perry, Coleman, and Delhopital 2008).

On the other hand, archaeological data from Zoara, Petra, Humayma, and Dhiban indicate that the lives of the former Nabataean citizens were greatly affected by annexation. The Babatha archive from near Zoara, at the southern end of the Dead Sea indicates that legal processes remained relatively consistent post-annexation; however, these documents also demonstrate the importance of Roman citizenship in legal affairs after 106 C.E. since the only woman in the documents permitted to act without guardianship was a Roman citizen, Julia Crispina, who was also able to act as a guardian on behalf of others in legal matters (Isaac 1992).

In addition, burials at Petra appear to have ceased within the city around the time of annexation in the late 1st or early 2nd century C.E. (Perry and Walker 2018). Following annexation in the 2nd century C.E., a Roman fort was built at the site along with a small town (Oleson and Brown 2010). While there is not enough evidence to suggest that the Nabataean city at Humayma was destroyed prior to annexation, portions of the town were certainly looted after the fort's construction (Reeves 2004). Ashlar blocks from the Nabataean buildings, including the community's shrine, were utilized in the construction of the fort and associated buildings, leaving only the foundations of the original Nabataean structures. The destructive appropriation of resources indicates that the Roman presence within this community was highly disruptive. Roman buildings were the most well-appointed and constructed buildings in the town while structures outside the military complex were reconstructed from earthen materials or inferior stone.

The Roman military also controlled the valuable water resources at Humayma via a stop cock fitted to the aqueduct reservoir. Additionally, the large military influx in the population would have reduced resources for the town's indigenous inhabitants possibly resulting in the displacement of hundreds of individuals (Reeves 2004). However, among the civilian populace, Nabataean cultural elements including burial practices and socioreligious iconography remain the same, so much so that the Roman population is distinguishable archaeologically (Reeves 2004, Reeves and Bevan 2010). While the indigenous Nabataean locals subsisted primarily on wild game and caprine animals[6], the Romans consumed more pork, chicken, and oysters and cooked in saucepans, which are rare finds outside the fort confines (Oleson 2004). Relations between the

[6] Primarily sheep/goat.

military and civilian populace improved in the late 2nd and early 3rd century C.E. when the garrisoned troops reconstructed the destroyed community shrine, installing both a traditional Nabataean betyl and altar bearing an inscription calling for the protection of Jupiter Ammon (Reeves 2004). The duality of the religious dedication reflected the continued importance of traditional Nabataean deities within the community.

Unlike some other Nabataean cities that continued to thrive under Roman rule, the 2nd and 3rd centuries signal a decline at Dhiban with the abandonment of the temple (Porter et al. 2007). Only a small community remained following annexation and several epigraphic inscriptions attest to a Roman military presence in the vicinity for maintenance of a road, likely the King's Highway. While the final publications from excavations within the Wadi Faynan district have not yet been produced, early research indicates that the Romans were heavily invested in copper mining in the area from annexation into the Byzantine period (Hauptmann 2007, Perry et al. 2009, Mattingly 2011). This ramp up in production may have facilitated employment for settlements in the area or specialized nomadism for the purposes of ore and fuel transport as it did during the Iron Age for the Wadi Fidan 40 cemetery population (Levy and Najjar 2007). Khirbet edh-Dharih also grew during the Roman period with the founding of a small village in the 2nd century C.E. and remodel of the site's olive mill.

For the most part, individual stories are conspicuously missing from the post-annexation narrative. While some evidence for the effects on the lives of individuals is presented at Humayma, much of the research literature focuses on large scale changes and resource accessibility, rather than the functional social, health, and cultural differences for the people of the former Nabataean province. Bioarchaeological analysis of cemeteries from two different sites with the Nabataean kingdom, Khirbet Qazone and Zabayir Zahir edh-Dhiyab, can illuminate the lifeways of the diverse subsistence communities on opposite sides of the Nabataean kingdom through an examination of stress indicators over the life course, diet, and activity.

2.4 KHIRBET QAZONE

The archaeological evidence from the 1st – 3rd century C.E. Khirbet Qazone cemetery, spans the period of Roman annexation, seems to indicate that this region maintained its importance as a trade center since the residents do not appear to have been impoverished over the course of the cemetery's use. Additionally, the presence of Greco-Roman style textiles recovered from the burials demonstrates that the local population was actively engaged in this broader cultural community, while the presence of Nabatean pottery suggests they still identified culturally with Nabataea as well (Granger-Taylor 2000, Politis, Kelly, and Usman 2005, Politis 1998, 2004). The Khirbet Qazone cemetery has not been definitively tied to a community, but nearby sites along the Wadi Kerak have been posited as likely locations for the primary habitation based upon contemporaneous ceramic finds (Politis 2004, 1998). The cemetery provides a systematically excavated and well-preserved skeletal collection to examine the lifeways of a Nabatean community in a region heavily reliant on agricultural production and trade.

The few graves goods from the cemetery demonstrate that the cemetery served a relatively cosmopolitan populous with access to enough wealth to dedicate tombstones, jewelry, glass, and other grave goods to the deceased members of their community (Politis 1998, Politis, Kelly, and Usman 2005, Politis 2004). The textiles recovered from graves capitulated Greco-Roman styles and patterns of construction, common throughout the eastern Mediterranean during the Roman period and similar textiles were also recovered from contemporaneous strata at the Cave of Letters site located on the western Dead Sea shore (Granger-Taylor 2000). In addition to their clothing some burials were also wrapped in cloth and or leather shrouds, which has been noted for other sites, including the Wadi Abu Khasharif and Wadi al-Mudayfi'at Cemeteries, as well as Khirbet edh-Dharih, Mada'in Saleh, and Wadi Ramm (Perry, al-Shiyab, and Falahat 2007, Lenoble, Al-Muheisen, and Villeneuve 2001, Bouchaud et al. 2015, Delhopital 2016, Granger-Taylor 2000, Perry and Jones 2008). When considered in conjunction with the cemetery's location in an area known for trade, the community at Khirbet Qazone appears to have been relatively well connected and thriving. The textiles, many of which show multiple repairs, also suggest that many individuals at Khirbet Qazone were not wealthy, but they were also not impoverished and could represent a middle-class citizenry. When taken together with the artifactual evidence, the community, as a whole, appears to have been a center of moderate wealth within the Nabataean territory.

2.5 ZABAYIR ZAHIR EDH-DHIYAB

As discussed in Section 1.2 archaeological research indicates that the Nabatean kingdom supported symbiotic relationships between sedentary and pastoral nomadic communities (Rosen 2007). However, pastoral nomadic societies in the Nabatean kingdom are much more difficult to document and study due to their transient material cultural composition and mobile lifestyle. The Zabayir Zahr ed-Diyab (Zabayir) cemetery, also known as the Queen Alia International Airport (QAIA) cemetery, was utilized during the first century following the Roman annexation of Nabataea (late 2nd century to mid-3rd century C.E.) (Ibrahim and Gordon 1987). Located approximately 25 km south of Amman and 22 km east of Madaba, the site was excavated in advance of the airport's construction beginning in 1978. The cemetery was situated in a broad plain defined by wadis to the east and west and was associated with a seasonal habitation located among an area of low hills. Ibrahim and Gordon (1987) note that for centuries this region has been considered an ecological transitional zone unsuitable for agricultural development but ideal for animal husbandry. Water control features, such as cisterns and possible reservoirs, were identified among the hills bordering the cemetery and Roman pottery was found on the surface near some caves, along with courtyards defined by roughhewn stones. Based upon the artifactual evidence and the cemetery's proximate seasonal habitation, the interred individuals were interpreted as members of a semi-nomadic populous.

As a uniquely well-preserved, large cemetery associated with a pastoral nomadic habitation site, Zabayir may be used to study the relationship between sedentary and pastoral nomadic communities in the region. Several agricultural sedentary communities have been identified within a relatively short distance from the cemetery and habitation at Zabayir, including major settlements at Hesban and Jalul as well as the nearby settlement of Zizia (modern Jiza), which housed military personnel, and al-Qastal where pottery indicates occupation from the Iron Age to the present (Parker 1989, Carlier and Morin 1987, Al-Shqour 2009, Mitchel 1992). A contemporaneous Thamudic inscription found at the Zabayir cemetery commemorates those who "were helpers" to Allat, a deity identified with the contemporary Greek and Roman goddesses Aphrodite and Venus (Ibrahim and Gordon 1987). The Zabayir cemetery's location to the east of the *limes Arabicus* and in proximity to Roman military installations along with the Thamudic dedication recovered from the site led Ibrahim and Gordon (1987) to believe that some individuals interred at Zabayir may have served in as *foederati*, locally hired auxiliary militia, or allies to the Roman army. The identification of artifacts that demonstrate Roman influence, such as *caligae* or Roman style hob-nail sandals have been cited as evidence for close association with Roman military communities. Other Greco-Roman artifacts demonstrate that the Zabayir community was well-connected to the surrounding towns at least economically, but perhaps also socioculturally as well. Previous examinations of the skeletal remains revealed muscle development and pathologies consistent with horseback riding, although none of the individuals interred in the cemetery could be directly associated with the Roman military based on available artifactual or skeletal evidence (Perry 2002a). An array of inscriptions in the 'Thamudic E' script found within the region tie these communities to a larger socio-linguistic culture with similar inscriptions located from the Hisma in South Arabia to the Hawran in Syria and across the Negev in North Arabia (Graf and Zwettler 2004). Whether individuals were formally engaged as Roman allies or militia for hire, it is clear that the pastoral community at Zabayir had strong socioeconomic interactions with the surrounding Greco-Roman communities in the former Nabatean territory and the broader "Thamudic E" culture.

Bioarchaeological research provides notable exceptions that begin to address the theoretical gap in understating community relationships during this period and has produced data that considers the lives of individuals living in the Nabataean territories before and after Roman annexation (e.g., Perry 2002a, Delhopital 2010, 2011, Perry, Coleman, and Delhopital 2008). The cemeteries at Khirbet Qazone and Zabayir provide an opportunity to examine the impact of stress, diet, and activity in sedentary and pastoral nomadic communities located with the former Nabataean territory within the socio-politically dynamic period.

3.0 CONTEXTUALIZING THE HUMAN LIFE COURSE IN ANTIQUITY USING THE HUMAN SKELETON

3.1 HUMAN SKELETAL INDICATORS OF NON-SPECIFIC STRESS

The assessment of non-specific skeletal stress indicators, including linear enamel hypoplasia, porotic hyperostosis, cribra orbitalia, and measures of growth, such as vertebral neural canal size, are employed to evaluate environmental stress and sociocultural conditions in archaeological contexts (Goodman and Rose 1990, 1991, Goodman et al. 1984, Goodman and Armelagos 1989, Walker et al. 2009). In the absence of causal injury or pathology, non-specific indicators of stress generally reference systemic disruptions resulting from an unidentifiable stressor(s). Excepting periostitis, the most measured stress indicators signal events that occurred primarily during development and are extrapolated to describe "health" more broadly for subadults and adults. A less frequent question is whether individuals recover from these early stress events or whether early stress characterizes an individual's later life experiences. Bioarchaeologists recognize that developmental events can impact an individual's longevity and the experience of stress in later life (Goodman and Armelagos 1988, Goodman 1996, Armelagos et al. 2009). Although many assessments of "health" are based upon the frequency of stress indicators within a population (e.g., Goodman and Armelagos 1989, Rose, Burnett, and Blaeuer 1984), bioarchaeologists have made strides assessing stress over the life course by attempting to correlate an individual's non-specific stress indicators with stature and age-at-death in place of, or in addition to, indicator frequencies within populations. Emerging life course research has also challenged the equanimity accorded different skeletal indicators in terms of severity and epigenetic consequence for specific populations. The following section explores human skeletal non-specific stress indicators commonly used in bioarchaeological research and the ways in which they have been employed to address questions regarding health over the life course.

3.1.1 Dental Pathology

Dental disease has been associated with a variety of environmental stresses and significantly correlated with a variety of chronic illnesses, including heart disease, diabetes, depression, and kidney failure (Garcia, Krall, and Vokonas 1998, Lund 2005, Warren et al. 2014, Vedin et al. 2016, Ausavarungnirun et al. 2016, DeStefano et al. 1993). Poor dental health may also directly contribute to death when an abscess or periodontal infection spreads to other tissues (Basyuni et al. 2015, Yoneda et al. 2011, Ewald, Kuhn, and Kalff 2006). In elderly individuals, increased tooth loss is correlated with increased risk for pulmonary infection and mortality (Awano et al. 2008); while regular dental care may increase life expectancy (Paganini-Hill, White, and Atchison 2011). Bioarchaeologically visible dental changes, such as calculus, caries, abscess, dental attrition, and wear, are important indicators of dental disease and diet in past populations (Hillson 1996, 2008).

Dental disease is the product of accumulations and modifications in dental plaque, which is the biofilm containing microbial communities, fluids, and sometimes food or other particulate inclusions present on oral surfaces (Hillson 2005). Mineralization of dental plaque on the dentition forms calculus deposits (Figure 3-1). Since the mineral component of calculus is supplied by saliva, the largest deposits are usually on the lingual surfaces of incisors and canines and the buccal surface of the upper molars, which are closest to the saliva producing parotid and salivary ducts. Studies of calculus have been used to examine diet and the human oral bacterial flora (Warinner et al. 2014, Huynh et al. 2016, Cristiani et al. 2018, Cristiani et al. 2016, Buckley et al. 2014, Jersie-Christensen et al. 2018, Luna and Aranda 2014, Munoz 2017). Calculus has been correlated with both high carbohydrate and high protein diets (Lieverse 1999). However, when examined in association with dental caries, calculus rates have proved more conclusive. High calculus and low caries rates have been associated with high protein diets, while high calculus in addition to high caries rates may indicate carbohydrate rich diets (Lillie 1996, Lillie and Richards 2000, Littleton and Frohlich 1993). Other factors also play a role in calculus formation and retention, including salivary production, water consumption and mineral content, chewing, dental hygiene, the utilitarian use of teeth as tools, and taphonomy (Lieverse 1999).

Figure 3-1. Dental calculus and periapical abscess of the maxillary left second premolar and second molar (Khirbet Qazone, θ2).

Acidification of dental biofilm caused by bacterial fermentation of carbohydrates can produce localized demineralization of dental tissues called caries lesions (Figure 3-2; Figure 3-3) (Selwitz, Ismail, and Pitts 2007, Quivey et al. 2013, Fejerskov, Nyvad, and Kidd 2015). Cavities are the most identifiable hallmark of dental caries and indicate an advanced disease progression, since the earliest phases of dental tissue destruction are often difficult to identify macroscopically (Selwitz, Ismail, and Pitts 2007). The disease process may be halted or reversed if a neutral biofilm pH is restored and enamel remineralization once again outpaces demineralization. Therefore, the archaeologically visible manifestation of dental caries disproportionately reflects the most severe cases of dental disease and may be affected by oral hygiene, fluoride uptake, food texture, dental wear and the topography of the tooth surface, which can allow bacterial accumulation in grooves or pits, such as LEHs (Pascoe and Seow 1994, Hillson 2001).

Figure 3-2. Example of dental caries on maxillary left second molar (Khirbet Qazone, K2).

Although most oral bacteria do not invade tissues inside the mouth, infection does sometimes occur, prompting an immune response and tissue inflammation (Hillson 2005). Periapical disease (dental abscess) is an infection of the tooth root that produces pus and inflammation at the tooth apex (Figure 3-1; Figure 3-3). Eventually, suppuration in the pulp cavity or periodontal tissues disrupts blood supply causing tissue necrosis and tooth loss. In some cases, abscess is caused by bacterial infection within the periodontal pocket, which can lead to a lateral periodontal abscess and eventually tooth loss. When microbes invade the gingiva or underlying periodontal tissues, chronic inflammation may occur as gingivitis or periodontitis, depending upon the tissue involved. Continued inflammation may produce bone remodeling to the extent that teeth become loose and are lost. This is the most common cause of age associated tooth loss in humans and is documented as antemortem tooth loss (AMTL) in bioarchaeological contexts (Figure 3-4) (Hillson 2005, Buikstra and Ubelaker 1994). Dental wear is also an attritional process and increases naturally with age, although severe wear may indicate the hardness of the diet or the inclusion of grit from grain processing on stone querns (Hillson 2008). Unusual, asymmetrical, or selective wear patterns on teeth may indicate the use of teeth as tools to hold, wear, or process fibrous materials revealing something about individual activities.

Figure 3-3. Right maxillary first premolar periapical abscess and third molar caries lesion (Khirbet Qazone Skeleton K8.1).

Figure 3-4. Antemortem tooth loss (Khirbet Qazone Skeleton K3).

The increased consumption of carbohydrates associated with an agricultural food economy has been positively correlated with poor dental health, including increased caries, abscess, and dental attrition (Munoz 2017, Lukacs 1992, Larsen 1981, Crittenden et al. 2017, Cook 1984, Driscoll and Weaver 2000, Larsen 1995, Larsen, Shavit, and Griffin 1991). Although, the transition to and intensification of agriculture produces the most striking change in dental health, heavy reliance on carbohydrate-rich food resources, even wild ones, may produce poorer dental health (Crittenden et al. 2017, Watson 2008, Cook 1984). In contrast, hunter-gatherer populations generally have low caries rates (Luna and Aranda 2014, Littleton 2018) and high calculus (Luna and Aranda 2014).

3.1.2 Linear Enamel Hypoplasia

Dental enamel hypoplastic defects (DEH) are commonly recorded indicators of dental growth interruption and include a variety of manifestations, including hypoplastic defects, opacities, and enamel discoloration. Linear enamel hypoplasia (LEH), which includes both furrow-form and plane defects visible as a horizontal line along the tooth enamel, have been used in numerous bioarchaeological studies to address stress during growth in skeletal populations (Figure 3-5) (King, Hillson, and Humphrey 2002, Goodman and Rose 1990, 1991, Goodman 1996, Armelagos et al. 2009, Temple 2014, Hillson 2014, King, Humphrey, and Hillson 2005). The rate and structure of tooth growth is heavily determined by genetic processes, although environmental conditions affecting the body may still influence tooth development and slow or suspend enamel formation (Hillson 2014). Normal enamel formation occurs via a process called amelogenesis as ameloblasts deposit enamel matrix in layers called perikymata. LEH defects are formed by an interruption of normal enamel matrix secretion during ameliogenesis resulting in abnormal spacing between perikymata in a portion of the tooth enamel (Hillson 2014). While LEH on a single tooth could be the result of localized infection or trauma, LEH occurring during the same developmental time period on different teeth indicates a systemic event (King, Humphrey, and Hillson 2005). Unlike bone tissue, enamel does not remodel making these defects unique among stress indicators since the timing of an LEH can be linked to the growth process of a tooth (Goodman and Rose 1990, Hillson 2005). Therefore, the timing of LEH occurrences can be calculated and compared with dietary changes detected in stable isotope samples taken at specific points on the dental enamel (Tykot 2004). LEH timing reflects a temporal range during development when these events may have occurred (Hillson 2014).

Figure 3-5. LEH on left mandibular canine and first premolar (Khirbet Qazone Skeleton K4).

Based on growth schedules produced by Schour and Massler (1940), the regression model developed by Goodman and Rose (1990) was the earliest system produced to estimate the chronological age of occurrence for LEH. However, this system assumes a uniform rate of tooth development and does not account for hidden enamel, which projects younger ages for LEH occurrence (Łukasik and Krenz-Niedbała 2014, Ritzman, Baker, and Schwartz 2008). Recent histological data highlights the importance of accounting for appositional enamel to avoid methods that underestimate the true age of LEH occurrence since LEHs are not generally identifiable on the crown surface prior to 1 year of age (Reid and Dean 2006). Furthermore, the enamel growth rate decreases over the course of tooth development and should be accounted for in growth models to accurately reflect LEH timing (Liversidge, Dean, and Molleson 1993). Goodman and Song

(1999) produced an updated regression equation which recognizes hidden enamel, but still produces slightly earlier estimates than a decile system based upon histological data developed by Reid and Dean (2000, 2006). In Reid and Dean's model, each tooth type is broken into ten sections and the variable growth rate for each section is calculated based upon histological observations. The growth schedule accounts for the curvilinear surface of the teeth as well as hidden enamel. However, their model does not completely account for the curvilinear surface of teeth resulting in a longer "crown length" than what is represented on the curved tooth surface. Therefore, "crown length" measurements included in their study cannot be used as a direct representation of tooth height or tied directly to non-linear measurement on the tooth surface such as LEH locations.

Methodologies unifying skeletal stress markers such as LEH with demographic and metric data have informed more insightful discussions of the environmental and cultural factors affecting stress events (Watts 2013, Temple 2008). Armelagos et al. (2009) cited a correlation between LEH occurrence and increased mortality for adults at the prehistoric Dickson Mounds site as confirmation of the Barker Hypothesis, which posits later life impacts for early life stress (Hales and Barker 2001). Younger age-at-death was also correlated with an earlier first occurrence of LEH in a study of known age and sex individuals from two 18th and 19th century cemeteries in London (King, Hillson, and Humphrey 2002). However, similar stress indicators may not communicate universal experiences of stress between populations. Indeed high LEH occurrence in the absence of significant longitudinal growth impacts has been interpreted as evidence for developmental plasticity (Temple 2008, Floyd and Littleton 2006). However, the occurrence of LEH prior to 18 months of age increased an individual's risk of multiple occurrences and together these criteria correlated with reduced height suggesting that stress timing and recidivism are important factors to consider in the evaluation of stress effects over the life course (Floyd and

Littleton 2006). In a subsequent study using incremental dental microstructures Temple (2014) also concluded that early LEH development was correlated with LEH recidivism and reduced longevity among the Jomon.

3.1.3 Porotic Hyperostosis and Cribra Orbitalia

Like LEH, porotic hyperostosis (PH) and cribra orbitalia (CO) have a long history of use as referential indications of stress in ancient contexts. PH is a non-specific pathological lesion produced by the expansion of cranial diploë and subsequent decrease in cortical bone thickness, in response to bone marrow hypertrophy (Figure 3-6) (Ortner 2003). CO is a localized pathological lesion on the frontal bone in the superior aspect of the orbit (Figure 3-7). Early bioarchaeological research attributed both PH and CO lesions to anemia (Angel 1966, El-Najjar, Lozoff, and Ryan 1975, Moore 1929, Stuart-Macadam 1987). However, anemia is symptomatic of several inherited and acquired conditions that contribute to insufficient red blood cell or hemoglobin function impairing oxygen transport throughout the body (Ortner 2003). Metabolic insufficiency, menstrual blood loss, trauma, parasitic infection, and disease, in addition to some hereditary conditions may produce anemias. Iron-deficiency (primary and secondary), megaloblastic, and hemolytic anemias as well as anemias resulting from chronic disease have all been explored as probable causes for PH and CO expression (Denic and Agarwal 2007, Stuart-Macadam 1987, Ryan 1997, El-Najjar, Lozoff, and Ryan 1975, Rothschild 2012, Walker et al. 2009, Rivera and Lahr 2017). Although, CO lesions sometimes co-occur with PH, recent research suggests that PH and CO lesions are morphologically distinct and result from different underlying conditions (Walker et al. 2009, Rothschild 2012, Rivera and Lahr 2017, Cole and Waldron 2019). CO lesions may occur as a result of trauma or other events producing hemorrhage and periosteal reactions, marrow hyperplasia, and inflammatory responses to infection (Ortner 2003, Ortner and Ericksen 1997, Wapler, Crubézy, and Schultz 2004, Cole and Waldron 2019).

Figure 3-6. The arrow indicates porotic hyperostosis on the lambdoidal suture of the cranium of Skeleton A.2 from Khirbet Qazone.

Figure 3-7. Cribra orbitalia on crania of Khirbet Qazone skeletons.

While anemia may occur anytime during life, the nature of bone marrow involution[7] along with clinical evidence for bony changes associated with anemia suggests the pathological bone changes expressed in PH and CO originate during childhood stress events (Stuart-Macadam 1985, Walker et al. 2009). While the debate surrounding CO and PH lesion etiology and the frequent clinical co-occurrence of possible causal conditions complicate a specific diagnosis, the presence of these lesions clearly indicate stress within an archaeological population and can provide information about the experience of individuals within the population.

3.1.4 Metric Assessments of Growth, Pathology, and Stress

Stature is widely employed to measure growth along a normalized curve within modern populations and in skeletal collections using stature estimates from long bone lengths as a proxy for living height (Cameron 2012, Hughes-Morey 2016, Taylor 2010, Gunnell, Rogers, and Dieppe 2001). In biomedical contexts, longitudinal growth is evaluated along a growth curve from infancy through adolescence. Although adult stature is genetically determined, it may also be heavily impacted by environmental factors such as dietary insufficiency and disease experienced during growth (Eveleth and Tanner 1976, Bogin 1999). Sociocultural factors related to differential experiences of stress or access to nutrition and health care, such as class, gender, age, migration, food economy, and urbanization, may also affect longitudinal growth potential (Steckel 1995, Tanner 1987, Smith et al. 2003, Stillman, Gibson, and McKenzie 2012, Franzen and Smith 2009).

[7] Bone marrow involution refers to the process by which red blood cell producing marrow, is replaced by yellow fatty or non-hematopoietic marrow. In adults, hematopoietic marrow is most prevalent in the trabecular bone of the axial skeleton and may also be retained in the skull, pelvis and the humeral and femoral heads (Brickley 2018; Stuart-Macadam 1985).

The impact magnitude of a growth insult depends upon the timing and duration of the event (Eveleth and Tanner 1976). Stress occurring during periods of high velocity growth such as infancy, middle childhood, and adolescence have a greater negative impact on adult stature (Bogin 1999, Tanner 1966, Eveleth and Tanner 1976). Similarly, short duration insults will have a more limited impact on adult height than chronic conditions, which may span one or more of these high velocity growth periods. Growth insults may be corrected through catch-up growth, or increased growth velocity if stressful conditions improve (Eveleth and Tanner 1976). Alternatively, growth may continue at a slower tempo for a longer period, up to two years, to correct for earlier growth stunting. For example, Antebellum records in the U.S. show that although child mortality among slaves was high due to early life stress, those that lived into adulthood underwent drastic periods of catch-up growth in the form of a slightly delayed, high velocity adolescent growth period (Steckel 1986, Schneider 2017, Komlos 1992). Despite periods of catch-up growth, Caribbean slaves never reached U.S. slave statures presumably due to poorer nutrition, rum rations—even for pregnant women—and stringent adolescent sugar plantation labor (Steckel 1995).

Bioarchaeological studies have also linked stature declines or decreases in long bone length with the adoption or intensification of agriculture, which is often accompanied by increased population size and aggregation (Kennedy 1984, Cook 1984, Martin et al. 1984). Growth curves constructed for a Sudanese Nubian population showed a decline in growth from one to seven years of age that was cited as support for increased stress during this period (Martin et al. 1984). Histological data demonstrated a decrease in cortical bone thickness beginning in childhood, which was interpreted as a biological trade-off allowing for continued longitudinal growth at the expense of cortical bone density. Not surprisingly, premature osteoporosis was evident in populations where agricultural production was most intense and cortical bone density decreased during bone growth. Furthermore, evidence for increased stress transcended class in the Lower Illinois Valley with high-status and lower status children impacted equally (Cook 1984). Increased mortality risk has also been linked to shorter long bone lengths in skeletal collections and shorter stature in modern populations (Hughes-Morey 2016, Gunnell, Rogers, and Dieppe 2001). Lovejoy, Russell, and Harrison (1990) emphasized the impact of infectious disease on growth velocity in a Native American population during the first three years of life by using long bone diaphyses to model growth velocity within the population.

Environmental stress many also produce asymmetrical growth in paired structures reflecting the body's inability to respond plastically to stress (Albert and Greene 1999). This asymmetry may consistently favor one side (directional asymmetry) or alternate between different sides (fluctuating asymmetry). Dental asymmetry is a common measure of stress (Perizigan 1977, Marado, Silva, and Irish 2017, Milella et al. 2018, Barrett, Guatelli-Steinberg, and Sciulli 2012) and various post-cranial elements have also been examined for bilateral asymmetry related to growth and environmental exposure or variable biomechanical loading (Kirchengast 2017, Kurki 2017, Waxenbaum and Sirak 2016, Albert and Greene 1999). Albert and Greene (1999) demonstrated significant asymmetry in post-cranial epiphyseal fusion (growth cessation) correlated with stress between Early and Late Christian Nubian populations. Similarly, Waxenbaum and Sirak (2016) reported asymmetrical growth in long bones from Ancestral Puebloan sites in the Southwestern US. Asymmetry has been shown to be affected by biomechanical loading such as handedness (Auerbach and Ruff 2006); however Albert and Greene (1999) noted that asymmetry due to biomechanical loading would follow a significant right directional pattern based upon handedness or differences by sex.

Lumbar vertebral neural canal (VNC) anterior-posterior and transverse dimensions, which represent a more limited period of growth prior to five years of age, have also been used to address growth plasticity and disruptions (Watts 2013, 2011). Clark et al. (1986) utilized VNC size to evaluate several vertebral growth-related measurements and age-at-death. In their study, VNC was correlated with early mortality and vertebral wedging, although not overall vertebral body height. Watts (2011) also found a significant relationship between small VNC size and stature for a medieval population from York, UK. Together these studies suggest that VNC size may be correlated with growth potential and risk of death. Furthermore, VNC is less impacted by catch-up growth than long bones since lumbar vertebrae VNC adult size is reached by around five years of age, well before the middle-childhood and adolescent growth spurts (Watts 2013).

The use of multiple indicators of non-specific stress may also be applied to discussions of differential growth experiences within a culture to explain the variable levels of stress based upon biocultural interactions. Watts (2013) identified biological sex specific changes related to different pathological indicators of non-specific stress and age-at-death in the UK; while the non-specific stress indicators in the study were not corelated with inhibited growth, developmental stress events did result in decreased life expectancy.

3.2 ACTIVITY

Wolff's Law of Transformation states that bones will respond plastically to the mechanical forces acting upon them as part of their functional use (Wolff 1892). Therefore, repetitive activity causing physical stress, either through joint friction or muscular strain, will affect the modeling, remodeling, and degeneration of osseous tissues to maximize the functionality of bone. Although bone requires nutritional and hormonal components for development, mechanical stress is the primary driver of development and remodeling (Frost 1998). Tendons, ligaments, and muscles join with bone through insertions in the periosteum and underlying osseous tissue (Hawkey and Merbs 1995, Benjamin et al. 1992, Benjamin et al. 2002, Enlow 1962). The exertion of mechanical forces at these sites produces increased blood flow within the periosteum, which encourages osteon remodeling producing more robust skeletal landmarks or MSMs as insertion sites become incorporated into the bone through ossification (Figure 3-8) (Kennedy 1989, Benjamin et al. 2002, Hawkey and Merbs 1995). Prolonged overuse of a muscle may exceed biomechanical capacity affecting the muscle's ability to absorb stress and tearing the muscle from the periosteum producing an osteolytic response that creates a pit or furrow along the endosteum referred to as a stress lesion (Hawkey and Merbs 1995, Kennedy 1989). Continued use of the muscle at the lesion can cause progressive destruction at the attachment site (Figure 3-9). During growth, however, MSM locations move along the growth axis and are continually remodeled as bone grows leaving little indication for activity performed during childhood (Enlow 1962).

Figure 3-8. Soleus muscle attachment site on posterior tibia (Khirbet Qazone Skeleton K2).

Figure 3-9. Stress lesion on radial tuberosity from on (Khirbet Qazone Skeleton M1).

Since MSMs correspond to the magnitude and frequency of muscle use, their development can provide some information about the activities that characterized a person's life (Hawkey and Merbs 1995). Hawkey and Merbs (1995) assessed musculoskeletal marker robusticity and stress lesions in their study of Thule Eskimos from the Hudson Bay area and created a standardized scoring system to document MSM expression. Other researchers have proposed alternative methods in an attempt to refine and formulate new recording methodologies recognizing the complexity of the MSM development process (Mariotti, Facchini, and Belcastro 2004, Henderson et al. 2013, Mariotti, Facchini, and Beicastro 2007, Villotte 2006, Havelková and Villotte 2007).

Overall body size, age, and biological sex have been correlated with MSM robusticity in various bioarchaeological studies (Niinimäki 2011, Weiss, Corona, and Schultz 2012, Weiss 2003, 2007, 2004). Differences observed between males and females may be a function of overall size variance associated with sexual dimorphism (Niinimäki 2011, Weiss 2003). While age and MSM robusticity are positively correlated in many studies, this appears to hit a plateau in elder individuals (Shuler, Zeng, and Danforth 2012, Niinimäki 2011). Whether this is the result of reduced activity or altered periosteal and osseous responses to muscular loading through time, is unclear (Niinimäki 2011). Injury, either acute or chronic, can result in overcompensation at other MSM sites or on the opposite side and handedness may skew an individual's overall upper limb scores higher for either the right or left side (Hawkey and Merbs 1995, Meyers et al. 2011). Although, the exclusion of individuals with obvious pathologies and tests for bilateral asymmetry in MSM assessment or the use an aggregate score may help mitigate these issues (Weiss 2003, Eshed et al. 2004). MSMs, particularly when employed as part of a constellation of skeletal features may provide information about the activity of individuals, especially where the activity began early in life (Weiss 2007). More generally, when age, sex, and overall size differences are accounted for, MSMs may also provide information about the distribution of labor or intensity of labor for individuals and groups within a larger population relative to their peers.

3.3 THE ROLE OF ISOTOPES

Differential experiences related to individual or group variation in food preferences or resource access can reveal information about social interactions and individual life histories within communities (Sandias and Muldner 2015, Appleton 2015, Killgrove and Tykot 2013, Sandberg 2012, Prowse et al. 2004, Tsutaya and Yoneda 2015, Reitsema and Vercellotti 2012, Papathanasiou, Richards, and Fox 2015). The period of weaning, which begins with the introduction of supplemental foods to the diet and ends with the cessation of breast milk provision, is a particularly stressful time during early development. Many studies implicate insufficient nutrition and the introduction of new bacteria along with weaning foods as factors in high mortality rates for individuals younger than five years of age, especially when combined with an illness or gastrointestinal upset and diarrhea (Caulfield, Richard, and Black 2004, Olofin et al. 2013, Mach et al. 2009, Motarjemi et al. 1993). Early life nutrition can be categorized by four stages: 1) gestational; 2) exclusive breast milk feeding; 3) complementary food supplementation or weaning and; 4) cessation of breast milk feeding or completion of weaning (Humphrey 2014). Weaning behavior may be influenced by numerous factors including subsistence modes, the availability of supplementary food resources, interbirth spacing and perceptions of infant maturity as well as maternal health, nutrition and workload (Sellen and Smay 2001, Sellen 2001b). Subsistence differences between communities may also produce differing weaning profiles. In a survey of ethnographic accounts of pastoral nomadic societies, Sellen and Smay (2001) found that the weaning process and liquid or solid food supplementation generally began at an earlier age in agricultural populations, which would produce isotopically measurable trophic level changes that begin earlier in childhood or infancy for agricultural populations when compared with pastoral communities.

Stable isotopes have been used as referential measures of diet and weaning within populations by measuring the proportions of isotopes or elements with different numbers of neutrons in human tissues (e.g., ^{14}C, ^{13}C, ^{12}C, ^{18}O, and ^{16}O) (Tsutaya and Yoneda 2015, Katzenberg 2008, Schwarcz and Schoeninger 1991, Ambrose 1993). While radioactive isotopes such as ^{14}C undergo regular decay, stable isotope ratios remain relatively constant for lengthy periods (Tsutaya and Yoneda 2015, Schwarcz and Schoeninger 1991). During photosynthesis and nutrient metabolism elements will fractionate producing measurable differences in isotope values between trophic levels (Schwarcz and Schoeninger 1991). The ratio of heavier to lighter isotopes in an element, such as $^{13}C/^{12}C$, $^{15}N/^{14}N$ or $^{18}O/^{16}O$, are evaluated against international standards, such as the Vienna PeeDee Belemnite (VPDB) or ambient inhalable reservoir (AIR), and represented as parts per thousand (‰) deviations from these baselines by the formula:

δ(‰)=(R_{sample}/$R_{standard}$ 1)10^3 (Schwarcz and Schoeninger 1991, Ambrose 1993). In this equation the "δ" symbol signifies the difference between the international standard and the ratio, while "R" represents the isotope ratio. Since stable isotopes are incorporated into human tissues through food and water consumption the isotopic ratios present within the dentition reflect uptake during tooth development (Nehlich 2015, Tsutaya and Yoneda 2015, Bentley 2006, Katzenberg 2008). Meanwhile, bone tissues regularly remodel throughout life producing isotopic values that represent the cumulative values of the isotopes consumed during the years prior to death. Isotope values from dentine or bone collagen are derived primarily from the protein portion of the diet while dental enamel and bone apatite isotope values reflect the combined consumption of carbohydrates, proteins, and lipids providing a more wholistic picture of dietary micronutrients (Ambrose 1993, Tsutaya and Yoneda 2015, Schwarcz and Schoeninger 1991, Tykot 2004).

$\delta^{13}C$ and $\delta^{15}N$ from collagen, and $\delta^{13}C$ and $\delta^{18}O$ from bioapatite may be used as biochemical indicators for diet and weaning (Nehlich 2015, Tsutaya and Yoneda 2015). $\delta^{13}C$ values reflect the photosynthetic pathway of carbon—either C_3, C_4, or CAM—used by the primary plant components in an individual's diet (Tykot 2004, Ambrose 1993). C_3 plants comprise most potential food sources for the study region including legumes, wheat, barley, olives, date palms, and grapes (Ramsay and Bedal 2015, Jacquat and Martinoli 1999, Bouchaud, Jacquat, and Martinoli 2017, Tholbecq, Durand, and Bouchaud 2008, Perry et al. 2013, Ramsay and Parker 2016, Ramsay and Smith 2013). At Petra, where the paleobotanical material has been well-studied, regionally available C_4, plants such as millet are underrepresented (Ramsay and Bedal 2015, Tholbecq, Durand, and Bouchaud 2008). Crassulacean acid metabolism (CAM) plants include several desert species such as cacti and succulents which yield a $\delta^{13}C$ value intermediate to C_3 and C_4 plants (Ambrose 1993). $\delta^{15}N$ from dentine collagen is a proxy for dietary protein consumption and reveals trophic variability (Sandberg 2012, Tsutaya and Yoneda 2015, Beaumont et al. 2013, Fuller et al. 2006, Fuller, Richards, and Mays 2003). Since infants ingesting breastmilk exhibit $\delta^{15}N$ levels indicative of the higher trophic level of the mother or other milk source, the timing and rate of decrease in $\delta^{15}N$ has been particularly influential in discussing the weaning process for infants and children. $\delta^{18}O$ values may offer insights regarding the composition of weaning diets if food supplementation is provided through water-based liquids and can also reflect changes in primary water sources due to geographic mobility (Tsutaya and Yoneda 2015, Schwarcz and Schoeninger 1991). However, $\delta^{18}O$ values are heavily impacted by environmental factors such as precipitation and aridity and cultural factors including cooking practices (Tuross et al. 2017, Brettell, Montgomery, and Evans 2012).

Attempts to define weaning practices using isotopic data generally rely on $\delta^{13}C$ and $\delta^{15}N$ values from dentine or bone collagen to model the weaning process (Eerkens, Berget, and Bartelink 2011, Tsutaya and Yoneda 2015, Beaumont et al. 2013, Fuller, Richards, and Mays 2003, Dupras and Tocheri 2007, Dupras, Schwarcz, and Fairgrieve 2001, Gregoricka, Sheridan, and Schirtzinger 2017, Gregoricka and Sheridan 2012). Although subadult bones may be used to model weaning isotopically, these studies are subject to mortality bias associated with the osteological paradox (Tsutaya and Yoneda 2015, Wood et al. 1992). The use of subadult bones relies on the portion of a population that was more susceptible to death during infancy and childhood precluding the examination of questions regarding the impact of age at weaning cessation between individuals who died during weaning and those who survived to adulthood. Since different bones actively remodel at variable rates this method also requires samples from the same element from age groups representing the entire developmental period (Tuross et al. 2017). However, the utilization of fully developed tooth crowns ensures that any individuals who survived periods of childhood stress are included in the analysis of weaning. In cases where collagen preservation is poor $\delta^{13}C$ and $\delta^{18}O$ from dental apatite have been employed to discuss weaning and childhood dietary patterns (Perry et al. 2020, Wright and Schwarcz 1999, 1998). Studies on South American populations have demonstrated trophic distinctions associated with weaning marked by a gradual enrichment of ^{13}C and depletion of ^{18}O (Wright and Schwarcz 1998, 1999). Perry et al. (2020) attempted to use inter-tooth dental sampling to examine weaning at Petra. The study was unable to identify a distinct weaning period, but a notable difference between the first and second molar $\delta^{13}C$ values demonstrated a clear change in diet concordant with previous archaeological studies of weaning for the region.

$\delta^{13}C$ can reflect a up to a 1‰ offset between mother and child (Fuller, Richards, and Mays 2003) while the child is breastfeeding, and thus as infants undergo weaning their $\delta^{13}C$ value will decline approximately 1‰, assuming that the introduced foods are isotopically similar to what the mother was eating during breastfeeding. isotopic value. However, if a child is fed more C_3 resources that what their mother consumes, a decline greater than 1 ‰ may be identified during weaning. On the other hand, if the childhood diet has a greater proportion of C_4 than the mother was consuming, there may be little to no detectable shift in weaning-related $\delta^{13}C$ values (Wright and Schwarcz 1998, 1999). Any dietary changes in C_3 versus C_4 plants throughout childhood beyond weaning also can be tracked through sampling tissues forming during this period for $\delta^{13}C$.

$\delta^{18}O$ has been shown to demonstrate a similar offset in completely breast-fed versus bottle-fed infants or those consuming solid foods and liquids from other sources. Roberts et al. (1988) compared $\delta^{18}O$ from the urine of individuals consuming 95% of their water intake from breast milk and infants consuming formula prepared with local meteoric water. At 5-6 weeks of age the breast-fed infant urine was enriched in ^{18}O 1.25‰ relative to their bottle-fed counterparts and by

11-16 weeks the breast-fed infant urine $\delta^{18}O$ was 2.69‰ higher than bottle fed infants. This shift from human breast milk to local meteoric sources also produces a gradual decline in $\delta^{18}O$ that has been documented for several archaeological populations (Wright and Schwarcz 1998, 1999, Dupras and Tocheri 2007). Through exploration of diet and weaning, isotopes can provide a valuable tool to help contextualize sociocultural experiences, life histories, and metabolic disease within ancient communities.

4.0 BIOARCHAEOLOGICAL APPROACHES TO HEALTH AND IDENTITY: THEORY AND PRACTICE FOR NABATAEAN AND EARLY/MIDDLE ROMAN JORDAN

This section examines the growth of bioarchaeological research in Jordan and the potential to use the human skeleton as a resource for discussing living populations and the roles of individuals and communities within society. Excavations throughout Hellenistic and Roman period Jordan have provided detailed excavation reports of mortuary contexts, including varying levels of information for human skeletal remains, at several sites including Petra, Khirbet Qazone, Khirbet edh-Dharih, Pella, Abila, Humayma, and Wadi Ramm, that allow for more holistic observations of Nabatean and local Roman mortuary ritual (Table 4-1). While cemetery excavations have been undertaken at other sites, the absence of detailed skeletal analysis, or inclusion of only basic osteological details (e.g., Kick 1985), limits the potential discussion for these funerary contexts to architectural elements and material culture, precluding a more holistic examination of the lives of Nabataeans and later Roman citizens.

Table 4-1. Nabataean and/or Roman period human skeletal remains in Jordan.

Site Name	**Skeletal Remains: Period (number)**	**Documentation of Paleopathology/Trauma by Individual (yes/no)**	**Citations**
Abila	Roman (n=134)	No	Kick 1985
Al-Jafr area Wadi Abu Khasharif & Wadi al-Mudayfi'at Cemeteries	Roman (n=4)	Yes	Perry, et. al 2007
Philadelphia (Amman)	Roman (n=33)	No	Smith and Zias 1980
Aila	Roman/Byzantine (n=46)	Yes	Perry 2002
Bir Madhkur	Roman (n=1)	Yes	Perry 2007
Hesban	Roman/Byzantine (n=191)	No	Grauer and Armelagos 1998
Humayma	Hellenistic/Roman (n=5)	Yes	Perry, et. al 2013
Khirbet edh-Dharih	Hellenistic/Roman/Byzantine (n=97)	Yes	Delhopital 2010; Delhopital 2011
Khirbet Qazone	Hellenistic/Roman (n=49)	No	Politis 1998; Politis, et. al 2005
Pella	Hellenistic/Roman/Byzantine (n=176)	No	Bourke 1992; Browne 1992
Petra	Hellenistic/Roman (n=250+)[1]	Partial; (Many contexts contain commingled remains; Johnson, et. al 2007 does not document pathology/trauma)	Bikai and Perry 2001; Canipe 2014; Delhopital 2010; Johnson, et. al 2007; Perry and Joukowsky 2006 Perry and Walker 2018
Qasr ar-Rabbah (Nazzāza Tomb)	Roman (n=11)	Yes	Perry and Al-Shiyab 2005
Umm el-Jimal	Roman/Byzantine (n=36)	Yes	Cheyney, et. al 2009
Umm Qais	Roman (n=2)	Yes	Henke and Wahl 1990
Wadi Ramm	Hellenistic (n=5)	No	Perry and Jones 2008
Zabayir (QAIA[2])	Roman/Byzantine (n=78)	Yes	Perry 2002

[1]Johnson, et. al 2007 does not provide an MNI for commingled contexts so the number of individuals represented in these five shaft tombs is unclear.
[2]Queen Alia International Airport skeletal collection

In Jordan, previous bioarchaeological studies have demonstrated the value of detailed human skeletal analysis for illuminating the lifestyles of the region's ancient inhabitants shedding light on health (Ortner and Frohlich 2011, 2007, Canipe 2014, Delhopital 2010, 2011, Perry 2002a, Judd 2020), activity (Ullinger, Sheridan, and Ortner 2012), child-rearing (Gregoricka and Judd 2016), movement and mobility (Perry et al. 2009, Perry, Coleman, and Delhopital 2008, Parker 2015, Perry, Jennings, and Coleman 2017), societal transitions (Perry, Parker, and Montgomery 2015, Sheridan et al. 2014), identity (Bonogofsky 2005, Sheridan et al. 2014, Bonogofsky 2004, Judd, Gregoricka, and Foran 2019), and even manner of death (Perry, Parker, and Montgomery 2015, Montgomery and Perry 2012). The application of the historical textual record as a stalwart resource has also been challenged by bioarchaeological research in historical periods allowing for a more judicious interpretation of the texts (Perry et al. 2012, Perry 2007a, Perry et al. 2009).

Until the development of processual archaeology, archaeologists working in Jordan focused primarily on descriptions of grave architecture and the artifactual contents of burials while skeletal data was typically summarized in site appendices containing minimal descriptive data (element inventory, age, sex, and minimum number of individuals) often without reference to the criteria or features used to derive the results (Judd 2009, Perry 2012). These practices followed a global trend in the use of biological anthropology for archaeological contexts, which initially focused on collecting descriptive demographic observations that were not generally well-integrated with other archaeological site data or applied to broader interpretations regarding the lives of ancient individuals (Judd 2009). However, the importance of mortuary contexts blossomed with the development of processual archaeology (Judd 2009, Perry 2012).

This "New Archaeology" attempted to correlate the snapshots of past life recovered from archaeological contexts with the behaviors of living communities through the application of social theory based upon ethnographic comparison (Parker Pearson 1999). From this perspective, Middle Range interpretations of mortuary contexts arose and challenged earlier approaches, which regarded them as a component of a united, unvarying cultural whole or, alternatively, as a transitory cultural element similar to aspects such as fashion, extravagance, and etiquette (Binford 1971). Building upon this idea, followers of systematics recognized mortuary practices as reflections of processual changes or diversity within a culture itself, varying directly "with the complexity of the overall organization of the society" including social organization by rank/class, technology, and subsistence strategy (Binford 1971:15). Indeed, mortuary ritual may be expressed differently based upon an individual's age, sex, social rank, the perception of an individual's identity by other members of the society, and even the circumstances of their death, or some combination of the above (Binford 1971, Ucko 1969). Therefore, examining the physical burial context, its associated artifacts and body placement and treatment, both before and after burial can provide some information regarding the identity of the individual in life.

However, some researchers believed that the processual Middle Range approach merely described burial practice without accounting for *why* particular mortuary customs occur (Parker Pearson 1999). Robb (2007) asserted that the focus on political process, rank, and status "conflate identity and hierarchical status and social order with elite dominance" (p.287) creating a tendency toward oversimplified categorizations of burials as "average" or "elite" in which average burials serve primarily as an interpretive reference point for high status graves. Moreover, Goodenough (1965) argued that an individual's identity is more relational than categorical. In his view identity formation relies on the contextualization of particular roles in terms of their "rights and duties" (Goodenough 1965:2-3), rather than allocation to a particular category since strict categorization ignores the myriad roles and social relationships that shape identity (Sofaer 2006).

Following the development of this new archaeological approach international trends in the study of human skeletal remains moved away from descriptive studies and toward population-based analyses (Cook and Powell 2008). A new evidence-based paradigm emerged in biological anthropology that utilized human skeletal remains as a resource to address archaeological research questions under the new name "bioarchaeology" (Buikstra 1977, Larsen 2002). This new approach recognizes the skeleton as a form of material culture affected by the biological, environmental, and cultural factors that comprise an individual's life experiences and can communicate information about an individual's health and identity(Sofaer 2006, Larsen 2002, Zvelebil and Weber 2013). The application of these bioarchaeological methods have begun to provide more detailed reconstructions of life for Nabatean and Early/Middle Roman populations in Jordan.

4.1 GENDER, AGE, AND IDENTITY

Within Nabataea, identity is discussed collectively, in terms of a distinct material culture, or sometimes in relation to socio-religious corporate or family units in mortuary contexts (Wadeson 2012, Nehmé 2013). On an intra-community level, some analyses provide disparate sources for evidence of life as reflected by sex and age categories, however, these are not generally employed in more detailed discussions of identity or personhood. Examination of burial inscriptions, tomb architecture, and body location within a tomb have been used to address the role of women in Nabataea. However, these interpretations are problematic since they use the body to ascribe meaning to the surrounding contextual material without integrated consideration of the body itself (Sofaer 2006). No apparent difference in the quality or type of tombs, or differential inclusion of artifacts has been reported between male and female burials for several cemeteries (Delhopital 2010, Lenoble, Al-Muheisen, and Villeneuve 2001, Parker and Perry 2013, Bikai and Perry 2001, Politis 1998, Politis, Kelly, and Usman 2005). The En Gedi papyri found south of the Dead Sea, relates the legal disputes of one Jewish resident, Babatha, in the late 1st and early 2nd C.E. with the families of her deceased husbands demonstrating that women not only owned and managed property, but participated in legal proceedings (Freeman 2008). A series of Nabataean coins bearing the likenesses of Queens and mortuary inscriptions at Mada'in Salih indicate that women owned property, dedicated tombs, and selected their own beneficiaries, however, there is no indication to suggest that women held civic or political offices begging the question of what is meant by “autonomy”, “power”, and “ownership” (Anderson 2005). While women, at least those in the upper classes, were accorded some importance in burial and financial spheres there is no direct evidence for how women were treated in households throughout Nabataea, much less the social roles they occupied as community members.

Age-at-death is also an area of social interest that has not been fully explored, despite the fact that we all pass through a life course during which our health, activity, and social roles change (Agarwal 2016). Collectively, the evidence from several cemeteries, including Petra, Wadi Ramm, Khirbet Qazone, Khirbet edh-Dharih, Umm el-Jimal, and Aila, suggests that children, even infants, were not excluded from typical burial features, implying recognition of their status as persons within the society (Bikai and Perry 2001, Parker and Perry 2013, Perry and Jones 2008, Politis 1998, Politis, Kelly, and Usman 2005, Delhopital 2010, Perry 2002a). In fact at Umm el-Jimal, infants were typically buried with more grave goods than adults, indicating their importance in society (Cheyney, Brashler, Boersma, Contant, DeWall, Lane, Smalligan, and Berg 2009). However, at Pella, infants and children were underrepresented in Roman contexts with “no satisfactory explanation” and an intrusive pit burial (150–100 B.C.E.) with a single 12–18 month old child evidencing unspecified “trauma” related to death suggests that the lives of children were not always valued (Bourke 1992:223). At Abila, 11% percent of the contexts explored contained only children, while 51% percent contained only adults, indicating some differentiation between age and burial place. Whether this is a difference between former Nabataean settlements and the Decapolis cities is unclear. While children were represented in later Byzantine burials at Aila, the remains of an infant found within the mud-mortar surrounding a pithos installed in a Roman building have prompted questions about the role of young children in society (Retzleff 2003).

Although no studies specifically focus on aging populations, a significant proportion of many Nabataean and Roman cemeteries consist of middle and older adults offering a rich opportunity to address questions related to these populations within the context of the Nabataean/Roman worldview (Bourke 1992, Politis 2004, 2007, Perry 2002a).

4.2 PALEOPATHOLOGY, SUBSISTENCE ECONOMIES, AND MOBILITY

Health is a focal topic in regional Nabataean and Roman period bioarchaeological research, uniting the perspectives of population-based analyses to discuss broader contextual issues of stress, disease, and injury between, and to a lesser extent within, sites. Paleopathological assessments have been completed with varying levels of detail for skeletal samples from Abila, Pella, Humayma, Bir Madhkur, Tell Hesban, Khirbet edh-Dharih, Umm el-Jimal, Zabayir, and Petra (Canipe 2014, Perry et al. 2013, Bikai and Perry 2001, Perry 2007b, Kick 1985, Browne 1992, Grauer and Armelagos 1998, Delhopital 2010, 2011, Cheyney, Brashler, Boersma, Contant, DeWall, Lane, Smalligan, and Berg 2009, Perry 2002a). However, intra-and inter-site statistical comparative research is less frequent due in part to the differing methodologies and reporting strategies employed by researchers and the small sample size for many of the studied populations, although the continuation of more bioarchaeologically focused projects for this period may alleviate the dearth of current comparative studies (Perry 2012).

While few instances of infectious disease have been noted for the region and period, several researchers have performed comparative analyses to examine health patterns across Nabataea and Roman Arabia using skeletal markers of generalized stress (e.g., Canipe 2014, Delhopital 2010, 2011, Perry 2002a). Perry (2002a) explored health for individuals at two post-annexation sites in the former Nabataean province—Zabayir and Aila—and a Byzantine farming village, Rehovot. Her research found differential experiences of stress between the groups. Childhood stress was greater among young children at the urban site of Aila and for older children and adolescents at Rehovot. Although stress for adults at Zabayir was relatively high, the experience for children was much less. Canipe (2014)'s paleopathological analysis of remains from Petra reported that LEH, which are disruptions in enamel growth, and porotic hyperostosis prevalence was significantly lower than other regional agricultural populations from Aila, Tell Hesban, and Jerusalem and showed greater similarity with regional nomadic populations. Evidence for generalized infection, trauma (mostly attributed to accidental causes), and osteoarthritis were not significantly different. These results are interesting since studies examining stress indicators for agricultural and pastoral nomadic populations outside the region have generally found higher frequencies for agricultural communities (Cohen and Armelagos 1984, Lukacs and Walimbe 1998). Delhopital (2010) examined skeletons from Khirbet edh-Dharih, Petra, and the southern Nabataean capital at Mada'in Saleh in Saudi Arabia. She documents dental caries on the permanent dentition and a relatively high prevalence of LEH—66% of subadults and 63% of adults. Since the assessment of LEH was only documented for individuals who had four or more observable teeth, the actual prevalence may have been much higher. These bioarchaeological analyses provide crucial population-based examinations of stress, although the experience for *individuals* throughout life in the Nabataean and Roman periods is still poorly understood.

4.2.1 Dietary Reconstructions and Subsistence

Dietary reconstructions and subsistence research provoke similar questions regarding food access, preferences, and trade across Nabataea. Osteological examinations of skeletal remains from Petra, Wadi Ramm, Humayma, and Aila noted similar dental wear patterns concurrent with a relatively low frequency of dental caries interpreted as the result of a gritty agricultural diet, possibly produced by the large quantity of ambient sand in the local environment (Perry et al. 2013). Stable isotope analysis for $\delta^{13}C$ for the non-elite population buried along Petra's North Ridge demonstrated that C_3 plants such as wheat and barley constituted the primary dietary fauna for these individuals (Appleton 2015, Perry et al. 2020). C_3 plants or fauna subsisting largely on a C_3 diet, represented the primary source of protein for these individuals. Paleobotanical evidence from various locations across Petra generally support these findings (Appleton 2015, Ramsay and Bedal 2015, Bedal, Cleason, and Schryver 2007, Studer 2007). Sheep and goat represent the primary sources of meat at the site, although chicken and several species of marine and freshwater animals were also identified in the faunal assemblage at Petra's elite residence ez-Zantur, suggesting trade with coastal Aila and areas with access to freshwater fish (Dolinka 2003, Studer 2007).

4.3 CONSIDERATIONS FOR BIOARCHAEOLOGICAL RESEARCH IN JORDAN

Given the way in which archaeological research in Jordan for the Nabataean and Roman periods was driven and defined by the presence of historical documents and Roman influence, it is not surprising that bioarchaeologically focused excavation and research projects were relatively slow to develop in the region. The scarcity of skeletal data reported from many sites poses a challenge to comparative research that might address regional questions about life in Nabataea and the later Roman province; however, several recent research projects (Delhopital 2010, 2011, Canipe 2014, Perry 2002a, Lieurance 2018) and new bioarchaeologically focused excavations along Petra's North Ridge and at Khirbet edh-Dharih provide promising opportunities for this type of research in the future (Parker and Perry 2013, Bikai and Perry 2001, Delhopital 2010, 2011, Perry and Walker 2018).

Furthermore, burial practices may also contribute to poor preservation. Along Petra's North Ridge, burials are placed within tombs cut into the sandstone bedrock (Perry and Walker 2018, Perry 2002b). These tombs do not allow for adequate drainage, which may contribute to poorer preservation. Similar burials are seen in other areas at Petra and throughout the region, including Khirbet edh-Dharih and Mada'in Salih (Delhopital 2010, 2011, Wadeson 2011, Wadeson and Abudanah 2016, Politis, Kelly, and Usman 2005). Furthermore, repeated burials within the same context and visitation post-inhumation may contribute to commingling and degradation of the skeletal elements complicating the analysis of individuals (Perry and Walker 2018).

The collective demographic representation of various populations has received less attention than the discussion of its individual parts, specifically age and sex, since few skeletal reports contain collective examinations of birth rates and mortality by age or sex (see Kick 1985; Perry et al. 2013). In some cases, basic age-at-death percentages or sex ratios are presented with little discussion (Browne 1992). Several issues impact demographic interpretations including the nature of many skeletal samples from the Hellenistic and Roman periods in Jordan, which do not reflect random sampling excavation strategies for cemeteries (Perry 2002a). Burials investigated are typically incidental inclusions in other contexts of primary interest, monumental tombs, and small or specific segments of a mortuary population (Renel and Mouton 2013a, Retzleff 2003, Parker 1994, Oleson and Somogyi-Csizmazia 2010, McNicoll, Smith, and Hennessy 1982, Wadeson 2011, Perry and Jones 2008, Parker and Perry 2013). As such, the excavated populations do not always accurately reflect the cemetery populations, although representative samples are becoming more available (Mare 2001, Politis 1998, Politis, Kelly, and Usman 2005, Delhopital

2010, 2011). Bocquet-Appel and Masset (1982) posit additional concerns with the methodology behind demographic modeling citing that it can inadvertently mirror the reference populations used to create systems for age and sex estimation. Furthermore, they imply that these methods create false categories which are not finite enough to assess the small increments involved in childhood growth and for adults the age categories produced are too large. Additional criticisms revolve around the assumption that human biology is static enough for reference populations from a particular place and time to adequately reflect those from different locations and temporal origins (Hoppa and Vaupel 2002a).

In response, a number of statistical techniques have been devised to combat these discrepancies, including estimating the probability for the entire age-at-death distribution before assessing individual ages (Hoppa and Vaupel 2002b). However, this requires a large sample size which may not always be available. For smaller populations, Konigsberg and Frankenberg (2002) proposed "hazards analysis" to account for the uncertainty of dealing with inferred age groups rather than known age individuals and Boldsen et al. (2002) have proposed transitional analysis which uses the probability of belonging in a particular age category compared to the confidence interval for an age indicator to refine an estimation (see Hoppa 2002 for additional information on the numerous statistical avenues for research). Many researchers still agree that a large degree of error, which cannot be completely altered, still results from the available osteological methodologies (Boldsen et al. 2002, Milner and Boldsen 2012b).

Some researchers feel that error may be lessened by examining age in terms of stages of skeletal change with a broader focus on the inclusion of numerous skeletal indicators (Jackes 2000, Milner and Boldsen 2012b). This is complicated for some existing datasets within the region since many older studies do not indicate which skeletal indicators were used to assess the age estimates provided (e.g., Bourke 1992, Kick 1985). Given the difficulties of working with the disparate and typically small sources available, demographic study can still produce worthwhile results given a combined statistical and broad osteological approach that may help facilitate better comparisons between populations in Hellenistic/Roman Jordan.

Differential burial practices based upon contemporaneity, gender, age, status, or even manner of death can also alter the perception of mortuary practices for a community, particularly since cemeteries are rarely excavated in their entirety. While random sampling can reduce bias, it is rarely eliminated altogether. Nevertheless, many examples demonstrate the utility of mortuary analysis for cemeteries in Jordan and the utility of bioarchaeological studies when these limitations are appropriately acknowledged (Parker Pearson 1999, Ullinger, Sheridan, and Ortner 2012, Ortner and Frohlich 2007, Chesson 1999, Beherec et al. 2016, Beherec 2011).

5.0 MATERIALS AND METHODS

To address the research questions, skeletal indicators for stress, diet, and activity will be examined individually for the skeletons excavated from Khirbet Qazone and Zabayir through the comparison of (1) demographic data; (2) indicators for non-specific stress, musculoskeletal robusticity and pathology in combination with; (3) isotopic analysis to evaluate diet and weaning. The results from these assessments will be combined with the available evidence for mortuary artifacts, archaeological, and historical contextual resources in the discussion to consider the role of identity within Khirbet Qazone, Zabayir, and rural post-annexation Nabataea more broadly. Data collection for the Khirbet Qazone skeletons occurred at the Museum at the Lowest Point on Earth (MATLPOE) in Ghor es-Safi, Jordan between 2012 and 2017. Skeletal data collection for the Zabayir skeletal remains was conducted in 2018 at the Smithsonian Institute's Museum Support Center in Suitland, Maryland. The necessary isotope sampling was completed from 2018 – 2019 and processed at the University of South Florida's Archaeological Sciences Laboratory.

5.1 SITE BACKGROUND AND SKELETAL SAMPLES

5.1.1 Khirbet Qazone

The Khirbet Qazone cemetery, located on the eastern Dead Sea littoral, was surveyed and excavated by the Hellenic Society for Near Eastern Studies from 1996 to 2004 under the direction of Konstantinos D. Politis (Figure 2-1) (Politis 1998, Politis, Kelly, and Usman 2005). Prior to the current data collection, only preliminary field observations regarding the skeletal remains have been reported (Politis 1998, Politis, Kelly, and Usman 2005). The skeletal collection of 49 individuals represents a sedentary population located outside the major Nabataean and later Roman centers.

The excavated portion of the cemetery includes only a small selection of the burial contexts identified during the survey, which recorded over 3,500 potential shaft graves, including many that were looted or disturbed (Figure 5-1) (Politis 1998). The limited sample of burials produces some risk in extrapolating data to the larger population. It is unknown whether the cemetery's geospatial organization follows a temporal or social/familial "grouping" pattern, which means that nearby burials would constitute a specific subset of the larger population. While such a small selection of burials cannot necessarily capture the entire range of variation present in such an extensive cemetery context, it can provide important insight into the lifeways for at least some members of the larger population. A full excavation catalogue with the complete details for all burials has not yet been published, but preliminary publications provide some details regarding grave architecture, skeletal positioning, burial treatment, and grave goods (Politis 1998, Politis, Kelly, and Usman 2005). The varied presentation of burials reflects the diverse cultural heritage of the region. Excavated graves included simple cist burials, shaft graves with individual interments, and multiple interments, each accompanied by variable orientations and unique features. A majority of the burials consisted of single interments in north-south oriented shafts with a loculus, or grave, undercut to the east and sealed with mudbricks (see Figure 5-2) (Politis 1998). All individuals within these tombs, regardless of sex or age, were positioned with the head to the south. Other pit graves were unsealed and filled with earth (Figure 5-3). Five individuals (θ2, θ3, Σ1, Σ2, Σ4) buried in the western portion of the cemetery were interred in north-south oriented shaft graves with loculi on the southern portion of the grave and a platform to the north. Burials from Trench Σ were all reburied without further examination and the skeletons could not be included in the current study. Another distinct grave type included two shaft graves with overlying capstones (R1 and R2) that contained multiple, commingled burials oriented east-west, with the head positioned to the west (Politis, Kelly, and Usman 2005).

Figure 5-1. Aerial view of the Khirbet Qazone cemetery showing impacts of looting (image used with permission from photographer Konstantinos Politis).

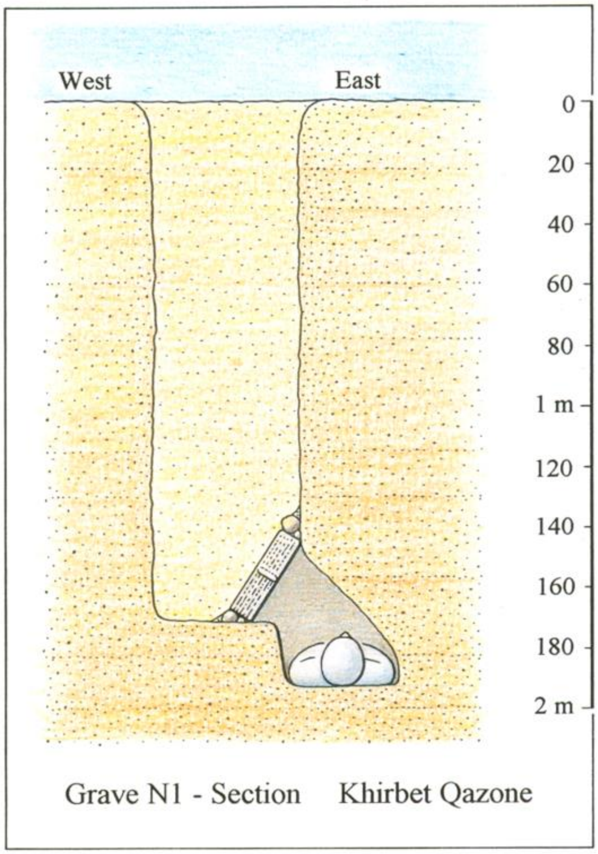

Figure 5-2. Typical shaft burial at Khirbet Qazone (Politis 1998).

Figure 5-3. Simple pit burial at Khirbet Qazone, Grave A1 (Politis 2005).

Few artifacts were recovered from the graves, however metalwork, including iron, copper, silver and gold, bracelets, earrings, necklaces, and other items along with beads, a scarab, a wooden staff, a pair of sandals, and a laurel wreath were recovered from intact and disturbed burial contexts (Politis 1998). Pottery, metalwork, and glass artifacts dating to the 1^{st} – 2^{nd} centuries C.E. were also recovered during surface collections and five funerary stelae, including four with Nabataean betyls and one bearing a Greek inscription, “Afseni the pretty one”, were collected from robbed tombs (Politis 1998). Many individuals were wrapped in leather, which in some cases was decorated, and/or tunics as well as one individual (Skeleton I1) who was wrapped in a cloth shroud that completely covered the body, including the face and feet (Politis, Kelly, and Usman 2005, Granger-Taylor 2000). Textiles—mostly wool and some dyed—from tunics, mantels and scarves of traditional Roman styles were excavated or recovered from looted graves and are thought to date primarily to the period following Roman annexation (Politis 1998, Politis, Kelly, and Usman 2005, Granger-Taylor 2000). Some graves included the remains of wooden coffins and one looted grave (Trench P) also contained a large stone sarcophagus (Politis, Kelly, and Usman 2005).

5.1.2 Zabayir Zahr ed-Diyab

The Zabayir cemetery, excavated in 1978 in advance of the Queen Alia International Airport (QAIA) construction, occupied a roughly circular area, although graves appeared to be irregularly placed in clusters or curving rows (Ibrahim and Gordon 1987). Most graves consisted of simple east-west oriented shafts in which the lower portion of the grave was slightly smaller than the main shaft, creating a small ledge around a central loculus that contained a single individual (Figure 5-4). Roughhewn limestone capstones were placed on the ledges to cover the loculus. However, like Khirbet Qazone, unique and less common burial patterns were also present. Fifteen burials contained multiple individuals, in which the deposition of additional individuals appear to have occurred simultaneously or in relatively quick succession. Five other burials contain multiple individuals, in which earlier burials were pushed to the east end of the shaft for later interments and two graves contained a second individual that was placed atop the capstone of the original burial. Three graves also had shallower pits constructed to the south, cutting the original burial's shaft, but in each case, the previous burial was respected and not removed for the new grave. This delineation of space suggests that while the exact location of the original burial was not known, it retained its importance among living individuals, implying that the individuals interred were members of a single community. Individuals were buried in a supine position or flexed slightly to the north or south with the heads positioned at the western end of the grave and the arms generally folded over the pelvis or extended at the sides. One grave was completely unique among others in the cemetery: a cremation in a lead ossuary was recovered from an oval grave (Grave 3) and buried with the only intentionally placed ceramic vessel in the cemetery.

Figure 5-4. Zabayir Grave 111 showing a middle-aged individual and two children wrapped in a single leather sheath (Ibrahim and Gordon 1987).

When compared with the Khirbet Qazone burials, a more diverse array of artifacts was recovered from the Zabayir cemetery and individuals were generally buried with greater numbers of artifacts, although most individuals (93%) were buried with five or fewer items. Jewelry and clothing, including sandals and footwear soles, comprise the most frequently recovered artifacts from burial contexts (Figure 5-5). Jewelry disproportionately accompanied the burials of adult females and children, while identifiable males had fewer personal adornments. Although the conspicuous consumption demonstrated by the presence of these artifacts may indicate wealth among certain individuals within the cemetery, these items hardly reflect the level of wealth experienced more broadly in the Nabataean and Roman world. Additionally, although many items indicate trade or cultural influences from Greco-Roman towns (i.e., coins, jewelry styles, figurines, and other personal items such as fibulae and tools), the inclusion of crafted leather goods, including shrouds and footwear provide information about local traditions (Figure 5-6).

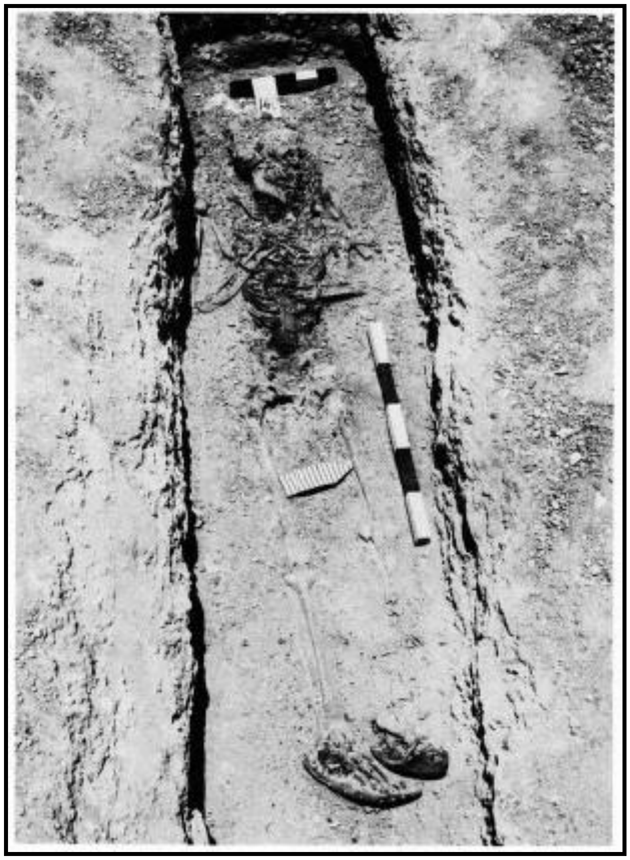

Figure 5-5. Zabayir Grave 140, individual with sandals (Ibrahim and Gordon 1987).

Like many Nabataean burials, leather was a predominate feature in several of the Zabayir graves. Several burials contained material so well-preserved it was apparent that individuals had been rolled in a leather sheet to create a shroud (Ibrahim and Gordon 1987). The leather sheets were comprised of smaller leather fragments stitched together and bore impressed checker-board patterns resembling camel or horse saddles depicted in contemporaneous statutes and art from sites in Yemen and Syria (Figure 5-7). The sheer volume of leather means that it was more accessible than some other grave goods and the excavators have proposed that it might have been a locally produced item that could be traded with communities for other goods. Other sites throughout the region have also demonstrated evidence for leather shrouds, including Khirbet Qazone, Khibet edh-Dharih, and Wadi Ramm (Granger-Taylor 2000, Lenoble, Al-Muheisen, and Villeneuve 2001, Perry and Jones 2008).

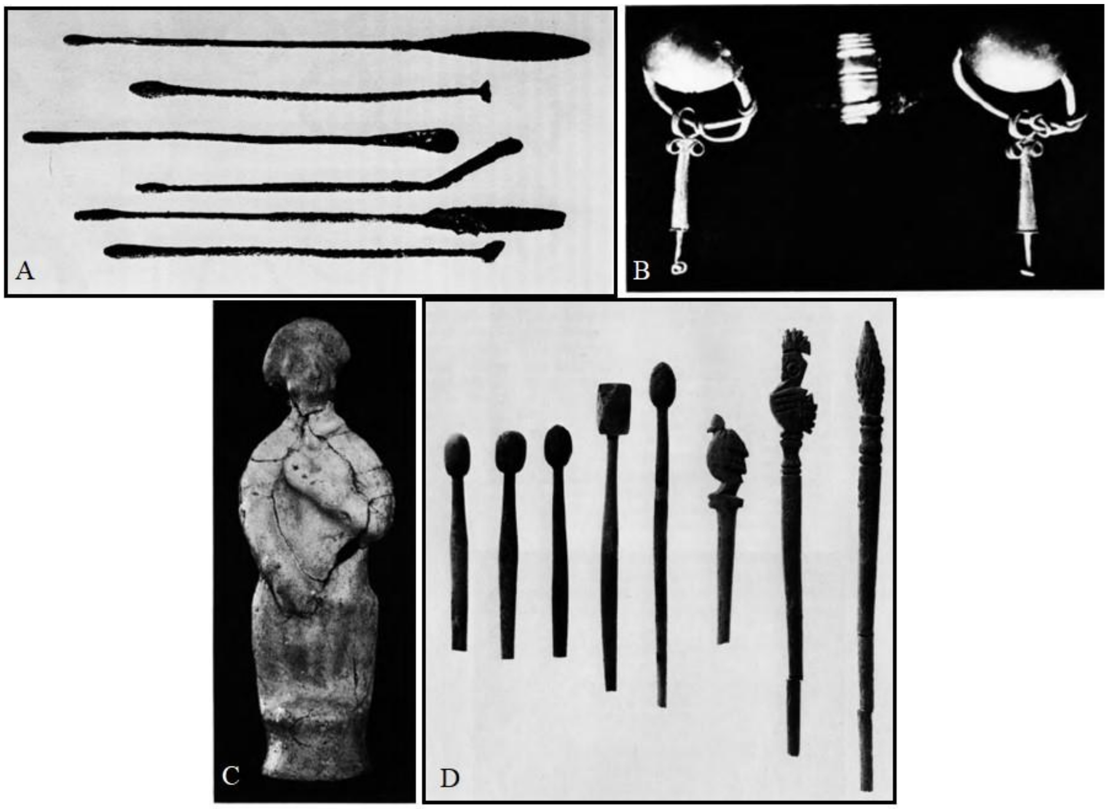

Figure 5-6. Selection of Zabayir cemetery artifacts: A) cosmetic spatulae and spoons; B) bone and metal earrings; C) figurine; D) hair pins (Ibrahim and Gordon 1987).

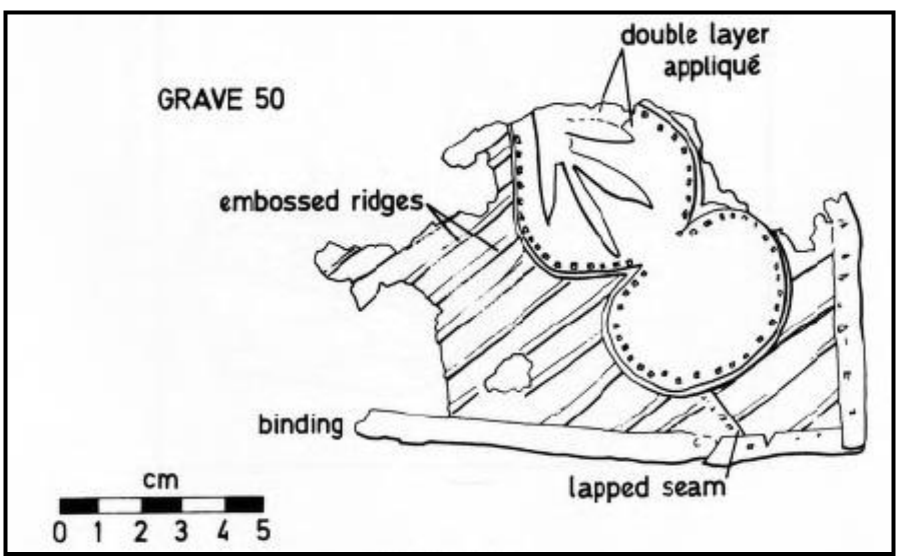

Figure 5-7. Fragment of leather shroud from Grave 50, Zabayir (Ibrahim and Gordon 1987).

Originally, 173 burials were excavated at Zabayir, however, only 73 individuals with reliable provenience information were available for study at the Smithsonian Institute's Museum Support Center for this study. Two previous researchers examined the skeletal remains from Zabayir. Bruno Frohlich began an inventory of the skeletons in Amman from 1978-1979. He later finished this preliminary inventory, which included 88 individuals (five of which remain in Jordan) after the skeletons were moved to the Smithsonian Institute in Washington, D.C. Unfortunately, during their export from Jordan and entry through U.S. customs, some contexts were combined, and 25 skeletons lost their original identification tags. As a result, some of the skeletal contexts could not be associated with the original excavation data and some skeletal material had to be relabeled. The original registration numbering system ('R-' number) was therefore replaced by a box number ('AP-' number) where the original designation was lost and by a 'UK-' number where the individual number and box number were no longer known.

In 1999, Megan Perry (2002a) examined LEH, porotic hyperostosis, and periostitis in relation to Greco-Roman artifacts from burials at the site. She found that differential experiences of stress were not correlated with access to or preference for these goods. Femoral buttressing or robust femoral insertion sites for the gluteus maximus and vastus lateralis muscles in combination with other activity-related pathologies, including vertebral osteoarthritis and trauma, were cited as possible evidence for riding. Although ^{87}Sr/8^{6}Sr analysis for dental and bone samples revealed no significant indications of mobility among this pastoral nomadic population, it is possible that the consistency in ^{87}Sr/^{86}Sr values between samples was due to the same mobility experience in childhood among all individuals tested (Megan Perry personal communication, September 2018). Damien Huffer previously collected samples of dental collagen for δ^{13}C and δ^{15}N analysis of the

Zabayir skeletons (France 2018), which will be used for comparison with the Khirbet Qazone material.

5.2 SKELETAL PRESERVATION AND COMPLETENESS

Skeletal completeness is integral to the investigation of skeletal pathology and stress since some conditions preferentially affect certain elements and the absence of elements can skew the prevalence of a condition within the population. A total of 143 individuals of all ages—46 from Khirbet Qazone and 97 from Zabayir—will be included in the study (Table A-1 and Table A-2). The Khirbet Qazone and Zabayir populations were selected for the current study, in part, due to their relative completeness compared to other Jordanian collections from the Nabataean and Early/Middle Roman period, which are commingled or only contain a few individuals. The completeness of individual skeletal elements will be evaluated for each individual and presented as a '1'-'3' score modified from Buikstra and Ubelaker (1994), with '3' being the most complete score for individuals with 75-100 percent of the skeletal elements represented, '2' indicating 25-75 percent complete, and '1' if less than 25 percent of the skeleton was available for observation. Adult completeness scores will be calculated separately for the major elements of the cranium, appendages, and axial skeleton. These three scores will be aggregated to achieve an overall completeness score and percentage. For subadults, completeness scores will comprise the major elements of the cranium, appendages, and axial skeleton, although some elements that may not be present in all subadult specimens, such as the bones of the hands and feet, patellae, and long bone epiphyses, will not be used to calculate the representation of subadult skeletons.

5.3 AGE ESTIMATION

Where possible, a variety of resources will be used to estimate age. For subadults, dental development, including tooth formation and eruption, is considered the most reliable indicator of age, since tooth development is less effected by environmental insults during growth than other bony tissues (Smith 1991, Hillson 2014). Therefore, subadult age will be preferentially estimated based on the stages of crown and tooth root completion (Moorrees, Fanning, and Hunt 1963b, Moorrees, Fanning, and Hunt 1963a) in addition to tooth eruption (Ubelaker 1989). In the absence of dentition, epiphyseal, occipital, spheno-occipital, and fontanelle fusion will be used to provide an age assessment (Scheuer and Black 2000, 2008). In cases, where epiphyseal fusion cannot be assessed, and dentition is not present, long bone lengths will be utilized to estimate age (Maresh 1970; Scheuer and Black 2000; 2008). For adults, age-related changes on the pubic symphyseal surface (Todd 1920, 1921, Brooks and Suchey 1990) and auricular surface of the ilium (Lovejoy et al. 1985) are widely used aging techniques. Where present, right and left pubic symphyses and auricular surfaces will be scored separately and all scores will be combined to provide the most robust individual age assessment.

Since age estimates fall within a range all individuals will be assigned a cohort for statistical comparative analysis (see Table 5-1). Cohort groups modified from Judd (2012), who utilized dental development to describe age groups that best fit the developmental periods discussed in Bogin (1999) will be used. While the adult age categories primarily agree with Buikstra and Ubelaker (1994), Judd added an Early Adult category that provides a more refined depiction of adult age data. For subadults who lack specific age indicators due to poor preservation or commingling, comparisons of general element size, shape, and development will be used to assign a cohort. If it is not possible to confidently allocate individuals to a specific age cohort, individuals will be assigned to ‘Cohort 0’ (indeterminate subadult), ‘Cohort 12’ (indeterminate adult), or ‘Cohort 13’ (unknown). If an individual’s age estimate incorporates more than one cohort, the oldest cohort will be used.

Table 5-1. Standardized age cohorts modified from Judd 2012.

Cohort	Age Category	Chronological Age Range
0	Indeterminate Subadult	birth – 16 years
1	Fetus	< birth
2	Neonate	birth – 6 months
3	Toddler	6 months – 2 years
4	Early Child	2 – 6 years
5	Late Child	6 – 12 years
6	Adolescent	12 – 16 years
7	Youth	17 – 20 years
8	Early Adult	20 – 25 years
9	Young Adult	25 – 35 years
10	Middle Adult	35 – 50 years
11	Old Adult	50 + years
12	Indeterminate Adult	20 – 50+ years
13	Unknown	Unknown

5.4 BIOLOGICAL SEX ESTIMATION

Biological sex will be assessed for individuals aged within the adolescent or adult cohorts—cohorts ‘6’-‘12’. Sex estimates will not be attempted for subadult skeletons in cohorts ‘0’-‘5’ since secondary sex characteristics, including sexually dimorphic skeletal indicators, occur with reproductive development following the onset of puberty (Buikstra and Ubelaker 1994). Consequently, osteological studies using known sex collections consistently demonstrate the ineffectiveness of using skeletal elements to address biological sex prior to adolescence (Reinman 2015, Klales and Burns 2017).

Sex estimation will utilize cranial and pelvic morphological indicators, including the ventral arc, subpubic concavity, ischiopubic ramus ridge, greater sciatic notch, nuchal crest, mastoid process, supraorbital margin, glabella, and mental eminence (Phenice 1969, Acsádi and Nemeskéri 1970, Buikstra and Ubelaker 1994).

Distal humerus morphology, vertical humeral head diameter, and femoral maximum head diameter will also be collected to increase the robusticity of biological sex categorization within the sample (Seidemann, Stojanowski, and Doran 1998, Buikstra and Ubelaker 1994, Acsádi and Nemeskéri 1970, Spradley and Jantz 2011, Rogers 1999). Four aspects of the distal humerus will be scored following criteria outlined in Rogers (1999) (Table 5-2). Each of the four traits will be scored '1' to '3', '1' being female, '2' ambiguous, and '3' male. Humeral vertical and femoral maximum head diameters < 43 mm will be scored as female, those > 47 mm as male, and diameters 43-47 mm will be considered ambiguous (Milner and Boldsen 2012a).

Table 5-2. Distal humerus sex scoring following Rogers (1999).

Trait	Humeral View	Female (Score=1)	Male (Score=3)
Trochlear Constriction	Posterior	Constricted or spool-shaped trochlea	No or little constriction
Trochlear Symmetry	Posterior	Symmetrical trochlea	Asymmetrical trochlea
Olecranon Fossa	Posterior	Deep oval fossa	Shallow triangular-shaped fossa
Medial Epicondyle Angle	Distal view with posterior surface up	Epicondyle angles upward distinctly	Epicondyle is flat or raised very little

Individual sex assessment scores will be weighted based on the relative sexual dimorphism for the specific skeletal element or bone feature. Following Kjellström (2004), pelvic sex criteria were assigned twice the weight (weight=2) of skull characteristics (weight=1) since pelvic features have consistently demonstrated more reliable identifications in populations of known biological sex. Post-cranial metric data will be weighted the same as cranial features (weight=1) based upon a study that demonstrated similar accuracy rates among the univariate post-cranial metric measurements utilized in this study and traditional ordinal scoring for skull characteristics (Spradley and Jantz 2011, Konigsberg and Hens 1998, Walker 2008, Stojanowski and Seidemann 1999). For the present study, distal humerus characteristics, which have reported success rates varying from 75.5% to 97%, were also assigned the same weight as skull characteristics (weight=1), which have reported similar accuracy rates (Falys, Schutkowski, and Weston 2005, Rogers 1999, Vance, Steyn, and L'Abbé 2011, Walker 2008, Konigsberg and Hens 1998).

Following Buikstra and Ubelaker (1994), a '1' to '5'-'1' being most female and '5' most male—ordinal scale will be used to assess the sciatic notch and facial features, however, a '1' to '3' scale is used for the subpubic concavity, ischiopubic ramus, and ventral arc. The pelvic features, along with the distal humeral characteristic scores—originally, '1' to '3'—will be normalized to a '1' to '5' scale for analysis. All metric and morphological observations for the appendicular skeleton will also be normalized to a '1' to '5' scale for analytical purposes. The resulting scores will be weighted, and a total biological sex score will be calculated using the formula:

$$\frac{\sum(W x X)}{\sum W}$$

A resulting score '1.00' - '2.00' indicates a female, '2.01' - '3.99' will be considered ambiguous, and '4.00' - '5.00' male. Only individuals with three or more sex traits will be included in sex specific analyses.

5.5 GROWTH & DEVELOPMENTAL DISRUPTION

Long bone lengths will be used as a proxy for stature to measure growth within the study since the use of stature estimates rely upon data sets constructed using American white males and females which may produce less accurate estimates for other populations (Trotter and Gleser 1977, 1952, Jantz 1992). Since the femur and tibia contribute most directly to living stature, femoral bicondylar length (FBL), which reflects the femoral contribution to height in anatomical position, and total tibia length (TTL) will be collected. VNC diameter measurements will also be collected for lumbar vertebrae with complete VNC closure. All available lumbar vertebra will be measured for two dimensions following Watts (2011): 1) a medial-lateral measurement within the VNC between the two pedicles and; 2) an anterior-posterior measurement within the VNC between the body and the anterior aspect of the spinous process (Figure 5-8). Each growth measurement will be compared with skeletal indicators of stress (LEH, CO, and PH) to determine the impact of stress on growth within each population.

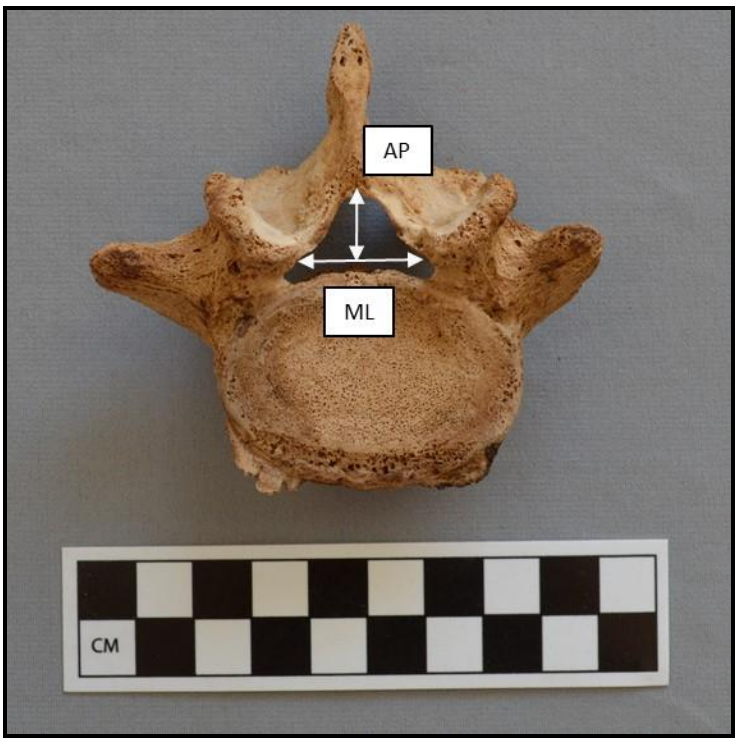

Figure 5-8. VNC dimensions for lumbar vertebrae.

LEH defects will be recorded to examine dental growth disruption. For the purposes of comparison in the research questions, an individual will only be counted as having LEH if they exhibit more than one hypoplastic event on more than one tooth. The occurrence of LEH defects visible at 10X magnification will be documented in millimeters (mm) above the cementoenamel junction (CEJ) for each tooth to estimate the timing of the disruption. Calculating the chronological age range during which a LEH occurred requires knowledge of the original tooth crown height. Since previous reports indicate that most individuals in the Khirbet Qazone and Zabayir populations were older adults with substantial tooth wear, meaningful average adult tooth heights could not be calculated for the population (Perry 2002a, Politis, Kelly, and Usman 2005, Frohlich 1987). However, the predictability of tooth growth across populations has allowed for the development of several methods focused on average crown heights for different teeth that can be applied to estimate chronological growth schedules for different sections of the tooth crown (Goodman and Rose 1990, Reid and Dean 2006, Goodman and Song 1999). Reid and Dean (2006) established substantial differences in tooth development between some populations, however, a growth schedule specific to Middle Eastern or Mediterranean populations has not yet been developed and it is unclear how these differences may impact LEH timing estimates (Martin et al. 2008). As discussed in Chapter 3.1.2, several methods have been developed to assess the age of occurrence for LEH; however, not all methods provide equations for each tooth type. Since Goodman and Song (1999) provide regression equations for all teeth except the third molars, their equation shown below will be used to estimate the chronological age at which LEH occurred using the defect width.

$$\text{Age at LEH Formation} = -[(1/\text{velocity}) \times (\text{CEJ to LEH distance})] + \text{crown completion age}$$

Velocity, measured in mm/year, is a function of total crown height and development time and, along with age at crown completion is different for each tooth. Tooth specific regression equations used to calculate age at LEH formation are shown in Table 5-3. Although LEH occurs most frequently on anterior teeth, all LEH present on any tooth will be recorded and measured.

Since multiple teeth are required to observe LEH overlap between teeth, only individuals with at least three teeth present for evaluation were included in the analysis (Goodman and Rose 1990, Hillson 2014).

Table 5-3. Age at LEH formation regression equation by tooth following Goodman and Song (1999).

Tooth	Equation[1]
Maxillary	
I1	Age= – (0.314 x Ht) + 4.5
I2	Age= – (0.239 x Ht) + 4.5
C	Age= – (0.434 x Ht) + 6.0
P1	Age= – (0.374 x Ht) + 6.0
P2	Age= – (0.333 x Ht) + 6.0
M1	Age= – (0.371 x Ht) + 3.5
M2	Age= – (0.496 x Ht) + 7.5
Mandibular	
I1	Age= – (0.340 x Ht) + 4.0
I2	Age= – (0.323 x Ht) + 4.0
C	Age= – (0.416 x Ht) + 6.5
P1	Age= – (0.480 x Ht) + 6.0
P2	Age= – (0.487 x Ht) + 7.0
M1	Age= – (0.323 x Ht) + 3.5
M2	Age= – (0.433 x Ht) + 7.0

[1]Age is measured in years; Ht refers to the measured location of the LEH in mm above the CEJ.

5.6 PALEOPATHOLOGY

Non-specific stress lesions (CO and PH) will be recorded and reported by individual using forms and recording codes from Buikstra and Ubelaker (1994) to facilitate comparative discussion since these forms and methods were used in previous studies for contemporaneous sites in the region, including Aila (Perry 2002a), Zabayir (Perry 2002a), and Petra (Bikai and Perry 2001, Canipe 2014). For each pathology recorded, crude prevalence rates (CPR) will be reported by calculating the number of individuals with the element in question against those with pathological expression. Porotic hyperostosis and cribra orbitalia will be recorded separately following the Buikstra and Ubelaker (1994) coding for porotic hyperostosis (Skeletal Pathology Code series 6.0.0; Table 5-4) along with bone preservation for the orbits, frontal, parietals, and occipitals. When examined in light of its etymology "porotic hyperostosis" does not specify a location, the term is used in this project for cranial lesions only (Brickley 2018). Similarly, Cole and Waldron (2019) argue that "cribra orbitalia" should be re-defined in its usage to refer to only orbital porosity that occurs due to normal growth processes, for the purposes of this document cribra orbitalia will refer to the common usage of this term refencing a pathological condition. The most severe porotic hyperostosis and cribra orbitalia score recorded for an individual element will be used for statistical comparison. Only individuals with at least one orbit present will be used to examine the prevalence of CO and only individuals with at least 25% of cranial elements present will be included in comparative analyses for PH.

Table 5-4. Porotic hyperostosis and cribra orbitalia recording scores.

Score Category	Code	Description
Degree	6.1.1	Barely discernible
	6.1.2	Porosity only
	6.1.3	Porosity with coalescence of foramina, no thickening
	6.1.4	Coalescing foramina with increased thickness
Activity	6.3.1	Active at time of death
	6.3.2	Healed
	6.3.3	Mixed reaction; evidence of healing and active lesions

5.7 DENTAL HEALTH

A full dental inventory documenting tooth presence as well as dental caries, wear, abscess, and calculus will be performed for each skeleton (Table 5-5). For data collection and reporting purposes teeth will be assigned a number following the Universal Numbering System described in Buikstra and Ubelaker (1994). Dental caries, tooth wear, and calculus will be scored for all individuals with at least one tooth present. Dental abscess and AMTL will be evaluated for all individuals with available maxillary or mandibular alveolar bone. Dental caries, abscess, and antemortem tooth loss will be evaluated as present or absent following the definition of these features outlined in Buikstra and Ubelaker (1994). Calculus will be recorded for each tooth surface based on a ‘0’ to ‘3’ severity scale and aggregated to produce a single score for each individual following a modified version of the Simplified Calculus Index (Table 5-6) (Greene, Kuba, and Irish 2005). Dental wear will be scored following Smith, Bar-Yosef, and Sillen (1984) for anterior teeth and premolars, and for each molar cusp after Scott (1979). An aggregate (mean) score will be calculated for individuals based upon the wear scores of all teeth present. The data collected for dental disease and attrition will be used to describe overall dental health for individuals since these conditions are specifically related to diet and convey important information regarding individual overall health. All evidence for dental disease, calculus, and wear will be reported by individual CPR unless otherwise indicated in the results.

Table 5-5. Dental inventory scoring modified from Buikstra and Ubelaker (1994).

Score	Description
1	Present, development incomplete and not in occlusion
2	Present, development completed, in occlusion
3	Missing with no associated alveolar bone
4	Missing with alveolus resorbing or fully resorbed (premortem loss)
5	Missing with no alveolar resorption (postmortem loss)
6	Missing due to congenital absence
7	Present but damage limits measurements and some observations
8	Present but unobservable (e.g., deciduous or permanent tooth in crypt)

Table 5-6. Calculus scoring following Greene, Kuba, and Irish (2005).

Score	Quantity	Description
0	None	None
1	Small	Narrow, thin (<2 mm) band covering less than 1/3 of the tooth surface
2	Moderate	Thin band covering more than 1/3, but less than 2/3 of the tooth surface
3	Large	Covers more than 2/3 of the tooth surface or continuous thick band (>2 mm) around cervical portion of tooth

5.8 ACTIVITY

Thirty-four post-cranial musculoskeletal attachment sites (Table 5-7) will be evaluated for robusticity and stress lesion development using a '1' – '6' scale based on the Hawkey and Merbs (1995) scoring system (Table 5-8). This system was selected since it has been well-established and widely used, which facilitates future comparisons. Like previous studies using the Hawkey and Merbs (1995) system, robusticity and stress lesion scores will be combined, rather than scored separately, to represent a continuum of MSM expression (Eshed et al. 2004, Molnar 2006, Schrader 2012). Both right and left robusticity and stress lesion scores will be collected by individual for a given MSM. Right and left scores will be averaged to produce an aggregate individual score for each muscle marker Eshed et al. (2004). These individual aggregate scores will be averaged to examine mean MSM scores for each site. Ossification exostoses will not be included in the current analysis since these features typically result from trauma at the attachment site (Hawkey and Merbs 1995). MSMs will not be scored on any bone with an antemortem fracture.

Table 5-7. Recorded musculoskeletal marker (MSM) landmarks.

Anatomical Region	Bone	Muscle/Tendon/Ligament
Upper Limb	Scapula	Triceps brachii
	Clavicle	Costoclavicular ligament Subclavius Trapezoid ligament
	Humerus	Supraspinatus/Infraspinatus Subscapularis Teres minor Common extensor tendon Common flexor tendon Deltoideus Teres major/latissimus dorsi Pectoralis major
	Ulna	Triceps brachii Brachialis Supinator
	Radius	Biceps brachii Brachioradialis Interosseus membrane Supinator Pronator teres Pronator quadratus
Lower Limb	Os Coxae	Semimembranosus/semitendinosus/biceps femoris
	Femur	Gluteus maximus Gluteus medius Gluteus minimus Psoas Gastrocnemius Quadratus femoris Vastus medialis
	Patella	Quadriceps tendon
	Tibia	Patellar ligament/Quadriceps tendon Popliteus Soleus
	Calcaneus	Calcaneal (Achilles) tendon

Table 5-8. MSM scoring following Hawkey and Merbs (1995).

Score Focus	Score	Definition	Description
Robusticity	0	Not Present	
	1	Faint	Barely visible, slightly rounded or barely roughened cortex
	2	Moderate	Roughened or uneven, possibly mound shaped surface; no crest or ridge
	3	Strong	Distinct, sharp crest or ridge, sometimes with a deep indentation only involving the cortex
Stress Lesion Development	4	Faint	Shallow furrow less than 1 mm in depth with limited pitting into the cortex
	5	Moderate	Pitting over a larger area with a furrow 1 - 3 mm in depth
	6	Strong	Marked pitting with a furrow greater than 3 mm in depth or over 5 mm long

5.9 ISOTOPE ANALYSIS

Bone and tooth samples will be selected from Khirbet Qazone and Zabayir for isotopic analysis using apatite from bone and tooth carbonate to examine $\delta^{13}C$ and $\delta^{18}O$ values for the populations. In addition, $\delta^{13}C$ and $\delta^{15}N$ values will be examined from bone and dentine collagen for Khirbet Qazone. Bulk values of $\delta^{13}C$ and $\delta^{15}N$ previously sampled from tooth collagen for Zabayir by Damien Huffer will be integrated for comparison (France 2018). All isotopic analyses will be performed at the University of South Florida's Archaeological Science Laboratory. The analysis of apatite and collagen from bones and teeth will be used to understand childhood and adult diets and infant weaning patterns at these two sites. The abbreviations in Table 5-9 will be used to differentiate each isotope ratio based upon the materials from which they are derived throughout this document. Although bone collagen samples were not available for this study, any comparative bone collagen samples will be referred to as $\delta^{15}N_{bone\_coll}$ or $\delta^{13}C_{bone\_coll}$.

Table 5-9. Isotopes samples and their abbreviations.

Isotope	Sample	Abbreviation
Nitrogen	Dentine collagen	$\delta^{15}N_{enamel\_coll}$
Carbon	Dentine collagen	$\delta^{13}C_{enamel\_coll}$
Carbon	Enamel carbonate	$\delta^{13}C_{enamel\_ap}$
Carbon	Bone carbonate	$\delta^{13}C_{bone\_ap}$
Oxygen	Enamel carbonate	$\delta^{18}O_{enamel\_ap}$
Oxygen	Bone carbonate	$\delta^{18}O_{bone\_ap}$

5.9.1 Bone and Tooth Root Collagen

Based upon previous analyses, the number of teeth from Zabayir available for sampling is relatively small and bulk values of $\delta^{13}C$ and $\delta^{15}N$ from dentine collagen were previously produced for the site by Damien Huffer, who has allowed the use of this data for the current study (France 2018). Therefore, collagen samples will be processed for the Khirbet Qazone specimens only. Sample processing will follow a modified version of the procedures outlined in Ambrose (1990). A minimum sample of 1 g of bone or dentine will be placed in a 2% HCl solution for 72 hours to remove bone apatite, then rinsed and placed in a 50 ml solution of 0.1M NaOH for 24 hours to remove humic acids. The samples will be dried using an oven and weighed to calculate the percentage yield for each sample. All samples that yield no less than 1% collagen will be processed using a ThermoFisher MAT253 isotope ratio mass spectrometer (IRMS)coupled to a GasBench-II with continuous flow. Initial efforts to process material from Khirbet Qazone yielded insufficient collagen from ribs for further analysis. Similarly, the teeth did not yield enough collagen thin sections from tooth roots or dentine so these elements from Khirbet Qazone will be processed as bulk samples for each tooth. Following apatite sample extraction from the dental enamel, each tooth will be cut at the CEJ using a wet saw to allow for collagen extraction from the tooth root. Results will be presented using the standard reference baseline Vienna PeeDee Belemnite (VPDB) for $\delta^{13}C_{coll}$ values and ambient inhalable reservoir (AIR) for $\delta^{15}N_{coll}$ values. When comparing collagen data with $\delta^{13}C_{enamel\_coll}$ and $\delta^{15}N_{enamel\_coll}$ values will be adjusted for enrichment when examining trophic level variation. $\delta^{15}N$ undergoes about a 3‰ increase with trophic level (Schwarcz and Schoeninger 1991). Similarly, $\delta^{13}C$ in collagen is enriched in ^{13}C about 5‰ above dietary values (DeNiro 1985). Adjusted dietary values based upon these enrichment values will be provided in the results.

5.9.2 Bone Apatite and Dental Enamel

For Khirbet Qazone and Zabayir, a rib sample will be taken from all skeletons in age cohorts 7-12 (17 – 50 + years of age) for which the element is present. A first (M1) and second molar (M2) or a canine (C) will also be sampled for all individuals from each site with minimal dental enamel attrition. First molars from subadults with completed CEJ development of this tooth will also be sampled for inclusion in dental analysis and will increase the sample size of individuals available for study and reduce bias produced by excluding individuals with early life mortality.

As the mineral component of bones and teeth, apatite is less affected by diagenesis than collagen and was more accessible for analysis (Ambrose 1993). Multiple incremental intra-tooth enamel carbonate samples were taken to address more specific questions related to weaning timing within the populations. A total of 56 samples from 13 individuals at Khirbet Qazone and 43 samples from 15 individuals at Zabayir were collected. While an effort was made to take intra-tooth samples at 2 mm intervals along each tooth, tooth enamel wear and taphonomic degradation led to tooth fracture during sampling, which resulted in fewer samples for some teeth or in some samples that covered a wider range of dental enamel. The age range for each enamel sample will be calculated using the same regression equations from Goodman and Song (1999) (see Section

5.5) that were used to calculate LEH formation times to facilitate comparison between the recorded pathological and isotopic data. Then the median age of each range will be calculated and used to place the sample within a 1-year sample age category that reflects the age of tissue formation to facilitate statistical comparisons (i.e., <1 year; 1-1.9 years; 2-2.9 years; 3-3.9 years; 4-4.9 years; 5-5.9 years; 6-6.9 years and; 7-7.9 years).

Apatite samples from bone and dental enamel will be processed following procedures outlined in Tykot (2004). Bones and teeth will be cleaned and then ground using a diamond drill to produce a 10 mg powdered sample. The samples will be soaked in 1 ml of a 2% bleach solution—bone for 72 hours and tooth enamel for 24—to remove collagen, bacterial protein, and humates. Each sample will be rinsed four times in distilled water and dried in an oven, then added to 1 ml of 1 M acetic acid solution for 24 hours before being rinsed in distilled water and dried again. Samples will be treated with 600 µl of 104% phosphoric acid at 25 degrees C for 24 hours and placed in an IRMS.

Dental enamel will be used to assess the utility of $\delta^{13}C$ and $\delta^{18}O$ values from sequential samples of dental enamel from first and second molars or canines to create a generalized weaning profile for the study populations. Weaning is recognized as a process marked by the initial introduction and gradual supplementation of breast milk with alternative solid and liquid food sources until the complete cessation of breast milk consumption by the child (Humphrey 2014). To observe these dietary changes, sequential enamel samples will be taken from the first and second molars. In some instances, a single canine will be used where two molars are not available. Each sample location will be measured along the tooth enamel from the CEJ and the age of formation calculated using regression equations from Goodman and Song (1999). Each sample will represent an average across a general period of tooth development and will be presented as a range (e.g.., Sample 1 from CEJ to 2 mm above the CEJ of the maxillary M1 would represent the period from two years nine months to three years six months). Results will be presented as $\delta^{13}C_{enamel\_ap}$ or $\delta^{13}C_{bone\_ap}$ and $\delta^{18}O_{enamel\_ap}$ or $\delta^{18}O_{bone\_ap}$ values using the standard VPDB baseline.

5.10 STATISTICAL ANALYSES

5.10.1 Research Question 1: Stress

The Chi-squared test, which measures the association between qualitative variables, will be used to determine whether the occurrences of LEH, CO, or PH are correlated with age-at-death using the cohorts outlined in Table 5-1. For comparisons with extremely small groups (n=<5) the Fisher's exact test will be employed. Since growth measurements are continuous variables, the Kruskal-Wallis H test will be employed to compare the relationship between lumbar VNC diameters, femur bicondylar length, and tibia maximum length with LEH, CO, and PH. The Kruskal-Wallis H is the nonparametric equivalent to the parametric analysis of variance (ANOVA) test. Unlike the parametric test, the Kruskal-Wallis H test does not assume a normal distribution or that sample variances are homogenous and is therefore preferable for archaeological samples. The Bonferroni correction will be applied to significant ($p \leq 0.05$) Kruskal-Wallis H results to control for potential Type I errors, or the increased probability of erroneously rejecting the null hypothesis in error due to a large number of tests on a single dataset.

5.10.2 Research Question 2: Diet, Weaning and Long-Term Outcomes of Stress

To examine dental health, the frequency of dental caries, periapical abscess and AMTL will be compared between sites using Chi-squared or Fisher's Exact tests. Calculus and wear scores will be compared between sites using the Mann-Whitney U test to examine the data distribution between the two sites. Any significant differences will be broken down by true prevalence rate (TPR), or the total number of diseased teeth divided by the total number of teeth present, so that they may be compared with other sites in the region.

Isotopic values for bone and bulk dental collagen will be compared between sites using the nonparametric Mann-Whitney U test. Intra-tooth enamel sample isotope values will be compared by median sample age between sites using the nonparametric Kruskal-Wallis H. Samples will be assigned to an age category (see Table 5-10) and then the changes between age categories will also be compared using the nonparametric analysis of variance.

Table 5-10. Sample age categories and sample sources.

Category Age Range	Sample Material
< 1 year	Dental enamel
1 – 2 years	Dental enamel
2 – 3 years	Dental enamel
3 – 4 years	Dental enamel
4 – 5 years	Dental enamel
5 – 6 years	Dental enamel
6 – 7 years	Dental enamel
7 – 8 years	Dental enamel
Age-at-death	Bone apatite

The long-term impacts of stress will be examined by comparing the frequency LEH before and after weaning as well as by age and sex using the Kruskal-Wallis H test. The frequency of LEH between populations will be compared by age group and biological sex using Chi-squared tests. LEH occurrence will be compared with the occurrence of other stress indicators (CO and PH) and age-at-death using Fisher's exact tests. Continuous measures of growth (FBL, TTL, and lumbar

VNC diameters) will be compared with LEH occurrence pre-and post-weaning using the Kruskal-Wallis H. The Bonferroni correction will be applied to any to significant ($p \leq 0.05$) Kruskal-Wallis H results and noted in the data tables.

5.10.3 Research Question 3: Activity

Aggregate scores for upper and lower muscles will be averaged and ranked then compared between groups using an analysis of variance test (ANOVA) to determine if there is a similar pattern in the development of specific MSMs between the two sites. Additionally, an aggregate MSM score will be calculated for each individual and compared between each population's adult age groups and biological sex category using the Mann-Whitney U and Independent Samples Median tests.

6.0 RESULTS AND DISCUSSION: POPULATION DEMOGRAPHICS & PRESERVATION

6.1 POPULATION DEMOGRAPHICS

A total of 143 individuals were assessed for biological sex and age-at-death. The individual demographic results for Khirbet Qazone and Zabayir are appended (Table A-1 and Table A-2, respectively). Skeletal remains from 46 individuals—32 adults and 14 subadults—were examined from Khirbet Qazone and 97 individuals were present from Zabayir, including 79 adults and 18 subadults (Table 6-1). Of the adults, 27 individuals from Khirbet Qazone and 50 individuals from Zabayir were identified as male or female. The demographic distribution of the skeletal population from each site is calculated by age (Figure 6-1; Figure 6-2; and Table 6-1) and by age and sex for adults (Figure 6-3; Figure 6-4; and Table 6-1).

Table 6-1. Demographic summary of individuals from Khirbet Qazone and Zabayir.

Cohort	Description	Khirbet Qazone								Zabayir							
		Female		Male		Unknown		Total		Female		Male		Unknown		Total	
		n	%	n	%	n	%	N	%	n	%	n	%	n	%	N	%
0	Indeterminate Subadult	—	—	—	—	0	0.00	0	0.00	—	—	—	—	2	4.26	2	2.06
1	Fetus	—	—	—	—	1	5.26	1	2.17	—	—	—	—	0	0.00	0	0.00
2	Neonate	—	—	—	—	0	0.00	0	0.00	—	—	—	—	0	0.00	0	0.00
3	Toddler	—	—	—	—	4	21.05	4	8.70	—	—	—	—	2	4.26	2	2.06
4	Early Child	—	—	—	—	4	21.05	4	8.70	—	—	—	—	5	10.64	5	5.15
5	Late Child	—	—	—	—	5	26.32	5	10.87	—	—	—	—	5	10.64	5	5.15
6	Adolescent	—	—	—	—	0	0.00	0	0.00	—	—	—	—	4	8.51	4	4.12
7	Youth	0	0.00	1	8.33	1	5.26	2	4.35	1	3.57	1	4.55	1	2.13	3	3.09
8	Early Adult	0	0.00	2	16.67	0	0.00	2	4.35	2	7.14	3	13.64	0	0.00	5	5.15
9	Young Adult	3	20.00	1	8.33	1	5.26	5	10.87	8	28.57	5	22.73	4	8.51	17	17.53
10	Middle Adult	9	60.00	5	41.67	1	5.26	15	32.61	3	10.71	4	18.18	3	6.38	10	10.31
11	Old Adult	2	13.33	2	16.67	0	0.00	4	8.70	8	28.57	2	9.09	1	2.13	11	11.34
12	Indeterminate Adult	1	6.67	1	8.33	2	10.53	4	8.70	6	21.43	7	31.82	20	42.55	33	34.02
Total		15	100.00	12	100.00	19	100.00	46	100.02	28	100.00	22	100.00	47	100.00	97	100.00

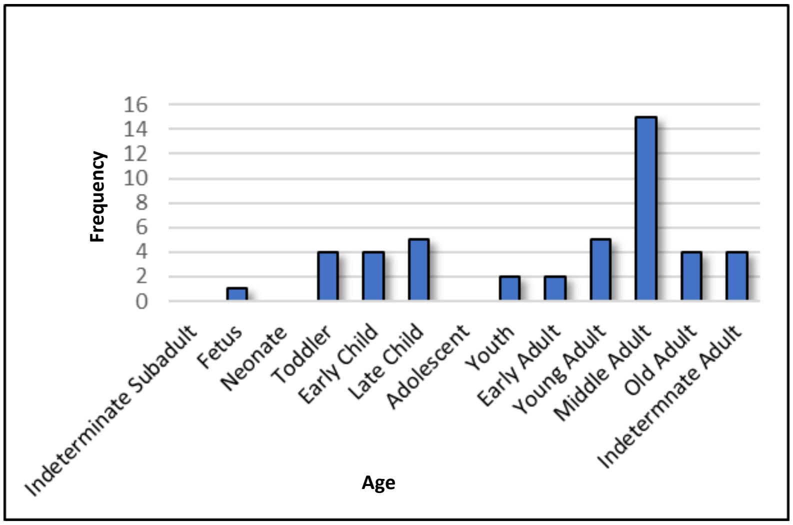

Figure 6-1. Khirbet Qazone sample distribution by age.

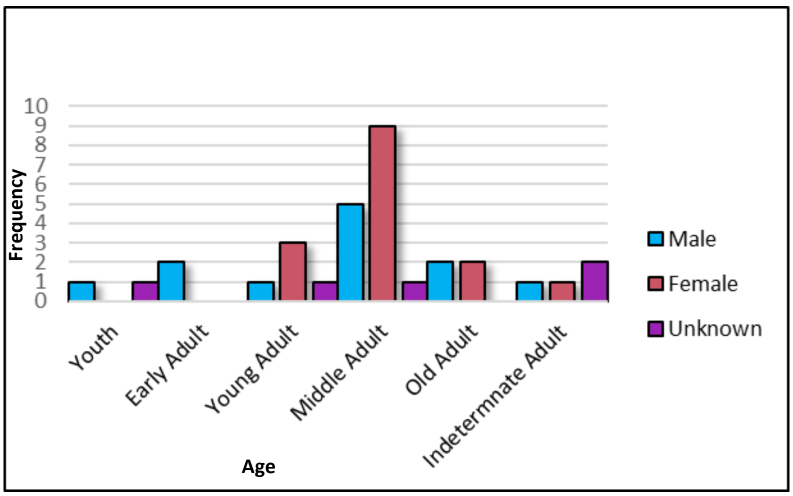

Figure 6-2. Khirbet Qazone adult population distribution by age/sex.

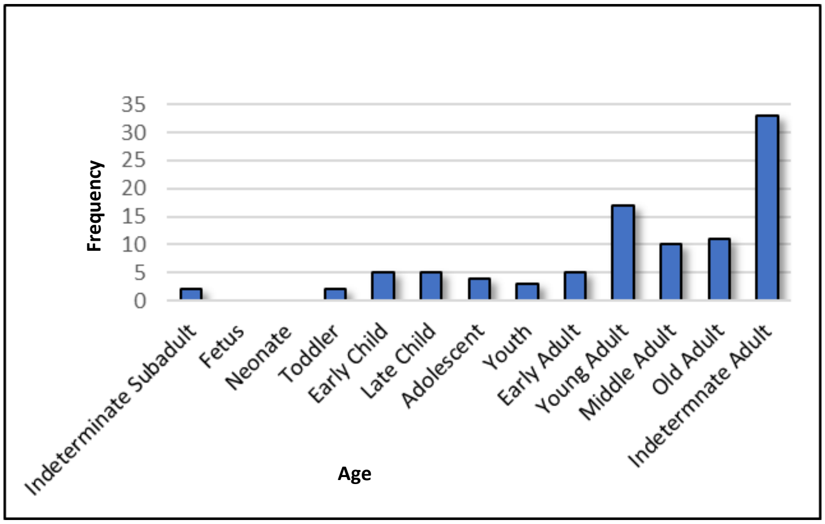

Figure 6-3. Zabayir sample distribution by age.

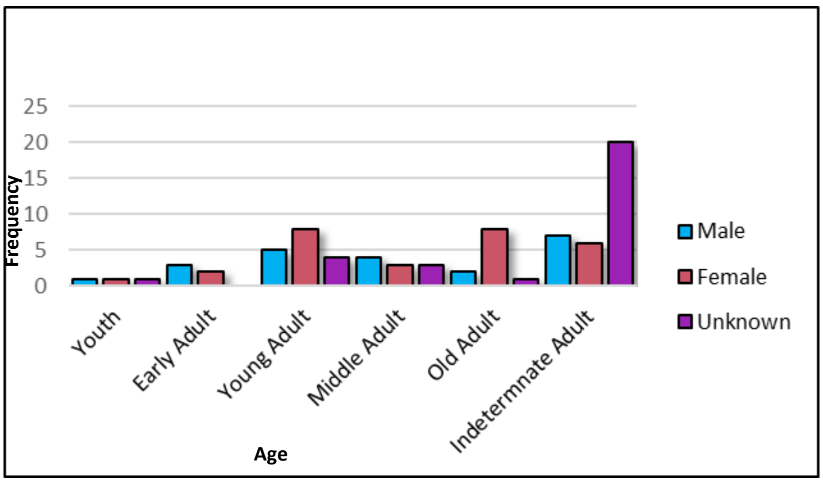

Figure 6-4. Zabayir adult population distribution by age/sex.

A majority of the Khirbet Qazone sample (n=15) died in middle adulthood (35-50 years). While the adult age distribution follows a relatively normal attritional pattern, the sample demonstrates a distinctive increase in late childhood (n=5) deaths. Neonates are decidedly underrepresented within the cemetery. While preservation at Khirbet Qazone was relatively good (see Section 1.2), neonate remains are fragile and easily damaged through taphonomy, generally resulting in decreased preservation within archaeological samples (Bello et al. 2006, Stodder 2018, Saunders 1992, Guy, Masset, and Baud 1997). However, the complete absence of any neonate remains suggests that these individuals may have received special treatment within the burial context and were buried elsewhere within the cemetery or at another location. Only a portion of the cemetery was excavated, and it is possible that infants were buried in a special location within the unexcavated portions of the cemetery (Politis 1998, Politis, Kelly, and Usman 2005). Infant remains may have also been deposited in shallow and easily eroded graves, although no examples of this were reported from the excavated contexts. Children and infants are reported for several Nabatean/Roman sites; however, age distribution is not always discussed (Perry and Jones 2008, Perry 2002a, b, Parker and Perry 2013, Delhopital 2010, Cheyney, Brashler, Boersma, Contant, DeWall, Lane, Smalligan, and Vandern Berg 2009). Two Decapolis sites—Pella and Abila—reported underrepresentation of infants and children in cemetery contexts (Bourke 1992, Kick 1985). While children were represented in later Byzantine burials at Aila, the remains of an infant found within the mud-mortar surrounding a pithos installed in a Roman building have prompted questions about the role of young children in society (Retzleff 2003). Adult females experienced greater risk of death than males from young through middle adulthood, which may in part be a result of difficulties related to pregnancy and childbirth. K8.1, a female aged 40-49 years at death, was buried with a fetus, which indicates that pregnancy extended into middle adulthood for some females.

The Zabayir sample also demonstrates an unusual absence of neonates and few toddlers (n=2) compared to individuals who died during early childhood (n=5), late childhood (n=5), and adolescence (n=4). Since Zabayir has been identified as a semi-nomadic population it is possible that many neonates were buried in a separate location or were buried in a special location away from the main cemetery. Nomadic mortuary culture is geospatially complex and may utilize existing structures along routes or multiple cemeteries that may or may not fluctuate seasonally, which could account for some variation in burial contexts (Ibrahim and Gordon 1987). Given the difficulties experienced during the transportation of the collection to the Smithsonian Museum, it is also possible that many of the youngest individuals were not available for inclusion in this study; however, few individuals were also reported in these age groups during preliminary data collection by Frohlich and Rolston in Jordan so this possibility is less likely (Ibrahim and Gordon 1987). As aforementioned, the underrepresentation of neonates is common among contemporaneous sedentary populations in the region and may demonstrate a broader cultural view of neonatal identity.

The adult population presents an early attritional pattern with deaths increasing from early through young adulthood. Young adult females may have experienced a greater risk of death due to pregnancy and childbirth. However, the largest number of age identifiable males also died during young adulthood (n=5), which may indicate male participation in especially high-risk behavior during this phase of life. Additionally, males and females were also likely engaged in activities related to animal husbandry, which would increase their exposure to zoonoses that could impact bone tissues (Barnes 2005). Perry (2002a) explored the possibility of Roman military conscription for this population. While she was not able to directly verify participation in the military, she cited femoral buttressing and vertebral pathology as possible evidence for horseback riding, perhaps associated with a militant lifestyle, and noted the presence of Roman grave goods that at least support trade between Zabayir and Roman communities. Ethnographic research suggests that pastoral life expectancy even in modern communities is also relatively short (Mace and Sear 1996, Walker et al. 2006) suggesting that the observed distribution may be the result of an overall shorter life history.

Alternatively, a sudden increase in stress or disease have been posited to produce similar catastrophic profiles (Gowland and Chamberlain 2005), although no indication of infectious disease was noted in the current examination. However, a spike in deaths may also suggest a relatively acute disease process or stress event that claimed those most susceptible leaving little osseous evidence (Wood et al. 1992). Finally, an increased number of early adult deaths may be correlated with stress indicator incidence earlier in life suggesting increased fragility due to early life stress (Armelagos et al. 2009).

The relatively large numbers of deaths during late childhood for Khirbet Qazone and Zabayir suggest that stress was equal to or greater for individuals following the first 6 years of life. High mortality rates among individuals in late childhood and adolescence has been attributed to work training, in areas such as animal husbandry, for individuals from Tell er-Rumeith based upon ethnographic accounts of labor for near eastern pastoral nomadic populations (Judd, Binkoski, and Seltzer 2015). Close association with livestock can also increase risk of infection for zoonoses such as tuberculosis and brucellosis (Barnes 2005).

6.2 SKELETAL COMPLETENESS

Generally, skeletons from Khirbet Qazone were well-preserved and complete, although two commingled graves, R1 and R2, offered exceptions. Completeness ranged from 3.46 to 100 % complete with a mean value of 67.62% (Table A-3 and Table A-4). Compared to the Khirbet Qazone skeletons, the Zabayir skeletal material was relatively poorly preserved, fragmented, and incomplete with completeness scores ranging from 3.39 to 61.02% with a mean value of 24.15% (Table A-5 and Table A-6). Multiple contexts at Zabayir were commingled and diagnostic elements from these burials could not always be attributed to a single individual. Therefore, only 78 individuals from the site could be score for completeness. In instances where completeness scores could not be fully assessed, those burials were excluded from individualized assessments of activity or analyses pertaining to the relationship between osteological pathologies and growth outcomes. Therefore, the total number of individuals included in each analysis is detailed in the results section for that data set.

The completeness distributions were compared using the Mann-Whitney U test which confirmed that the samples are significantly different at a 95% confidence interval, suggesting some bias between the completeness of the two samples (Table 6-2). While no corrections could be made for this bias, they are considered in the results of the study.

Table 6-2. Mann-Whitney U comparison of completeness scores between sites.

N	Test statistic	Significance value
124	551	0.000[1]

[1]Significance at $p \leq 0.05$

7.0 RESULTS AND DISCUSSION: STRESS

The non-specific stress indicators LEH, CO, and PH were evaluated against mortality and growth to determine if stress demonstrated long term effects within the sample populations. Non-specific stress indicators were relatively high within the Khirbet Qazone and Zabayir populations (Table 7-1). The occurrence of LEH was significantly higher among individuals from Khirbet Qazone than Zabayir (Table 7-2). Similarly, CO and PH were more frequent within the Khirbet Qazone sample than Zabayir, although these relationships were not statistically significant (Table 7-2).

Table 7-1. Non-specific stress incidence by site.

Site	LEH			CO			PH		
	Total	**LEH**	**%**	**Total**	**CO**	**%**	**Total**	**PH**	**%**
Khirbet Qazone	28	22	78.57	38	20	52.63	34	4	11.76
Zabayir	19	8	42.11	27	12	44.44	29	1	3.45
Totals	47	30	63.83	65	32	49.23	63	5	7.94

Note: total=number of individuals observed

Table 7-2. Chi-squared[1] comparison of non-specific stress indicators between sites.

Comparison	Test Statistic	df	p-value
LEH	6.520	1	0.011*
CO	0.423	1	0.515
PH	1.402	1	0.366

[1]Two-sided
*=significance at $p \leq 0.05$

The severity of each non-specific stress condition was also evaluated in low and high stress categories (Table 7-3). Proportionally, the severity of LEH, CO, and PH within the two populations did not differ significantly based on a two-sided Fisher's exact test (Table 7-4). Severe cases of CO and PH were defined as those with scores of 6.1.3 or 6.1.4 meaning that porosity had coalesced and/or cortical thickening was observed.

Table 7-3. Criteria for establishing non-specific severity categories.

Stress Condition	Severity	
	Low	**High**
LEH	≤5 LEH/individual	>5 LEH/individual
CO	Score <6.1.3	Score ≥6.1.3
PH	Score <6.1.3	Score ≥6.1.3

Table 7-4. Non-specific stress incidence by site and severity.

Stress Condition	Khirbet Qazone		Zabayir		p-value[1]
	n	**%**	**n**	**%**	
LEH Low	9	40.90	3	37.50	1.000
LEH High	13	59.10	5	62.50	
Total	22	100.00	8	100.00	
CO Low	5	25.00	6	50.00	0.250
CO High	15	75.00	6	50.00	
Total	20	100.00	12	100.00	
PH Low	3	75.00	1	100.00	1.000
PH High	1	25.00	0	0.00	
Total	4	100.00	1	100.00	

[1]p-value derived from a two-sided Fisher's exact test. Significance level = $p \leq 0.05$

Stress indicator co-occurrence was only observed at Khirbet Qazone. Of the individuals for which all three non-specific stress indicators could be scored, eight from Khirbet Qazone presented with more than one condition (Table 7-5). Only one of the 23 Khirbet Qazone individuals with observable bones for the three non-specific stress indicators exhibited no stress indicators; a majority demonstrated one stress indicator. Only 26.09% of the population exhibited two non-specific stress indicators, while all three indicators were observed for 8.69%. Fewer individuals from Zabayir could be examined for all three stress indicators, however, a majority of those (66.67%) had only one of the three stress indicators. The remaining 33.33% showed no stress indicators.

Table 7-5. Co-occurrence of non-specific stress indicators within individuals by site.

Stress Indicator Presentation	Site				Total	
	Khirbet Qazone		Zabayir			
	n	%	n	%	n	%
No Indicators	1	4.35	3	33.33	4	12.50
1 Indicator	14	60.87	6	66.67	20	62.50
2 Indicator	6	26.09	0	0.00	6	18.75
3 Indicator	2	8.69	0	0.00	2	6.25
Total	23	100.00	9	100.00	32	100.00

7.1 MORTALITY

The impact of LEH, CO, and PH on mortality was explored to determine if any stress indicators were correlated with age-at-death.

7.1.1 Mortality & LEH

7.1.1.1 Khirbet Qazone

Twenty-eight individuals were examined for LEH and 22 (78.57%) demonstrated a hypoplastic dental response (Table 7-1). The number of LEHs observed per individual ranged from three hypoplastic indicators up to 24. LEH occurrence was spread widely across age cohorts and the relationship between age-at-death and LEH occurrence was not statistically significant based on a two-sided Fisher's exact test (Figure 7-1; Table 7-6; Table 7-10). The number of LEHs an individual experienced also did not significantly impact age-at-death based on a Kruskal-Wallis H test (Table 7-7).

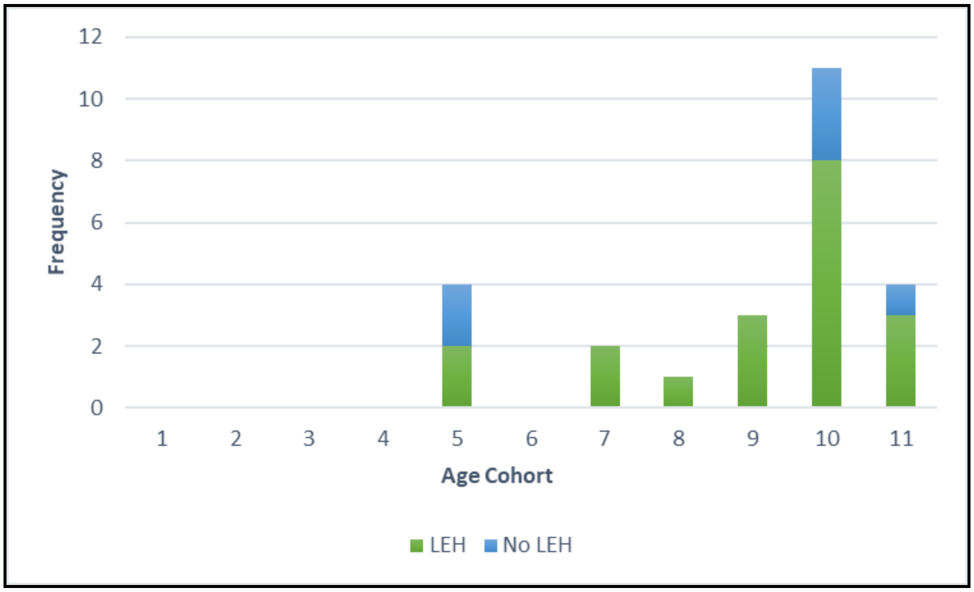

Figure 7-1. Khirbet Qazone LEH distribution by age cohort.

Table 7-6. Khirbet Qazone LEH and age-at-death Fisher's exact test comparison.

Comparison	Test Statistic	p-value
LEH & Age Cohort	3.176	0.866

Significance level = $p \leq 0.05$

Table 7-7. Khirbet Qazone LEH number and age-at-death Kruskal-Wallis H comparison.

Comparison	Test Statistic	df	p-value
LEH & Age Cohort	4.752	5	0.447

Significance level = $p \leq 0.05$

7.1.1.2 Zabayir

Of the 19 individuals examined, nine (47.37%) had at least one instance of LEH (Table 7-1). The number of LEHs observed per individual ranged from 2 to 11. Most instances of LEH demonstrated in the Zabayir population appear to correlate with an earlier age-at-death with no observed cases of LEH in age cohorts 10 and 11, although the relationship is not significant based on a two-sided Fisher's exact test (Figure 7-2; Table 7-8; Table 7-10). Based on a Kruskal-Wallis

H comparison with age-at-death the number of LEHs was also not significant across age cohorts (Table 7-9).

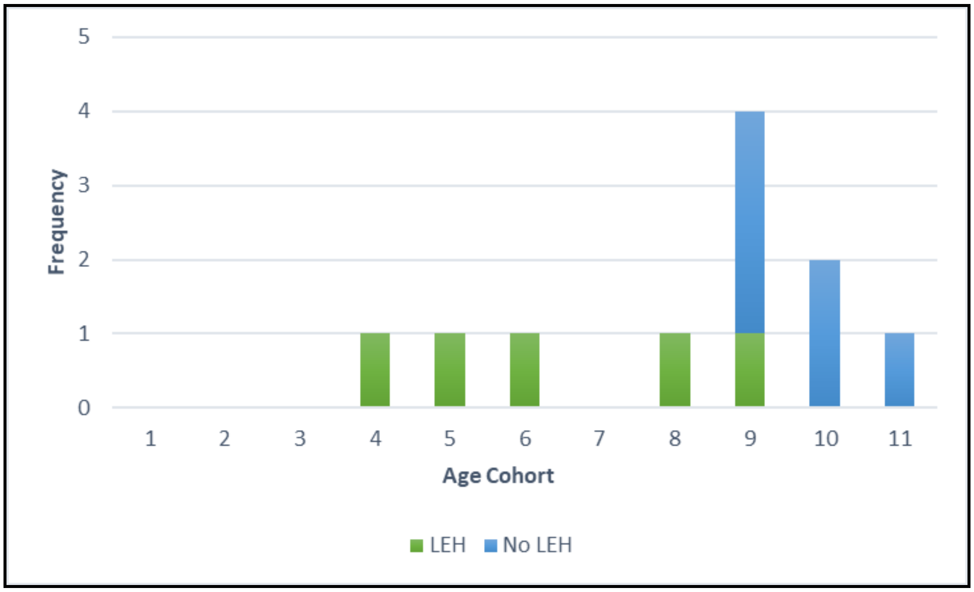

Figure 7-2. Zabayir LEH distribution by age cohort.

Table 7-8. Zabayir LEH and age-at-death Fisher's exact test comparison.

Comparison	Test Statistic	p-value
LEH & Age Cohort	7.772	0.154

Significance level = $p \leq 0.05$

Table 7-9. Zabayir LEH number and age-at-death Kruskal-Wallis H comparison.

Comparison	Test Statistic	df	p-value
LEH & Age Cohort	10.191	6	0.117

Significance level = $p \leq 0.05$

Table 7-10. LEH incidence by site.

Age Cohort	KHIRBET QAZONE							ZABAYIR						
	No LEH			LEH			Total	No LEH			LEH			Total
	Female	Male	Unknown	Female	Male	Unknown		Female	Male	Unknown	Female	Male	Unknown	
0	—	—	—	—	—	—	**—**	—	—	—	—	—	—	**—**
1	—	—	—	—	—	—	**—**	—	—	—	—	—	—	**—**
2	—	—	—	—	—	—	**—**	—	—	—	—	—	—	**—**
3	—	—	—	—	—	—	**—**	—	—	—	—	—	—	**—**
4	—	—	—	—	—	—	**—**	—	—	—	—	—	1	**1**
5	—	—	2	—	—	2	**4**	—	—	—	—	—	1	**1**
6	—	—	—	—	—	—	**—**	—	—	—	—	—	1	**1**
7	—	—	—	—	1	1	**2**	—	—	—	—	—	—	**—**
8	—	—	—	—	1	—	**1**	—	—	—	—	1	—	**1**
9	—	—	—	1	1	1	**3**	—	1	1	2		1	**5**
10	1	—	—	5	4	1	**11**	—	2	—	—	—	—	**2**
11	—	1		2	1	—	**4**	1	—	—	—	—	—	**1**
12	—	—	—	1	1	1	**3**	2	—	1	—	3	1	**7**
Total	**1**	**1**	**2**	**9**	**9**	**6**	**28**	**3**	**3**	**2**	**2**	**4**	**5**	**19**

7.1.2 Mortality & CO

7.1.2.1 Khirbet Qazone

Of the 38 individuals examined for CO, 20 (52.63%) exhibited some degree of osseous change in the superior orbit (Table 7-1). Cases of CO were widely distributed across age groups; however, 80% of individuals aged 12 years or younger exhibited some evidence for CO (Figure 7-3; Table 7-11). Indeed, of those with CO, 45% were aged 12 years or younger. Over 86% of individuals who exhibited no indication of CO were middle or older adults suggesting that CO may index fragility within the population. A two-sided Fisher's exact comparison between age cohort distributions for individuals with and without CO revealed a relationship at the 90% confidence interval (Table 7-12). Although this is not significant, CO appears to represent a stress event(s) that increased an individual's risk of mortality. Most cases of CO were severe (scored as either 6.1.3 or 6.1.4) for the Khirbet Qazone population (Figure 7-4). When CO severity is defined as only those individuals with supraorbital porosity scores of 6.1.3 or 6.1.4 the relationship between CO and age is significant at a 95% confidence interval (Table 7-12). CO severity, including all scores, was also significantly correlated with age-at-death at a 95% confidence interval.

Incidence of active CO was higher in individuals under 12 years of age, although at least three adults also experienced stress resulting in CO at the time of death (Figure 7-5). Most adults who exhibited CO had healed lesions, although mixed healed and active lesions among individuals in age cohorts 5 and 7 suggests that CO producing events were repetitive events for some individuals. This suggests that while some individuals survived early life stressors, they were not protected from stress events in later childhood and adolescence.

Table 7-11. CO incidence by site.

Age Cohort	KHIRBET QAZONE							ZABAYIR						
	No CO			CO			Total	No CO			CO			Total
	Female	Male	Unknown	Female	Male	Unknown		Female	Male	Unknown	Female	Male	Unknown	
0	—	—	0	—	—	0	**0**	—	—	—	—	—	—	—
1	—	—	0	—	—	0	**0**	—	—	—	—	—	—	—
2	—	—	0	—	—	0	**0**	—	—	—	—	—	—	—
3	—	—	1	—	—	3	**4**	—	—	—	—	—	1	**1**
4	—	—	0	—	—	2	**2**	—	—	—	—	—	—	—
5	—	—	1	—	—	4	**5**	—	—	—	—	—	—	—
6	—	—	0	—	—	0	**0**	—	—	—	—	—	1	**1**
7	0	0	0	0	1	1	**2**	—	—	—	—	—	1	**1**
8	0	0	0	0	1	0	**1**	1	1	—	—	—	—	**2**
9	1	1	0	2	0	1	**5**	3	—	1	1	—	1	**6**
10	6	3	0	2	2	0	**13**	—	1	—	—	1	—	**2**
11	2	2	0	0	0	0	**4**	—	1	—	1	—	—	**2**
12	0	0	1	0	1	0	**2**	2	4	1	2	1	2	**12**
Total	**9**	**6**	**3**	**4**	**5**	**11**	**38**	**6**	**7**	**2**	**4**	**2**	**6**	**27**

Table 7-12. Khirbet Qazone CO and age-at-death comparison using Fisher's exact test.

Comparison	Test Statistic	p-value
CO/No Co & Age Cohort	12.758	0.061[1]
CO (Scores 6.1.3/6.1.4)/No CO & Age Cohort	16.555	0.006[2]
CO Severity & Age Cohort	21.777	0.045[2]

[1]Significance at $p \leq 0.1$
[2]Significance at $p \leq 0.05$

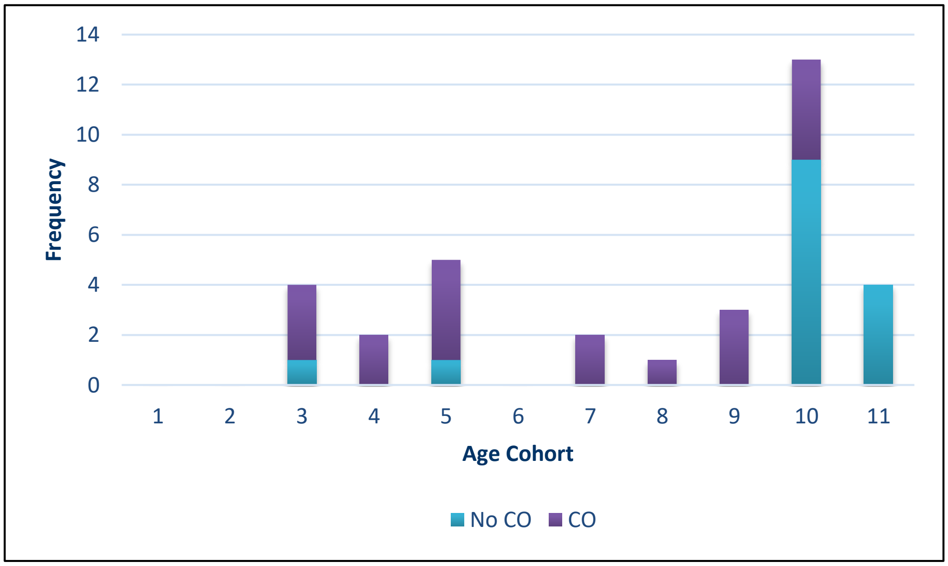

Figure 7-3. Khirbet Qazone distribution of CO by age cohort.

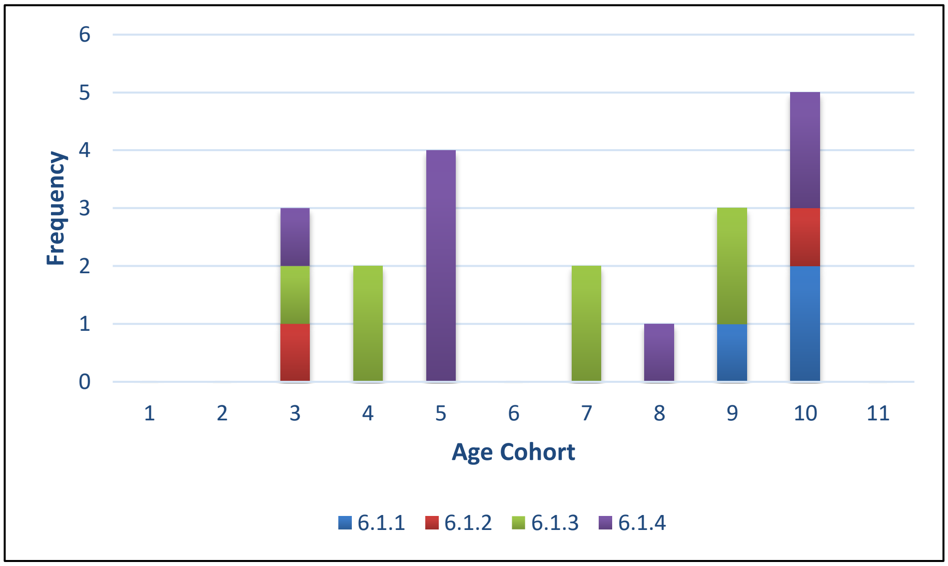

Figure 7-4. Khirbet Qazone CO severity by age cohort.

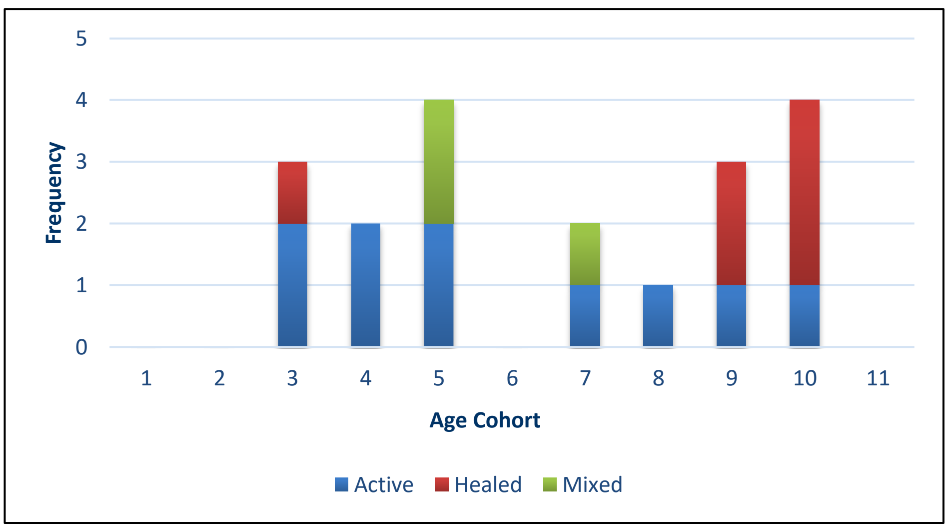

Figure 7-5. Khirbet Qazone CO activity by age cohort.

7.1.2.2 Zabayir

Of the 27 individuals examined for CO, 12 (44.44%) skeletons demonstrated evidence for osseous lesions in the superior orbit (Table 7-11). Unlike the Khirbet Qazone sample for which subadult skeletal preservation was relatively good, only two subadults in the Zabayir sample had well preserved orbits and both individuals demonstrated CO. Ten adults were also affected; however, apart from one case all showed evidence of lesion healing.

Like the Khirbet Qazone sample, CO is widely distributed across age groups (Figure 7-6). However, the small number of individuals available for examination in the youngest age cohorts means that the distribution of this data must be viewed with caution. It is revealing that all individuals who were examined for CO aged 20 years or younger at death exhibited evidence of the stress indicator. Unlike Khirbet Qazone, most individuals without CO died in the Early and Young Adult age cohorts, however, this also appears to be a function of the overall population distribution (Table 6-1).

Overall severity at Zabayir was less than at Khirbet Qazone (Figure 7-7). Comparison between individuals with and without CO across age categories found no significant difference based on a two-sided Fisher's exact test (Table 7-13). When CO was redefined as only cases scoring 6.1.3 and 6.1.4, the relationship between age-at-death and CO occurrence was still not considered significant. Similarly, severity was not significantly correlated with age-at-death. All individuals who experienced CO active at death died before 17 years of age, while all CO lesions observed on aged adults were healed at the time of death (Figure 7-8).

Table 7-13. Zabayir CO and age-at-death comparison using Fisher's exact test.

Comparison	Test Statistic	p-value
CO/No Co & Age Cohort	5.504	0.702
CO (Scores 6.1.3/6.1.4)/No CO & Age Cohort	5.152	0.857
CO Severity & Age Cohort	12.226	0.333

Significance level = $p \leq 0.05$

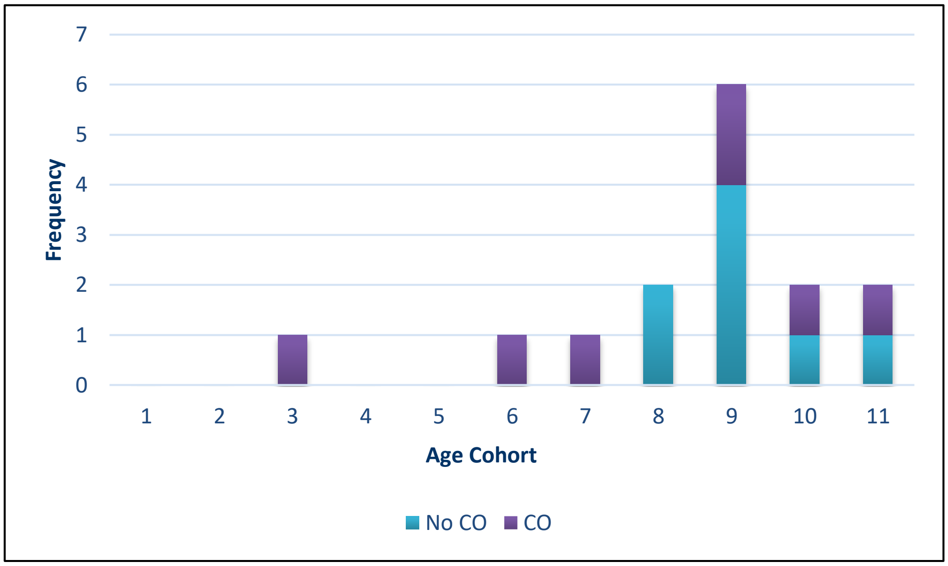

Figure 7-6. Zabayir distribution of CO by age cohort.

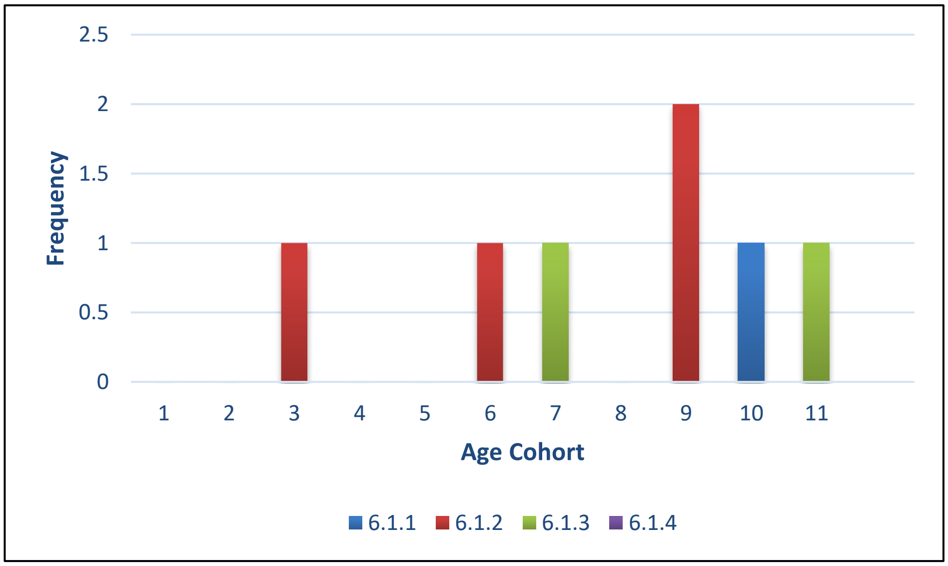

Figure 7-7. Zabayir CO severity by age cohort.

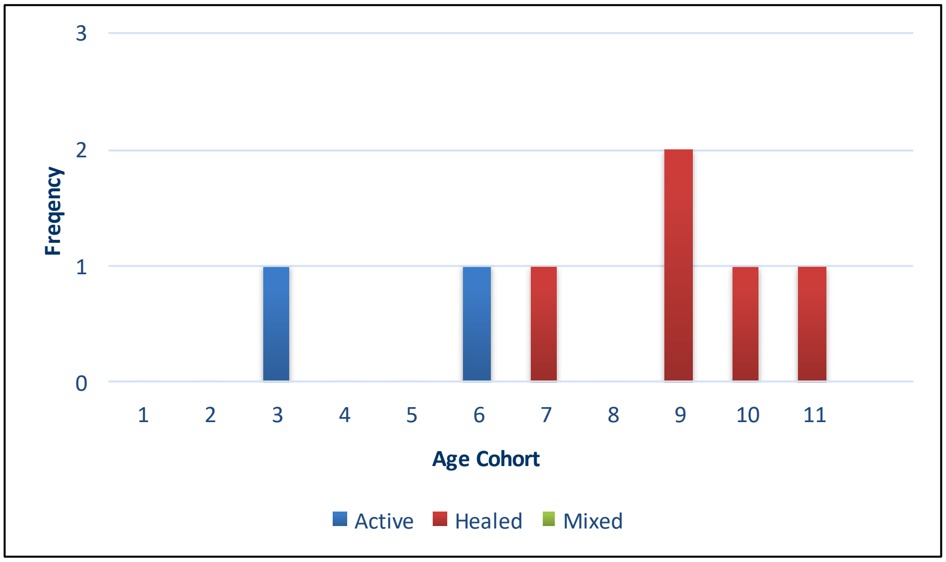

Figure 7-8. Zabayir CO activity by age cohort.

7.1.3 Mortality & PH

7.1.3.1 Khirbet Qazone

Thirty-four individuals were examined for cranial porosity and four (11.76%) cases were identified (Table 7-1; Table 7-15). Three of the four individuals with PH were adults; one case occurred in a 2-4-year-old (Figure 7-9). At Khirbet Qazone only one severe case of PH (6.1.3) was identified on Skeleton T2 (Figure 7-10). All observed PH lesions were active, although Skeleton T2 presented a mixed reaction in which active lesions were recorded alongside healed lesions. At Khirbet Qazone, PH was not significantly related to age-at-death (Table 7-14).

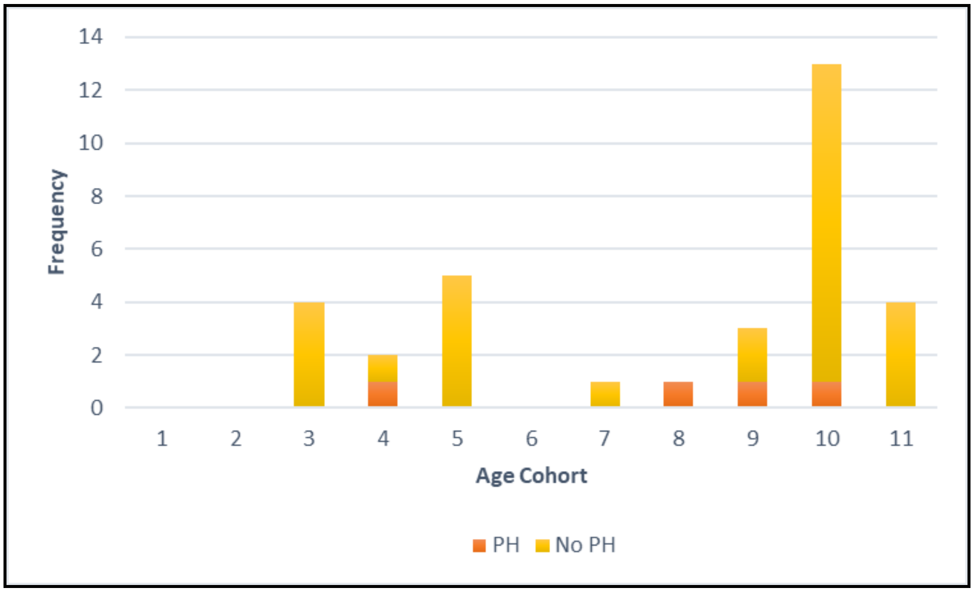

Figure 7-9. Khirbet Qazone PH distribution by age cohort.

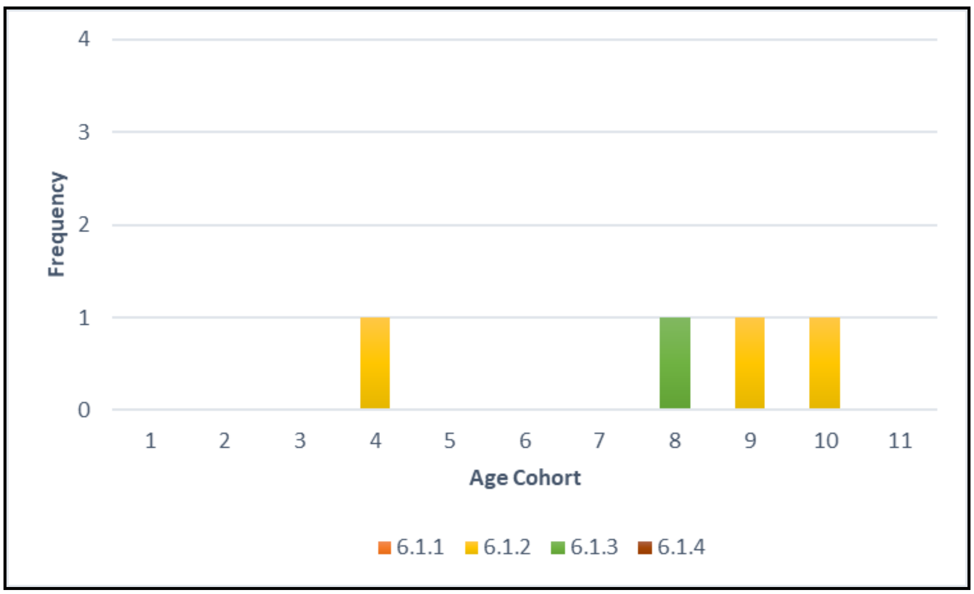

Figure 7-10. Khirbet Qazone PH severity distribution by age cohort.

Table 7-14. Khirbet Qazone PH and age-at-death comparison using Fisher's exact test.

Comparison	Test Statistic	p-value
PH/No CO & Age Cohort	10.982	0.136
PH (Scores 6.1.3/6.1.4)/No PH & Age Cohort	15.587	0.088[1]
PH Severity & Age Cohort	3.6678	1.00

[1]Significance at $p \leq 0.10$

7.1.3.2 Zabayir

Of the 29 Zabayir individuals, only one (3.45%), Skeleton AP-7/3, exhibited evidence of PH cranial porosity (Table 7-1; Table 7-15). The lesions observed were healed and barely discernable (6.1.1). Since the single case observed was low severity and occurred on an adult individual for which age could not be defined more precisely and sex was unknown, further statistical analyses were not completed.

Table 7-15. PH incidence by site.

Age Cohort	KHIRBET QAZONE							ZABAYIR						
	No PH			PH			Total	No PH			PH			Total
	Female	Male	Unknown	Female	Male	Unknown		Female	Male	Unknown	Female	Male	Unknown	
0	—	—	—	—	—	—	**0**	—	—	—	—	—	—	**0**
1	—	—	—	—	—	—	**1**	—	—	—	—	—	—	**0**
2	—	—	—	—	—	—	**0**	—	—	—	—	—	—	**0**
3	—	—	4	—	—	0	**4**	—	—	—	—	—	—	**0**
4	—	—	1	—	—	1	**2**	—	—	1	—	—	—	**1**
5	—	—	5	—	—	—	**5**	—	—	—	—	—	—	**0**
6	—	—	—	—	—	—	**0**	—	—	—	—	—	—	**0**
7	—	1	—	—	—	—	**1**	1	—	1	—	—	—	**2**
8	—	—	—	—	1	—	**1**	1	1	1	—	—	—	**3**
9	1	1	—	—	—	1	**3**	3	1	1	—	—	—	**5**
10	7	5	—	1	—	—	**13**	1	3	—	—	—	—	**4**
11	2	2	—	—	—	—	**4**	2	1	—	—	—	—	**3**
12	1	—	—	—	—	—	**1**	3	4	3	—	—	1	**11**
Total	**11**	**9**	**10**	**1**	**1**	**2**	**34**	**11**	**10**	**7**	**0**	**0**	**1**	**29**

7.2 GROWTH & STRESS

The growth impact of stress was assessed using VNC anterior-posterior (A-P) and medial-lateral (M-L) diameters along with femoral bicondylar length (FBL) and total tibia length (TTL) for three non-metric stress indicators—LEH, CO, and PH. The number of individuals for which growth measures could be obtained and for which the appropriate skeletal elements to assess LEH, CO, or PH were available varied between the two sites due to preservation and are reported in Table 7-16. At both sites, lumbar vertebrae were the most widely preserved element for growth measurement. Seventeen individuals from Khirbet Qazone and four skeletons from Zabayir with lumbar vertebrae showed at least one non-specific stress indicator. The specific number of individuals that exhibited each pathological condition for which growth measures were available are listed in Table 7-17. Several individuals had lesions from more than one non-specific stress indicator (Table 7-18). However, the co-occurrence of multiple stress indicators did not significantly impact growth based on Kruskal-Wallis H comparisons for individuals who could be scored for all three stress conditions and growth measures (Table 7-19; Table 7-20). This result implies that some stress events may have been more impactful than others, which is confirmed by the individual stress indicator comparisons demonstrating the relative impacts of LEH, CO, and PH.

Table 7-16. Number of skeletons observed by growth measure and stress condition.

Growth Measure	Khirbet Qazone				Zabayir			
	N	LEH	CO	PH	N	LEH	CO	PH
VNC	22	18	20	19	36	9	13	15
FBL	17	12	16	15	20	1	5	5
TTL	17	12	16	15	18	4	5	9

Table 7-17. Stress indicator incidence by growth measurement category.

Site	Growth Measures	Stress Indicator											
		LEH		No LEH		CO		No CO		PH		No PH	
		n	%	n	%	n	%	n	%	n	%	n	%
Khirbet Qazone	VNC	14	77.78	4	22.22	9	45.00	11	55.00	3	15.79	16	84.21
	FBL	10	83.33	2	16.67	4	25.00	12	75.00	1	6.67	14	93.33
	TTL	10	83.33	2	16.67	4	25.00	12	75.00	1	7.14	13	92.86
Zabayir	VNC	3	33.33	6	66.67	5	38.46	8	61.54	0	0.00	15	100.00
	FBL	0	0.00	1	100.00	1	20.00	4	80.00	0	0.00	5	100.00
	TTL	0	0.00	4	100.00	2	40.00	3	60.00	0	0.00	9	100.00

Table 7-18. Non-specific stress indicator comorbidity observed by growth measures.

Site	Comorbidity of non-specific stress indicators	Growth Measure					
		VNC		FBL		TTL	
		n	%	n	%	n	%
Khirbet Qazone	No Indicators	1	5.56	1	8.33	1	8.33
	1 Indicator	11	61.11	9	75.00	9	75.00
	2 Indicators	4	22.22	2	16.67	2	16.67
	3 Indicators	2	11.11	0	0.00	0	0.00
Site Total		18	100.00	12	100.00	12	100.00
Zabayir	No Indicators	2	33.330.00	1	1000.00	0	0.00
	1 Indicator	4	66.6750.00	0	0.00	0	
	2 Indicators	0	0.00	0	0.00	2	100.00
	3 Indicators	0	0.00	0	0.00	0	0.00
Site Total		6	100.00	1	100.00	2	100.00

Table 7-19. Kruskal-Wallis H test comparison of VNC growth by number of stress indicators.

VNC	Khirbet Qazone			Zabayir		
	Test Stat.	df	p-value	Test Stat.	df	p-value
L1 AP	1.564	3	0.668	1.000	1	0.317
L1 ML	1.406	3	0.704	1.000	1	0.317
L2 AP	1.785	3	0.618	1.000	1	0.317
L2 ML	2.250	3	0.522	1.000	1	0.317
L3 AP	1.689	3	0.639	1.500	1	0.221
L3 ML	2.363	3	0.501	1.500	1	0.221
L4 AP	1.061	3	0.786	1.000	1	0.317
L4 ML	1.347	3	0.718	1.000	1	0.317
L5 AP	1.069	3	0.785	1.000	1	0.221
L5 ML	0.937	3	0.816	1.000	1	0.221

Significance level = $p \leq 0.05$

Table 7-20. Kruskal-Wallis H test comparison of long bone growth by number of stress indicators.

Long Bone Measurement	Khirbet Qazone			Zabayir		
	Test Stat.	df	p-value	Test Stat.	df	p-value
FBL	0.021	2	0.989	—	—	—
TTL	0.265	2	0.876	1.500	1	0.221

7.2.1 Growth & Stress: VNC Diameter

The number of individuals for which LEH was evaluated against VNC diameter varied by measurement (Table 7-21). VNC diameters did not differ significantly based upon the presence or absence of LEH at either site (Table 7-21). At Khirbet Qazone, individuals with CO lesions exhibited significantly smaller L3 ML and L5 ML diameters at a 95% confidence interval (Table 7-22). VNC measurements did not differ for individuals with PH at Khirbet Qazone (Table 7-23). Skeletons AP-7/1, AP-7/2, and AP 7/3 were commingled and could not be completely separated or evaluated for completeness and crania could not be confidently reassociated with post-cranial elements for VNC measurements.

Table 7-21. VNC diameter Kruskal-Wallis H comparisons by site for LEH.

VNC	LEH	Khirbet Qazone				Zabayir			
		n	Test Stat.	df	p-value	n	Test Stat.	df	p-value
L1 AP	No LEH	4	0.132	1	0.716	4	—	—	—
	LEH	12				0			
L1 ML	No LEH	4	0.298	1	0.585	4	—	—	—
	LEH	12				0			
L2 AP	No LEH	3	2.083	1	0.149	4	0.500	1	0.480
	LEH	12				1			
L2 ML	No LEH	3	0.521	1	0.470	4	2.000	1	0.157
	LEH	12				1			
L3 AP	No LEH	4	1.705	1	0.192	3	1.800	1	0.180
	LEH	11				1			
L3 ML	No LEH	4	0.068	1	0.794	3	1.800	1	0.180
	LEH	11				1			
L4 AP	No LEH	4	1.846	1	0.174	4	2.000	1	0.157
	LEH	13				1			
L4 ML	No LEH	4	0.115	1	0.734	4	2.000	1	0.157
	LEH	13				1			
L5 AP	No LEH	3	0.750	1	0.386	4	0.214	1	0.643
	LEH	12				2			
L5 ML	No LEH	4	1.038	1	0.308	4	0.000	1	1.000
	LEH	13				2			

Significance level = $p \leq 0.05$

Table 7-22. VNC diameter Kruskal-Wallis H test comparisons by site for CO.

VNC	CO	Khirbet Qazone				Zabayir			
		n	Test Stat.	df	p-value[1]	n	Test Stat.	df	p-value[1]
L1 AP	No CO	9	2.965	1	0.170	2	0.333	1	1.000
	CO	9				3			
L1 ML	No CO	9	1.756	1	0.370	2	1.333	1	0.496
	CO	9				3			
L2 AP	No CO	10	0.238	1	1.00	2	3.000	1	0.166
	CO	7				3			
L2 ML	No CO	10	1.610	1	0.410	2	1.404	1	0.472
	CO	7				3			
L3 AP	No CO	9	1.33	1	0.496	4	0.214	1	1.000
	CO	8				2			
L3 ML	No CO	9	5.333	1	0.042*	4	0.214	1	1.000
	CO	8				2			
L4 AP	No CO	11	0.170	1	1.000	3	0.286	1	1.000
	CO	8				4			
L4 ML	No CO	11	1.970	1	0.320	3	0.500	1	0.960
	CO	8				4			
L5 AP	No CO	9	0.037	1	1.000	7	0.325	1	1.000
	CO	8				3			
L5 ML	No CO	10	5.607	1	0.036*	7	2.195	1	0.276
	CO	9				3			

[1]Bonferroni correction applied to all values.
*Significance at $p<0.05$.
**Significance at $p<0.10$.

Table 7-23. VNC diameter Kruskal-Wallis H comparisons by site for PH.

VNC	PH	Khirbet Qazone				Zabayir			
		N	Test Stat.	df	p-value	n	Test Stat.	df	p-value
L1 AP	No PH	15	0.056	1	0.859	—	—	—	—
	PH	3				—			
L1 ML	No PH	15	0.200	1	0.813	—	—	—	—
	PH	3				—			
L2 AP	No PH	15	2.689	1	0.101	—	—	—	—
	PH	2				—			
L2 ML	No PH	15	0.200	1	0.655	—	—	—	—
	PH	2				—			
L3 AP	No PH	15	0.800	1	0.371	—	—	—	—
	PH	2				—			
L3 ML	No PH	15	0.089	1	0.766	—	—	—	—
	PH	2				—			
L4 AP	No PH	17	0.635	1	0.425	—	—	—	—
	PH	2				—			
L4 ML	No PH	17	0.635	1	0.425	—	—	—	—
	PH	2				—			
L5 AP	No PH	16	1.921	1	0.166	—	—	—	—
	PH	3				—			
L5 ML	No PH	16	0.013	1	0.911	—	—	—	—
	PH	3				—			

Significance level = $p \leq 0.05$

7.2.2 Growth & Stress: Long Bone Lengths

The long bone lengths of individuals exhibiting different stress indicators were compared with those that did not demonstrate the stress marker. None of these relationships were considered significant for either site (Table 7-24). Not enough Zabayir skeletons could be assessed for long bone measurements and LEH precluding statistical comparisons. Only one case of PH (Skeleton AP-7/3) was identified from Zabayir, however, Skeletons AP-7/1, AP-7/2, and AP 7/3 were commingled, and the adult crania could not be confidently reassociated with all post-cranial elements for FBL and TTL measurement and comparison.

Table 7-24. Summary of Kruskal-Wallis test for long bone length comparison by stress group.

Long Bone Measurement	LEH	Khirbet Qazone				Zabayir			
		n	Test Stat.	df	p-value	n	Test Stat.	df	p-value
FBL	No LEH	2	0.576	2	0.750	1	—	—	—
	LEH	10				0			
TTL	No LEH	2	1.173	2	0.556	0	—	—	—
	LEH	10				4			
FBL	No CO	12	0.052	2	0.974	4	1.128	1	0.288
	CO	4				1			
TTL	No CO	12	0.170	2	0.919	3	2.995	2	0.224
	CO	4				2			
FBL	No PH	15	1.424	1	0.233	—	—	—	—
	PH	1				—			
TTL	No PH	14	2.625	1	0.105	—	—	—	—
	PH	1				—			

Significance level = p≤0.05

7.3 SUMMARY OF RESULTS AND HYPOTHESIS EVALUATION

7.3.1 Mortality and Stress

The hypothesis that the non-specific stress indicators LEH, CO, and PH will be more negatively correlated with age-at-death was partially supported. None of the osseous indicators of stress measured were significantly correlated with age-at death for the Zabayir population (Table 7-8; Table 7-9; and Table 7-13). However, the data for Khirbet Qazone were more complex. While LEH and PH did not correlate with mortality, CO was significantly related to age-at-death suggesting that CO markers indicate stress events that may have impacted long-term health outcomes for the affected individuals (Table 7-12). Indicators of stress, including LEH, CO, and PH, have been well-documented as a consequence of agricultural subsistence (Larsen 1995, Cohen and Armelagos 1984, Driscoll and Weaver 2000, Larsen 1981, Lukacs and Walimbe 1998). Severity of lesion expression at Khirbet Qazone may be involved in the relationship between lesion incidence and decreased age-at-death since cases of CO were generally more severe at Khirbet Qazone than Zabayir (Table 7-4). Severity of CO was also significantly related to age-at-death at Khirbet Qazone (Table 7-12). When PH is defined as only severe (6.1.3/6.1.4) lesions, PH also showed a relationship with age-at-death at the 90% confidence interval, but this is likely a result of the small sample size of cases with PH (n=1) under this condition (Table 7-14).

Although CO and PH exhibit similar lesions, their pathogenesis differs (Walker et al. 2009, Rivera and Lahr 2017, Rothschild 2012). Anemic PH is produced by several conditions that produce extensive cellular destruction and initiate marrow hyperplasia and diploic expansion in the cranium (Rothschild 2012). PH etiologies include hemolytic anemias, such as thalassemia and sickle cell anemia, conditions causing enzymatic deficiencies and abnormalities in cell membranes. Some nutritional anemias have also been implicated in the occurrence of skeletal PH lesions, including megaloblastic anemias, which are usually caused by vitamin B_{12} or vitamin B_9 (folic acid) deficiencies (Rothschild 2012, Walker et al. 2009). Of these conditions megaloblastic anemia caused by vitamin B_{12} deficiency is the most widespread and was proposed by Walker et al. (2009) as the most likely cause of PH lesions in archaeological populations. Assessing PH in archaeological populations may be further complicated by the co-occurrence of iron and vitamin B_{12} deficiencies which may inhibit marrow hyperplasia and the occurrence of PH lesions, causing researchers to underestimate stress within a population (McIlvaine 2015). Additionally, cranial porosity without diploic expansion may occur as a result of other nutritional deficiencies, such as vitamin C, or decreased bone mass in the form of osteopenia or osteoporosis (Ortner 2003). Within the Khirbet Qazone sample the effects of CO lesion severity was examined using two conditions: 1) in which all cases of porosity regardless of severity were defined as CO and; 2) in which only the most severe scores with coalescing foramina and cortical thickening indicative of true diploic expansion were defined as CO. In both cases, the relationship between CO was correlated with age-at-death, although the relationship was statistically significant ($p \leq 0.05$) for the second condition (Table 7-12 and Table 7-14). The relationship between lesion severity, including low and high severity lesions, was also significantly related to age-at-death.

The relationship between earlier age-at-death and CO severity in the Khirbet Qazone population suggests that stress was more severe for the youngest members of the population; however, the initiation of new stress events (active/mixed activity lesions) among some adults indicates the precarity of adequate nutrition within the population throughout life. This suggests that stress within the Khirbet Qazone group was relatively high throughout the life course. While the osteological paradox identifies individuals who survive stress events during early life as more resilient, it does not mean that their susceptibility to future risk is decreased (Wood et al. 1992). Early life stress may even have made some individuals more susceptible or less resilient to subsequent nutritional insults increasing their risk of premature death from these events in later life (Armelagos et al. 2009). However, at Zabayir, lesions associated with CO seemed to be primarily an early life issue that did not reoccur in older individuals.

At Khirbet Qazone, lesion severity did not preclude advancement into middle adulthood, however, it also did not protect individuals from the recurrence of osseous stress indicators in the future. This suggests that while some individuals were more resilient to some stress events, stress was relatively pervasive within the population. Additionally, no individuals with CO aged older than 50 years at death were identified in the Khirbet Qazone population and a majority of the individuals aged over 36 years at death showed no CO (Table 7-11; Figure 7-3). These data indicate that individuals at Khirbet Qazone experienced more stress, over a longer duration, which had a greater impact on overall physiologic frailty impacting longevity. Therefore, CO was associated with selective mortality compounded by an increased frailty factor based upon lesion severity.

7.3.2 Growth and Stress

The hypothesis that LEH, CO, and PH will be better predictors of decreased growth for the population at Khirbet Qazone compared to the Zabayir population based upon VNC diameters and long bone lengths was partially supported. Of the three stress indicators examined only LEH is directly tied to childhood stress since it is a localized, temporally measurable cessation of growth; however, its occurrence did not appear to affect more systemic growth mechanisms for VNC development or long bone length. Indeed, growth among both groups was not significantly impacted by the occurrence or gross number of LEH. The type of stress events contributing to LEH formation do not appear to have had long term effects either in increased mortality or decreased growth potential. Since many LEHs occur prior to the adolescent growth spurt, or the period of greatest long bone growth, the absence of a relationship between LEH occurrence and FBL or TTL suggests that individuals were able to respond plasticly to growth insults through later growth compensation.

In a similar comparison, Temple (2008) found that LEH occurrence did not permanently affect longitudinal growth among Jomon foragers in eastern and western Japan. Rather, the higher prevalence of LEH among the western Jomon with no significant variation in stature was posited as evidence for catch-up growth among the survivors of stress events. Floyd and Littleton (2006) affirm the role of developmental plasticity in their study of mid-20th century Aboriginal Australian populations drawn from an intensive examination of dental casts as well as longitudinal and cross-sectional height and weight data. Like the Jomon, LEH occurrence did not result in decreased stature among the Aboriginal populations. Improved diet after two years of age resulted in catch-up growth and normal adult height.

Lumbar VNC diameter growth is completed around 5 years of age, which overlaps with at least a portion of permanent tooth crown development for all teeth except the third molar (Watts 2013, Smith 1991, Ubelaker 1989). Therefore, VNC diameters would be less effected by catch-up growth occurring during middle childhood and adolescence and more sensitive to early life stress indicators such as LEH (Watts 2013). However, LEH does not appear to impair the growth potential of VNC diameters. Once again, it appears that individuals were able to respond plasticly to stress such that systemic growth processes were not impacted. Further investigation of LEH timing and recidivism will be explored in results Chapter 10 to determine if these play a role in various later life effects including mortality and growth.

Some noteworthy complications are presented in the data. Sample sizes for both sites are relatively small, but especially small for some comparative categories for growth from Zabayir. This precluded some statistical comparisons and the absence of evidence for a significant result cannot be considered conclusive for the site. Additionally, the high frequency of LEH at Khirbet Qazone may also play a role in the analysis outcome. Since most of the individuals measured exhibited at least one instance of LEH, it is possible that the stresses producing these lesions are too common in the population to be adequately indexed for growth effects without a much larger sample size. However, CO was relatively common at both sites and growth differences were associated with this pathology at Khirbet Qazone.

Like LEH, neither CO nor PH were significantly correlated with long bone growth (Table 7-21). Again, this suggests that the stress events experienced led to the mortality of the most susceptible individuals, but those that survived the stress event were able to respond plasticly during later growth phases to complete longitudinal growth along the normal curve for their population. This outcome is predicted by the osteological paradox, which posits that individuals who survive a stress event and therefore display skeletal evidence of its effects may in fact be the proportion of the population less severely impacted by the event (Wood et al. 1992).

VNC diameters, which are more susceptible to early life stress events, were adversely impacted by CO in the Khirbet Qazone sample (Table 7-22). Not surprisingly at Khirbet Qazone, where more subadult skeletons were preserved, the most severe cases of CO occurred in individuals 12 years or younger at age of death. Given that VNC development is generally thought to be completed by around 5 years of age, VNC size would be the most affected growth measure

(Watts 2011). This indicates that while the individuals who survived the stress event were able to recover normal growth status by middle childhood and adolescence, the immediate effects of stress were still significantly severe to impact growth in some structures developing concurrent with the stress event.

Overall, stress indicators at Khirbet Qazone appear to have a more pronounced effect on VNC growth for individuals with skeletal indicators of stress than those without, although a significant relationship was only documented for two of the five medial-lateral VNC dimensions measured. Since not all VNC measurements showed significant relationships with CO occurrence, it is unclear what the extent of the relationship between growth and CO is for this population. All analyses were impacted by relatively small samples sizes, which precluded some analyses. Further research using a larger sample may produce more conclusive results regarding the relationship between CO and growth for sedentary communities in this region. The data demonstrate that growth impacts were also present at Zabayir, however, it is apparent that growth was less effected by the lesions observed, possibly because the population at Zabayir was more resilient or adaptive to stress events. The small number of well-preserved subadult skeletons may also play a role in the examination of VNC diameters since many of the most affected individuals likely died during the VNC developmental period.

In summation, CO at Khirbet Qazone indicates significant stress events related to both age-at-death and growth potential. At Zabayir, none of the stress indicators investigated were significantly related to growth or age-at-death. Therefore, it is evident that early life stress at both sites, but particularly within the Khirbet Qazone population, did have measurable correlations with later life outcomes.

8.0 RESULTS AND DISCUSSION: DIET AND WEANING

This chapter is organized around the different data used to address the hypothesis related to diet. The section begins with the results and discussion of the dental health analysis followed by the isotope results along with a discussion of the data's implications for diet and weaning.

8.1 DENTAL HEALTH AND DIET

8.1.1 Permanent Dentition and Dental Health

Individuals from age cohorts 7-12 were included in the dental pathology analysis, which included only permanent, fully erupted teeth. A total of 412 permanent teeth from 25 Khirbet Qazone adults and 146 teeth from 22 Zabayir adults were observed for dental caries, calculus, and AMTL (Table B-2; Table B-4; Table B-7; Table B-9). Alveolar bone from 22 Khirbet Qazone and 31 Zabayir individuals were examined for periapical abscesses and AMTL. The observed crude prevalence rates (CPR) by sex and age category are presented for dental caries (Table 8-1), periapical abscesses (Table 8-2), AMTL (Table 8-3), and dental calculus (Table 8-4). Both dental calculus and wear are reported as aggregate scores, or the mean value of all teeth scored for each trait.

Table 8-1. Frequency of adult dental caries by age cohort and sex (CPR).

Age Cohort	KHIRBET QAZONE							ZABAYIR						
	No Caries			Caries			Total	No Caries			Caries			Total
	F	M	U	F	M	U		F	M	U	F	M	U	
7	—	1	1	—	—	—	**2**	—	—	1	—	—	—	**1**
8	—	1	—	—	—	—	**1**	—	1	—	—	—	—	**1**
9	1	—	1	1	1	—	**4**	2	1	2	1	—	—	**6**
10	1	1	1	5	3	—	**11**	—	3	—	—	—	—	**3**
11	1	—	—	1	2	—	**4**	—	—	—	1	—	—	**1**
12	1	1	1	—	—	—	**3**	3	2	4	—	—	1	**10**
Total	**4**	**4**	**4**	**7**	**6**	**0**	**25**	**5**	**7**	**7**	**2**	**0**	**1**	**22**

Note: F=female, M=male, U=unidentified

Table 8-2. Frequency of adult periapical abscesses by age cohort and sex (CPR).

Age Cohort	KHIRBET QAZONE							ZABAYIR						
	No Abscess			Abscess			Total	No Abscess			Abscess			Total
	F	M	U	F	M	U		F	M	U	F	M	U	
7	—	1	—	—	—	—	**1**	—	—	1	—	—	—	**1**
8	—	1	—	—	—	—	**1**	1	1	—	—	—	—	**2**
9	2		1	—	1	—	**4**	2	1	3	1	—	—	**7***
10	5	4	—	2	1	—	**12**	1	2	1	—	1	—	**5**
11	1	1	—	1	1	—	**4**	2	1	—	—	—	—	**3**
12	—	—	—	—	—	—	**0**	2	3	5	1	1	—	**12**
Total	**8**	**7**	**1**	**3**	**3**	**0**	**22**	**8**	**8**	**10**	**2**	**2**	**0**	**30***

Note: F=female, M=male, U=unidentified
*One individual was excluded from calculations due to the limited amount of alveolar bone present.

Table 8-3. Frequency of adult AMTL by age cohort and sex (CPR).

Age Cohort	KHIRBET QAZONE							ZABAYIR						
	No AMTL			AMTL			Total	No AMTL			AMTL			Total
	F	M	U	F	M	U		F	M	U	F	M	U	
7	—	1	—	—	—	—	**1**	—	—	1	—	—	—	**1**
8	—		—	—	1	—	**1**	—	1	—	1	—	—	**2**
9	—	1	—	2	—	1	**4**	1	—	1	3	1	2	**8**
10	1	1	—	6	4	—	**12**	1	—	1	—	3	—	**5**
11	—	—	—	2	2	—	**4**	—	—	—	2	1	—	**3**
12	—	—	—	—	—	—	**0**	1	2	2	2	2	3	**12**
Total	**1**	**3**	**0**	**10**	**7**	**1**	**22**	**3**	**3**	**5**	**8**	**7**	**5**	**31**

Note: F=female, M=male, U=unidentified

Table 8-4. Frequency of adult dental calculus by age cohort and sex (CPR).

Age Cohort	KHIRBET QAZONE							ZABAYIR						
	No Calculus			Calculus			Total	No Calculus			Calculus			Total
	F	M	U	F	M	U		F	M	U	F	M	U	
7	—	—	1	—	1	—	**2**	—	—	1	—	—	—	**1**
8	—	1	—	—	—	—	**1**	—	—	—	—	1	—	**1**
9	1	—	—	1	2	1	**5**	—	—	—	3	1	2	**6**
10	1	1	—	5	4	—	**11**	—	—	—	—	2	—	**2**
11	—	—	—	2	1	—	**3**	—	—	—	1	—	—	**1**
12	—	1	—	1	—	1	**3**	1	2	3	2	1	2	**11**
Total	**2**	**3**	**1**	**9**	**8**	**2**	**25**	**1**	**2**	**4**	**6**	**5**	**4**	**22**

Note: F=female, M=male, U=unidentified

The population at Khirbet Qazone demonstrated a relatively high incidence of dental disease (Table 8-5). Indeed, among the skeletons at Khirbet Qazone, only one individual (Skeleton N1) for which dental caries, abscess, and AMTL could be assessed exhibited no indication of dental disease. In contrast, eight individuals from Zabayir for which all three disease indicators (dental caries, abscess, and AMTL) could be observed exhibited no evidence for dental disease. Dental disease rates at Zabayir were also relatively high, especially for a pastoral population (Table 8-5) (Munoz 2017, Judd et al. 2018). Comparison between the rates of dental caries, periapical abscess, and AMTL revealed that only the frequency of dental caries varied significantly between the two populations (Table 8-6).

Table 8-5. Summary of adult dental disease by individual for each site.

Site	Caries			Abscess			AMTL		
	N	Present	%	N	Present	%	N	Present	%
Khirbet Qazone	25	14	56.00	22	6	27.27	22	18	81.82
Zabayir	22	3	13.64	30*	4	13.33	31	20	64.52

*One individual was excluded from calculations due to the limited amount of alveolar bone present.

Table 8-6. Comparison of adult dental disease between sites using Fisher's exact test[1].

Comparison	Test Statistic	p-value
Caries	7.67	0.007*
Abscess	1.58	0.290
AMTL	1.89	0.223

[1]Two-sided

*=significance at $p \leq 0.05$

The mean calculus score for both populations was relatively low and did not significantly differ between the two populations (Table 8-7; Table 8-8). Calculus scores for both sites are positively associated with age until cohort 10 and then drop in cohort 11 (Figure 8-1). While this trend could be related to dental attrition, the number of teeth lost by individual also peak in age cohort 10 and decrease in cohort 11 (Figure 8-2). Similarly, wear scores were relatively moderate and not significantly different between the Khirbet Qazone and Zabayir groups (Table 8-7; Table 8-8). Wear is clearly positively associated with age at Khirbet Qazone, although this relationship is less apparent in the Zabayir data (Figure 8-3). The distribution of wear scores by sex is similar for each site with females demonstrating less variance than males, which does not account for the variance observed at Zabayir by age (Figure 8-4).

Table 8-7. Summary of adult dental calculus and wear by individual for each site.

Site	Calculus				Wear	
	Total	Present	%	Mean Score	Total	Mean Score
Khirbet Qazone	25	19	76.00	1.05	25	4.15
Zabayir	22	15	68.18	1.11	21	3.62

Table 8-8. Mann-Whitney U comparison between sites for adult calculus and wear scores.

Calculus			Wear		
Test Statistic	SE	Significance[1]	Test Statistic	SE	Significance[1]
138.00	27.90	0.872	235.00	45.342	0.544

[1]Significance level = $p \leq 0.05$

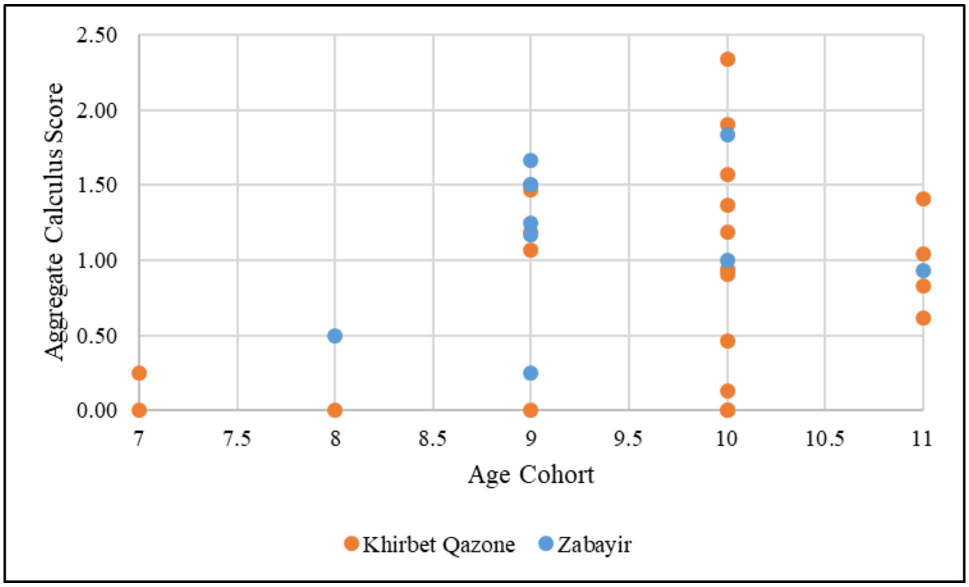

Figure 8-1. Dental calculus scores by age cohort.

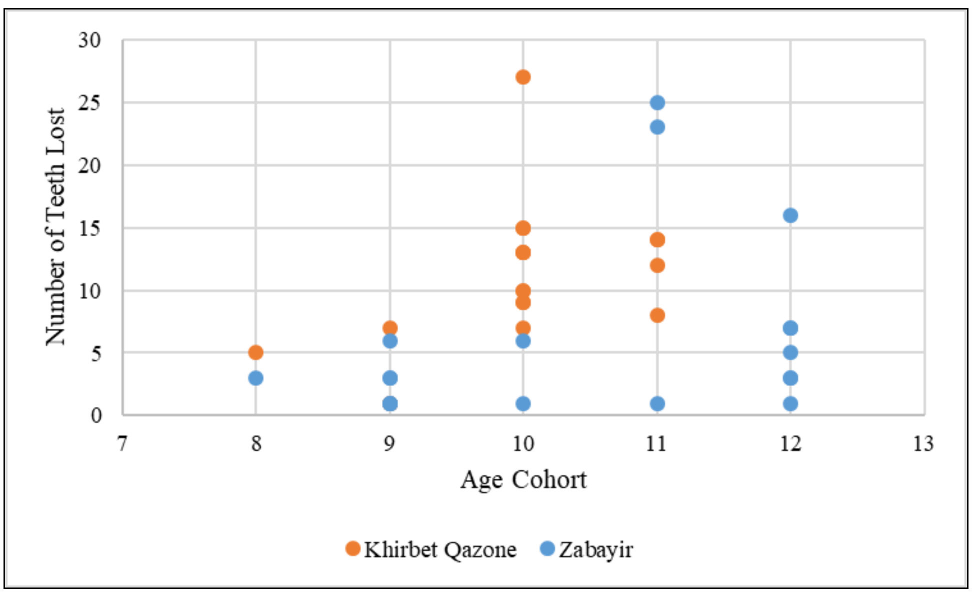

Figure 8-2. AMTL by age cohort.

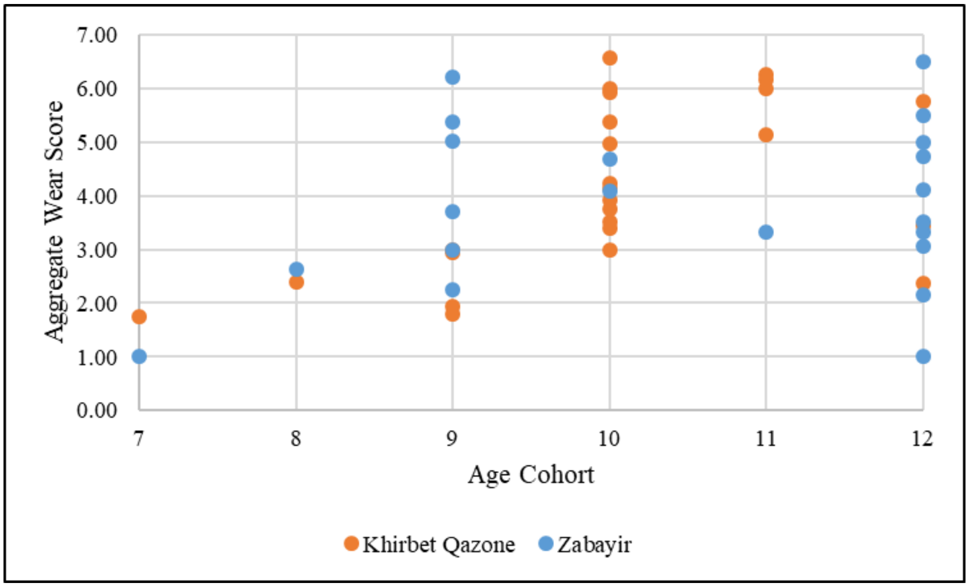

Figure 8-3. Aggregate wear scores by age.

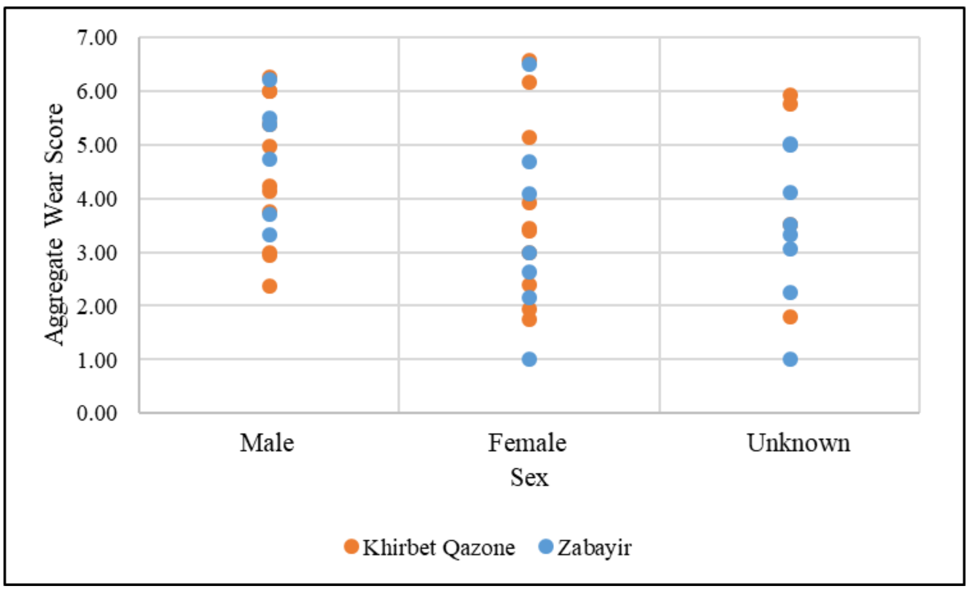

Figure 8-4. Dental wear scores by sex.

8.1.2 Deciduous Dentition and Dental Health

A total of 107 deciduous teeth from 11 Khirbet Qazone individuals and 11 deciduous teeth from five Zabayir individuals were included in the subadult dental analysis for individuals assigned to age cohorts 0-5. All teeth, permanent and deciduous, were inventoried for subadults and are included in Table B-6 and Table B-8. Most available permanent teeth for these individuals had not yet erupted or were only partially erupted and exhibited no evidence for dental disease, calculus, or notable attrition. Therefore, the scores presented in Table B-1 and Table B-3 and in the figures below include only deciduous teeth. No evidence for dental disease in the form of caries, AMTL, or abscess was observed for the Zabayir group. The true prevalence of dental disease among subadults from Zabayir is likely underrepresented due to poor preservation, especially for children.

Among the Khirbet Qazone subadults, 10 carious lesions were observed on four individuals (TPR=36.36%) along with one periapical abscess (TPR=9.09%) on a carious tooth from Skeleton R2.1. Dental caries and periapical abscesses were only present on individuals from cohort 5 while younger individuals demonstrated no dental disease or significant attrition. Calculus accumulations were not present for any of the subadults at Khirbet Qazone.

8.1.3 Dental Heath Discussion

Dental disease was ubiquitous at both sites. Skeleton N1 (male), the only individual from Khirbet Qazone without dental disease fell within the youngest adult cohort (cohort 7). Except for the third molars, which were still erupting, the complete permanent dentition for Skeleton N1 was available for examination. Since dental disease is a progressive deterioration of tooth and alveolar tissues it is likely that Skeleton N1 was simply too young to exhibit the macroscopic effects of dental caries lesions, periapical abscess, or significant wear, all of which can contribute to antemortem attrition. The eight Zabayir skeletons without dental disease included individuals from cohorts 7, 8, and 9. However, few teeth or minimal alveolar bone were available for examination from these individuals, which may have impacted these observations. By most measures dental health does not differ significantly between the two populations. Only dental caries frequency was significantly greater for the Khirbet Qazone population; however, the larger sample of molars available for observation at Khirbet Qazone may contribute to a more accurate assessment of caries frequency than that observed for the population at Zabayir, particularly since other indicators of dental health were relatively similar (Table 8-6). Pits and crenulations on the tooth surface are the most common sites for caries formation making molars more susceptible to dental caries than anterior teeth (Hillson 1996, Selwitz, Ismail, and Pitts 2007). For Khirbet Qazone skeletons 39% of the expected molars were present while only 22.7% of the expected molars for Zabayir were available for examination. This discrepancy is even greater when examining only the first molar, which erupts earliest and is exposed to caries risk for the greatest period with 46% of expected teeth available for examination at Khirbet Qazone and only 18% for Zabayir.

Dental disease, including dental caries, abscesses and AMTL, is often associated with agricultural food production (Cook 1984, Crittenden et al. 2017, Driscoll and Weaver 2000, Kelley and Larsen 1991, Larsen 1995, Larsen, Shavit, and Griffin 1991, Larsen 1981, Lukacs 1992, Munoz 2017, Temple and Larsen 2007). The dental caries TPR for Khirbet Qazone and Zabayir were both similar to rates reported for Nabatean sites relying on agricultural subsistence economies (Table 8-9) (Lieurance 2018, Delhopital 2010). The larger numbers of carious lesions observed for Khirbet Qazone, consistent with other agricultural communities in the region, suggests a diet with higher proportions of cariogenic foods such as cultivated carbohydrates than that consumed at Zabayir. The rate of dental caries observed among deciduous teeth was relatively high compared to many other sites, however, the small number of subadults included in the comparison samples may have contributed to this discrepancy (Table 8-10).

Table 8-9. Reported Nabataean and Early/Middle Roman permanent tooth caries frequencies (TPR).

Site	Tomb	Total Tooth Count	Teeth with Caries Lesions	Caries Frequency (%)	Citation
Khirbet Qazone	—	412	23	5.58	Current Study
Zabayir	—	146	4	2.74	Current Study
Petra	Wadi Farasa	53	3	5.66	Delhopital 2010
	303 d'Ath-Thughrah	403	13	3.03	
	Façade Tombs	234	8	3.40	Lieurance 2018
	Shaft Chamber Tombs	696	25	3.60	
	Petra Hinterland	132	7	5.30	
Khirbet edh Dharih	C1	381	23	6.03	Delhopital 2010
	C2	204	11	5.30	
	North Cemetery	56	5	8.92	
Mada'in Salih	IGN 20	60	1	1.66	
	IGN 117	241	19	7.88	

Table 8-10. Reported Nabataean and Early/Middle Roman deciduous tooth caries frequencies (TPR).

Site	Tomb	Total Tooth Count	Teeth with Caries Lesions	Caries Frequency (%)	Citation
Khirbet Qazone	—	107	10	9.35	Current Study
Zabayir	—	11	0	0.00	Current Study
Petra	Wadi Farasa	2	0	0.00	Delhopital 2010
	303 d'Ath-Thughrah	25	0	0.00	
Khirbet edh Dharih	C1	56	1	1.76	
	C2	76	0	0.00	
	North Cemetery	—	—	—	
Mada'in Salih	IGN 20	10	0	0.00	
	IGN 117	26	3	11.53	

The similarity observed between rates of dental calculus and wear also support a similar diet between the two populations. The mean dental calculus score for both populations was relatively low. Only one individual (Khirbet Qazone skeleton M1) from the combined sample demonstrated a mean score above 2.00. High calculus and low caries rates have been associated with high protein diets (Lillie 1996, Lillie and Richards 2000, Littleton and Frohlich 1993). Calculus has also been shown to play a role in the progression of periodontitis, which along with dental caries contributes to AMTL (Greene, Kuba, and Irish 2005, Hillson 2008, Chapple et al. 2017). Calculus present at Khirbet Qazone and Zabayir suggest at least moderate protein consumption. Other factors also play a role in calculus formation and retention, including, water consumption, water mineral content, salivary production, the oral microbiome, taphonomy, chewing, dental hygiene, and the use of teeth as tools (Lieverse 1999). Khirbet Qazone may have had relatively high protein consumption for an agricultural population based upon the calculus scores observed.

Based upon the assessment of dental health hypothesis (2.2) assertion that both sites will display similar patterns to burials at Petra is supported, which suggests that Zabayir may have relied significantly on agricultural resources via the production of agricultural products within the community or through trade.

8.2 ISOTOPE ANALYSIS: DIET AND WEANING

In addition to dental disease, diet was also evaluated using $\delta^{13}C_{enamel\_ap}$ isotope values and $\delta^{13}C_{bone\_ap}$ as well as $\delta^{15}N_{dentine\_coll}$ and $\delta^{13}C_{dentine\_coll}$ values from dentine. The $\delta^{15}N$ and $\delta^{13}C$ values in dentine collagen reflect the protein component of an individual's diet during the period of dentine formation. $\delta^{13}C$ in apatite from bone or enamel carbonate is a product of the combined consumption of carbohydrates, proteins, and fats (Tykot 2004, Ambrose 1993). Dental enamel and dentine samples provide information about diet during the period of dental development for that tooth and values taken from bone samples evidence diet during the period shortly before an individual's death.

In addition to the analysis of diet, $\delta^{13}C_{enamel\_ap}$ and $\delta^{18}O_{enamel\_ap}$ from incremental dental enamel samples were used to examine changes in the infant diet and the ages in between which weaning occurred. Incremental samples taken from dental enamel or dentine reflect isotope values during sequential periods of tooth growth which can be correlated with chronological ages (Tsutaya and Yoneda 2015, Beaumont et al. 2013). The poor collagen preservation in these samples meant incremental isotope analysis could only utilize dental enamel, rather than collagen. The ratio of $\delta^{13}C$ helps determine the predominant micronutrient contributions during tooth growth and the ratio of $\delta^{18}O$ reflects the consumption of dietary liquids, particularly water (Tsutaya and Yoneda 2015, Ambrose 1993, Tykot 2004). However, both show shifts in value throughout the reduction of breastfeeding and increase in solid foods that occurs during the weaning process. A complete list of the dental samples processed as part of this study are shown in Table B-10 and Table B-11. Detailed sample information, including demographic information such as age and sex and material sampled for collagen samples are included in Table B-12 and for bone carbonate and enamel apatite samples in Table B-13.

8.2.1 Nitrogen Isotope Analysis

The nitrogen isotope ratio data from the two sites included thirteen samples from Zabayir provided by Damien Huffer but only four out of 24 samples from Khirbet Qazone with viable quantities of collagen for analysis, precluding an individual analysis by tooth (Table 8-11). Values of $\delta^{15}N_{dentine\_coll}$ in bulk dentin samples from Khirbet Qazone ranged from 9.30‰ to 17.00‰ with a mean value of 12.45 ± 3.51‰ (Table 8-12). The Zabayir data showed slightly less variance in $\delta^{15}N_{dentine\_coll}$ values, which ranged from 9.30‰ to 13.50‰ with a mean value of 11.30 ± 1.19‰. Mean $\delta^{15}N_{dentine\_coll}$ values were not significantly different between sites based on a Mann-Whitney U comparison (Table 8-12; Table 8-13). Mean $\delta^{15}N_{dentine\_coll}$ declined by 0.2‰ for each subsequently forming tooth type (M1, M2, M3), although none of these differences were statistically significantly (H=0.853, df=2, p=0.653; Table 8-14; Figure 8-5). One exception was noted in the Zabayir data. Skeleton R-25's third molar value was 2.4‰ higher than the sample mean of $\delta^{15}N_{dentine\_coll}$ for third molars, unfortunately no other samples from Skeleton R-25 were available for bone or enamel apatite comparison. The mean $\delta^{15}N_{dentine\_coll}$ values for second molars at Khirbet Qazone were 1.3‰ lower than first molars (U=1.00, p=1.00; Table 8-14; Figure 8-5), and no third molars were analyzed. One clear outlier in the data was Khirbet Qazone Skeleton K7. This outlying value came from the only canine tooth in the sample yielded a $\delta^{15}N_{dentine\_coll}$ value (17.00‰) that fell over one standard deviation outside the sample mean pooled for all teeth at either site. The Khirbet Qazone data is heavily impacted by small sample sizes. Since dentine collagen was only available from one second molar and no third molars were available for comparison, the data may be disproportionately affected by a single datapoint that does not accurately reflect the range of variation for the entire site. Dietary values of $\delta^{15}N_{dentine\_coll}$ were calculated by adjusting for a 3‰ increase per trophic level. Khirbet Qazone dietary $\delta^{15}N_{dentine\_coll}$ values ranged from 3.30‰ to 14.00‰. Only one second molar and one canine were available from Khirbet Qazone with dietary $\delta^{15}N_{dentine\_coll}$ values of 7.1‰ and 14.00‰, respectively. First molars yielded a mean dietary value of 8.35 ± 2.90‰. For Zabayir dietary $\delta^{15}N_{dentine\_coll}$ values ranged from 8.30 ‰to 8.60‰ for first molars with a mean of 8.50 ± 0.14‰. Second molar values ranged from 6.30‰ to 10.00‰ with a mean value of 8.30 ± 1.37‰ for second molars and third molars values fell between 6.30‰ and 10.50‰ with a dietary mean 8.10 ± 1.75‰.

Table 8-11. $\delta^{15}N$ and $\delta^{13}C$ bulk dentine collagen values by tooth type and site.[1]

Site	Skeleton	Tooth Type	$\delta^{13}C_{deintine\_coll}$	$\delta^{15}N_{dentine\_coll}$	C:N	Dietary $\delta^{13}C$	Dietary $\delta^{15}N$
Khirbet Qazone	K7	C	-13.8	17.0	3.6	-18.8	14.0
Khirbet Qazone	K5	M1	-17.9	13.4	3.6	-22.9	10.4
Khirbet Qazone	θ2	M1	-19.0	9.3	3.3	-24.0	6.3
Khirbet Qazone	θ3	M2	-18.3	10.1	3.3	-23.3	7.1
Zabayir	AP-24	M2	-19.2	10.8	3.7	-24.2	7.8
Zabayir	AP-28B	M2	-18.2	13.0	3.3	-23.2	10.0
Zabayir	R-25	M3	-17.2	13.5	3.3	-22.2	10.5
Zabayir	R-36	M2	-18.6	9.3	3.3	-23.6	6.3
Zabayir	R-37	M2	-18.2	11.9	3.3	-23.2	8.9
Zabayir	R-53	M3	-18.5	9.3	3.3	-23.5	6.3
Zabayir	R-73	M3	-18.4	10.9	3.3	-23.4	7.9
Zabayir	R-76	M1	-18.2	11.6	3.4	-23.2	8.6
Zabayir	R-97	M1	-18.7	11.3	3.3	-23.7	8.3
Zabayir	R-99	M3	-18.2	10.7	3.2	-23.2	7.7
Zabayir	R-100	M2	-18.5	11.5	3.3	-23.5	8.5
Zabayir	R-105	M1	-18.3	11.6	3.3	-23.3	8.6
Zabayir	R-146	M1	-17.7	11.5	3.2	-22.7	8.5

[1]Additional information regarding samples, including lab numbers, can be found in Table B-12 and Table B-13.

Table 8-12. Descriptive statistics for dentine collagen isotope values between sites.

Site	Isotope	n	Minimum	Maximum	Mean	SD	Variance
Khirbet Qazone	$\delta^{13}C_{dentine\_coll}$	4	-19.00	-13.80	-17.25	2.34	5.50
	$\delta^{15}N_{dentine\_coll}$	4	9.30	17.00	12.45	3.51	12.35
Zabayir	$\delta^{13}C_{dentine\_coll}$	13	-19.20	-17.20	-18.30	0.48	0.23
	$\delta^{15}N_{dentine\_coll}$	13	9.30	13.50	11.30	1.19	1.43

Table 8-13. Mann-Whitney U comparison of $\delta^{13}C_{dentine\_coll}$ and $\delta^{15}N_{dentine\_coll}$ values between sites.

Site	n	Variable	Test Statistic	SE	Significance[1]
Khirbet Qazone	4	$\delta^{13}C_{dentine\_coll}$	20.500	8.767	0.549
Zabayir	13				
Khirbet Qazone	4	$\delta^{15}N_{dentine\_coll}$	24.000	8.799	0.871
Zabayir	13				

[1]Significance = $p \leq 0.5$

Table 8-14. Summary of $\delta^{13}C_{dentine\_coll}$ and $\delta^{15}N_{dentine\_coll}$ values by tooth type and site.

Site	Tooth Type	n	$\delta^{13}C_{dentine\_coll}$				$\delta^{15}N_{dentine\_coll}$			
			Minimum	Maximum	Mean	SD	Minimum	Maximum	Mean	SD
Khirbet Qazone	M1	2	-19.00	-17.90	-18.50	0.78	9.30	13.40	11.40	2.90
	C	1	-13.80	-13.80	—	—	17.00	17.00	—	—
	M2	1	-18.60	-18.60	—	—	10.10	10.10	—	—
	M3	0	—	—	—	—	—	—	—	—
Zabayir	M1	4	-18.70	-17.70	-18.20	0.42	11.30	11.60	11.50	0.16
	C	0	—	—	—	—	—	—	—	—
	M2	5	-19.20	-18.20	-18.60	0.41	9.30	13.00	11.30	1.38
	M3	4	-18.5	-17.2	-18.1	0.57	9.30	13.50	11.10	1.76

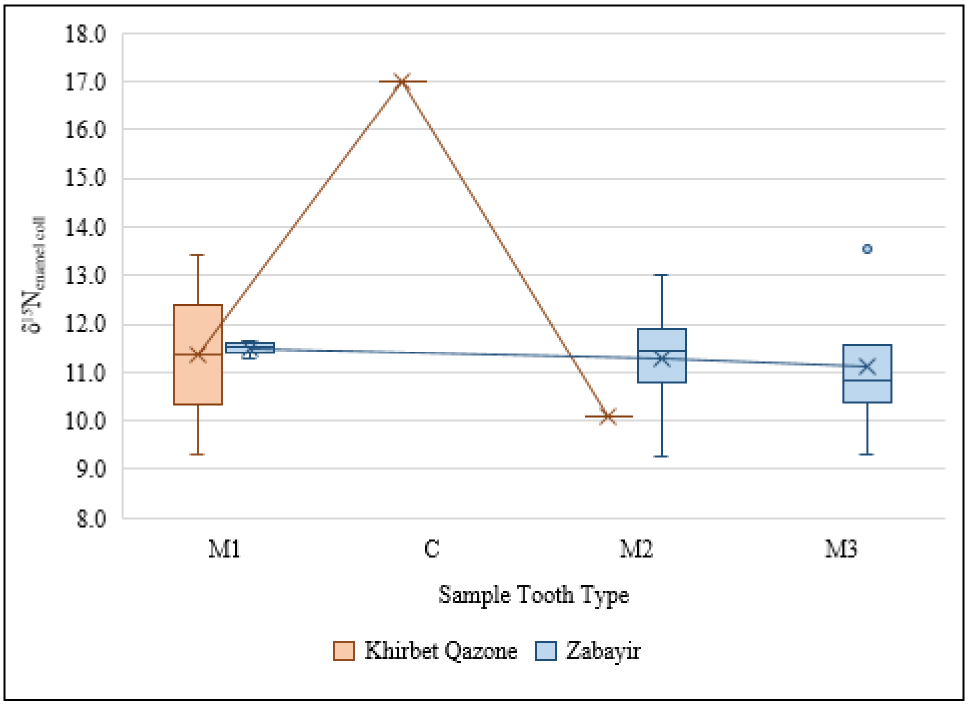

Figure 8-5. $\delta^{15}N_{enamel\_coll}$ values by sample tooth type and site. Abbreviations: M1=first molar; C=canine; M2=second molar; M3=third molar; X=mean value and; dots indicate outliers.

8.2.2 Carbon Isotope Analysis

Carbon from Dentine Collagen

$\delta^{13}C_{dentine\_coll}$ values taken from dentine collagen for Khirbet Qazone ranged from -19.00‰ to -13.80‰ with a mean value of -17.25 ± 2.34‰ (Table 8-12). The Zabayir $\delta^{13}C_{dentine\_coll}$ values from dentine collagen were not significantly different from the Khirbet Qazone sample data (U=20.50, p=0.549) (Table 8-13), with values ranging from -19.20‰ to -17.20‰ and a sample mean of -18.30 ± 0.48‰ (Table 8-12). When samples were examined by tooth type and site only a 0.10‰ differences was observed between first and second molars (Table 8-14; Figure 8-6). The canine $\delta^{13}C_{dentine\_coll}$ value from Skeleton K7 was 4.7‰ higher than first molars and 4.8‰ higher than the second molar available for comparison. Similarly, the $\delta^{15}N_{dentine\_coll}$ value for this individual was at least 3.6‰ higher than other teeth from the site.

Zabayir mean $\delta^{13}C_{dentine\_coll}$ values were 0.4‰ lower for second molars compared to first molars and 0.5‰ higher for third molars compared to second molars (Table 8-14; Figure 8-6). Two outliers were observed in the Zabayir data. Skeleton AP-24 had a second molar $\delta^{13}C_{dentine\_coll}$ value 0.6‰ lower than the sample mean, but the $\delta^{15}N_{dentine\_coll}$ value was consistent with the second molar sample mean (Table 8-14; Figure 8-6). For Skeleton R-25, third molar $\delta^{13}C_{dentine\_coll}$ values were 0.9‰ higher than the sample mean for the site (Table 8-14; Figure 8-6). $\delta^{15}N_{dentine\_coll}$ values for this individual were also 2.4‰ higher than the sample mean. However, Zabayir $\delta^{13}C_{dentine\_coll}$ ratios were not significantly different across tooth types (H=1.296, df=2, p=0.523). For Khirbet Qazone, second molars were 0.2‰ higher than first molars, although this relationship was not statistically significant (U=1.00, p=1.00; Table 8-14; Figure 8-6). Dietary values of $\delta^{13}C_{dentine\_coll}$ were calculated by adjusting for a 5‰ increase over $\delta^{13}C$. Khirbet Qazone dietary $\delta^{13}C_{dentine\_coll}$ values ranged from -18.80‰ to -24.00‰ with a mean value of -22.25 ± 2.34‰. Zabayir dietary values of $\delta^{13}C_{dentine\_coll}$ ranged from -22.20‰ to -24.20‰ with a mean value of -23.30 ± 0.48‰.

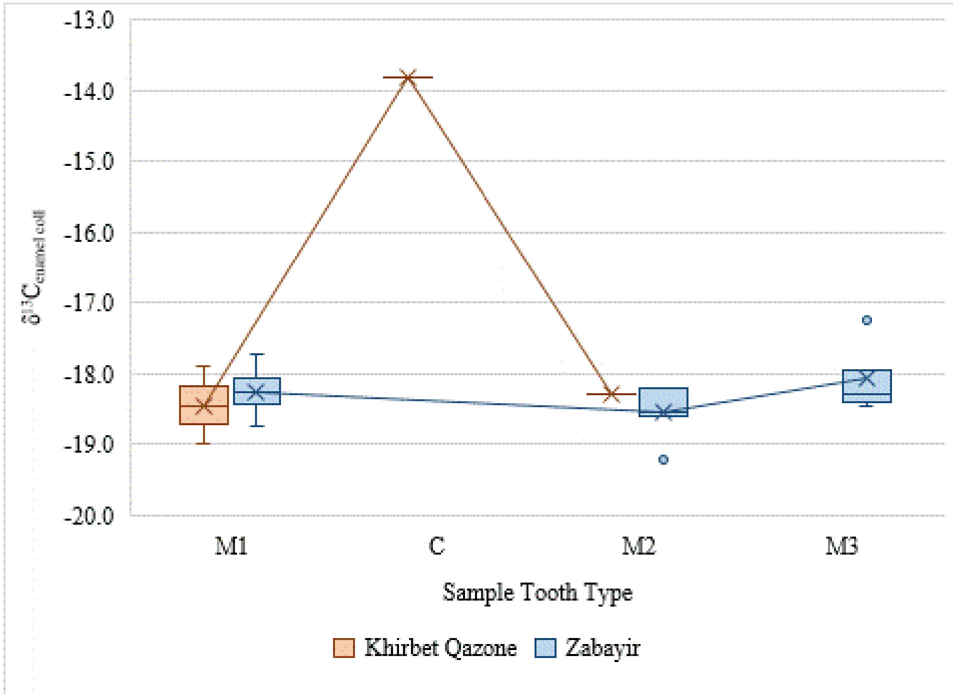

Figure 8-6. $\delta^{13}C_{dentine\_coll}$ values by sample tooth type and site. Abbreviations: M1=first molar; C=canine; M2=second molar; M3=third molar; X=mean value and; dots indicate outliers.

Carbon from Bone Carbonate

Bone carbonate was sampled from 24 Khirbet Qazone and 28 Zabayir skeletons in age cohorts 7-12 (17 – 50 + years of age) that provides information about diet shortly before an individual's death. Values of $\delta^{13}C_{bone\_ap}$ for Khirbet Qazone ranged from -14.80‰ to -11.20‰ with a mean value of -13.90 ± 0.85‰ (Table 8-15). For Zabayir $\delta^{13}C_{bone\_ap}$ sample values were between -13.70‰ to -11.70‰ with a mean of -12.63‰ ± 0.44‰. Mean $\delta^{13}C_{bone\_ap}$ values were significantly higher for the adult individuals from Zabayir than from Khirbet Qazone (Figure 8-7; Table 8-15; Table 8-16). Like the $\delta^{13}C_{dentine\_coll}$ from teeth, the value of $\delta^{13}C_{bone\_ap}$ for Khirbet Qazone Skeleton K7 (-11.2‰) was also an outlier for the site and exhibited higher $\delta^{13}C_{bone\_ap}$ values than those observed within the Zabayir dataset as well.

Table 8-15. Descriptive statistics for bone apatite values between sites.

Site	Isotope	n	Minimum	Maximum	Mean	SD
Khirbet Qazone	$\delta^{13}C$	21	-14.80	-11.20	-13.90	0.85
	$\delta^{18}O$	21	-2.00	3.80	-0.35	1.71
Zabayir	$\delta^{13}C$	26	-13.70	-11.70	-12.63	0.44
	$\delta^{18}O$	26	-3.00	-1.00	-2.12	0.54

Table 8-16. Mann-Whitney U comparison of bone apatite isotope values between sites.

Site	n	Variable	Test Statistic	SE	Significance
Khirbet Qazone	21	δ13C	497.000	46.651	0.000*
Zabayir	26				
Khirbet Qazone	21	δ18O	67.000	46.690	0.000*
Zabayir	26				

*=significance at <p=0.05

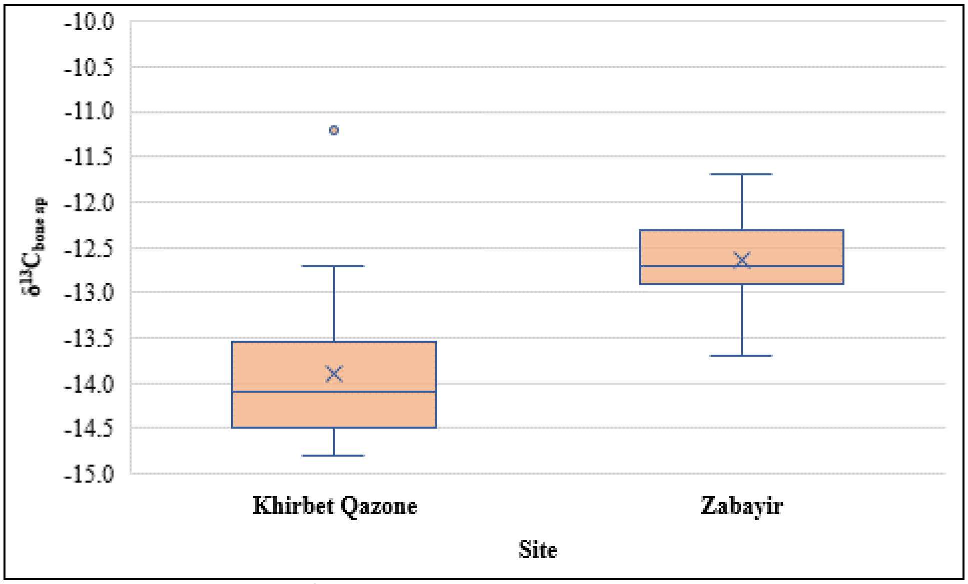

Figure 8-7. $\delta^{13}C_{bone\_ap}$ values from bone carbonate by site. Abbreviations: x=mean value and dots indicate outliers.

Khirbet Qazone Carbon Incremental Tooth Enamel Samples

Twelve individuals at Khirbet Qazone with three or more samples representing different periods through childhood were examined for $\delta^{13}C_{enamel\_ap}$ (Table 8-17; Table 8-18). The samples included $\delta^{13}C_{enamel\_ap}$ values for the 12 individuals between 1 and 7.5 years of age, ranging from -13.70‰ to -7.80‰ with a mean of -12.10 ± 1.10‰. The incremental dental enamel analysis by age within the samples shows a distinct shift in mean $\delta^{13}C_{enamel\_ap}$ between 2-2.9 and 3-3.9 years of age, likely demonstrating a dietary shift from late weaning or early post-weaning foods to a typical childhood diet (Figure 8-8). The later childhood diet has a slightly greater proportion of C_4 resources compared to the earlier childhood/infant diet. The $\delta^{13}C_{bone\_ap}$ values are consistently lower and have a greater C_3 signature than the childhood dental enamel values (U=1055, p=0.000; Figure 8-8). This may suggest adults had a different diet from children, or it reflects as-of-yet undiscovered inherent variation between $\delta^{13}C$ in dental enamel versus bone apatite.

Table 8-17. Number of incremental enamel apatite samples by site and age of tissue formation.

Category Age Range	Khirbet Qazone	Zabayir	Total
< 1 year	0	0	0
1 – 1.9 years	11	7	18
2 – 2.9 years	10	8	18
3 – 3.9 years	8	3	11
4 – 4.9 years	8	5	13
5 – 5.9 years	8	3	11
6 – 6.9 years	8	4	12
7 – 7.9 years	1	0	1
17 – 50 + years	21	21	42
Total	74	51	126

Table 8-18. Khirbet Qazone intra-tooth sample descriptive statistics by age of enamel formation.

Age	Isotope	n	Minimum	Maximum	Mean	SD	Variance
<1 year	δ13C	—	—	—	—	—	—
	δ18O	—	—	—	—	—	—
1 – 1.9 years	δ13C	11	-13.30	-12.10	-12.70	0.42	0.18
	δ18O	11	-2.40	1.20	-1.25	0.99	0.99
2 – 2.9 years	δ13C	10	-13.70	-11.90	-12.61	0.54	0.30
	δ18O	10	-2.60-	0.20	-1.09	0.90	0.82
3 – 3.9 years	δ13C	8	-12.60	-11.40	-12.03	0.48	0.23
	δ18O	8	-1.90	0.30	-1.12	0.73	0.53
4 – 4.9 years	δ13C	8	-12.70	-11.30	-12.20	0.43	0.18
	δ18O	8	-2.90	0.50	-1.71	1.08	1.16
5 – 5.9 years	δ13C	8	-12.80	-11.30	-12.23	0.57	0.33
	δ18O	8	-2.90	1.00	-1.20	1.24	1.55
6 – 6.9 years	δ13C	7	-12.60	-11.20	-12.00	0.54	0.30
	δ18O	7	-2.20	0.80	-0.84	1.15	1.33
7 – 7.9 years	δ13C	1	-11.80	-11.80	-11.80	—	—
	δ18O	1	-1.10	-1.10	-1.10	—	—
17 – 20 years	δ13C	1	-14.20	-14.20	-14.20	—	—
	δ18O	1	-2.00	-2.00	-2.00	—	—
20 – 25 years	δ13C	2	-13.90	-13.40	-13.65	0.35	0.13
	δ18O	2	-0.60	3.80	1.60	3.11	9.68
25 – 35 years	δ13C	2	-14.80	-14.00	-14.40	0.57	0.32
	δ18O	2	-2.00	-1.60	-1.80	0.28	0.08
35 – 50 years	δ13C	12	-14.70	-11.20	-13.71	1.02	1.04
	δ18O	12	-2.00	3.00	-0.31	1.65	2.72
50 + years	δ13C	4	-14.80	-13.60	-14.25	0.59	0.35
	δ18O	4	-1.60	0.90	-0.30	1.24	1.53

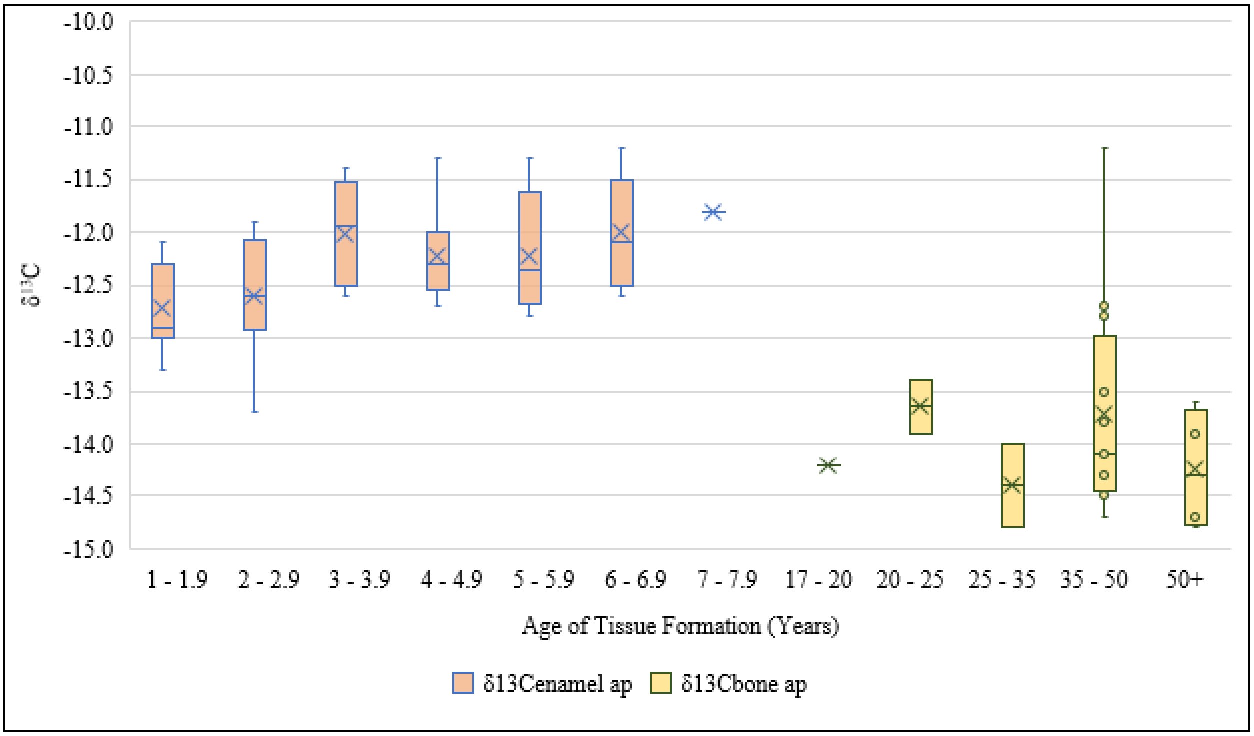

Figure 8-8. Incremental $\delta^{13}C_{enamel\_ap}$ values and $\delta^{13}C_{bone\_ap}$ values from Khirbet Qazone. Abbreviations: X=mean value and dots indicate outliers.

Most of the individuals at Khirbet Qazone show a gradual increase in $\delta^{13}C_{enamel\_ap}$ with age, represented by an increase in C_4 contributions with age (Figure 8-9). However, two individuals, N1 and T2, seem to be driving the large shift between 3-3.5 years seen in the combined sample (Figure 8-10). Both individuals have a decline of slightly over 0.5‰ between 1 and 2 years of age, followed by an increase of 1-2‰ between 2 and 3 years of age, after which the values level off, as with N1, or decline again, as seen in T2. Individuals K2 also had a decline in $\delta^{13}C_{enamel\_ap}$ between 3 and 5 years of age that somewhat mirrors N1 and T2. The change observed between age at tissue formation by individual was not significant and did not demonstrate a statistically significant patten based on a Kruskal Wallis H test (H=5.535, df=4, p=0.237).

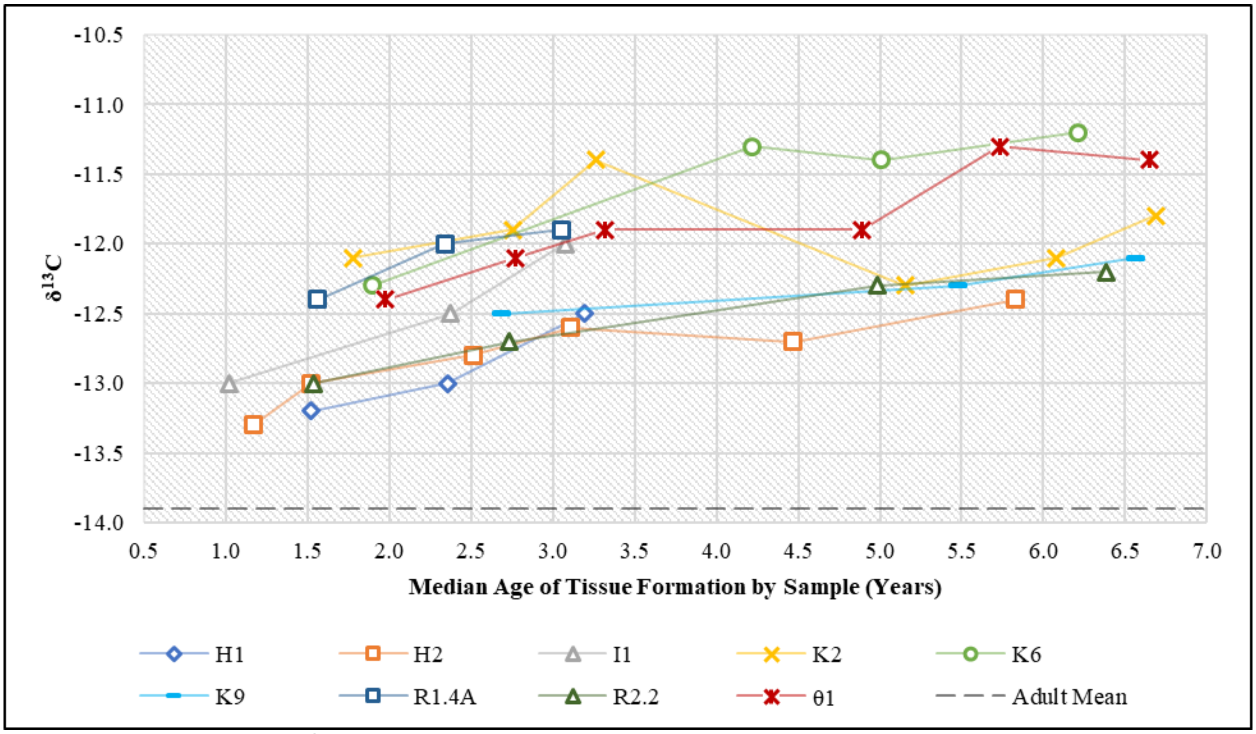

Figure 8-9. Incremental $\delta^{13}C_{enamel\_ap}$ values by age for Khirbet Qazone majority pattern plotted in relation to the adult $\delta^{13}C_{bone\_ap}$ mean value.

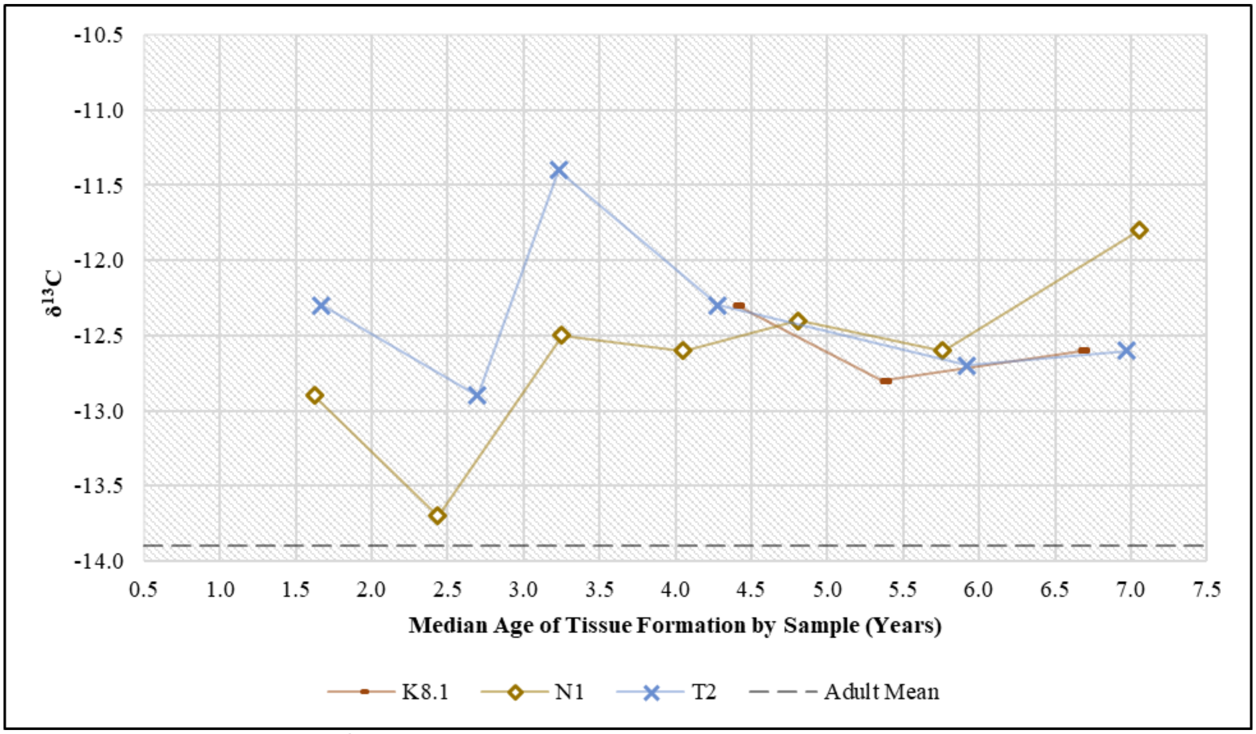

Figure 8-10. Incremental $\delta^{13}C_{enamel\_ap}$ values for Khirbet Qazone pattern 2 plotted in relation to the adult $\delta^{13}C_{bone\_ap}$ mean value.

Zabayir Carbon Incremental Tooth Enamel Samples

Intra-tooth sampling for Zabayir yielded eight individuals with three or more sequential samples for $\delta^{13}C_{enamel\_ap}$ analysis (Table 8-17; Table 8-19). The samples included $\delta^{13}C_{enamel\_ap}$ values for the eight individuals between 1 and 7 years of age that ranged from -12.10‰ to -9.20‰ with a mean of -11.60 ± 0.54‰. The combined $\delta^{13}C_{enamel\_ap}$ values from the site had a similar, although slightly smaller increase in $\delta^{13}C_{enamel\_ap}$ at 3-3.5 years, and childhood dental enamel values higher on average than adult bone apatite $\delta^{13}C$ (U=709, p=0.000; Table 8-19; Figure 8-11). Again, this difference could be diet-related or influenced by carbon isotope uptake in the two tissue types.

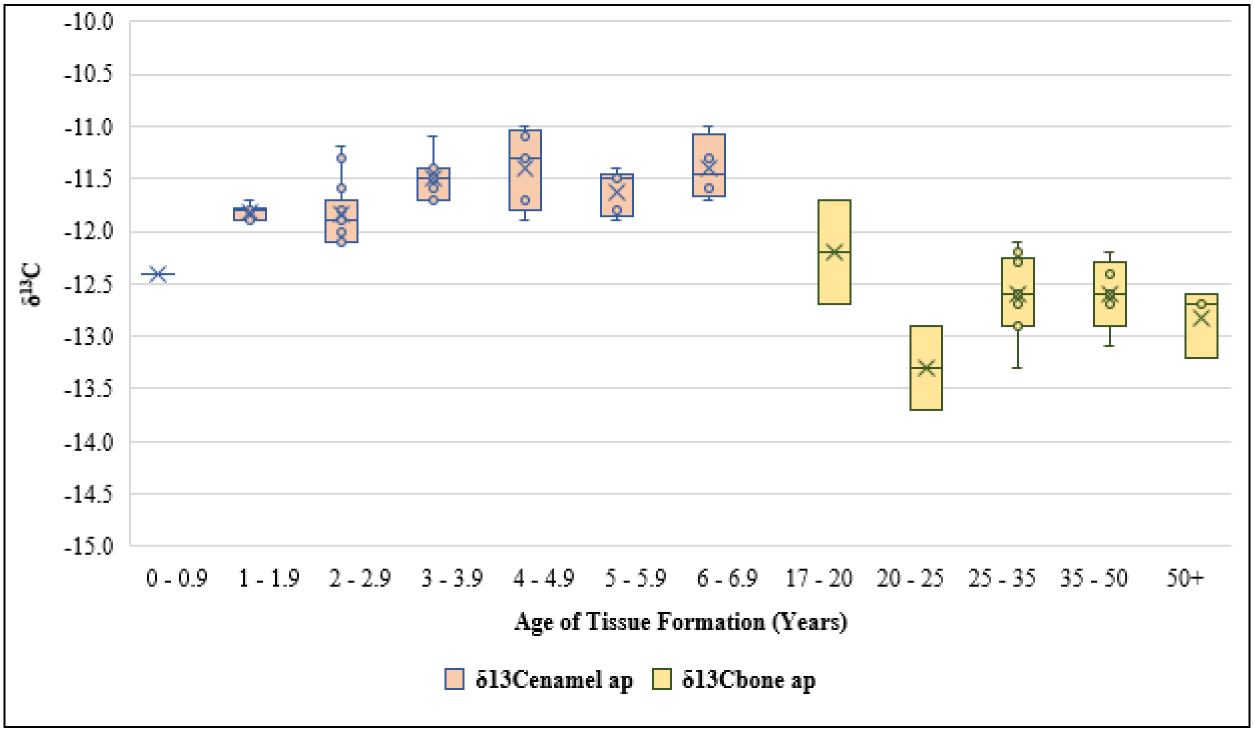

Figure 8-11. Incremental $\delta^{13}C_{enamel\_ap}$ values and $\delta^{13}C_{bone\_ap}$ values from Zabayir. Abbreviations: X=mean value and dots indicate outliers.

When the data were examined by individual, two distinct patterns were identified. Most of the individuals have an increase in $\delta^{13}C_{enamel\_ap}$ until 2.5 to 3 years, after which some have a decline and others a more gradual increase (Figure 8-12). Two individuals (Skeletons R-71 and R-89/98/97

MA[8]) demonstrated a decrease in $\delta^{13}C_{enamel\_ap}$ values until around 2.5 years followed by a gradual increase in ^{13}C throughout the remainder of childhood (Figure 8-12). R-89/98/97 (YA) demonstrated a unique spike in the $\delta^{13}C_{enamel\_ap}$ data between 4 and 4.5 years of age, 1.9‰ higher than the mean value of all enamel tissues formed during this period (Figure 8-13). While this could be the result of a sampling error, it is also possible that this may indicate a period of illness or intense stress, which has been shown to affect $\delta^{15}N$ and $\delta^{13}C$ from collagen (King et al. 2018, Beaumont et al. 2015). This individual also had six LEHs, four of which occurred between 3 and 4.9 years of age, or the period represented by this higher $\delta^{13}C_{enamel\_ap}$ value; the other two occurred just after this period between 5 and 5.9 years of age. Aside from this spike, $\delta^{13}C_{enamel\_ap}$ values for this individual during tooth formation are consistent with the other individuals from this population, including a slight decrease in $\delta^{13}C_{enamel\_ap}$ between 2.5 and 3 years of age. This may indicate for some individuals; the age of 2.5 to 3.0 years represents an important dietary shift to either to more C_4 contribution or in some varied levels of decline in C_4 sources in the diet. Two other individuals had $\delta^{13}C_{enamel\_ap}$ values that remained relatively consistent throughout childhood (Figure 8-14). No significant difference was observed between mean $\delta^{13}C_{enamel\_ap}$ values by age of tissue formation based on a Kruskal Wallis H test (H=4.998, df=3, p=0.172).

[8] R-89/98/97 is a mixed context containing at least 3 individuals (listed in Table A-2 as R-89/1, R-89/2, and R-89/3). Two of these individuals could not be aged more precisely than age cohort 12 or adult. The dentition of these individuals was separated based upon dental development and wear to assign them a general age. YA=young adult, MA=middle adult, and OA=old adult.

Table 8-19. Zabayir intra-tooth sample descriptive statistics by age of enamel formation.

Age	Isotope	N	Minimum	Maximum	Mean	SD	Variance
<1 year	δ13C	—	—	—	—	—	—
	δ18O	—	—	—	—	—	—
1 – 1.9 years	δ13C	7	-11.90	-11.40	-11.76	0.17	0.03
	δ18O	7	-3.30	-1.20	-2.23	0.72	0.52
2 – 2.9 years	δ13C	8	-12.10	-11.20	-11.80	0.38	0.14
	δ18O	8	-2.90	-1.30	-2.04	0.59	0.35
3 – 3.9 years	δ13C	3	-11.50	-11.40	-11.47	0.06	0.01
	δ18O	3	-3.00	-2.20	-2.63	0.40	0.16
4 – 4.9 years	δ13C	5	-11.90	-9.20	-11.10	1.08	1.16
	δ18O	5	-3.10	-1.60	-2.42	0.59	0.35
5 – 5.9 years	δ13C	3	-11.80	-11.50	-11.60	0.17	0.30
	δ18O	3	-3.40	-1.60	-2.67	0.95	0.89
6 – 6.9 years	δ13C	4	-11.70	-11.00	-11.40	0.32	0.10
	δ18O	4	-3.40	-1.20	-2.50	0.93	0.87
7 – 7.9 years	δ13C	—	—	—	—	—	—
	δ18O	—	—	—	—	—	—
17 – 20 years	δ13C	2	-12.70	-11.70	-12.20	0.71	0.50
	δ18O	2	-1.60	-1.30	-1.45	0.21	0.05
20 – 25 years	δ13C	2	-13.70	-12.9	-13.30	0.57	0.32
	δ18O	2	-1.90	-1.50	-1.70	0.28	0.08
25 – 35 years	δ13C	9	-13.30	-12.10	-12.59	0.40	0.16
	δ18O	9	-2.90	-1.50	-2.28	0.48	0.23
35 – 50 years	δ13C	5	-13.10	-12.20	-12.60	0.34	0.12
	δ18O	5	-3.00	-1.70	-2.40	0.51	0.27
50 + years	δ13C	3	-13.20	-12.60	-12.83	0.32	0.10
	δ18O	3	-2.40	-1.90	-2.13	0.25	0.06

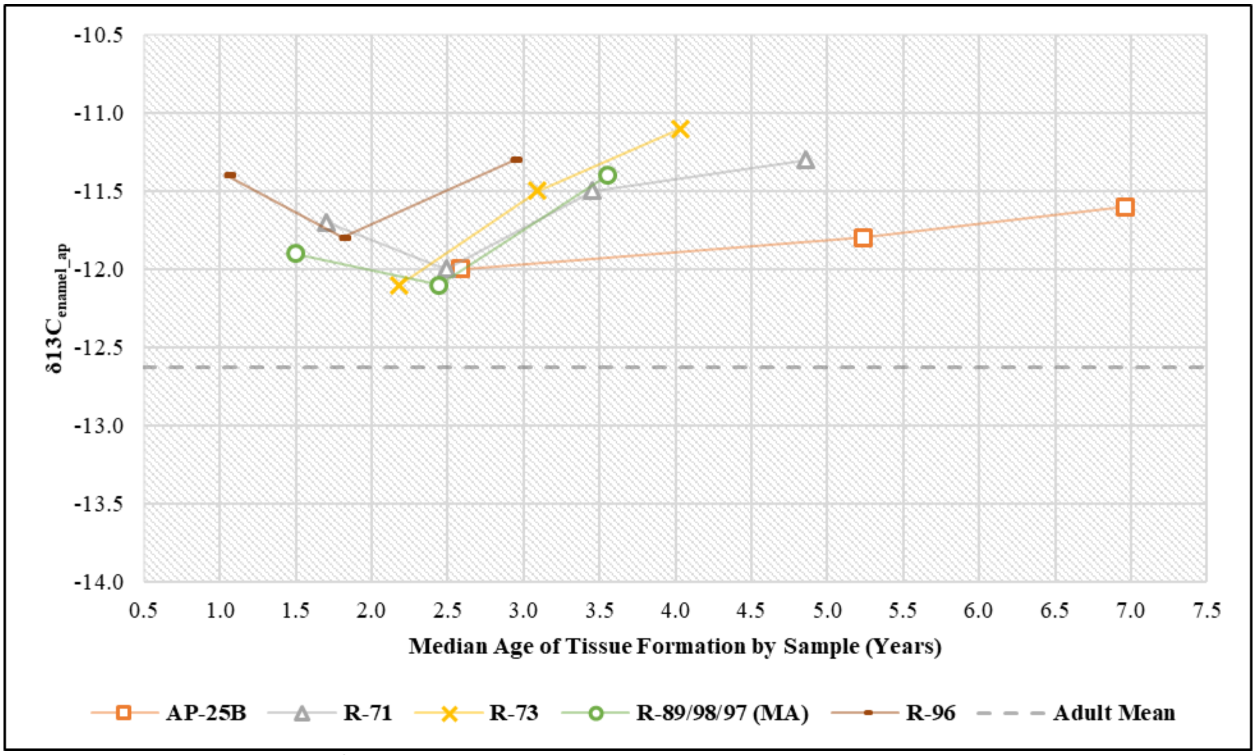

Figure 8-12. Incremental $\delta^{13}C_{enamel\_ap}$ values by age showing pattern 1 at Zabayir plotted in relation to the adult $\delta^{13}C_{bone\_ap}$ mean value.

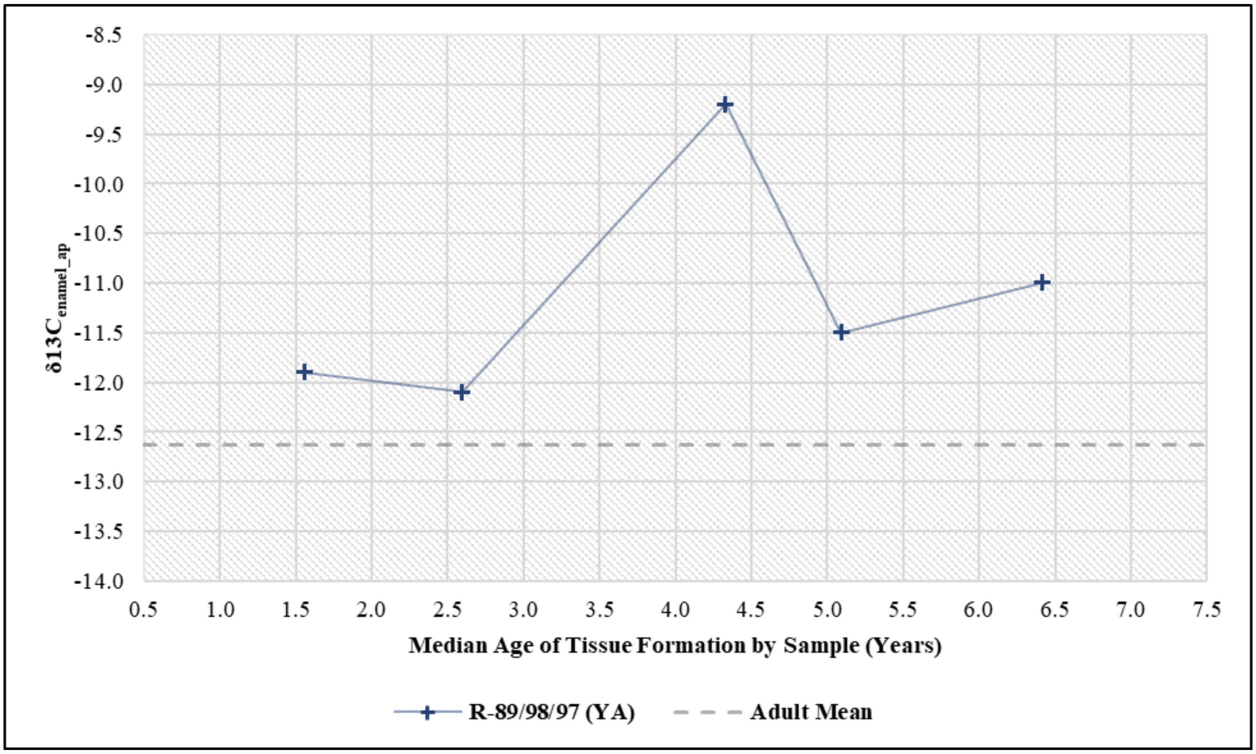

Figure 8-13. Incremental $\delta^{13}C_{enamale\_ap}$ values by age showing R-89/98/97 (YA) pattern at Zabayir plotted in relation to the adult $\delta^{13}C_{bone\_ap}$ mean value.

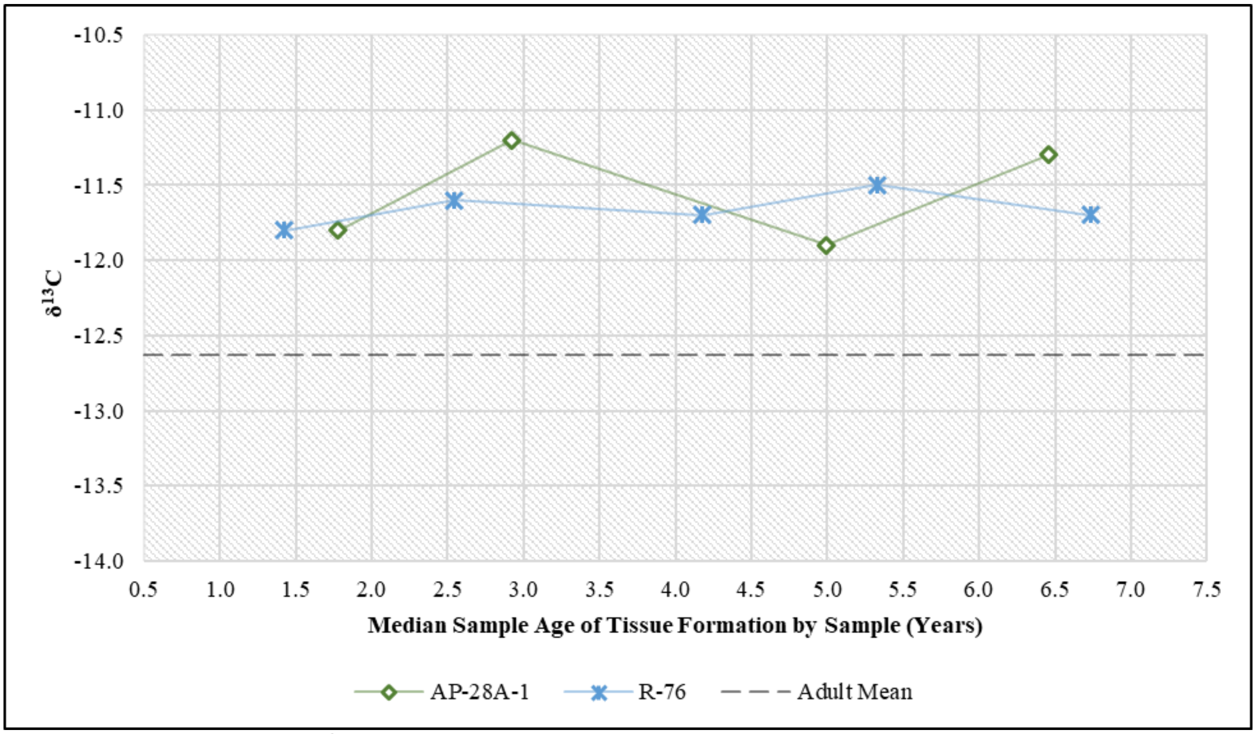

Figure 8-14. Incremental $\delta^{13}C_{enamale\_ap}$ values by age showing other patterns at Zabayir plotted in relation to the adult $\delta^{13}C_{bone\_ap}$ mean value.

8.2.3 Oxygen Isotope Analysis

Oxygen from Bone Carbonate

Twenty-four Khirbet Qazone and 28 Zabayir skeletons from age cohorts 7-12 (17 – 50 + years of age), which provide information regarding water source and/or human or natural alterations to water during adulthood. $\Delta^{18}O_{bone\_ap}$ values for Khirbet Qazone ranged from -2.00‰ to 3.80‰ with a mean value of -0.35 ± 1.71‰ (Table 8-15). Two individuals, Skeleton K7 and M2, were particularly unique when compared with other individuals in the data. Skeleton K7's $\delta^{18}O_{bone\_ap}$ value was 3.35‰ higher than the mean for the population; however, $\delta^{13}C_{enamel\_coll}$ and $\delta^{15}N_{enamel\_coll}$, and $\delta^{13}C_{bone\_ap}$ values also differed noticeably from the population mean. Skeleton M2 had a $\delta^{18}O_{bone\_ap}$ value 4.15‰ higher than the population mean, but $\delta^{13}C_{bone\_ap}$ values for this individual were consistent with the other members of the population. Skeleton M2's skull was not present for examination, but K7 did not have CO, PH, or LEH, however, LEH was difficult to score for this individual due to high ATML and wear. For Zabayir $\delta^{18}O_{bone\_ap}$ sample values were between -3.00‰ to -1.00‰ with a mean of -2.12‰ ± 0.54‰, significantly lower than the individuals from Khirbet Qazone (Figure 8-15; Table 8-16). $\Delta^{18}O_{bone\_ap}$ values were more widely distributed for Khirbet Qazone while Zabayir showed very low variability among individuals (Figure 8-15).

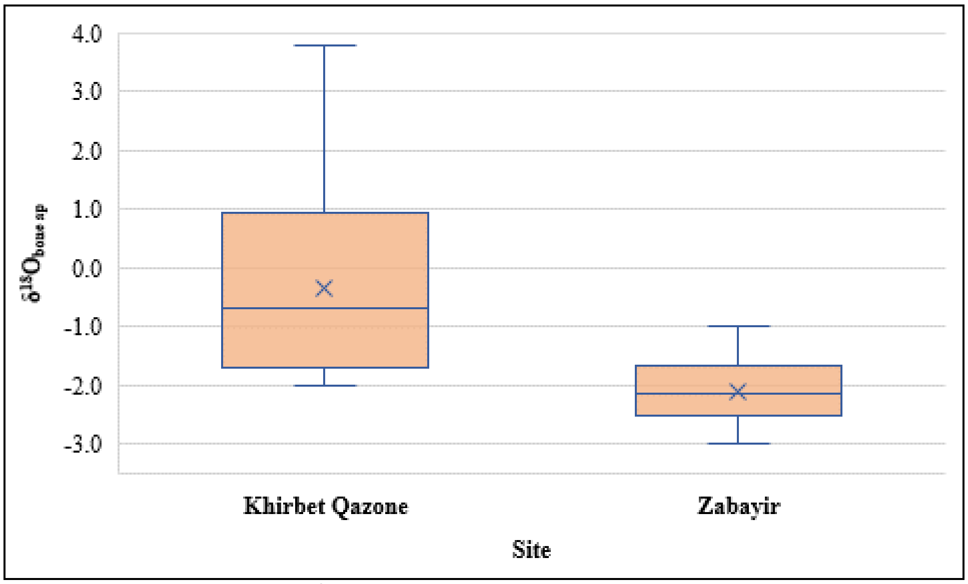

Figure 8-15. $\delta^{18}O_{bone\_ap}$ values from bone carbonate by site. Abbreviations: x=mean value.

Khirbet Qazone Oxygen Incremental Tooth Enamel Samples

Twelve individuals from Khirbet Qazone with three or more enamel samples representing different periods throughout childhood were examined for $\delta^{18}O_{enamel\_ap}$ (Table 8-17; Table 8-18). The samples included $\delta^{18}O_{enamel\_ap}$ ratios for the 12 individuals represent values between 1 and 7.5 years of age that ranged from -2.90‰ to 4.60‰ with a mean of -0.90 ± 1.50‰. The data showed a wide distribution in the $\delta^{18}O_{enamel\_ap}$ values for each age group representing enamel formation from 1-7.9 years of age (Table 8-17; Table 8-18; Figure 8-16). When all samples were examined by age at tissue formation for each individual, the mean $\delta^{18}O_{enamel\_ap}$ values in tissues forming between 1 and 5.9 years of age hover between -1.0 and -2.0 (Figure 8-17; Figure 8-18). The wide range of variation demonstrated between 1 and 1.9 years may indicate individualized differences in weaning and/or differences in the preparation of weaning foods since boiling has been shown to result in ^{18}O enrichment (Tuross et al. 2017, Brettell, Montgomery, and Evans 2012).

The individual-level isotope patterns by age of enamel formation show seven out of 12 individuals are driving the overall pattern of only slight shifts in $\delta^{18}O_{enamel\_ap}$ with age (Figure 8-17). Five other individuals showed slightly different patterns (Figure 8-18). One individual, T2, had a sharp increase in $\delta^{18}O_{enamel\_ap}$ of approximately 2.0‰ at 2.5 years of age followed by a similar decrease. The $\delta^{18}O_{enamel\_ap}$ values of individual K6 decline a little over 2.5‰ between the ages of 1.75 and 4.25 years of age. N1, R1.4A, and Θ1 also have a decline in $\delta^{18}O_{enamel\_ap}$ in childhood, although for a shorter duration than K6 (Figure 8-18). Individual Θ1 overall has much higher childhood $\delta^{18}O_{enamel\_ap}$ than the other individuals from Khirbet Qazone, which may indicate their childhood was spent in a region characterized by meteorological water more depleted in ^{18}O. Many individuals buried at Qazone show a rise in $\delta^{18}O_{enamel\_ap}$ starting around 5 years of age (Figure 8-17; Figure 8-18). $\Delta^{18}O_{enamel\_ap}$ did not differ significantly by age of tissue formation based on a Kruskal Wallis H test ($H=5.461$, $df=8$, $p=0.707$). Subadult $\delta^{18}O_{enamel\_ap}$ values were not significantly different from adult values of the isotope extracted from bone apatite ($U=410.50$, $p=0.098$).

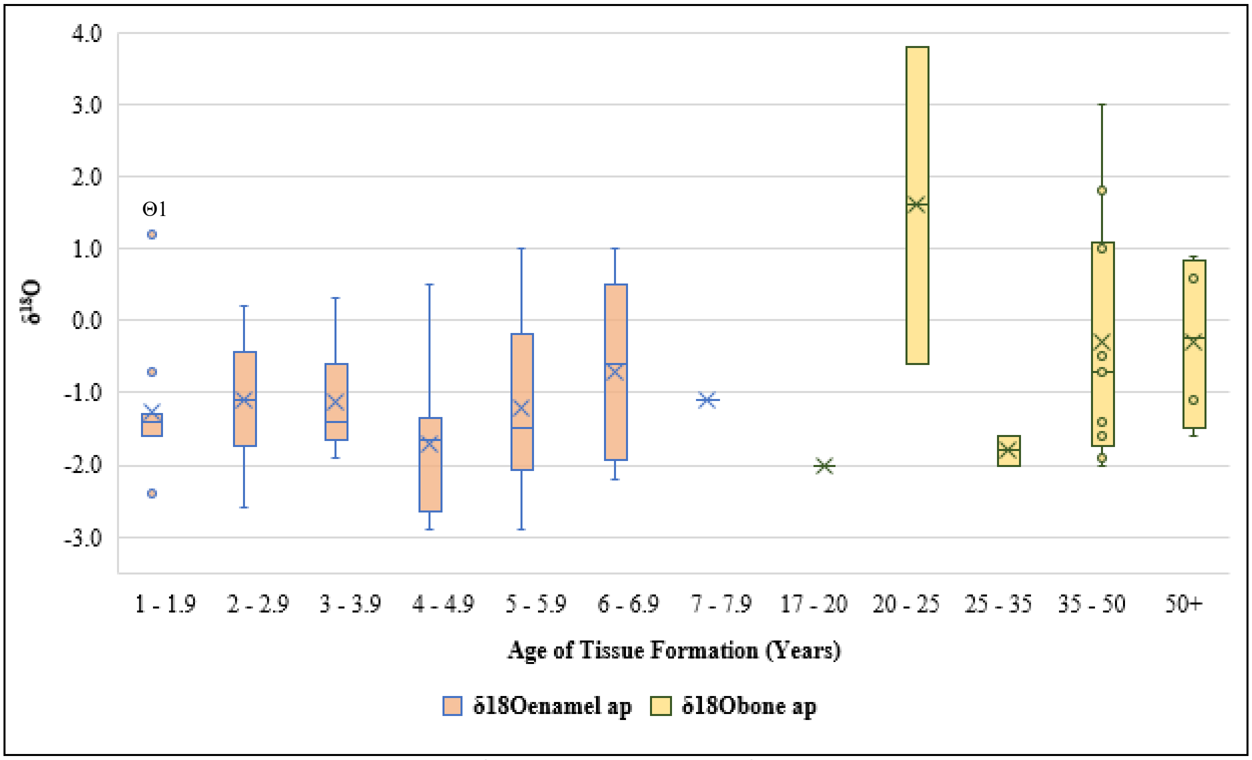

Figure 8-16. Incremental $\delta^{18}O_{enamel\_ap}$ values and $\delta^{18}O_{bone\_ap}$ values from Zabayir. Abbreviations: X=mean value and dots indicate outliers.

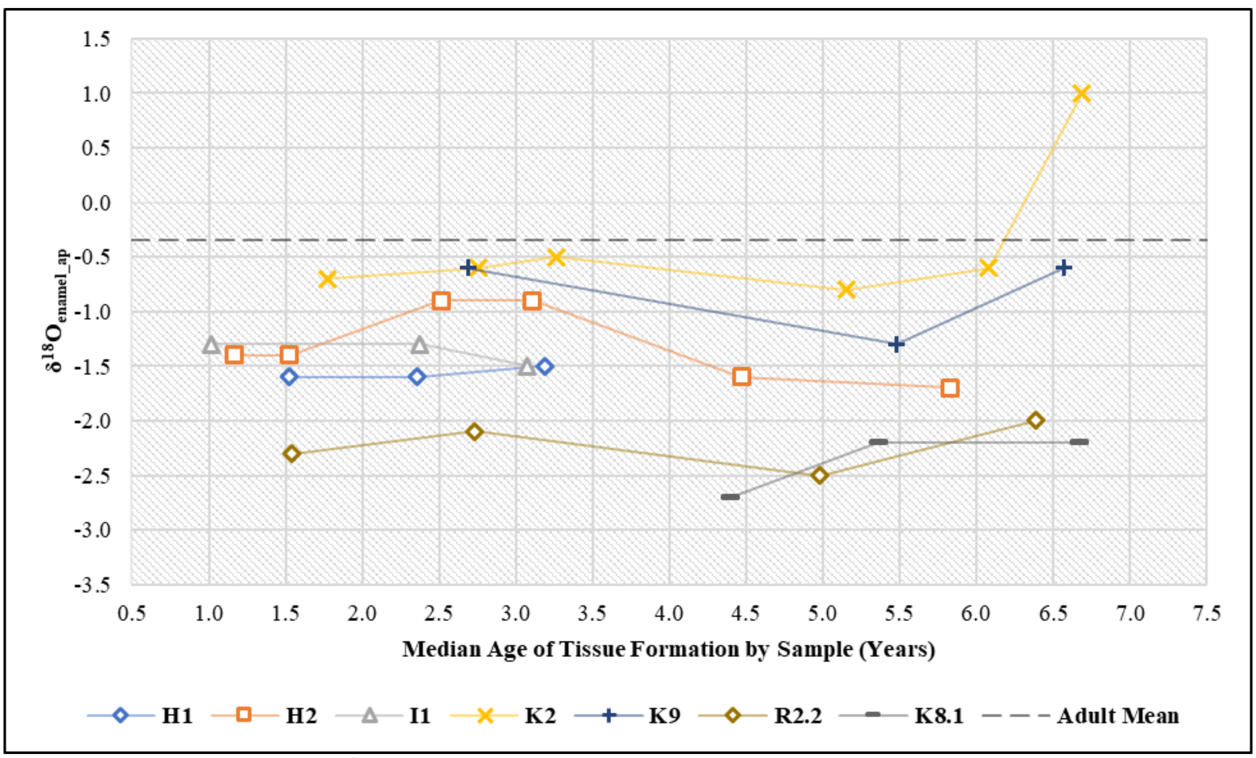

Figure 8-17. Incremental $\delta^{18}O_{enamel\_ap}$ values by age showing other patterns at Khirbet Qazone plotted in relation to the adult $\delta^{18}O_{bone\_ap}$ mean value.

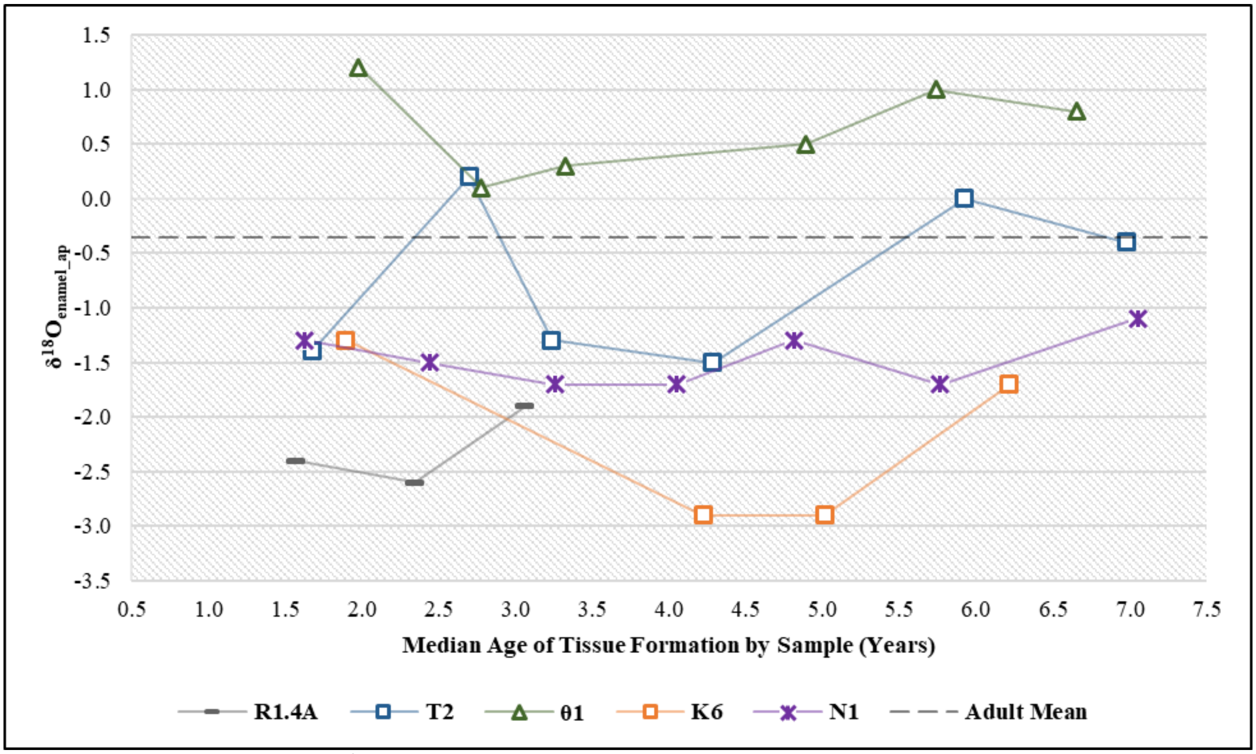

Figure 8-18. Incremental $\delta^{18}O_{enamel\_ap}$ values by age showing other patterns at Khirbet Qazone plotted in relation to the adult $\delta^{18}O_{bone\_ap}$ mean value.

Zabayir Oxygen Incremental Tooth Enamel Samples

Eight individuals at Zabayir with three or more samples representing different periods through childhood were examined for $\delta^{18}O_{enamel\_ap}$ (Table 8-17; Table 8-19). The samples included $\delta^{18}O_{enamel\_ap}$ values for the eight individuals representing periods between 1 and 7 years of age that ranged from -3.40‰ to -1.2‰ with a mean of -2.40 ± 0.67‰. Except for birth to 0.9 years of age, $\delta^{18}O_{enamel\_ap}$ values at Zabayir are rather homogeneous throughout childhood, with mean values ranging between -2.0 and -2.5‰ until 6.9 years and little change in the level of variation between ages (Table 8-19; Figure 8-19). Most of the individuals have a decline in $\delta^{18}O_{enamel\_ap}$ values until anywhere between 2 and 5 years of age, which may represent a prolonged weaning process but possibly other factors such as food preparation techniques or the use of different water sources (Figure 8-20). Three individuals, AP-28A-1, R-73, and to some extent R-89/98/97 (MA) have a short decline before 3 years of age followed by a sharp increase during the following year, however tissues developing later in childhood are unavailable to place this early pattern into context (Figure 8-21). The variation of $\delta^{18}O_{enamel\_ap}$ across age at tissue formation was also not significantly different based on a Kruskal Wallis H test (H=1.386, df=4, p=0.847). Intra-tooth $\delta^{18}O_{enamel\_ap}$ values for the individuals at Zabayir were not significantly different from values observed in adult bone apatite (Mann Whitney: U=305, p=0.162) (Table 8-19).

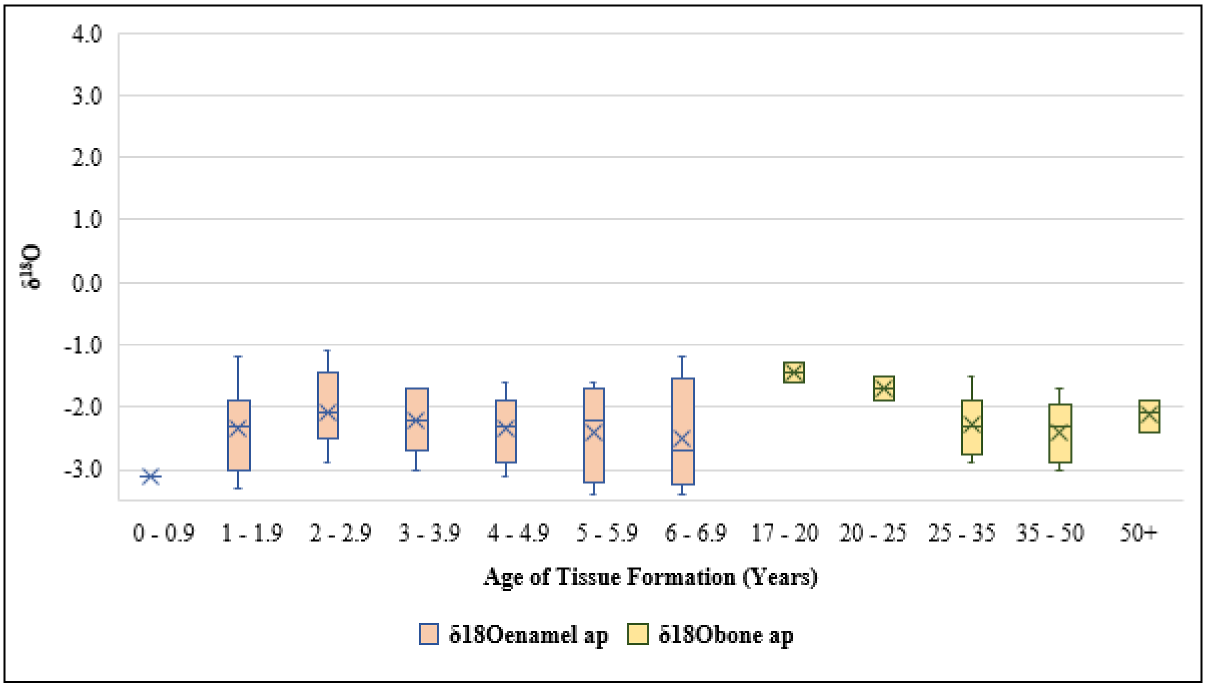

Figure 8-19. Incremental $\delta^{18}O_{enamel\_ap}$ values and $\delta^{18}O_{bone\_ap}$ values from Zabayir. Abbreviations: X=mean value and dots indicate outliers.

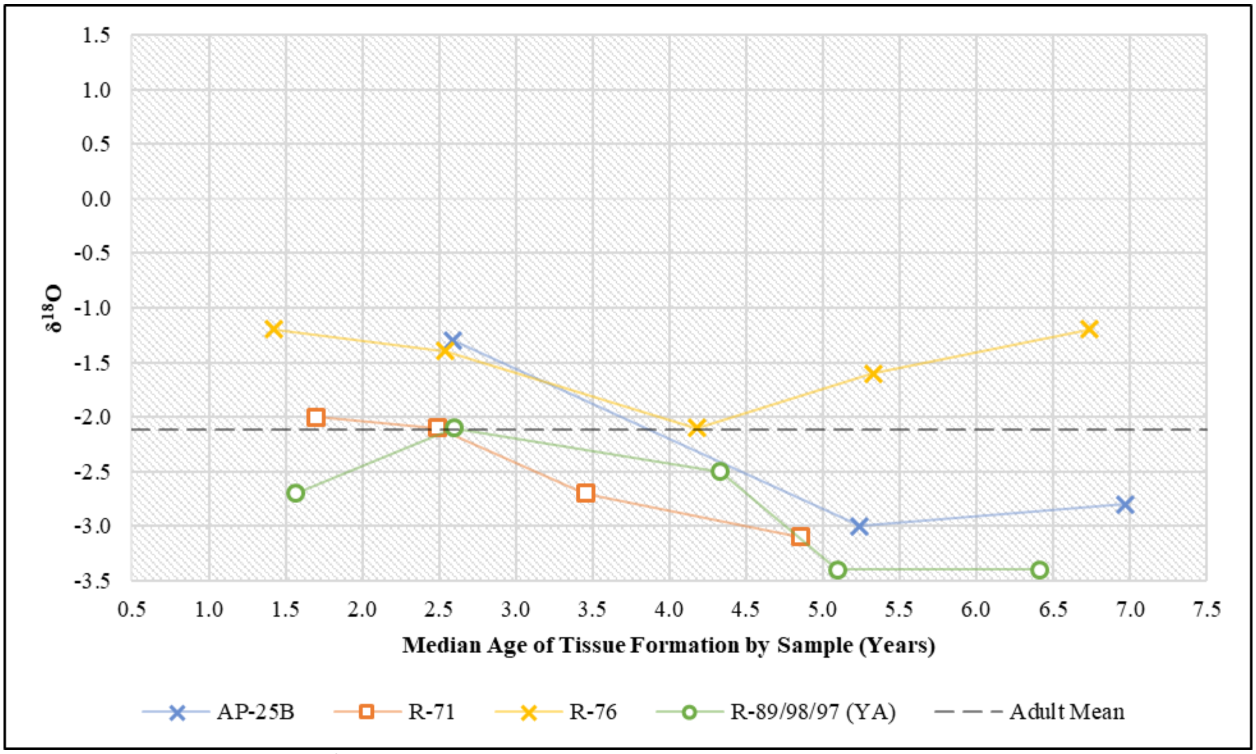

Figure 8-20. Incremental $\delta^{18}O_{enamel\_ap}$ values by age showing other patterns at Zabayir plotted in relation to the adult $\delta^{18}O_{bone\_ap}$ mean value.

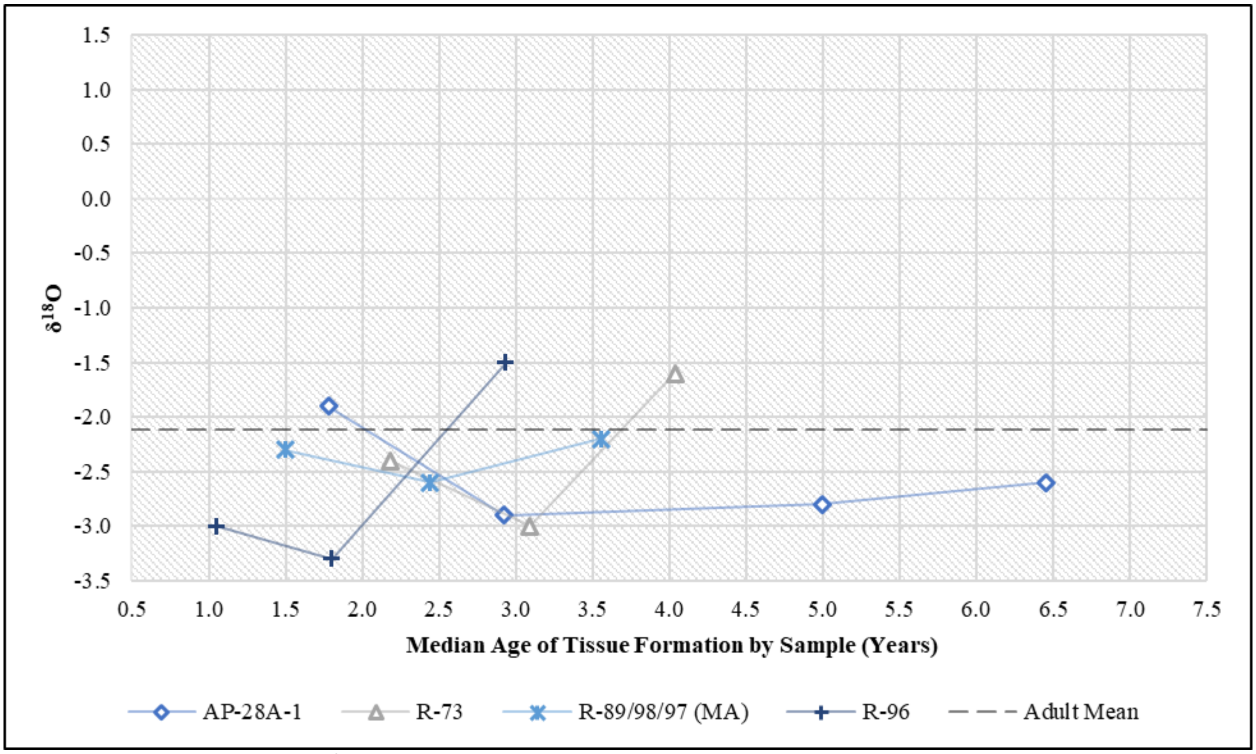

Figure 8-21. Incremental $\delta^{18}O_{enamel\_ap}$ values by age showing other patterns at Zabayir plotted in relation to the adult $\delta^{18}O_{bone\_ap}$ mean value.

8.2.4 Isotope Analysis Discussion

Diet

The combined $\delta^{13}C$ and $\delta^{15}N$ values from dentine collagen as well as the $\delta^{13}C$ and $\delta^{18}O$ ratios from bone apatite and incremental tooth enamel showed that the diets at Khirbet Qazone and Zabayir were generally consistent with archaeological and isotopic data in the region, however, important differences emerged between the two communities. Archaeological data corroborate the preferential cultivation of C_3 resources in the region, such as wheat and barley (Ramsay and Smith 2013, Ramsay and Bedal 2015, Ramsay and Parker 2016, Tholbecq, Durand, and Bouchaud 2008). While some C_4 plants like millet appear in paleobotanical samples from several sites, they generally comprise a much smaller proportion of the assemblage (Ramsay and Parker 2016, Ramsay and Smith 2013, Perry et al. 2013). Sheep/goat was documented as the primary protein resource at Petra, but other animals such as chickens and pigs were also consumed, and marine and freshwater fish have been documented in the region as well (Studer 2007). Studies of dung fuel also suggest that barley (C_3) was a primary source of fodder for domesticated animals along with wild grasses (Ramsay and Smith 2013, Ramsay and Parker 2016). However, a recent study by Vaiglova et al. (2020) examining faunal remains from the Negev desert determined that the diets of grazing sheep/goat included both C_3 and C_4 resources and that C_3/C_4 plant consumption varied seasonally based upon the ecological patterns of available wild plants.

The $\delta^{13}C_{dentine\_coll}$ or $\delta^{15}N_{dentine\_coll}$ values for Khirbet Qazone and Zabayir were not significantly different, which suggests that children from both sites consumed protein sources with a strong C_3 component (Table 8-13; Figure 8-22). The isotope data accord well with the archaeological data for dietary resources presumably available to residents at both sites. Assuming calculated dietary values are accurate in this environment, and that dentine collagen is directly comparable to bone collagen, the protein sources at both sites were terrestrial animals that fed mostly on C_3 dietary sources (Vaiglova et al. 2020, Tykot 2004) (Table 8-11; Figure 8-23; Figure 8-24). These calculated values representing dietary sources are similar to isotope values from sheep/goats, chickens, and pigs from Nabataean and Roman Petra ($\delta^{13}C_{bone\_coll}$ $\bar{X}$ = -18.33 ± 0.48‰; $\delta^{15}N_{bone\_coll}$ $\bar{X}$ = 9.46 ± 1.55‰) (Appleton 2015). he data from Petra demonstrated that animals at the site were primarily C_3 plant consumers (Appleton 2015), which indicates that urban grazing practices may have focused on gleaning from harvested agricultural fields, where C_3 crops were a focal cultivar, or provisioning animals with fodder from C_3 resources. However, data for sheep and goats from the Negev ($\delta^{13}C_{dentine\_coll}$ $\bar{X}$ = -16.40 ± 1.50‰; $\delta^{15}N_{dentine\_coll}$ $\bar{X}$ = 10.6 ± 1.20‰; $\delta^{13}C_{bone\_coll}$ $\bar{X}$ = -17.20 ± 1.10‰; $\delta^{15}N_{bone\_coll}$ $\bar{X}$ = 8.2 ± 0.60‰) demonstrated a greater contribution of C_4 sources from seasonal grazing (Vaiglova et al. 2020). Another study from Northern Jordan comparing Bronze Age and Late Roman/Byzantine sheep/goat and human $\delta^{13}C_{bone\_coll}$ or $\delta^{15}N_{bone\_coll}$ values noted greater variation and higher $\delta^{13}C_{bone\_coll}$ values among earlier animal samples, which were interpreted as evidence for changes in animal herding through time with earlier periods engaging in more transhumant practices that would have incorporated a larger proportion of semi-arid or C_4 plant resources (Sandias and Muldner 2015). Similarly, isotopic studies at other Roman and Byzantine sites reinforce the importance of C_3 resources, such as wheat and barley, throughout the area of modern Jordan and Israel during these periods (Gregoricka, Sheridan, and Schirtzinger 2017, Al-Bashaireh et al. 2010, Gregoricka and Sheridan 2012, Sandias and Muldner 2015).

The $\delta^{15}N_{dentine\_coll}$ and $\delta^{13}C_{dentine\_coll}$ values from dentin in the third molars, which generally start forming at 7.5 years of age and continue until about age 23.5 (AlQahtani, Hector, and

Liversidge 2010), demonstrated that older children and young adults from Zabayir consumed proteins derived primarily from C_3 plant resources, perhaps with some C_4 contributions, or terrestrial animals that grazed primarily on a mixed diet of C_3 and C_4 resources. The higher $\delta^{13}C_{dentine\_coll}$ value from third molars indicated that proteins consumed by individuals at Zabayir post-weaning included more C_4 sources than those consumed by younger children, whose diet was represented by slightly lower first and second molar mean values. The lack of sampled third molars and the low collagen yields from adult bone samples from the Khirbet Qazone population prevents examination of the diets of older children and young adults from $\delta^{15}N_{enamel\_coll}$ and $\delta^{13}C_{enamel\_coll}$, however, bone and enamel apatite values are discussed below.

The similar rate of dental calculus present at Khirbet Qazone and Zabayir also suggests comparable levels of protein consumption between the two communities. Dental calculus rates, however, should be interpreted with caution as a variety of conditions can contribute to its presence in archaeological samples, including skeletal preservation, which was overall much poorer for the Zabayir sample (Lieverse 1999). Dental calculus is more frequently observed in proximity to salivary ducts on the lingual surfaces of incisors and canines and the buccal surface of the upper molars (Hillson 2005). The overall preservation of these teeth, particularly the incisors, differed between the two sites (Table B-5), which may have contributed to the similarity observed between individuals. AMTL, which reflects the culmination of dental attrition through dental disease, had a high crude prevalence at Khirbet Qazone and Zabayir, signifying that individuals at both sites were impacted heavily by dental attrition possibly the result of dental disease due to high carbohydrate consumption in their diets. However, a significantly greater occurrence of dental caries at Khirbet Qazone accords well with rates for other Nabataean sites and implies a richer consumption of carbohydrates among the agricultural population in line with other sedentary

Nabataean communities (Lieurance 2018, Delhopital 2010). The consumption of *Lactobacillus sp.* In milk and dairy products has been shown to have a protective effect against the caries forming bacteria *Streptococcus mutans* and may contribute to lower caries rates in pastoral populations (Wasfi et al. 2018).

$\Delta^{13}C_{bone\_ap}$ also indicates that the primary carbohydrates consumed at both sites derived from C_3 plants. However, variation in $\delta^{13}C_{bone\_ap}$ at Khirbet Qazone and Zabayir indicates greater levels of individual variation at Khirbet Qazone (Table 8-16). Additionally, the Khirbet Qazone mean $\delta^{13}C_{bone\_ap}$ value (-13.90 ± 0.19‰) compared to the mean $\delta^{13}C_{bone\_ap}$ value (-12.63 ± 0.09‰) for Zabayir demonstrated a more ^{13}C-enriched diet at Khirbet Qazone. Values are comparable to the mean $\delta^{13}C_{bone\_ap}$ values at Petra (-12.89 ± 0.87‰) reported by Appleton (2015). If $\delta^{13}C_{bone\_ap}$ values are considered a proxy for agricultural investment, Khirbet Qazone, which demonstrated significantly more enriched $\delta^{13}C_{bone\_ap}$ values than Zabayir and a lower mean value than Petra may have had the greatest focus on agricultural development among the three populations, while Zabayir demonstrated the least.

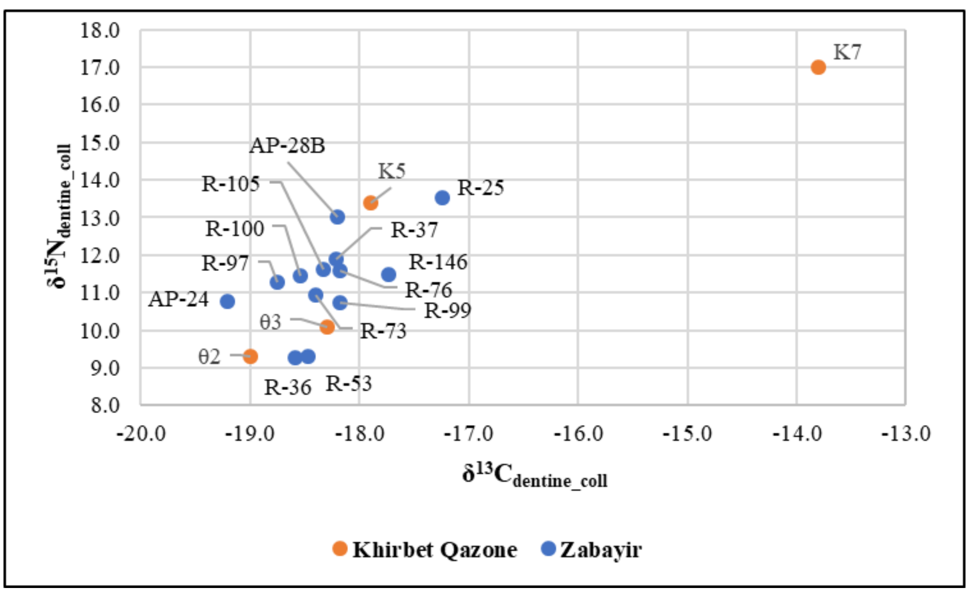

Figure 8-22. Collagen $\delta^{13}C_{dentine\_coll}$ and $\delta^{15}N_{dentine\_coll}$ values from dentine plotted by site.

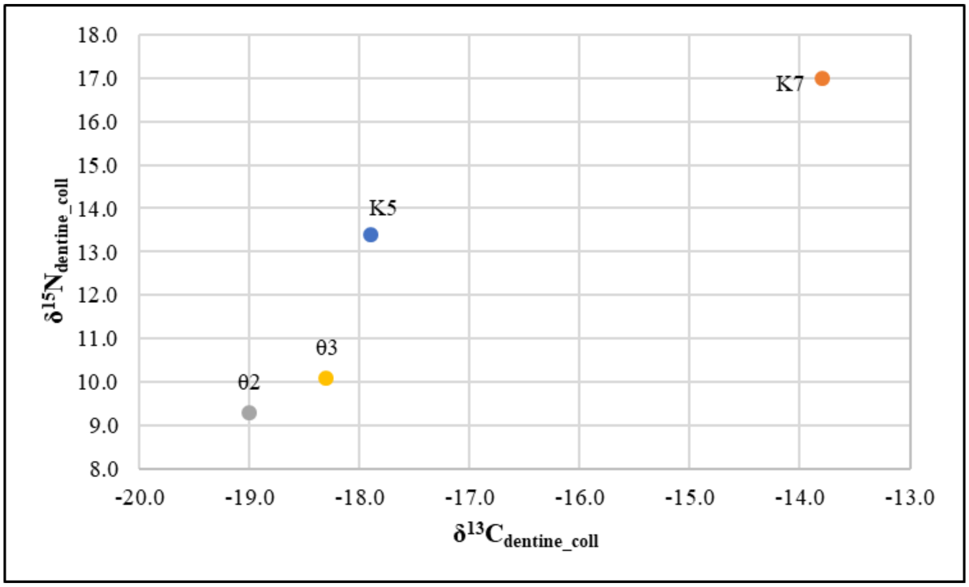

Figure 8-23. Khirbet Qazone dentine collagen values.

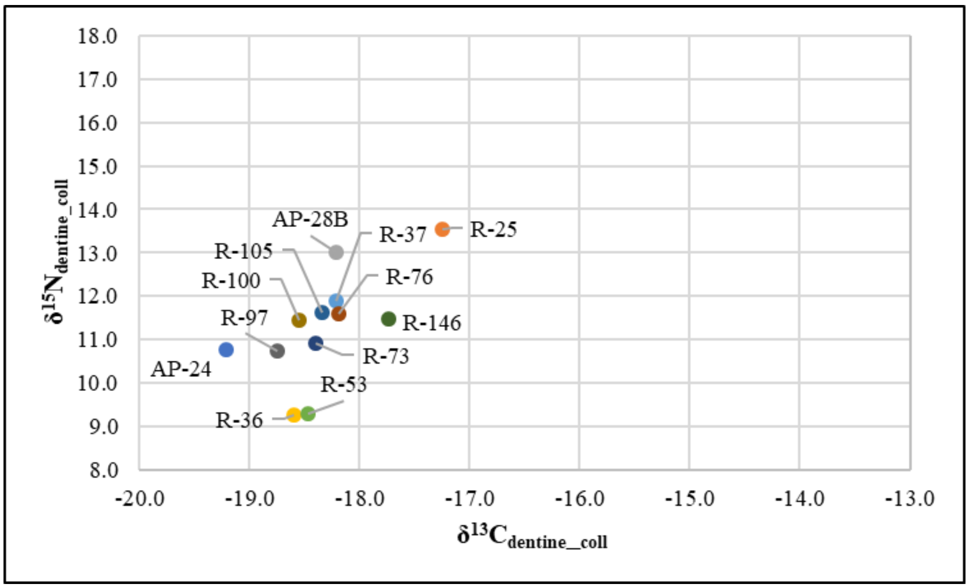

Figure 8-24. Zabayir dentine collagen values (data courtesy of Damien Huffer).

Isotope Variation between Sites: Mobility or Diversity in Cultural Practices

All isotopes measured demonstrated greater variance at Khirbet Qazone than Zabayir (Figure 8-25). This suggests that the diet at Khirbet Qazone was more variable by individual than that at Zabayir. Comparison of $\delta^{18}O_{bone\_ap}$ revealed a very tight cluster of values for Zabayir with a relatively wide distribution for Khirbet Qazone and the mean $\delta^{18}O_{bone\_ap}$ for Zabayir (-2.12 ±

0.11‰) is significantly depleted in ^{18}O compared to Khirbet Qazone (-0.35 ± 0.37‰) (Table 8-16). An examination of the individual $\delta^{13}C_{bone\_ap}$ and $\delta^{18}O_{bone\_ap}$ values at Khirbet Qazone revealed that while most individuals fell within a tight cluster, seven individuals showed greater variability in one or both values (Figure 8-26). Skeleton M2, an 18-24-year-old male, had notably higher $\delta^{18}O_{bone\_ap}$ than other members of the population, $\delta^{13}C_{bone\_ap}$ values were consistent with other members of the Khirbet Qazone population. Due to migration. For Skeleton M2 this suggests that while the overall dietary micronutrients for this individual were like the rest of the population and consisted primarily of C_3 food sources, their primary source of fluids or food preparation were different. All isotope values measured for Skeleton K7, a female aged 4-44 years at death, differed from the population mean indicating that this individual's diet was consistently dissimilar throughout childhood and most of their adult life.

Skeleton K7 from Khirbet Qazone had a canine with a $\delta^{15}N_{dentine\_coll}$ value and a $\delta^{13}C_{dentine\_coll}$ value over one standard deviation from the Khirbet Qazone means for these isotope ratios. Higher $\delta^{15}N_{dentine\_coll}$ are linked to more arid, hotter climates (Ambrose 1993), although Skeleton K7's $\delta^{15}N_{dentine\_coll}$ values were less negative than the other members of either Khirbet Qazone or Zabayir, suggesting that this might not fully explain the difference observed. The higher $\delta^{15}N_{dentine\_coll}$ may support possible marine or freshwater fish contributions to the diet or demonstrate that access to foods like *garum*, a preserved fish preparation (Table 8-11). (Tykot 2004, Ambrose 1993, Richards and Hedges 1999) Additionally, the lower $\delta^{13}C_{dentine\_coll}$ value for this individual compared to the site mean suggests that the sources of protein consumed may also have been derived from a non-terrestrial food web or sources with a much higher C_4 contribution than other members of the population at either site. Marine food resources may have a $\delta^{13}C$ value closer to C_4 plant resources due to lower fractionation involved in CO_2 photosynthesis by phytoplankton (Richards and Hedges 1999). Sandias (2011) examined marine fish from Ya'amun in northern Jordan and documented marine fish $\delta^{13}C_{bone\_coll}$ values ranging from -9.7‰ to -4.7‰ and $\delta^{15}N_{bone\_coll}$ values ranged from 8.2‰ to 12.6‰, which accord well with the dietary values of $\delta^{13}C_{dentine\_coll}$ and $\delta^{15}N_{dentine\_coll}$ values for Skeleton K7. The $\delta^{13}C_{bone\_ap}$ value for Skeleton K7 was also 2.7‰ higher than the population mean. Marine and freshwater fish have also been documented in archaeological contexts at Petra (Studer 2007). All identified marine fish species found at the site were native to the Red Sea, including tuna, mackerel, and emperors, which comprised a bulk of the identified fish (Studer 2007). However, the large difference in $\delta^{18}O_{bone\_ap}$, when considered in light of the other isotope data may indicate that this individual migrated to the site from elsewhere. In some studies, a difference of 2‰ in $\delta^{18}O$ has been attributed to migration since $^{16}O/^{18}O$ ratios vary geographically between water sources (Wright and Schwarcz 1998, Wright 2013, Kenoyer, Price, and Burton 2013). Future research examining strontium isotope data may help clarify the role of mobility in the lives of individuals like K7 and M2.

While mobility could contribute to the observed $\delta^{18}O_{bone\_ap}$ values for some individuals, variation throughout all age groups, including during childhood as represented by $\delta^{18}O_{enamel\_ap}$ values, points to variation in community water resources. Within the human body $\delta^{18}O$ values are impacted primarily by the overall consumption of water and preferential uptake of ^{18}O (Longinelli 1984, Luz, Kolodny, and Horowitz 1984). Meteoric water values can differ drastically by location and season and are affected by altitude, rainfall, temperature, and humidity, especially in arid environments where evaporation increases $\delta^{18}O$ values seasonally in natural aquifers as well as stored water (Gat and Dansgaard 1972, Daux et al. 2008, Tuross et al. 2017). Arid lakes have been shown to be enriched up to 15‰ in ^{18}O above meteoric water, which suggests that curated water sources like catchments and cisterns would also show large variation in $\delta^{18}O$ from meteoric water values based upon evaporation due to aridity, especially where rainfall is low (Horton et al. 2016).

The proportion of C_3 versus C_4 plants in the diet can also impact ^{18}O uptake since in arid environments $\delta^{18}O$ values can vary by up to 10‰ between C_3 versus C_4 plants (Leonel, Michael, and Hyrum 1984). Mixed C_3 versus C_4 feeders will have higher $\delta^{18}O$ values compared to primarily C_3 feeders (Hervé et al. 1996). Like environmental evaporation, food preparations involving boiling, dehydration, and fermentation may also increase $\delta^{18}O$ (Brettell, Montgomery, and Evans 2012). Cooking practices, which are commonly used to process agricultural food resources can increase $\delta^{18}O$ values in food and beverages by over 2‰ and simply boiling water can elevate $\delta^{18}O$ by 0.4‰ (Tuross et al. 2017, Brettell, Montgomery, and Evans 2012). Some individuals may have preferred cooking methods or brewed beverages that resulted in higher $\delta^{18}O$ values. Labneh, which is a condensed, fermented goat milk product consumed throughout the Middle East, was traditionally prepared by Bedouin through heavy salting and drying to create a desiccated, shelf-stable cheese (Zervas and Tiplakou 2013). Consumption of dehydrated proteins, like labneh, could also impact the $\delta^{18}O$ values in human bones and teeth since labneh is dehydrated and derived from milk, both of which would make labneh enriched in ^{18}O relative to meteoric water, although the extent of this type of food preparation on $\delta^{18}O$ values in bone has not been measured directly. Although mobility cannot be completely ruled out, the significant variation in $\delta^{18}O$ observed between adult individuals suggests that $\delta^{18}O$ values probably reflect the environmental effects of the arid Dead Sea environment and cultural practices such as the use of water cisterns as well as differences in food preparation and supplementation more than any other factor in this agricultural community. Future research incorporating strontium analysis could help support or clarify the role of mobility in the pattern of variation observed in the $\delta^{18}O_{bone\_ap}$ data.

At Zabayir, very little variation was observed in $\delta^{18}O_{bone\_ap}$ values, which suggests that the individuals were relatively less mobile than the traditional view of a semi-nomadic population might imply (Figure 8-27). In this case individuals would have to use the same water source and engaged in similar food preparation to achieve the variation observed in the $\delta^{18}O_{bone\_ap}$ values. However, if the population were engaged in seasonal mobility as a group, the entire population would be expected to demonstrate a range of $\delta^{18}O_{bone\_ap}$ values tightly clustered around the mean value for the water sources at seasonal sites. This agrees with strontium analysis conducted for the site by Perry (2002a), which also showed no significant variation among the sample.

The greater variability of $\delta^{18}O_{bone\_ap}$ values at Khirbet Qazone compared to Zabayir may also indicate differences in mobility between individuals within the two populations. The small amount of variance observed in the Zabayir group means that they likely engaged in movement as a community, while the variation between individuals a Khirbet Qazone would mean that mobility was more individualized and pervasive if $\delta^{18}O_{bone\_ap}$ were not affected by any other factors. In any case, the relatively high amounts of variation seen in $\delta^{18}O_{bone\_ap}$ values at Khirbet Qazone and low variance observed in $\delta^{18}O_{bone\_ap}$ values for Zabayir suggest that mobility, food preparation, and water procurement strategies were more individualized for the Khirbet Qazone population.

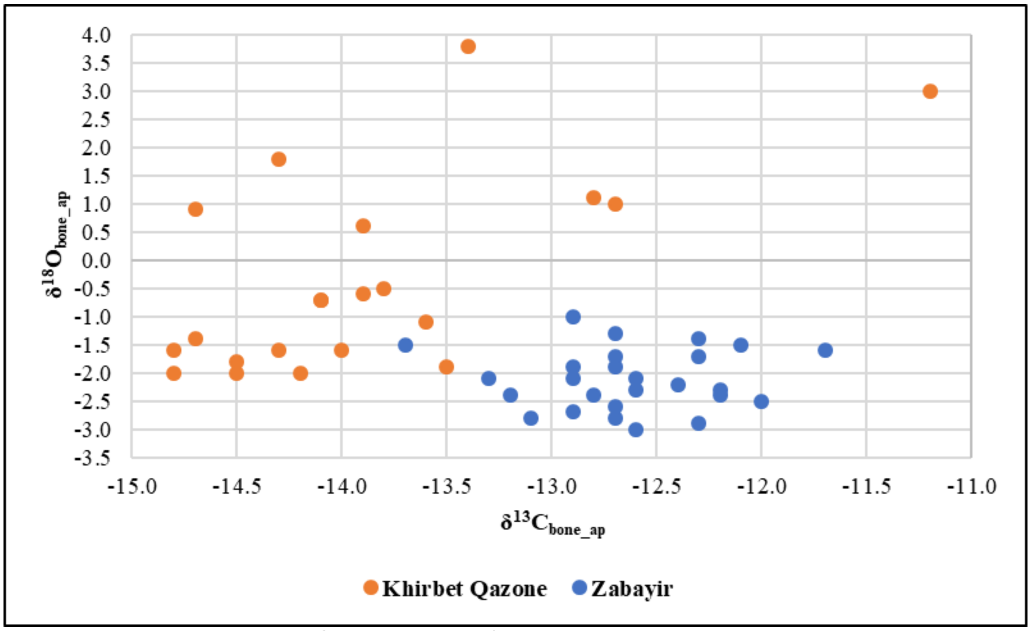

Figure 8-25. $\delta^{13}C_{bone\_ap}$ and $\delta^{18}O_{bone\_ap}$ value distribution by site.

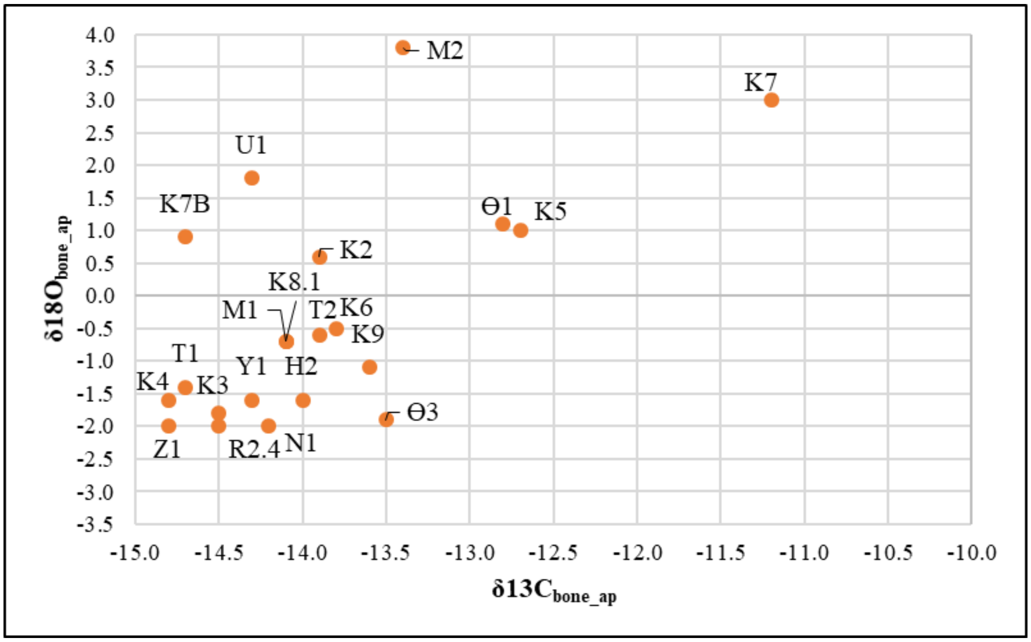

Figure 8-26. Khirbet Qazone $\delta^{13}C_{bone\_ap}$ and $\delta^{18}O_{bone\_ap}$ value distribution.

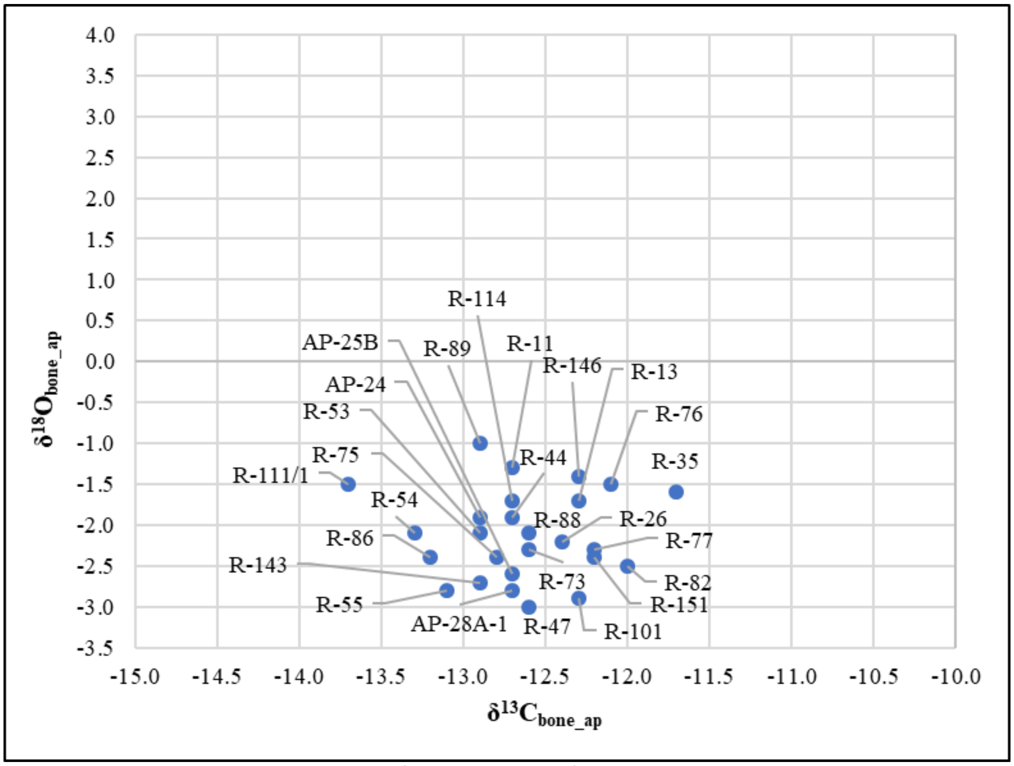

Figure 8-27. Zabayir $\delta^{13}C_{bone\_ap}$ and $\delta^{18}O_{bone\_ap}$ value distribution.

Discussion of Incremental Tooth Samples and Weaning

Incremental dental samples of $\delta^{18}O_{enamel\_ap}$ and $\delta^{13}C_{enamel\_ap}$ were used to examine childhood diet and identify a general timeframe for weaning cessation. Based upon generalized models of human weaning practices, it is likely that weaning, in terms of complementary food provisioning, began before 1 year of age (Sellen and Smay 2001, Sellen 2001a); however, the presence of only a single sample from Zabayir from the first year of life and no samples from the Khirbet Qazone population representing this period of development precluded the ability to document the initiation of weaning. The samples examined here likely reflect the period of solid and liquid food supplementation of breastmilk during weaning and the shift to mostly solid foods after weaning ceased (Humphrey 2014). It was expected that weaning (increasing food supplementation of breastmilk) would be indicated by a gradual decrease in $\delta^{18}O$ and either an increase or decrease in $\delta^{13}C$ depending upon the type of resources that were incorporated into the diet from complementary foods.

At Khirbet Qazone, three individuals demonstrated the predicted decrease in $\delta^{18}O_{enamel\_ap}$ between 1.5 and 3.5 years of age, while a majority showed a gradual increase or leveling off in $\delta^{18}O_{enamel\_ap}$ between 1.5 and 3.5 years of age with a later decrease in $\delta^{18}O$ occurring for most individuals between 4 and 6 years of age (Figure 8-17; Figure 8-18). Mean $\delta^{13}C_{enamel\_ap}$ values examined by age of tissue formation, showed an increase in $\delta^{13}C$ for individuals at Khirbet Qazone with age indicating that weaning was probably completed for most of the population between age 3 and 3.5 years of age. Taken together these data suggest that the timing of weaning varied within the population. While some individuals seem to have been weaned by 1.5 years of age, others likely continued to receive breast milk until 2-3.5 years of age.

The increase in $\delta^{18}O$ and $\delta^{13}C$ until about 3.5 years of age for many individuals may indicate that animal milk was a common weaning or post-weaning food for children. It is possible that the differences in the $\delta^{18}O_{enamel\_ap}$ trends observed at Khirbet Qazone evidence a relatively earlier decrease in breast milk (before 1.5 years of age) for some individuals followed by the increased consumption of boiled foods, such as porridges and gruel in place of breast milk, along with animal milk that could produce higher $\delta^{18}O$ values, particularly in the arid Dead Sea environment where water catchments, which can demonstrate large seasonal fluctuations in $\delta^{18}O$ due to evaporation and decreased rainfall, were also likely used as primary water sources. If cereal grains comprised the bulk of weaning foods, $\delta^{13}C_{enamel\_ap}$ values would also be expected to move toward the adult mean as the preferred C_3 cultivars were added to the diet. However, if childhood diets consisted of greater contributions of C_4 resources, or animal milk than adult diets, then $\delta^{13}C_{enamel\_ap}$ values may increase, which is what we see in the case of Khirbet Qazone. For both sites, $\delta^{13}C_{enamel\_ap}$ values were significantly higher among subadults than adult $\delta^{13}C_{bone\_ap;}$; however, these tissues may not provide comparable representations of diet or carbon uptake (Figure 8-28; Figure 8-29). A similar effect was noted for individuals from Petra by Perry et al. (2020), in their study of bulk $\delta^{13}C_{enamel\_ap}$ and by Dupras and Tocheri (2007). Animal milk couldincrease childhood $\delta^{13}C_{enamel\_ap}$ values if the milk was obtained from animals grazing primarily on C_4 plants (Daux et al. 2008, Dupras and Tocheri 2007). Faunal remains from grazing herd animals in the Negev desert have yielded mean $\delta^{13}C$ values from dental enamel carbonate ($\bar{X}$ = -7.7 ± 2.1‰), dental collagen ($\bar{X}$ = -16.4 ± 1.5‰) and bone collagen ($\bar{X}$ = -17.2 ± 1.1‰) that all indicate a diet relatively rich in C_4 material (Vaiglova et al. 2020). Individuals who experienced the more gradual decrease between 2 and 3 years of age may have experienced a slower breast milk reduction and introduction of other, less processed food substitutes and less animal milk.

Animal milk is also mentioned alongside other weaning foods, such as softened/cooked cereals, eggs, and honey that was either boiled or mixed with animal milks, in historical texts from the Mediterranean (Dupras and Tocheri 2007, Fildes 1986).

The later increase in $\delta^{18}O_{enamel\_ap}$ evidenced for most individuals at Khirbet Qazone between 4 and 6 years of age could be the result of a shift in food preparation or types of foods consumed. This increase along with a decrease observed at the same time for other individuals, such as Θ1 and T2, bring individual $\delta^{18}O_{enamel\_ap}$ values closer to the adult $\delta^{18}O_{bone\_ap}$ mean. However, this shift in $\delta^{18}O_{enamel\_ap}$ is not accompanied by a similar shift in $\delta^{13}C_{enamel\_ap}$ values, which indicates that while the diet remained relatively similar in proportions of C_3/C_4 consumed for children, food preparation may have changed. Furthermore, most individuals show a gradual decline between about 3.5 years of age and the later increase in $\delta^{18}O_{enamel\_ap}$ values, while $\delta^{13}C_{enamel\_ap}$ continues to gradually increase for most of those individuals. This may suggest that animal milk supplementation decreased gradually throughout the period of childhood.

Individuals at Zabayir showed less variation than Khirbet Qazone, but still appeared to depict two specific weaning tempos and complete weaning slightly earlier than the Khirbet Qazone population. $\Delta^{18}O_{enamel\_ap}$ indicated that while some children at Zabayir were likely weaned between 2.5 and 3 years of age, other children may have stopped receiving breast milk prior to 1.5 years of age, although there are no samples prior to this age to provide direct evidence for the expected decrease in $\delta^{18}O_{enamel\_ap}$ for these individuals (Figure 8-20; Figure 8-21). Instead, many of these individuals had a gradual decrease in $\delta^{18}O_{enamel\_ap}$, like that seen at Khirbet Qazone, until about 4 to 5.5 years of age. $\delta^{13}C_{enamel\_ap}$ values for these same individuals generally begin to show a slight decrease between 1.5 and 3 years of age, suggesting the incorporation of C_3 dietary resources, followed by a slight increase or relatively stable $\delta^{13}C_{enamel\_ap}$ values throughout the remainder of childhood (Figure 8-12; Figure 8-14). $\delta^{13}C_{enamel\_ap}$ values at Zabayir were also significantly higher than adult $\delta^{13}C_{bone\_ap}$ values throughout childhood, while $\delta^{18}O_{enamel\_ap}$ values generally tended to approach the adult $\delta^{18}O_{bone\_ap}$ mean during later childhood (Figure 8-29). Like Khirbet Qazone, elevated $\delta^{13}C_{enamel\_ap}$ among children may indicated that milk consumed in greater quantities by children at Zabayir than adult individuals.

These assessments are generally supported by the bulk dentine data. First molar dentine develops from birth to 10.5 years of age, and thus includes the pre-weaning and weaning periods (AlQahtani, Hector, and Liversidge 2010). Second molar dentine develops from 2.5 to 14.5 years of age, which in most cases only encompasses the very end of weaning as well as the post-weaning period. The shift in $\delta^{15}N_{dentine\_coll}$ values between these two teeth seen in the aggregated sample, while not significant, may reflect different periods of the weaning process. The shift generally accords with expectations for weaning based on previous studies using inter-tooth samples (Gregoricka, Sheridan, and Schirtzinger 2017, Gregoricka and Sheridan 2012, Dupras and Tocheri 2007, Stantis, Schutkowski, and Sołtysiak 2019). The slightly higher $\delta^{13}C_{dentine\_coll}$ values in second versus first molars at Khirbet Qazone indicates the introduction of primarily C_4 proteins into the diet through complementary foods, while Zabayir shows a slightly lower $\delta^{13}C_{dentine\_coll}$ value in second versus first molars indicating a C_3 contribution. However, the changes in $\delta^{13}C_{dentine\_coll}$ values for both sites are relatively small and limited in power by small sample sizes, particularly for Khirbet Qazone. When looking at the individualized $\delta^{13}C_{enamel\_ap}$ and the $\delta^{13}C_{bone\_ap}$, the Zabayir population showed less overall variation in the sample so it is also possible that the Zabayir subadult diet was more similar to the adult diet in terms of C_3/C_4 contributions than the subadult diet at Khirbet Qazone.

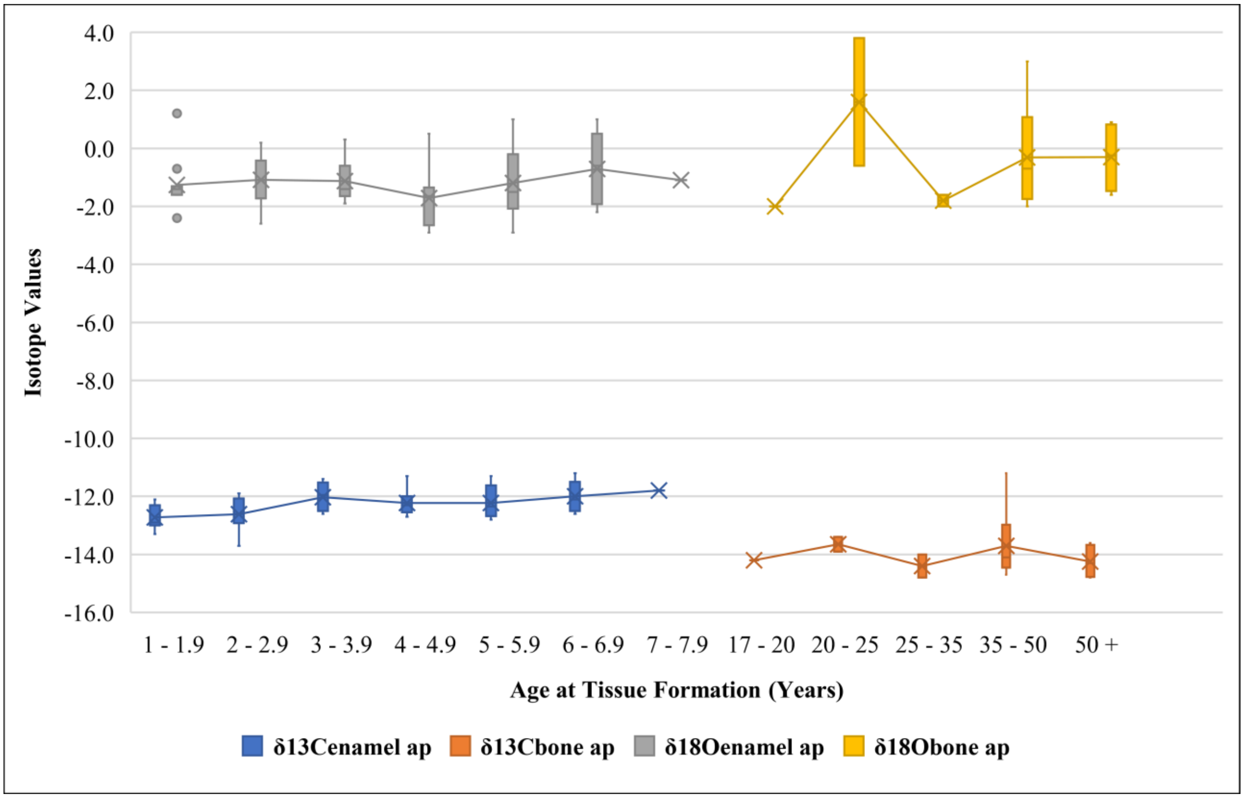

Figure 8-28. Khirbet Qazone isotope values from enamel apatite and bone carbonate plotted by age at tissue formation. Abbreviations: X=sample mean value and dots indicate outliers. Mean sample values are connected for each sample group by a linear plot.

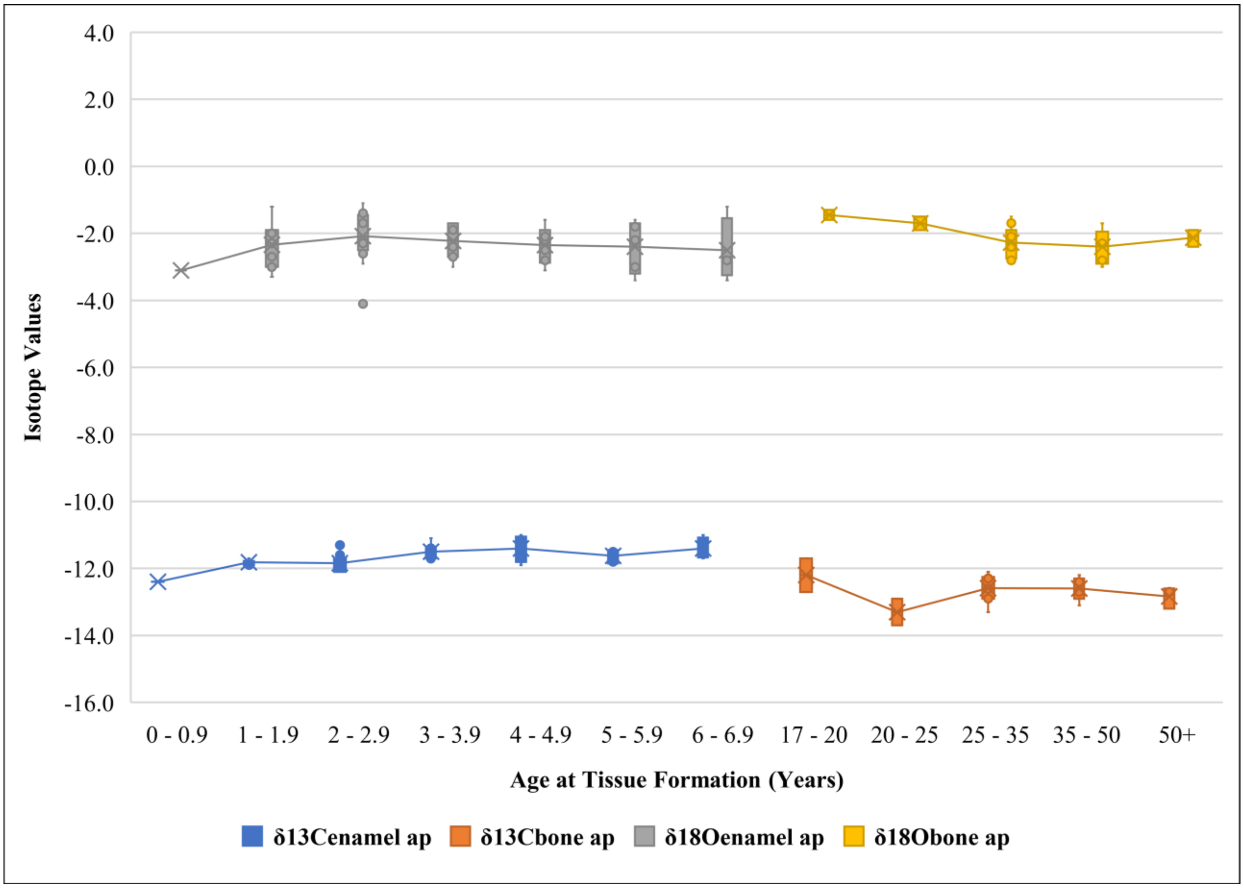

Figure 8-29. Zabayir isotope values from enamel apatite and bone carbonate plotted by age at tissue formation. Abbreviations: X=sample mean value and dots indicate outliers. Mean sample values are connected for each sample group by a linear plot.

The increase in $\delta^{13}C$ at Khirbet Qazone among most individuals during weaning compared with the decrease in $\delta^{13}C$ experienced by most individuals at Zabayir is also informative. While Zabayir subadults generally had higher $\delta^{13}C$ values throughout childhood compared to children at Khirbet Qazone, Zabayir infants were primarily provisioned with more C_3 resources compared to adults in the community, while Khirbet Qazone subadults experienced increased incorporation of C_4 dietary contributions relative to adults. This result suggest that while the overall diet at Zabayir incorporated more C_4 plant resources or animals that grazed on greater amounts of C_4 plants, both populations seem to have utilized animal milk as a complementary weaning food since subadult values are enriched in ^{13}C throughout childhood. However, the adult diet at Khirbet Qazone included fewer C_4 resources than Zabayir, therefore supplementation with animal milk from wild resources, rather than agricultural fields, could explain the relative increase in $\delta^{13}C$ at Khirbet Qazone and a decrease in $\delta^{13}C$ at Zabayir during weaning for most individuals.

The individual values of $\delta^{13}C_{enamel\_ap}$ and $\delta^{18}O_{enamel\_ap}$ were most variable for each population between 5 and 6 years of age. Perry et al. (2020) also observed the most variation of bulk $\delta^{13}C_{enamel\_ap}$ and $\delta^{18}O_{enamel\_ap}$ for their sample from Petra in the second molar, which includes the developmental period between 5 and 6 years of age. This accords relatively well with the subadult dental health data that demonstrate evidence for dental disease or significant wear only in cohort 5 (6-12 years), following the estimated cessation of weaning by about two years during which time regular dietary habits were probably formed and began to contribute significantly to dental health. Together these data suggest a transition to more individualized dietary patterns during this period. The introduction of childhood labor could alter an individual's schedule and proximity to food impacting the quantity and variety of food resources available to an individual as well as how those foods were prepared. For instance, children working within the household may have greater access to cooked food resources, which would be evident by enrichment in ^{18}O. Childhood divisions of labor generally follow adult patterns as training or preparation for performing these roles in adulthood.

Historical Perspective on Weaning

Weaning practices are not detailed in the known ancient textual sources from the Nabatean or Roman Near East, however, the Hellenistic and Roman influence demonstrated in other aspect of the region's culture likely means that the latest medical texts and advice from the Mediterranean may also have been known to some in the region. Other weaning foods mentioned in these historical texts include cooked cereals, eggs, honey (moderately boiled or mixed with goat milk), spelt soup, and bread softened with a mixture of water and honey, sweet wine, honey wine or milk (Fildes 1986, Dupras and Tocheri 2007, Temkin 1991). Water along with watered down wine were recommended to sate thirst (Temkin 1991). Soranus, of Ephesus, writing in the 1st century C.E. recommended breast milk only until about 6 months of age when soft foods, such as softened breads, eggs, honey, and spelt soups could be added to the diet, followed by a gradual reduction in breast milk beginning between 1.5 and 2 years of age (Temkin 1991, Fildes 1986). Claudius Galen writing in the 2nd century C.E. also supported a breast milk only infant diet until 6 months of age when soft foods could be added but supported a later cessation of breast milk provision at around 3 years of age (Fildes 1986, Johnston 2018). The ages proposed in the historical texts accord well with what is evidenced for other regional populations (Dupras and Tocheri 2007, Perry et al. 2020, Gregoricka, Sheridan, and Schirtzinger 2017, Gregoricka and Sheridan 2012), although several of these studies rely only on inter-tooth comparisons rather than intra-tooth or sequential sampling techniques, which allow for greater resolution in looking at temporal changes.

8.2.5 Considerations for Future Research

One area of weakness in the current study given the poor collagen preservation is the absence of Fourier Transform Infrared Spectroscopy (FTIR), either FTIR-ATR or FTIR-KBr, which can be used to check the level of diagenetic change in bone apatite and dental enamel (Roberts et al. 2018). Future publication or expansion of the current study will incorporate this data to examine mineral preservation in the samples. Additionally, faunal bones were not available for either site in the study area. The absence of faunal comparative data makes drawing direct conclusions about diet difficult; however, local faunal data provide a good proxy consistent with the available human data for the sites as well as data from other sites in the region to address the research questions in the current study. Future research including an examination of locally available fauna from contemporaneous sites may provide clarification and reveal further information regarding diet.

Future research incorporating subadult bones to examine weaning practices may be compared with the intra-tooth data from the current study to determine if any significant differences exist between those individuals who succumbed to early life stress and those who did not. The relatively small sample sizes for both sites means that this data must be interpreted with some caution. The data from the two sites had to be pooled to create a large enough sample size for meaningful statistical comparisons, precluding inter-site comparisons of the data for dietary changes by the developmental period represented for each tooth. Therefore, further research with a larger sample size and additional dental samples would be needed to carry out a more complete comparison of the diets between the two populations. Research comparing a larger number of samples from a greater variety of sites might also reveal more distinct patterns between agricultural and pastoral communities. Additionally, analyses incorporating other isotopes, such as strontium and sulphur, may be useful in examining mobility within these populations and clarifying the utility of $\delta^{18}O$ within different geographic regions throughout Jordan. The use of other isotopes, such as sulphur, could also provide additional information about diet for individuals with like Skeleton K7 from Khirbet Qazone.

Finally, AMTL recording for the dentition was made difficult by the fact that the Buikstra and Ubelaker (1994) dental recording system used does not differentiate between teeth present in alveolar bone or teeth present without associated alveolar bone. It is recommended that future research account for this discrepancy by subcategorizing the existing scoring system (e.g. 2a or 2b) to indicate tooth presence with or without associated alveolar bone.

8.2.6 Summary of Results and Hypothesis Evaluation

An evaluation of dental health and isotopic analysis of $\delta^{15}N$ and $\delta^{13}C$ from dentine collagen as well as $\delta^{13}C$ and $\delta^{18}O$ from dental enamel and bone apatite demonstrated overall similar diets between the Khirbet Qazone and Zabayir populations. The isotopic data reinforce the importance of C_3 resources seen throughout the region from isotopic studies (Appleton 2015, Sandias and Muldner 2015, Al-Bashaireh and Al-Muheisen 2011) and archaeobotanical data (Perry et al. 2013, Ramsay and Bedal 2015, Ramsay and Parker 2016, Ramsay and Smith 2013, Tholbecq, Durand, and Bouchaud 2008, Bouchaud, Jacquat, and Martinoli 2017). While the data indicate that Khirbet Qazone relied more heavily on C_3 resources, which include the most prevalent agricultural cultivars in the region, the data still support the overall similarity with larger regional data from sites like Petra. Therefore, Hypothesis 2.1 that the two sites would both exhibit relatively similar dental health and C_3 diets is accepted.

The isotope data was also used to assess weaning patterns for both sites that will be used in Chapter 9 to examine stress related to weaning. Khirbet Qazone and Zabayir both demonstrated some variability in the cessation of weaning; however, both populations appeared to show a similar overall pattern in the weaning process with children demonstrating greater C_4 contributions in their diet than adults throughout childhood. Weaning was completed by 3.5 years of age for individuals at Khirbet Qazone and by around 3 years of age for Zabayir.

9.0 RESULTS AND DISCUSSION: STRESS AND WEANING

9.1 LEH AGE OF OCCURRENCE

9.1.1 Khirbet Qazone

A total of 254 LEHs were recorded on the dentition of 22 individuals previously documented (Chapter 7.0 Results and Discussion: Stress) to have experienced at least two or more LEH. The number of LEHs experienced by individual ranged from 3 to 24 and the mean age of LEH varied by individual from 2.21 ± 0.06 to 5.26 ± 0.27 years (Table 9-1). Each LEH was assigned to one of the sample age cohorts used for isotope analysis to facilitate comparison between groups (Table 8-17). While LEHs were present throughout childhood, over 50% of LEHs occurred prior to 4 years of age with a majority formed between 3 and 4 years of age (Table 9-1; Table 9-2). Skeletons K9 and R2.2 were the only individuals with LEHs that did not display at least one LEH occurrence prior to 4 years of age (Figure C-1). Similarly, only two individuals—Skeletons I1 and R2.3—had no LEHs after 4 years of age. However, both individuals died between 6 and 12 years of age and not all dentition had erupted so later age LEHs may have been present but could not be observed on the unerupted dentition still within the alveolar bone.

When the LEH mean age by individual is examined the sample is split evenly with 11 individuals with mean LEH ages under 4 years and 11 skeletons for whom the mean LEH age was older than 4 years. This suggests that while a majority of the LEHs occurred within the population during the weaning period, stress continued into later childhood for most individuals.

LEH mean age was also evaluated by sex; neither the number of LEH nor the LEH mean age of occurrence were significant between the sexes (Table 9-3; Figure C-2).

Table 9-1. Summary of Khirbet Qazone LEH age of occurrence (years).

Skeleton	LEH (n)	Minimum Age	Maximum Age	Mean Age	SD	Variance
H2	21	1.59	5.94	4.30	1.20	1.45
I1	4	2.04	2.35	2.21	0.13	0.02
K3	20	2.68	6.04	4.16	1.04	1.09
K4	5	4.44	5.15	4.74	0.28	0.08
K5	18	2.06	6.37	3.58	1.11	1.24
K7B	3	4.57	5.37	4.92	0.41	0.17
K8.1	22	2.45	4.84	3.42	0.67	0.45
K9	4	4.34	5.37	4.85	0.52	0.27
K10	9	2.92	6.19	4.40	1.18	1.39
N1	3	4.25	5.76	5.00	0.76	0.57
R1.1	3	3.54	4.02	3.79	0.24	0.06
R1.1A	3	3.10	4.96	3.82	1.00	1.00
R1.3A	23	2.05	5.18	3.62	0.73	0.53
R1.4A	6	2.65	6.71	5.23	1.45	2.11
R2.2	4	4.62	5.34	4.90	0.32	0.10
R2.3	16	1.42	3.97	2.97	0.65	0.43
R2.4	14	2.22	5.35	3.88	1.09	1.18
T2	15	2.81	5.67	4.67	0.80	0.64
Y1	18	2.05	5.66	3.59	1.12	1.24
Θ1	24	2.10	7.05	5.26	1.30	1.69
Θ2	3	2.71	5.13	3.62	1.32	1.73
Θ3	16	2.61	5.48	3.88	0.87	0.76

Table 9-2. Khirbet Qazone frequency of LEH by age.

Age (Years)	LEH Frequency	Percent
1 – 1.9	2	0.80
2 – 2.9	53	20.90
3 – 3.9	79	31.10
4 – 4.9	60	23.60
5 – 5.9	48	18.90
6 – 6.9	11	4.30
7 – 7.9	1	0.40
Total	254	100.00

Table 9-3. Khirbet Qazone Kruskal-Wallis comparisons for sex and LEH.

Comparison	Test Statistic	df	p-value
LEH Mean Age & Sex	0.284	2	0.242
LEH # & Sex	0.506	2	0.776

Significance = p value ≤ 0.50.

9.1.2 Zabayir

At Zabayir, 53 LEHs were measured for 9 individuals for which at least two LEHs were previously recorded (Chapter 7.0 Results and Discussion: Stress). One individual, Skeleton R-96, was previously documented as having multiple LEHs present, but these could not be measured accurately due to CEJ damage and were excluded from these analyses. The number of LEHs experienced ranged from 2 to 11 and varied in mean age by individual from 3.58 ± 0.62 to 5.41 ± 0.13 years (Table 9-4).

When separated into sample age categories for further analysis, over 50% fell between 5 and 6 years of age and only one individual, Skeleton R-143 had an LEH that occurred before 3 years of age (Table 9-5; Figure C-3). The isotope data suggested that weaning at Zabayir was completed prior to 5 years of age for most individuals. The LEH age of occurrence supported a more stressful period post-weaning for this semi-nomadic population; however, most available data suggests that this would be much older than other regional weaning periods or among other pastoral nomads (Bourbou and Garvie-Lok 2009, Sellen and Smay 2001, Sellen 1998, 2001b, Dupras and Tocheri 2007). Alternatively, the addition of occupational activities during this period could have exposed children to additional risk factors for illness or nutritional stress. For example, involvement in herding may increase exposure for zoonoses or injury and subsequent infection though interaction with animals. Although the data were insufficient to compare the experience of stress between males and females, one of the two females observed experienced the earliest LEH occurrence (Skeleton R-143). Differential wear between the two populations could also contribute to the loss of the earliest LEHs; however, mean wear was worse for the Khirbet Qazone population (see Table 8-7) ruling out differential wear as the cause for the later stress pattern observed at Zabayir.

Table 9-4. Summary of Zabayir LEH age of occurrence (years).

Skeleton	LEH (n)	Minimum Age	Maximum Age	Mean Age	SD	Variance
AP-24	8	3.78	5.71	4.92	0.71	0.51
R-82	11	4.30	5.52	4.93	037	0.14
R-91	5	4.07	5.77	4.89	0.68	0.46
R-97	6	3.60	5.58	4.51	0.77	0.60
R-101	3	4.59	5.39	5.06	0.42	0.18
R-123	7	3.82	5.24	4.72	0.60	0.35
R-143	3	2.79	4.80	3.58	1.07	1.15
R-146	8	3.75	5.21	4.77	0.50	0.25
R-151/1	2	5.28	5.54	5.41	0.18	0.03

Table 9-5. Zabayir frequency of LEH by age.

Age (Years)	LEH Frequency	Percent
1 – 1.9	—	—
2 – 2.9	1	1.90
3 – 3.9	7	13.20
4 – 4.9	18	34.00
5 – 5.9	27	50.90
6 – 6.9	—	—
7 – 7.9	—	—
Total	53	100

9.2 LEH AGE OF OCCURRENCE & LATER LIFE OUTCOMES

The timing of weaning showed some variation at both sites based upon an examination of incremental $\delta^{13}C_{enamel\_ap}$ and $\delta^{18}O_{enamel\_ap}$, most individuals at Khirbet Qazone appeared to have been completely weaned by 3.5 years of age and by 3 years of age at Zabayir. For Khirbet Qazone, individuals were divided into two groups according to their mean age of LEH score—individuals with mean LEH younger than 3.5 years and those with a mean LEH greater than 3.5 years (see Table 9-1). Then these groups were compared for their overall frequency of LEH by individuals, CO, PH, longevity, and growth measures (FTL, TTL, and VNC). For Zabayir, only one individual had an LEH, which formed prior to 3 years of age. This is likely a result of sampling bias and the relative poorer preservation of dentition at Zabayir. While 51.50% of the expected Khirbet Qazone dentition was available for examination, only 20.74% of the Zabayir dentition was present (Table B-5). Therefore, it was not possible to address the relationship between the timing of LEH related to weaning and the experience of comorbidity or later life effects on longevity and growth for Zabayir.

The number of LEHs experienced by an individual did not differ by having a mean age of LEH occurrence above or below 3.5 years of age (Table 9-6). Similarly, no difference in age-at-death was noted based upon the mean age of occurrence of LEH (Table 9-7). Of the 22 individuals with LEH, 21 were evaluated for CO and 10 demonstrated the condition. Individuals with mean LEH ages below 3.5 years were not more likely to experience comorbidity with CO and there was no relationship with CO severity (Table 9-7). Similarly, of the 19 individuals with LEH that were evaluated for PH there was no relationship between comorbidity in relation to LEH mean age of occurrence (Table 9-7). Since only two individuals had both LEH and PH and both had only low severity lesions, the impact of PH severity could not be evaluated. The mean age of LEH occurrence in relation to weaning did not impact growth outcomes for affected individuals (Table 9-8).

Table 9-6. Khirbet Qazone Mann-Whitney U comparisons.

Comparison	Test Statistic	SE	p-value[1]
LEH # & LEH Mean Age Group	18.500	11.661	0.141

[1]Significance = p value ≤ 0.50.

Table 9-7. Khirbet Qazone two-sided Fisher's exact comparisons.

Comparison	Test Statistic	p-value
LEH Mean Age Group & Age Cohort	6.925	0.144
LEH Mean Age Group & CO Prevalence	1.104	0.586
LEH Mean Age Group & CO Severity	0.741	1.000
LEH Mean Age Group & PH Prevalence	0.643	1.000
LEH Mean Age Group & PH Severity	—	—

Significance = p value ≤ 0.50.

Table 9-8. Khirbet Qazone Growth Mann-Whitney U comparisons.

Comparison	Test Statistic	SE	p-value[3]
LEH Mean Age Group[1] & FBL	6.000	2.291	0.500
LEH Mean Age Group[1] & TTL	4.000	2.291	1.000
LEH Mean Age Group[2] & L1-AP	5.000	4.655	0.364
LEH Mean Age Group[2] & L1-ML	3.000	4.655	0.182
LEH Mean Age Group[2] & L2-AP	10.00	4.243	1.000
LEH Mean Age Group[2] & L2-ML	2.000	4.243	0.145
LEH Mean Age Group[2] & L3-AP	8.000	4.243	0.909
LEH Mean Age Group[2] & L3-ML	3.000	4.243	0.218
LEH Mean Age Group[2] & L4-AP	6.000	4.655	0.485
LEH Mean Age Group[2] & L4-ML	3.000	4.655	0.182
LEH Mean Age Group[2] & L5-AP	4.000	3.162	0.909
LEH Mean Age Group[2] & L5-ML	7.000	4.655	0.606

[1]Sample sizes were extremely small. Only one individual has a mean LEH during the weaning period and 7 individuals had a post-weaning mean age of LEH occurrence.
[21]Sample sizes were extremely small. Only two individuals had a mean LEH during the weaning period.; Bonferroni correction was not performed as none of the relationships were significant.
[3]Significance = p value ≤ 0.50.

9.3 STRESS AND WEANING DISCUSSION

The data examining LEH age of occurrence confirms a relatively high level of stress throughout childhood for the Khirbet Qazone population. LEH development is greatest prior to 4 years of age and most concentrated between 3 to 4 years of age. Assuming the isotope data provides an accurate picture of weaning for the population, this period covers the period prior to and immediately following the cessation of breast milk provision for many members of the Khirbet Qazone populous. At Petra, LEH age of occurrence also ranged throughout childhood with a peak between 3 and 4 years of age (Lieurance 2018, Perry et al. 2020). This suggests that the most severe period of stress resulting in LEH at Khirbet Qazone coincides with the estimated period of weaning cessation based upon the examination of $\delta^{18}O$ and $\delta^{13}C$ in dental enamel within the population.

While more detailed comparisons were not possible due to the small sample sizes, the distribution of LEH at Zabayir offers a different depiction of stress from that seen for Khirbet Qazone. Most LEHs recorded at Zabayir occurred between 5 and 6 years of age. This age group also had high numbers of LEHs for the Khirbet Qazone population as well and it is possible that the earlier stressful periods associated with weaning were obscured by the poor preservation of teeth at Zabayir. It is also possible that LEH producing stress events may have been more prevalent or severe during late childhood at Zabayir.

9.3.1 Possible Weaning Supplements, Nutrition, and Stress

LEHs occurred most frequently during the period when many individuals appeared to have been completely weaned at Khirbet Qazone. The years during weaning (2-2.9 years) and immediately following weaning (4-4.9 years) are also periods with large numbers of LEHs. The dietary changes associated with this period of transition may have contributed to the formation of LEH during these periods of childhood.

Breastmilk is a nutrient rich food source containing vital antimicrobial and immune building components (Lönnerdal 2000). Early cessation or limiting of breastmilk consumption in favor of supplemental foods can decrease access to resources crucial for growth and development. The weaning process may also expose an infant to stress due to malnutrition and the introduction of bacteria, parasites, and contaminants in supplemental foods. (Motarjemi et al. 1993). Weaning stresses may be exacerbated by environmental and sociocultural factors or contribute to the severity and mortality of comorbid disease processes (Caulfield, Richard, and Black 2004, Gray, Akol, and Sundal 2008). Weaning foods mentioned in historic texts include cooked cereals, eggs, honey, goat milk, spelt soup, and bread softened with a mixture of water and honey, sweet wine, milk or some combination of these (Fildes 1986, Temkin 1991). Cooked cereals on their own provide few nutrients and goat milk supplementation has a lower folate content than breast milk and may contribute to megaloblastic anemia if used too extensively (Zervas and Tiplakou 2013, Verduci et al. 2019, Combs and Combs Jr 2012, O'Connor 1994). Additionally, animal products such as milk may introduce harmful bacteria to susceptible neonates and lack the proper micronutrient balance and immune support of human breast milk (Cacho and Lawrence 2017, Lönnerdal 2000, Amenu et al. 2019). Honey can contain spores of *Clostridium botulinum* which produce botulism poisoning (Bourbou and Garvie-Lok 2009). As children continue to consume a greater variety of adult foods, stress may increase significantly as the supplementation of nutrient rich maternal milk is completely replaced by food sources that may be less nutritious. Additionally, exposure to a wider range of new foods and food preparation styles may further increase or decrease risk of parasitic and bacterial infections (Motarjemi et al. 1993).

The isotopic data suggest that animal milk may be one possible weaning food. A variety of animal milks may have been used as weaning supplements, including sheep, goat, and camel milk. However, the use of animal milks as breast milk substitutes may not always ensure an adequate nutritional balance of essential vitamins and minerals. Folate (vitamin B_9) is important for healthy red blood cell production through its role in DNA synthesis and methylation as well as neural tube development (Combs and Combs Jr 2012). Folate has also been shown to mitigate the impacts of megaloblastic anemia caused by vitamin B_{12} deficiency and it interacts with vitamin B_{12} and B_6 in the synthesis of nucleic acids and proteins (Wintergerst, Maggini, and Hornig 2007). Both vitamin $B_{9\text{ and }}B_{12}$ also play a role in immune function, particularly the regulation of Natural Killer or (NK) cells. While goat milk and camel milk are relatively deficient in folate, sheep milk is actually a better source of folate than human breast milk (Verduci et al. 2019, Fukuda 2013, Guente et al. 2013). However, when fermented, as in yogurt, goat milk is a nutritious supplement fortified with ample amounts of folate.

Vitamin B_{12} induces methionine synthesis, which is essential for the synthesis of proteins and polyamines and plays a key role in the synthesis of the amino acid creatine, phospholipids, and the neurotransmitter acetylcholine (Combs and Combs Jr 2012).Vitamin B_{12} deficiencies cause megaloblastic anemia and may contribute to the functionality of folates as well. Vitamin B_{12} is not typically found in plant-derived foods and can be deficient in diets that contain minimal animal products. Sheep and camel milk are both good sources of vitamin B_{12}, but goat milk contains far less of this nutrient (Guente et al. 2013, Verduci et al. 2019, Fukuda 2013). However, goat milk still contains about the same amount of this vitamin as human breast milk (Zervas and Tiplakou 2013, Verduci et al. 2019).

Vitamin C is another essential nutrient and powerful antioxidant, which plays a critical role in immune function, and promotes iron bioavailability (Combs and Combs Jr 2012, Wintergerst, Maggini, and Hornig 2007). Unlike many animals, humans do not produce vitamin C and must ingest adequate dietary amounts. Sheep and camel milk both contain high amounts of vitamin C while goat milk is a comparatively poor source of this nutrient (Verduci et al. 2019, Zervas and Tiplakou 2013, Fukuda 2013, Guente et al. 2013). Cooking can also reduce the amount of vitamin C in plant-based foods and heating milk at high temperatures or for long periods may similarly decrease its vitamin C content (Combs and Combs Jr 2012).

Iron is an essential mineral for oxygen transport via hemoglobin, immune response to pathogens, and the production of energy (ATP) and cellular proliferation (Lynch et al. 2018). Iron is available in foods in several different forms, some of which are more bioavailable than others. Meats contain heme iron, which is easily utilized by the body, but absorption of non-heme iron from dietary plants and animals is more variable. Human breast milk contains relatively small amounts of iron although this iron is highly bioavailable and easily utilized by the body (Domellöf et al. 2004, Siimes, Vuori, and Kuitunen 1979). While the iron content in breast milk is not tied to maternal mineral levels, the quantity of iron in breast milk decreases with prolonged breast feeding. Therefore, infants relying primarily on breast milk for longer periods of time during weaning may be more at risk for iron deficiency anemia. Similarly, weaning supplements from plant-derived foods can pose similar issues for iron deficiency and while animal milks, such as camel, goat, and sheep, provide some iron, they do not provide substantially greater quantities of iron than human breast milk and in some cases may provide slightly less (Zervas and Tiplakou 2013, Verduci et al. 2019, Fukuda 2013, Siimes, Vuori, and Kuitunen 1979, Guente et al. 2013).

Overall, no one animal substitute supplies the same nutrient and immune support provided by breast milk (Eriksson and Liden 2012). Sheep milk seems to be the best alternative followed by camel milk and then goat milk, however, we have no direct evidence for which milk may have been used or if several different types of milk were consumed by individuals or different populations. Similarly, different resources may have been provided for male and female children or children of different socioeconomic status leading to dissimilar health outcomes.

Camel milk has received little attention as a complementary food source during weaning in the literature for the Near East. Camel milk is commonly consumed among Bedouin and was likely available, especially in more mobile or pastoral communities (Musil 1928, Reinhard 1947). Musil (1928) observed that milk was considered a staple of the Rwala Bedouin diet and camel milk was commonly drunk immediately after milking or heated before drinking. Sometimes the milk was also boiled and used in the production of cheeses, which could be used in stew and eaten with bread. As a human breast milk substitute, camel milk is fortified in vitamins B_{12} and C and is also a good source of iron and essential minerals; however, like goat milk, it has a relatively low folate content compared to human breast milk (Fukuda 2013).

At Khirbet Qazone, the relatively high rate of cribra orbitalia (CO) compared to Zabayir could have been impacted by greater supplementation with goat milk or plant-based foods deficient in vitamin C. Similarly, as aforementioned vitamin C is sensitive to heat and increased cooking can decrease overall vitamin C availability in food. Differential cooking methods, including boiling or stewing food products, are also one possible explanation for the variation observed in $\delta^{18}O_{enamel\_ap}$ values at Khirbet Qazone (Section 8.2.4). The availability of other milk supplements such as sheep or camel milk, which are both relatively high in vitamin C, could help explain the relatively lower rates of CO observed for Zabayir (Verduci et al. 2019, Fukuda 2013). Animal milk supplementation rich in vitamin B_{12} or folate may also help explain the relatively low prevalence of PH at both sites, since this condition has been demonstrated to be the result of megaloblastic anemias, which are produced by vitamin B_{12} deficiencies (Walker et al. 2009).

Animal milk substitutes also carry the risk of exposure to zoonotic diseases such parasitic and bacterial infections, including *Brucella melitensis*, which is the most virulent Brucella species in humans, along with other pathogens that may cause diarrhea. (Sazmand, Joachim, and Otranto 2019, Rossetti, Arenas-Gamboa, and Maurizio 2017, Amenu et al. 2019). According to recent worldwide data, diarrhea is still a leading cause of death for children under 5 years of age worldwide and would have certainly posed risks for children in past populations (UNICEF 2020). Similarly, ingestion of milk that has not been boiled or has been left to spoil before feeding can expose infants to harmful bacteria (Eriksson and Liden 2012). Boiling animal milks can help prevent zoonotic infections and it would also lead to the ^{18}O enrichment of individuals within a population and the degradation of vitamin C. Breastmilk also has a higher carbohydrate content than supplemental milks which promotes the growth of beneficial colon bacteria and produces short chain fatty acids that increase water absorption and reduce the risk of diarrhea (Eriksson and

Liden 2012). Human milk oligosaccharides further help prevent diarrhea through their ability to bind with pathogens in the gut, preventing their interaction with epithelial cells in the colon. Therefore, while animal milk provides a good alternative to breast milk, it is not a perfect replacement and can result in increased exposure to metabolic deficiencies and pathogens.

9.3.2 Cultural Factors: Stress and Weaning

Cultural factors also play a tremendous role in sanitation and food preparation, quality of supplemental food nutrients, and frequency of feeding during weaning (Amenu et al. 2019). The temporal occurrence of weaning is the complex intersection of food availability, material workload and health, child health, and cultural norms. Breastfeeding frequency, which may be impacted by maternal workload, has also been positively correlated with growth, physical development, and lowered mortality (Gray 1995, Fildes 1995). In one study of Turkana pastoralists it was found that female workloads that do not allow for "on demand" breast feeding could lead to increased food supplementation through fewer overall breast feeding sessions (Gray 1995). Socioeconomic status also increased the number of hours a mother was way from her child, reducing breast feeding frequency, since lower socioeconomic status mothers were more likely to have herding duties or other work that kept them outside the house for long periods of time. In a study of pre-industrial societies from regions across the globe, communities more reliant on agricultural production tended to introduce complementary foods earlier and cease breast milk provision sooner than pastoralist groups (Sellen and Smay 2001). In interviews with rural East African pastoralists, females cited a number of reasons for weaning cessation including maternal illness, the perception of the child being "big enough", the child's ability to eat other foods, maternal judgement of child "readiness", pregnancy, and insufficient animal milk supplements (Sellen 2001b). Breast milk generally bolsters and aids in early immune function and development and decreased breast milk consumption, either through the earlier commencement of weaning or decreased "on demand" feeding, can result in suppressed immune function (Cacho and Lawrence 2017).

Previous studies have documented an increase in LEH attributed to dietary changes associated with the development of agriculture (Munoz 2017, Cohen and Armelagos 1984). Lukacs and Walimbe (1998) use a decrease in LEH to help document health improvements due to a subsistence shift from agriculturalism to nomadism for the prehistoric (1100-700 B.C.E.) Jorwe culture in western India. In a survey of ethnographic accounts examining different subsistence strategies and weaning trends from pre-industrial societies worldwide, Sellen and Smay (2001) found that delayed solid food supplementation was positively correlated with pastoralism and that liquid supplementation tended to occur earlier in pastoral populations. Additionally, predominately agricultural populations tended to exhibit earlier first cessation of weaning events. While subsistence strategies likely had a tremendous impact on weaning choices, particularly in pre-industrial societies it was likely not a function of the availability of nutritional resources, but the balance between a child's and mother's needs. With increased workloads or workload specializations for women, opportunities for breastfeeding may become limited and food supplementation can provide alternatives to create more flexibility for women. Women in modern pre-industrial societies that consider breastmilk a better source of nutrition have also reported that non-human milk and solid food supplementation provide a beneficial alternative to alleviate time constraints for busy mothers' (Sellen 1998). Similarly, the provisioning of breastmilk can be costly for a mother if disease load or stress is high or nutritional resources are limited (Sellen and Smay 2001). Therefore, culturally selected weaning practices likely balance the competing needs for infant and maternal health with maternal social roles and obligations.

In later childhood, increased stress may be due to the advent of childhood work. Participating in adult activities such as animal herding, farming, food preparation, craft production, or childcare could expose children to increased risk of zoonoses, parasitic and bacterial infections, and crowd diseases. Childhood work has been documented in numerous cultures. Throughout the middle east Bedouin children were known to participate in a variety of activities including agricultural work in agro-pastoral communities (Judd, Binkoski, and Seltzer 2015, Katakura 1977). The high variance seen in the $\delta^{13}C$ values at Zabayir between 5 and 6 years of age may indicate a dietary shift during this period that produces varied dietary outcomes for different individuals and could result in increased stress. Inclusion in a variety of work practices might lead to a change in schedule or proximity to food, which can impact food availability and choice. Similarly, weaned children may be confronted with solid foods that are difficult to chew or have to conform suddenly to an adult meal schedule that may lead to missed meals and less nutritive meal substitutes (Fildes 1995). Alternatively, the later peak age of LEH seen for individuals at Zabayir may in part suggest a later weaning date for these individuals, but this could not be confirmed with the isotope data in the current study and LEH may occur for a variety of non-specific stresses unrelated to weaning. Increased access to animal milk throughout a longer period of childhood would produce the gradually decreasing overall, less negative $\delta^{13}C$ values seen at Zabayir compared to those at Khirbet Qazone for the same period of childhood. Additionally, animal milk supplementation could provide a nutrient rich alternative to other weaning foods such as vegetable or grain gruel and porridge.

Although the LEH age of occurrence could not be evaluated against weaning for the Zabayir population, a majority of the LEHs observed for Khirbet Qazone occurred during the proposed weaning period for the population. This suggests that weaning had a significant impact on health a Khirbet Qazone that was either delayed or not observed at Zabayir. Therefore, Hypothesis 2.2 is supported by the evidence available.

While the prevalence of LEH was high at Khirbet Qazone, the age of occurrence in relation to weaning was not significantly related to the overall number of LEH experienced, age-at-death, comorbidity with other non-specific stress indicators or growth outcomes. This suggest that the individuals at Khirbet Qazone who experienced a stress event resulting in LEH were able to respond plastically and accords with observations made in (Chapter 7.0). Therefore, Hypothesis 2.3 is not supported and suggests that while LEH may serve as an index for childhood health, it does not reference long-term health deficits or outcomes for individuals within the Khirbet Qazone population.

9.4 SUMMARY OF RESULTS AND HYPOTHESIS EVALUATION

Diet as evaluated by dental health and isotopic data was similar to that observed at Petra. The analysis revealed that both Khirbet Qazone and Zabayir relied significantly on C_3 resources and terrestrial sources of protein. Therefore, Hypothesis 2.1 was supported by the data. The isotopic evaluation of the data could only account for weaning variation observed in the Khirbet Qazone population and therefore Hypotheses 2.2-2.3 could only be addressed fully for the Khirbet Qazone sample. The distribution of $\delta^{18}O$ and $\delta^{13}C$ from dental enamel suggests that weaning was completed at Khirbet Qazone by 4 years of age. Although the age of occurrence for LEH in the Khirbet Qazone population indicated that most individuals exhibited a significant amount of stress during the weaning period with a peak between 3 and 4 years of age, the stress driving these hypoplastic events did not produce long term health outcomes or coincide with other non-specific stress lesions. In summary, Hypothesis 2.2, which posited that LEH would occur more frequently during the period of weaning for the agricultural population was supported for Khirbet Qazone, but Hypothesis 2.3, which stated that individuals with LEHs experienced prior to the cessation of weaning would experience an overall greater number of LEH, comorbidity with CO and PH, mortality, and reduced growth outcomes was rejected. These hypotheses could not be fully explored at Zabayir due to the limited number of LEH available, which was may have been impacted by the overall small sample size of teeth from the site. In future, examining a larger pool of teeth from a greater number of pastoral nomadic communities could provide a more robust sample to test this hypothesis so that data between agricultural and pastoral nomadic communities may be compared more effectively to address this research question.

10.0 RESULTS AND DISCUSSION: ACTIVITY

10.1 MSM ROBUSTICITY BETWEEN SITES

A total of 81 individuals were evaluated for MSM robusticity bilaterally at 21 locations that characterize upper extremity movement and 13 locations pertaining to lower extremity motion. Of these, 26 individuals from Khirbet Qazone—12 female, 11 male, and 3 individuals of unknown sex—and 55 from Zabayir—20 female, 20 male and 15 of unknown sex—were examined. Since preservation dictated the availability of various MSMs for scoring, the specific number of MSMs scored in each category is reported below (Table 10-1 and Table 10-2). The numbers reported reflect the aggregation of right and left scores from the same individual and all scores are reported by individual and ranked mean MSM robusticity scores were similar between individuals from Khirbet Qazone and Zabayir for both the upper and lower limbs (Tables D-1, D-2, D-3, and D-4). The humeral insertion of pectoralis major showed the greatest robusticity in the upper limb for each population (Table 10-1; Figure 10-1). Furthermore, the common extensor and flexor tendons as well as the humeral insertion of subscapularis were also among the top five most used muscles for each site based on ranked mean scores. The mean MSM values for these muscles between Khirbet Qazone and Zabayir were significantly similar, which also suggests that the physical stress exerted on these muscles at each site was relatively equivalent in terms of the activities performed. Although there was some slight variation in the ranking, pronator teres and teres major/latissimus dorsi were among the least used muscles for each site.

Table 10-1. Upper extremity MSM ranking and comparison between sites.

Bone	No.	Muscle/Ligament Attachment	Khirbet Qazone (KQ)			Zabayir (Z)			p-values KQ v. Z
			n[1]	X	R	n[1]	x	R	
Scapula	1	Triceps brachii	42	2.26	6	43	2.49	**3**	0.303
Clavicle	2	Costoclavicular ligament	37	1.78	21	41	2.41	8	0.009*
	3	Subclavius	38	2.00	12	37	2.03	15	0.666
	4	Trapezoid ligament	42	2.00	12	32	2.06	14	0.519
Humerus	5	Supraspinatus/ Infraspinatus	36	1.94	15	29	1.83	17	0.465
	6	Subscapularis	38	2.42	**4**	25	2.48	**4**	0.794
	7	Teres minor	38	1.89	17	35	2.23	11	0.085
	8	Common extensor tendon	38	2.45	**2**	36	2.47	**5**	1.000
	9	Common flexor tendon	41	2.34	**5**	32	2.53	**2**	0.098
	10	Deltoideus	39	2.08	10	57	2.19	12	0.343
	11	Teres major/ latissimus dorsi	42	1.88	18	50	1.82	18	0.825
	12	Pectoralis major	42	2.81	**1**	50	2.62	**1**	0.993
Ulna	13	Triceps brachii	41	2.07	11	27	2.11	13	0.902
	14	Brachialis	42	2.24	7	46	2.46	6	0.113
	15	Supinator	42	2.14	9	46	2.46	6	0.031*
Radius	16	Biceps brachii	41	1.90	16	39	2.36	9	0.013*
	17	Brachioradialis	33	2.42	**3**	9	2.33	10	0.809
	18	Interosseus membrane	42	1.86	19	31	1.71	21	0.495
	19	Supinator	42	2.00	12	30	1.77	20	0.401
	20	Pronator teres	41	1.83	20	38	1.97	16	0.475
	21	Pronator quadratus	37	2.19	8	19	1.79	19	0.150

[1]n includes all right side and left side scores; R=mean rank; *=significance indicated by p-values <0.05.

The most used lower extremity muscles, gluteus maximus, gastrocnemius, and soleus, were also similar at both sites based on ranked MSM mean comparisons (Table 10-2). Again, mean values between Khirbet Qazone and Zabayir for these muscle attachment sites were not significantly different. The least used muscles, quadriceps and popliteus, on the lower extremity were also the same between the two sites.

Therefore, based upon an analysis of the upper and lower extremity MSM scores the hypothesis that MSMs would indicate greater repetitive activity for the agricultural Khirbet Qazone population is rejected. The most used muscles were similar between sites and the individual MSM mean scores between populations did not differ significantly suggesting a relatively similar level of physical stress and pattern of muscular use between the two sites.

Table 10-2. Lower extremity MSM ranking and comparison between sites.

Bone	No.	Muscle/Ligament Attachment	Khirbet Qazone (KQ)			Zabayir (Z)			p-values KQ v. Z
			n[1]	x	R	n[1]	x	R	
Os Coxa	1	Semimembranosus/ Semitendinosus/ biceps femoris	40	2.43	**5**	30	2.23	7	0.525
Femur	2	Gluteus maximus	39	2.69	**2**	69	2.74	**1**	0.546
	3	Gluteus medius	38	2.37	8	20	2.25	6	0.516
	4	Gluteus minimus	38	2.42	6	39	2.33	**4**	0.418
	5	Psoas	32	2.41	7	38	2.32	**5**	0.716
	6	Gastrocnemius	37	2.70	**1**	39	2.46	**2**	0.162
	7	Quadratus femoris	32	2.09	12	14	2.00	12	0.700
	8	Vastus medialis	38	2.26	9	69	2.14	10	0.391
Patella	9	Quadriceps tendon	39	2.00	13	13	1.77	13	0.251
Tibia	10	Patellar ligament/ quadriceps tendon	35	2.26	10	32	2.19	8	0.808
	11	Popliteus	34	2.15	11	26	2.04	11	0.671
	12	Soleus	39	2.44	**3**	49	2.41	**3**	0.982
Calcaneus	13	Calcaneal tendon	44	2.43	**4**	19	2.16	9	0.089

[1]n includes all right side and left side scores; R=mean rank; *=significance indicated by p-values <0.05.

Figure 10-1. Pectoralis major MSM faint score (1) depicted on the left and a high score (6) right.

10.1.1 Subsistence and Craft Activities

The highest ranked upper limb MSM at both sites, pectoralis major, is a flexor as well as an adductor and medial rotator of the arm at the shoulder and therefore could be involved in numerous activities important to agricultural or pastoral life such as lifting, carrying, hoeing, and activities related to animal husbandry and leather processing among others. Like the current study, pectoralis major was the highest ranked mean score among the upper limb muscles observed for Neolithic agriculturalists (Eshed et al. 2004). However, activities like hoeing are common to both agriculturalist and pastoral nomadic lifestyles. Hoeing roots for food and fuel was observed by Reinhard (1947) among both sexes for the Rwala Bedouin. Pronounced pectoralis major and brachialis attachments have been associated with lifting, especially from a squatted position, and carrying heavy loads (Capasso, Kennedy, and Wilczak 1999).

Similarly, subscapularis is an important rotator cuff muscle involved in the medial rotation and adduction of the arm (Standring 2016). Some researchers specifically noted an increase in upper limb muscles involved in flexion and extension with agricultural development, which include the muscles that originate from the common flexor and extensor tendons that contribute to activities such as the use of large mortar and pestle grinding stones (Bridges 1989, Shuler, Zeng, and Danforth 2012). However, other activities could account for the use of these muscles such as those related to leather processing, which has been proposed for the Zabayir group (Ibrahim and Gordon 1987). For Khirbet Qazone, brachioradialis was also heavily utilized while triceps brachii ranked high among individuals from Zabayir. Brachioradialis is a forearm flexor when the forearm is midpronated (Standring 2016). This muscle would be used in activities such as scraping or grinding. The long head of triceps brachii, which originates on the scapula stabilizes the humeral head during abduction and extends and adducts (at the shoulder), supporting actions such as rowing and hoeing. Additionally, the combined utilization of the highest ranking MSMs for Zabayir (costoclavicular ligament, triceps brachii, pectoralis major, forearm flexors and extensors) are prominent functional components in archery.

Only cemetery contexts were excavated at either site and provide scant material culture indicative of specific activities. The Khirbet Qazone burials contained few grave inclusions aside from clothing and some jewelry. A number of artifacts were recovered from the Zabayir burials and although few could be considered evidence for more utilitarian occupations, a few tools were found including fragments of a pair of scissors, two bone needles and a rubbing stone (Ibrahim and Gordon 1987). These tools may have been included within graves as mementos of activities performed during life that defined or formed aspects of individual identities.

Leatherwork, which has been posited among the individuals from Zabayir (Ibrahim and Gordon 1987), may also require repetitive use of similar muscle groups as those used in agricultural production. Traditional leatherwork, which requires animal skinning, hide soaking, flesh and hair removal, tanning, and crusting (drying, softening, and oiling the hides), is a labor-intensive process (Gebremichael 2016). The decorative leather found at Zabayir suggests additional skilled craftsmanship including embossing and sewing (Ibrahim and Gordon 1987). Therefore, leather working would require labor intensive activities such as lifting and moving qualities of leather (and perhaps water or solid waste removed from the skins), stretching, and scraping as well as fine motor skills like sewing. Gebremichael (2016) depicts many of these processing activities being performed by traditional leatherworkers in Ethiopia assuming a squatting position with the torso flexed forward (Figure 10-2). Near eastern communities in later periods also supplied the Roman military with valuable leather goods (Crone 2007).

Figure 10-2. Leather craftsman scraping fats from a hide courtesy of Gebremichael (2016:10).

The development of agriculture produced an overall increase in musculoskeletal labor demands in multiple studies examining diaphyseal development, osteoarthritis, and musculoskeletal markers (Shuler, Zeng, and Danforth 2012, Bridges 1989, Eshed et al. 2004). Shuler, Zeng, and Danforth (2012) demonstrated that agriculturalists experienced an increased risk of entheseal change for the common extensors, brachialis, as well as the triceps and biceps insertions compared to hunter-gatherer communities. Given the number of corresponding actions to which a muscle or group of muscles may contribute, it is difficult to associate MSM use with specific activities or even a specific pattern of life; however, other studies examining upper extremity MSMs for agricultural and hunter-gatherer populations have demonstrated some differences in overall activity patterns, perhaps related to different habitual behaviors, or the magnitude of MSM aggregate scores (Eshed et al. 2004, Shuler, Zeng, and Danforth 2012). Eshed et al. (2004) found that overall activity levels as measured by MSM robusticity scores increased with the adoption of agriculture, which is consistent with other studies that posit increased physical stress among agriculturalists (Bridges 1989, Shuler, Zeng, and Danforth 2012). However, the

Khirbet Qazone and Zabayir upper extremity MSM scores suggest that habitual activities as well as the relative magnitude of physical stress were extremely similar between the two sites. In general, the similarity between upper extremity MSM ranked means, and the absence of significant differences between these means, suggests that the two communities participated in similar activity patterns and levels of physical stress.

10.2 MSM ROBUSTICITY BY AGE COHORT

10.2.1 Khirbet Qazone

Within the Khirbet Qazone sample, upper and lower extremity MSM aggregate scores clearly increase with age (Figure 10-3; Figure 10-4). While some studies have cited a positive correlation between increasing age and MSM scores (Niinimäki 2011, Weiss 2004), age only accounts for 36.9% of the variation in upper limb MSM robusticity among the Khirbet Qazone skeletons (Table 10-3). According to an ANOVA test, age is a significant predictor of MSM robusticity, however, it clearly does not account for the bulk of the variation seen within the Khirbet Qazone sample. Age is also a significant predictor of lower limb MSM robusticity. Indeed, lower extremity MSM robusticity scores are more accurately predicted by age than upper limb scores with over 68.2% of the variability observed among Khirbet Qazone skeletons accounted for by age.

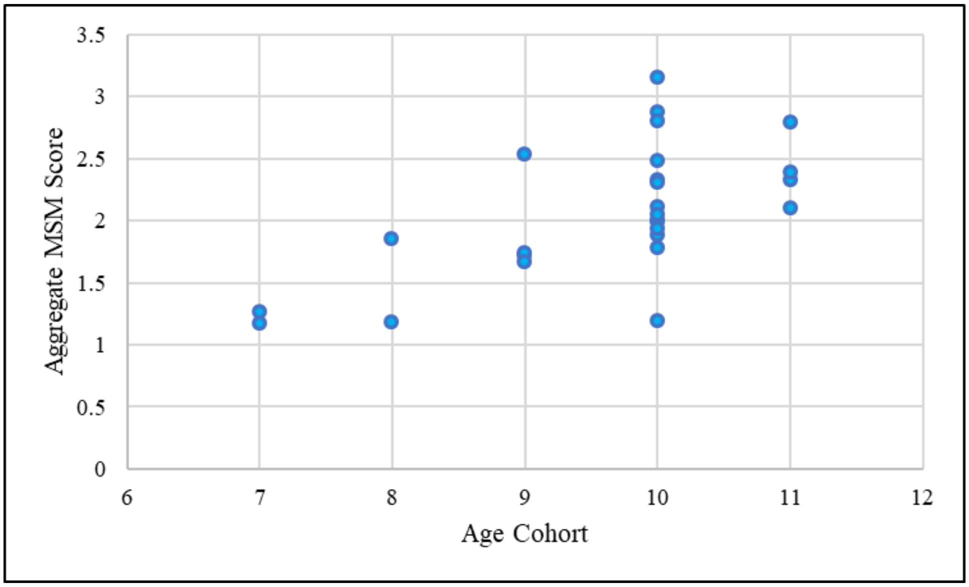

Figure 10-3. Khirbet Qazone aggregate upper limb MSM robusticity scores by age cohort.

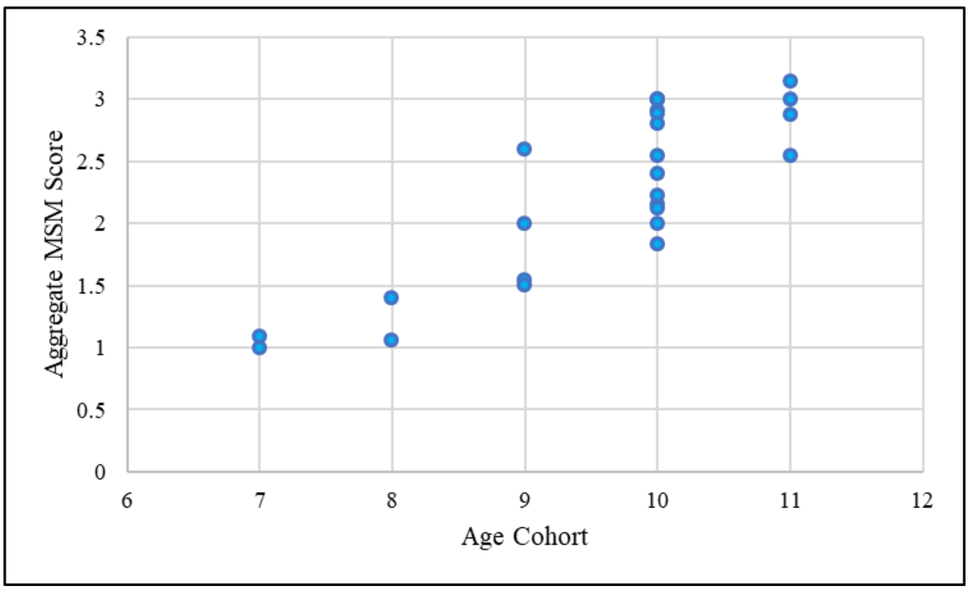

Figure 10-4. Khirbet Qazone aggregate lower limb MSM robusticity scores by age cohort.

Table 10-3. Khirbet Qazone regression analysis for MSM robusticity by age cohort.

Site	Extremity	Adjusted R Square	ANOVA			
			df	Mean Square	F statistic	Significance[1]
Khirbet Qazone	Upper	0.369	1	2.819	15.598	0.001
	Lower	0.682	1	7.860	52.366	0.000
Zabayir	Upper	0.247	1	2.682	12.498	0.001
	Lower	-0.028	1	0.007	0.015	0.904

[1]Values <0.05 considered significant

10.2.2 Zabayir

Aggregate mean Zabayir upper limb MSM robusticity scores also show a clear increase with age, however, only 24.7% of the variation in robusticity can be accounted for by age (Figure 10-5; Table 10-3). While an ANOVA suggests that this is a significant contributor to variation, it clearly does not explain the full range of variation seen in the MSM robusticity scores. Unlike the Khirbet Qazone population, lower limb MSM robusticity scores were not correlated with age and age does not significantly contribute to the variability observed between scores (Figure 10-6; Table 10-3). The negative adjusted R-square value essentially indicates that none of the variability in the MSM robusticity scores can be explained by age. The Zabayir data appear to follow a more complicated pattern with a wide range of variation observed in all age groups, including several obvious outliers, which may indicate that factors such as socially derived labor practices based on corporate groups, skill, or other criteria may be more responsible for the varied development of lower extremity MSMs. The data appear to reflect a varied activity level in aging individuals. Some individuals demonstrated atrophy or relative inactivity among the oldest members in the population and others exhibited relatively high aggregate MSM scores compared to younger age cohorts. Some researchers have noted the increased potential for MSM development among younger individuals within a population and this may also be a factor in the distribution observed in the Zabayir data (Shuler, Zeng, and Danforth 2012). Additional research examining the variation observed in the age cohorts against mortuary data and cortical bone density may be helpful in determining the precise nature of the observed distribution.

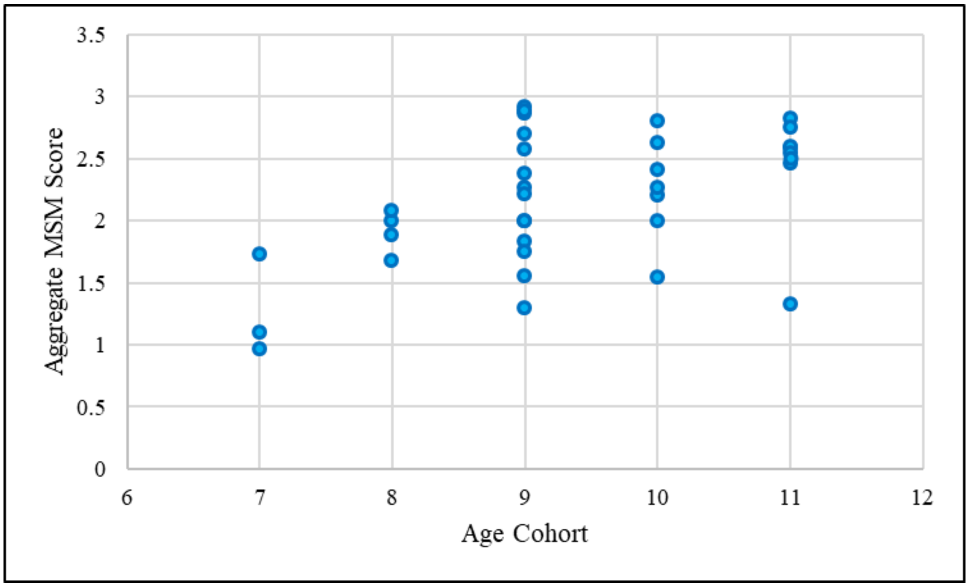

Figure 10-5. Zabayir upper extremity MSM robusticity scores by age cohort.

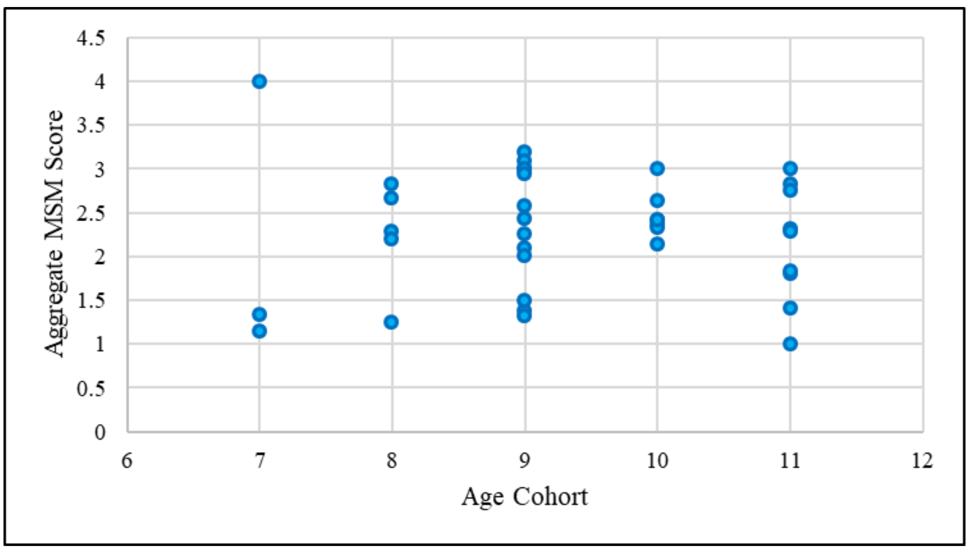

Figure 10-6. Zabayir lower extremity MSM robusticity scores by age cohort.

10.3 MSM ROBUSTICITY AND BIOLOGICAL SEX

10.3.1 Khirbet Qazone

Previous research examining the relationship between robusticity and agricultural development noted key differences in activity patterns or physical stress between males and females (Bridges 1989, Shuler, Zeng, and Danforth 2012, Eshed et al. 2004). While some studies suggest that female musculoskeletal stress increased relative to an overall decline in male stress (Bridges 1989), other studies suggest the opposite result (Shuler, Zeng, and Danforth 2012). In their study of Native American communities in the Southeastern United States, Shuler, Zeng, and Danforth (2012) found that transitioning to agriculture led to the greatest increase in labor among males. The authors determined that the redistribution of labor among females of different ages may account for the absence of a significant increase in female labor due to the development of an intensive agricultural subsistence economy. These conflicting results imply a complex depiction of agricultural practices in which behaviors are determined by the cultural practices that define gender roles rather than the fundamental requirements of an agricultural lifestyle.

Since little variation in the muscles used or the relative intensity of their use were not significantly different between the Khirbet Qazone and Zabayir samples, it is important to understand whether any differences may be observed between males and females within the two populations. Similar to the larger population data, aggregated scores for upper and lower extremity MSM robusticity between males and females from Khirbet Qazone were not significantly different indicating that the activities of daily life were similarly strenuous for both males and females (Table 10-4; Table 10-5). Despite these commonalities, there were some differences observed in the most used muscles between males and females at Khirbet Qazone. Brachioradialis and pronator quadratus robusticity scores were higher among Khirbet Qazone females and relatively lower for males suggesting more intense use of these muscles for females. Brachioradialis is a forearm flexor during midpronation, which would be involved in scraping or grinding motions and pronator quadratus pronates the forearm at the wrist. Together, these muscles could be used in various crafts involving fine motor skills such as sewing, weaving, flint knapping, carving, leather work, or creating pottery. The forearm extensors also rank high among the MSMs observed for females by Eshed et al. (2004), which they use to suggest an increase in fine motor activities for agriculturalist females compared to their Natufian counterparts. The use of large two-handed metate have been posited for other agricultural populations and would rely on the subscapularis, pectoralis major, and the forearm muscles, which show high scores among both Khirbet Qazone males and females (Eshed et al. 2004). The greater use of triceps brachii among males could imply a variety of actions requiring stabilization of the humeral joint during abduction as well as extension and adduction of the shoulder joint including archery and rowing.

Lower extremity MSM values at Khirbet Qazone were more dissimilar (Table 10-6). Both males and females demonstrate relatively high use of gastrocnemius and soleus, which is consistent with a relatively active population engaged in walking over rough terrain. Wade et al. (2010) demonstrate a significant difference in the activation of the medial head of gastrocnemius during walking on railroad ballast versus ballast free terrain. Railroad ballast consists of crushed stone and offers a good comparison for the rocky terrain at the study cemeteries. The medial head of gastrocnemius has also been implicated in foot inversion at the ankle, which would help stabilize the gait on rough terrain (Vieira et al. 2013).

Females used the gluteal muscles, which are major hip extensors and abductors, more frequently developing more robust attachments at these sites. The combined actions of the gluteal muscles including lateral and medial hip rotation, hip abduction and thigh extension could be the result of repetitive squatting activity (Figure 10-7). Reinhard (1947) depicts squatting as a casual resting posture and describes people of both sexes performing a variety of activities including waiting, congregating, eating, and resting in this position. One electromyographical study of lower limb muscles during squatting indicates that gluteus maximus along with biceps femoris recruitment is increased with the degree of torso flexion (Lee, Song, and Kwon 2016). When viewed in concert with the upper limb data this suggests that women may have been engaged in squatting while bending forward to perform a craft or activity involving fine motor control. Males also demonstrated high rank means for gluteus maximus, soleus, and gastrocnemius muscles, which along with psoas may be heavily recruited in horse riding postures (Djukic et al. 2018).

Table 10-4. Comparison of aggregate MSM robusticity scores between males and females.

Site	**Extremity**	***N***	**Mann-Whitney U**			**Independent Samples Median Test**			
			Test Statistic	**SE**	**Significance[1]**	**Median**	**df**	**Test Statistic**	**Significance[1]**
Khirbet Qazone	Upper	23	75.00	16.192	0.608	2.10	1	0.034	1.00
	Lower	23	63.50	16.200	0.880	2.54	1	1.051	0.414
Zabayir	Upper	37	174.00	32.907	0.940	2.31	1	0.026	0.866
	Lower	40	209.00	36.935	0.820	2.30	1	0.000	0.752

[1]Values <0.05 considered significantly different.

Table 10-5. Khirbet Qazone upper extremity MSM robusticity by sex.

Bone	No.	Muscle/Ligament Attachment	Female			Male		
			n[1]	x	R	n[1]	x	R
Scapula	1	Triceps brachii	20	2.10	10	21	2.43	**4**
Clavicle	2	Costoclavicular ligament	17	1.47	21	18	2.17	11
	3	Subclavius	18	1.72	18	18	2.28	7
	4	Trapezoid ligament	18	1.94	15	21	2.05	14
Humerus	5	Supraspinatus/ Infraspinatus	17	1.71	19	19	2.16	12
	6	Subscapularis	18	2.39	**4**	20	2.45	**3**
	7	Teres minor	18	1.61	20	20	2.15	13
	8	Common extensor tendon	19	2.42	**3**	18	2.50	**2**
	9	Common flexor tendon	19	2.26	7	21	2.43	**4**
	10	Deltoideus	19	2.16	8	18	2.00	15
	11	Teres major/latissimus dorsi	18	1.89	16	20	2.00	15
	12	Pectoralis major	18	2.44	**2**	20	3.30	**1**
Ulna	13	Triceps brachii	21	1.95	14	20	2.20	8
	14	Brachialis	21	2.29	6	20	2.20	8
	15	Supinator	21	2.14	9	20	2.20	8
Radius	16	Biceps brachii	20	2.00	13	20	1.85	20
	17	Brachioradialis	19	2.53	**1**	14	2.29	6
	18	Interosseus membrane	21	2.10	11	20	1.65	21
	19	Supinator	21	2.10	11	20	1.95	17
	20	Pronator teres	20	1.80	17	20	1.90	19
	21	Pronator quadratus	21	2.38	**5**	16	1.94	18

[1]n includes all right side and left side scores; R=mean rank

Figure 10-7. Khirbet Qazone Skeleton K4 right femur showing developed attachments for psoas, gluteus maximus and vastus medialis.

Table 10-6. Khirbet Qazone lower extremity MSM robusticity by sex.

Bone	No.	Muscle/Ligament Attachment	Female			Male		
			n[1]	X	R	n[1]	x	R
Os Coxa	1	Semimembranosus/ Semitendinosus/ biceps femoris	15	2.00	3	19	2.37	6
Femur	2	Gluteus maximus	29	2.66	**1**	19	2.42	**5**
	3	Gluteus medius	7	2.29	**5**	22	2.27	8
	4	Gluteus minimus	15	2.27	**4**	21	2.33	7
	5	Psoas	17	2.00	10	16	2.63	**1**
	6	Gastrocnemius	16	2.25	**2**	18	2.61	**2**
	7	Quadratus femoris	7	2.00	13	18	2.06	12
	8	Vastus medialis	30	2.03	9	19	2.21	9
Patella	9	Quadriceps tendon	3	2.00	12	21	1.86	13
Tibia	10	Patellar ligament/ quadriceps tendon	14	2.07	7	17	2.18	10
	11	Popliteus	8	2.13	10	18	2.11	11
	12	Soleus	22	2.27	7	18	2.56	**3**
Calcaneus	13	Calcaneal tendon	4	2.00	6	21	2.43	**4**

[1]n includes all right side and left side scores; R=mean rank

10.3.2 Zabayir

Based on the ranked mean aggregate MSM scores for Zabayir, pectoralis major was heavily utilized by both males and females within the sample (Table 10-7). Triceps brachii was also among the most robust muscles for both sexes. However, other MSMs in upper extremity mean scores demonstrated some differences in muscle use. Among females, the subscapularis attachment on the humerus and triceps brachii attachment on the scapula were most developed while for males the costoclavicular ligament as well as the common flexor and extensor tendons were also well-developed. This differs somewhat from the observations at Khirbet Qazone where the triceps brachii attachment scores were most prominent among males only. Females at Zabayir also appear to be engaged in different activities than their Khirbet Qazone counterparts based upon ranked MSM scores for which brachioradialis or pronator quadratus, commonly used at Khirbet Qazone, were ranked relatively low. In fact, the female upper limb activity pattern at Zabayir appears more similar to the Khirbet Qazone male activity pattern based upon the top few ranked MSMs, while the pattern of ranked use among males at Zabayir suggests a greater focus on forearm flexion and extension. This might suggest that while women at Khirbet Qazone were more involved in subsistence activities and crafts involving fine motor skills, males at Zabayir may have been more involved in activities such as leatherworking that would have utilized these muscle groups.

Ranked mean scores for lower extremity attachment sites were less different between males and females (Table 10-8). Soleus, gastrocnemius, and the glute muscles were highly developed for both males and females. This is a relatively similar pattern of muscle robusticity to that observed at Khirbet Qazone and may represent similar activity patterns between the sexes within both populations. The gluteus medius muscle, which like gluteus maximus abducts the thigh and also medially rotates the thigh, was well-developed in females suggesting that abduction of the thigh during activities such as squatting, or possibly even riding, may have been a highly repetitive action performed by these individuals. For males, the gastrocnemius muscles were also well-developed. This muscle is engaged during walking helping to plantar flex the foot and could simply be indicative of the mountainous, rough terrain in the areas surrounding both cemeteries and throughout much of Jordan.

Like the Khirbet Qazone population, psoas was also a more heavily used leg muscle. The most highly utilized muscles are all consistent with riding postures, squatting, or mobility over rough terrain. Riding, possibly associated with military conscription was explored by Perry (2002a). Although, there was no proof for direct military participation by the individuals at Zabayir, some support for riding was cited in the presence of vertebral osteoarthritis and trauma as well as femoral buttressing or prominent gluteus maximus and vastus lateralis attachment sites for some individuals. Further exploration of MSMs including an examination of adductor muscles, iliacus, and quadratus lumborum may also supply additional support regarding participation in this type of activity.

Table 10-7. Zabayir upper extremity MSM robusticity by sex.

Bone	No.	Muscle/Ligament Attachment	Female			Male		
			n[1]	x	R	n[1]	x	R
Scapula	1	Triceps brachii	16	2.63	**3**	20	2.55	**5**
Clavicle	2	Costoclavicular ligament	14	2.36	8	18	2.72	**1**
	3	Subclavius	13	2.23	11	16	1.69	20
	4	Trapezoid ligament	11	2.27	10	16	1.75	17
Humerus	5	Supraspinatus/ Infraspinatus	9	2.22	13	13	1.69	19
	6	Subscapularis	10	2.70	**2**	11	2.45	7
	7	Teres minor	13	2.23	11	15	2.40	8
	8	Common extensor tendon	15	2.60	5	14	2.57	**3**
	9	Common flexor tendon	10	2.40	7	18	2.72	**1**
	10	Deltoideus	19	2.11	15	24	2.29	10
	11	Teres major/ latissimus dorsi	19	1.63	20	20	1.95	16
	12	Pectoralis major	18	2.72	**1**	21	2.57	**3**
Ulna	13	Triceps brachii	7	2.00	16	12	2.08	15
	14	Brachialis	20	2.60	**5**	14	2.29	11
	15	Supinator	18	2.61	**4**	16	2.31	9
Radius	16	Biceps brachii	13	2.31	9	13	2.46	6
	17	Brachioradialis	2	2.00	16	5	2.20	13
	18	Interosseus membrane	10	2.20	14	12	1.50	21
	19	Supinator	8	1.13	21	12	2.17	14
	20	Pronator teres	14	1.71	18	14	2.29	11
	21	Pronator quadratus	6	1.67	19	10	1.70	18

[1]n includes all right side and left side scores; R=mean rank

Table 10-8. Zabayir lower extremity MSM robusticity by sex.

Bone	No.	Muscle/Ligament Attachment	Female			Male		
			n[1]	X	R	n[1]	x	R
Os Coxa	1	Semimembranosus/ Semitendinosus/ biceps femoris	15	2.00	9	13	2.38	7
Femur	2	Gluteus maximus	29	2.66	**1**	21	2.76	**1**
	3	Gluteus medius	7	2.29	**2**	7	2.43	6
	4	Gluteus minimus	15	2.27	**4**	16	2.56	**4**
	5	Psoas	17	2.00	9	16	2.56	**4**
	6	Gastrocnemius	16	2.25	**5**	20	2.60	**2**
	7	Quadratus femoris	7	2.00	9	6	2.00	11
	8	Vastus medialis	30	2.03	8	20	2.25	9
Patella	9	Quadriceps tendon	3	2.00	9	7	1.86	13
Tibia	10	Patellar ligament/ quadriceps tendon	14	2.07	7	13	2.23	10
	11	Popliteus	8	2.13	6	16	2.00	11
	12	Soleus	22	2.27	**3**	17	2.59	**3**
Calcaneus	13	Calcaneal tendon	4	2.00	9	10	2.30	8

[1]n includes all right side and left side scores; R=mean rank

10.3.3 Riding

Previous research examining osteological indications for riding has suggested the presentation of an associated group of skeletal features that constitute “Horseback Riding Syndrome” (Baillif-Ducros et al. 2012, Pálfi and Dutour 1996). These studies identify a suite of MSMs, osteoarthritis, and trauma that may be attributed to riding behavior, although the exact features used in each study vary (Blondiaux 1994, Baillif-Ducros et al. 2012, Reinhard et al. 1994, Berthon et al. 2019, Pálfi and Dutour 1996, Djukic et al. 2018). Prominent MSMs featured in bioarchaeological studies of horseback riding indicate extensive use of the gluteal, quadriceps, hip adductors, and hamstrings, as well as iliopsoas, gastrocnemius, and soleus (Djukic et al. 2018, Blondiaux 1994, Molleson and Blondiaux 1994, Pálfi and Dutour 1996, Reinhard et al. 1994). These studies focus specifically on horseback riding; however, camel caravans were a prominent economic and cultural aspect of life in Nabataea. A highly mobile population living in Nabataea or the province of Arabia would have relied heavily on camels, which are well adapted to the arid environment of the Nabatean kingdom (Rosen and Saidel 2010). Unfortunately, research documenting the effects of dromedary riding have not been explored in the clinical or bioarchaeological research.

Camel saddles and riding styles differ significantly from those used in horse riding. Although saddle shape is similar, camel saddles do not have stirrups. Traditional camel saddles accommodate a posture that allows the legs to hang at the sides or rest crossed in front of the rider. This alters the constellation of muscles employed in riding behavior. In one recent study examining the therapeutic effect of horseback riding, the use of stirrups increased muscle recruitment, particularly for the quadriceps and tibialis anterior as measured by electromyography (Ribeiro et al. 2017). The gluteal and adductor muscles would be required to maintain the seated posture with the hips flexed and adducted and would be less likely to be affected by the type of saddle or riding posture used. However, stirrups also adjust the degree of hip adduction and require the use of gastrocnemius and soleus to maintain the flexion at the knee. Dickson (1951:390) also provided ethnographic support for Bedouin horseback riding without the use of saddles or stirrups in the Arabian Peninsula. The posture assumed while riding a camel or horse without stirrups would rely most heavily on the gluteal muscles and lessen the tension on the quadriceps, gastrocnemius, and soleus. Additionally, the seated position described for camel riding would most likely involve the superior gemellus muscle, which laterally rotates the extended thigh at the hip. Although, instances of traumatic tendinous ossification when stress exceeds physiological capacity called exostoses were not included, several skeletons from Khirbet Qazone, both male and female, exhibited exostoses on the ischial spine where superior gemellus inserts and may suggest camel riding as a possibility for this population (Figure 10-8). Additionally, one individual demonstrated a pronounced exostosis at the site of the adductor brevis insertion on the posterior femur (Figure 10-9). Both exostoses would be consistent with habitual riding behavior.

MSM expression at Khirbet Qazone and Zabayir both reflect the use of muscles that would be important in riding postures, particularly among males. However, the pattern reflected could represent horseback riding or camel riding with a considerable amount of walking over rough terrain, which would also be consistent with significant gastrocnemius and soleus MSM development. Given the MSM expression as well as the ethnoarchaeological evidence for riding behavior it is likely that riding did comprise a significant portion of the activity for individuals at both sites, particularly for males. More important for the current research project, the overall pattern of activity expression related to riding based on MSMs does not differ significantly between the two populations. Therefore, any riding behaviors were likely similar among the two groups.

Figure 10-8. Exostosis of superior gemellus insertion on the left iliac spine of Khirbet Qazone Skeleton K8.1.

Figure 10-9. Ossification exostosis of the adductor brevis muscle insertions on the left femur (Khirbet Qazone Skeleton Ɵ1).

10.4 CONSIDERATIONS FOR FUTURE RESEARCH

The data clearly demonstrates similarity in the workload and types of activities performed at both sites and revealed some patterns that may be able to be associated with more specific activities. A more integrated examination of MSMs with specific regard for trauma, including exostoses, and osteoarthritis would allow for a more detailed study of the activity patterns between the two sites. For example, many studies related to horseback riding examine multiple behavioral indications including osteoarthritis of the spine as well as spinal trauma and acetabular shape among others (Blondiaux 1994, Reinhard et al. 1994, Berthon et al. 2019, Pálfi and Dutour 1996). Forward torso flexion during squatting can also increase stress on the lower back through intervertebral disc compression and contribute to lower back pain (Lee, Song, and Kwon 2016), which may be evident bioarchaeologically as osteoarthritis. A detailed examination of osteoarthritis at the sites could provide further support for more specific repetitive activities among some individuals and may suggest alternative repetitive activities that could help explain the musculoskeletal data for the two sites.

10.5 SUMMARY OF RESULTS AND HYPOTHESIS EVALUATION

In summary, MSM robusticity scores reflect some interesting observations regarding the lifestyles of the people buried in the Khirbet Qazone and Zabayir cemeteries. Based on the musculoskeletal data workload and general activities are relatively similar between the two sites suggesting that neither participated in what we might characterize as a completely agriculturalist or pastoralist lifestyle. There is possible evidence of riding at Khirbet Qazone among a large proportion of the population, although further research is needed.

Despite their similarities, both populations also clearly demonstrate some variability in their muscular development that cannot be explained by mere age-related progressive muscle use. Therefore, these scores likely represent the impact of repetitive or strenuous muscle use. Overall, the two sites appear to have similar MSM development and demonstrate a significant dissimilarity in the overall activity level between males and females as measured by upper and lower extremity aggregate MSM scores. Therefore, the hypothesis positing greater activity levels for the agricultural population at Khirbet Qazone is rejected. However, some differences in specific activities by sex both within and between the sites is apparent upon closer examination of the data. These differences as well as the wide variance associated with age cohorts within the Zabayir population warrant further research. Future research incorporating mortuary data and non-metric skeletal traits may aid in determining if cultural factors such as familial, social, or trade groupings affected MSM development and robusticity within the two populations. Research examining more MSM markers combined with osteoarthritis, overall upper and lower limb size and cortical bone thickness may also provide additional insights regarding activity between the two sites.

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11.0 CONCLUSIONS

The examination of activity, diet, mobility, and health over the life course at Khirbet Qazone and Zabayir sheds light on the complex nature of subsistence economies and regional community identity. Identity for any individual is a complex composition of personal roles and responsibilities within a social community (Goodenough 1965). These are contextualized and balanced in the larger fabric of society and culture to dictate social behaviors and community relationships. Within these spheres we can begin to understand the cohesive identities that unite (and divide) territories and allow groups to live and work together within larger sociopolitical structures. Although communities may be identified and defined by subsistence economies and their differing roles within past societies, those roles were always changing to better accommodate the identity needed to respond to and interact with the broader social community. Many of these choices and behaviors such as human burial, diet, mobility, and repetitive activities leave lasting impacts that can be used to define them. Two rural subsistence communities—the agricultural Khirbet Qazone (1^{st} – 3^{rd} centuries C.E.) population and the pastoral nomadic Zabayir (2^{nd} – 3^{rd} centuries C.E.) group—were explored to better understand the relationships within and between communities in Nabataean and Early/Middle Roman Jordan. The results of each hypothesis discussed in the previous chapters are addressed in Table 11-1 then summarized and discussed below in the context of implications for broader community relationships and identities.

Table 11-1. Research question summary and hypotheses conclusions.

Research Questions	Hypothesis	Conclusion
1) How did physiological stress affect the experience of health over the life course and does subsistence practice effect an individual's ability to respond to stress in Nabatean and Early/Middle Roman period Jordan?	1.1) The individuals who experienced LEH, CO, and PH will have a greater risk of death than those individuals who do not show skeletal evidence of LEH, CO, and PH, suggesting that these conditions may be correlated with greater stress over the life course.	Partially Accepted
	1.2) LEH, CO, and PH will occur in association with decreased growth more frequently for the agricultural Khirbet Qazone population compared to the semi-nomadic Zabayir community. Growth will be assessed using VNC size as well as FBL and TTL.	Partially Accepted
2) How did dietary practices, including weaning, influence the experience of stress for individuals based upon their subsistence economy?	2.1) Based on dietary studies at Petra and historical evidence for widespread trade within the region, isotopic and dental health are expected to demonstrate similar dietary conditions for Khirbet Qazone and Zabayir despite their differing subsistence economies. The study sites are expected to exhibit relatively comparable dental health and $\delta^{13}C$ levels associated with a primarily C_3 diet.	Accepted
	2.2) LEH age of occurrence, as estimated using the Goodman and Song (1999) regression equation, will occur more frequently during weaning within the sedentary population as measured by $\delta^{13}C$ and $\delta^{18}O$ values from incremental tooth enamel samples.	Accepted
	2.3) Individuals with LEHs experienced prior to the cessation of weaning will have a greater number of overall LEH occurrences, other stress indicators, as well as a younger age-at-death along with decreased long bone lengths and VNC diameters.	Rejected
3) Are differences in activity patterns evident on skeletons from the different subsistence groups?	3.1) Based on previous bioarchaeological studies evidencing more robust upper limb musculoskeletal insertion development with agriculture (Eshed et al. 2004), it is expected that MSMs will indicate greater activity levels for the Khirbet Qazone population in all adult age categories.	Rejected

11.1 LIFE COURSE HEALTH

The exploration of health over the life course at Khirbet Qazone and Zabayir provides support that non-specific stress as measured by osteological indicators did have measurable long-term health outcomes for some individuals. Furthermore, these outcomes were generally worse for the sedentary population at Khirbet Qazone. There is also evidence that symbiosis between subsistence communities may have mitigated potential stresses for Zabayir, although the Khirbet Qazone community benefited less from these types of interactions in terms of stress impacts. This is in opposition to the general assumption that sedentary communities were the primary beneficiaries of relationships with pastoral nomadic communities (Stein 2002). The relative number of individuals at Khirbet Qazone and Zabayir who experienced CO and PH was not significantly different suggesting that both communities experienced similar rates of stress events producing these skeletal lesions. At both sites the overall number of PH stress lesions was low and not significantly related to age-at-death or growth. At Zabayir, CO showed no association with age-at-death; however, the occurrence of CO stress lesions and their severity were both significantly related to age-at-death at Khirbet Qazone, presenting a fragility factor for individuals within the agricultural community. Active or mixed reaction CO was recorded for all but one of the subadults and a greater number of those who survived to adulthood had no CO stress lesions indicating that CO inducing stress event(s) actively contributed to mortality. Nevertheless, CO stress events also clearly had a negative impact on some adults.

Those who survived CO into adulthood at Khirbet Qazone also experienced growth interruptions affecting VNC diameter measurements. Growth outcomes for Zabayir showed fewer impacts related to CO occurrence with only a single VNC diameter negatively correlated with CO occurrence. VNC and long bone lengths could only be compared with PH skeletal lesions for the Khirbet Qazone population and VNC measurements and PH occurrence were not related. Long bone length was not associated with either CO or PH occurrence, indicating that the stress events producing these lesions also did not negatively affect longitudinal growth potential. The completion of VNC development among the age cohorts that demonstrate the severest CO stress lesions may have produced growth impacts for the vertebrae that did not impact long bones, which growth through adolescence, since delays in longitudinal growth may be compensated for by "catch up" growth once the stressor was relieved.

Most etiologies for CO involve a metabolic insufficiency. The frequency of CO occurrence and age-at-death as well as LEH timing both coincide relatively well with the end of the weaning period for Khirbet Qazone indicated by the $\delta^{13}C$ intra-tooth sampling data but extend beyond the weaning period as well. This suggests that intense dietary stress was a significant health risk for individuals throughout childhood. Most active cases of CO, including many of the severest cases, coincide with the weaning dietary change demonstrated in the $\delta^{13}C$ intra-tooth sampling data, or the period immediately following this time (6-12 years of age). Vitamin B_{12} insufficiency resulting in megaloblastic anemia is the most likely etiology of PH in archaeological contexts (Walker et al. 2009). Vitamin B_{12} and C deficiencies are both commonly reported etiologies for CO (Ortner and Ericksen 1997, Ortner 2003, Wapler, Crubézy, and Schultz 2004). However, in their study of CO Cole and Waldron (2019) demonstrate that CO is not related to the progression or severity of anemic PH and that CO may be broken into three types with differing etiologies. Specifically, new periosteal formation associated with supraorbital hemorrhage, porosity associated with severe inflammation, and porosity resulting from the development of vascular channels as part of the normal growth process. Most individuals with very low severity (6.1.1) CO lesions seem to represent the latter category as the product of normal developmental growth. More severe lesions, however, may be the result of scurvy related inflammation and hemorrhage, trauma, infection, marrow hyperplasia, or some combination of the above. Many individuals also exhibited active porosity on the sphenoid, which has been considered pathonomic for Vitamin C insufficiency by some researchers (Ortner and Ericksen 1997, Geber and Murphy 2012, Brickley, Schattmann, and Ingram 2016). Several subadults with sphenoid porosity also showed evidence for endocranial lesions that have also been associated with scurvy, but also with injury and inflammation of the meninges, tuberculosis and other vitamin deficiencies (Lewis 2004). The presence of new periosteal formation or lesions scored (6.1.4, coalescing foramina with increased bone thickness) suggests that the more severe supraorbital lesions may be indicative of vitamin C deficiency when associated with sphenoid porosity, however comorbidity with megaloblastic anemia cannot be ruled out for many individuals (Ortner and Ericksen 1997, Ortner 2003). In addition to scurvy, some childhood illnesses such as whooping cough, measles, and lacrimal gland inflammation can also contribute to supraorbital hemorrhage, which would result in increased periosteal deposition (Cole and Waldron 2019).

Overreliance on cereal-based food supplements, including gruel or porridge, or even goat milk during the weaning period followed by a relatively low protein diet in the years after weaning could result in a diet deficient in vitamin C, especially if other factors such as diarrhea or infection were also common. In their examination of subsistence communities from regions across the globe, Sellen and Smay (2001) found that agricultural populations tended to begin weaning earlier than pastoralists. A greater preoccupation of female labor on tasks that decrease “on demand” breastfeeding can produce reduced access to the crucial nutritional and immunological benefits of breastmilk, which may impact immunological development and increase susceptibility to diseases and infections (Gray 1995, Cacho and Lawrence 2017, Lönnerdal 2000). The MSM data suggest that labor for women at Khirbet Qazone was more specialized or focused on tasks requiring fine motor dexterity, which may not necessarily be conducive to an “on demand” feeding schedule for infants. Some adults had active, severe CO lesions, which suggests that CO inducing stress remained an issue into adulthood, and throughout life for some individuals. These adult conditions may result from infections, trauma, including lifting heavy weights, and increased blood pressure, for example during difficult childbirths, or metabolic insufficiency (Cole and Waldron 2019). Two of the three adults with active CO at death were females of reproductive age. Nutritional stress in mothers may also have detrimental impacts to breast milk micronutrient contents depending upon the micronutrient and could conceivably decrease both maternal and infant health outcomes (Fujita et al. 2019, Corbitt, Paredes Ruvalcaba, and Fujita 2019, Cole and Waldron 2019).

Unlike CO and PH, the occurrence of LEH was significantly higher for Khirbet Qazone. Preservation of the anterior dentition at Zabayir was much poorer than for the Khirbet Qazone sample and likely contributed to the difference in LEH frequency between the two populations. While LEH has long been associated as a measure of individual stress and health, more recent research suggests that the stresses causing LEH and individual responses to LEH stress lesions were much more variable in life. Some studies suggest that LEH occurrence may be related to increased risk of mortality or decreased growth; however, for other populations high LEH frequencies and no association to growth or mortality have been attributed to developmental plasticity (Temple 2014, Temple, Nakatsukasa, and McGroarty 2012, Watts 2013, Floyd and Littleton 2006). Neither the number of occurrences of LEH nor LEH timing impacted long term consequences, including childhood mortality or growth outcomes, for individuals at Khirbet Qazone. Childhood mortality was also high for Khirbet Qazone and three of four subadults with some permanent dentition aged 6 to 12 years old (Skeletons I1, R2.1, and R2.3) had several LEHs at the time of death. While this suggests that some individuals may have perished before LEH could develop on the permanent dentition, all but three adults who could be scored for LEH showed at least one hypoplastic event, which indicates that the experience of LEH demonstrates plasticity and adaptability for most individuals at Khirbet Qazone. LEH also suggests that stress occurred throughout childhood for most individuals and thus may mark the ability to adaptively respond to stress physiologically. LEH occurred early enough that most individuals were able to respond plastically through "catch up" growth and achieve normal stature for the population. In the case of Khirbet Qazone, the widespread documentation of LEH suggests that stress was ubiquitous, but the population was robust. Other early life stress events, such as those producing severe CO skeletal lesions, likely contributed more to early population attrition.

The Osteological Paradox states that cemetery samples do not mirror living populations due to their inability to accurately depict the effects of attritional mortality and individual variation in relative risk of mortality due to factors such as early life stress (Wood et al. 1992). The high rate of childhood mortality at Khirbet Qazone demonstrates that early life stresses impacted mortality at the site. The significant relationship between age-at-death and the occurrence of severe, active CO skeletal lesions suggests that this stress indicator may represent early stress events that contributed to mortality, such as malnutrition, infection, or trauma. Adults with evidence for healed CO lesions suggests that they were able to respond plastically to the causes of these stress indictors. Some VNC measurements were significantly reduced for CO affected individuals, indicating that these individuals also experienced growth disruptions during early childhood, but adapted to achieve normal adult stature for the population, as indicated by long bone measurements.

Since neonates are underrepresented within the cemetery context for both groups and at other sites within the region, these individuals likely experienced differential burial practices and therefore cannot be included in an assessment of community mortality profiles (Perry et al. 2020, Retzleff 2003, Kick 1985, Bourke 1992). Despite the lack of neonates, at Khirbet Qazone we see that early life events still impact the demographic distribution of the remaining individuals. However, severe stress resulting in CO was still possible for adults, which could be explained by the variability observed in the $\delta^{13}C$ and $\delta^{18}O$ bone apatite data that suggest diverse dietary and cooking practices among individuals at the site. The dietary variability demonstrated at Khirbet Qazone, for adults and subadults, may indicate variable access or preferences for different foods and cooking styles that could produce greater nutritional stress for some members of the agricultural community. The data for Zabayir demonstrate less variability in the bone apatite isotope data, when considered with lower rates of some non-specific stress indicators may indicate that the lack of dietary diversity may have had a positive impact on individual health within the community. Sedentary communities generally live in more densely populated settlements increasing exposure to communicable diseases. A relative difference in stress experiences between sedentary and semi-nomadic communities was also supported in other paleopathological studies for the region, including a pervious study utilizing the Zabayir sample (Canipe 2014, Perry 2002a).

Although some important conclusions were evident from the data, there were challenges posed by the data collection and analysis. Relatively small samples sizes were available for analysis, which may have impacted the results and should be acknowledged in any future comparative research utilizing the data. Preservation and post-excavation curation differed between the two sites. The Zabayir collection was more fragmentary with less complete skeletons that had been somewhat commingled during transport and curation, while most of the Khirbet Qazone skeletons were complete and well-preserved. Finally, the absence of growth impacts, especially for Khirbet Qazone, could be a function of the overall high level of stress within the community. Most individuals examined for stress indicators exhibiting at least one stress impact LEH, CO, or PH. This could mean that stress impacts, especially for long bone growth were so severe that long bone length was reduced for the entire population, essentially obscuring the impacts of non-specific stress lesions for individuals. Additionally, the evaluation of growth did not consider differences in sex, however, sexually dimorphic growth patterns should be considered in any future analyses to determine whether this impacted the data set. Furthermore, only some VNC measurements were correlated with stress indicators and additional research should be conducted with a larger sample size to explore other factors that might influence vertebral growth. Finally, due to commingling and the poor preservation of other skeletal populations, comparative data from other Nabataean and Early/Middle Roman period sites is relatively small. Compiling data from a greater diversity of sites across the Nabataean territory would provide a better representation of the diversity present throughout the territory for any future studies.

11.2 SUBSISTENCE AND IDENTITY IN THE NABATAEAN ROMAN WORLD

The current study depicts the Nabataean/Roman social landscape as a tapestry with unique threads, but a cohesive design and form. The effects of Roman annexation have often been described as minimal with symbols of Nabataean culture perpetuated well beyond the kingdom's annexation throughout the region of its former political influence (Politis 2007). Nabataean culture in the form of shared beliefs and social relationships were embodied in the implementation of a distinct material culture distinguishable from the many influences in the Greco-Roman, Persian, and surrounding Levantine cultures that it built upon. The enduring strength of the Nabataean culture, arising as a kingdom with nomadic roots, may have been the complete incorporation of a broad range of communities and subsistence styles into its socioeconomic structure and cultural norms that allowed it to tap into more temporally enduring fluctuations within a subsistence spectrum.

Subsistence strategies—including nomadism, transhumance or semi-nomadism, and sedentarization—in modern Jordan are most appropriately viewed on the household level as vacillating along a subsistence spectrum in response to changes in climate, food production, and world-systems (LaBianca 1990, LaBianca 1994). LaBianca (1990; 1994) discussed modern tribal household affiliation as being generally organized around patrilineal family ties based upon ethnographic research, although the most important relationships observed were those formed through mutual ritual and political mores. Territoriality, even for fully nomadic groups, is an integral part of the subsistence structure and exists within a set of institutionalized relationships that allow for shared resources and protection (Banning 1986, LaBianca 1990). These ethnographic observations realize a much more complicated system than is traditionally espoused for nomads in a core-periphery model. Similarly, nomadic groups may rely more on socialized norms to help sustain their cultural independence in times of transition. While the Khirbet Qazone group demonstrates a large amount of variance, the semi-nomadic population of Zabayir maintained relatively homogenous within group dietary and activity-related behaviors and simultaneously engaged successfully with the outside world. Perhaps, like the original consolidation of Nabataean culture, coalescence around a strong group identity can amplify influence with other groups and communities. The material culture at Zabayir evidences such interaction with surrounding communities in the material cultural goods included in the cemetery contexts that would have been obtained from nearby urban centers such as seals, jewelry, and other items of personal adornment (Ibrahim and Gordon 1987).

This study provides additional support for Nabataean and Early/Middle Roman regional community relationships along a subsistence spectrum. Although differences exist in the extent to which stress was experienced, stress was relatively high for both communities. There were no significant differences in dental health between the two communities apart from dental caries, which were more frequent at Khirbet Qazone and likely a result of intensified reliance on carbohydrates as well as exposure to caries causing bacteria. The isotopic data indicate that both communities relied primarily on C_3 plant resources and terrestrial protein from primarily C_3 feeding animals; however, Zabayir's mean $\delta^{13}C_{bone\_ap}$ value was significantly higher than Khirbet Qazone's indicating a greater contribution of C_4 resources in the adult diet. The significant difference in $\delta^{13}C_{bone\_ap}$ between the two sites is not unexpected for individuals from different subsistence communities. This may mean that Zabayir's pastoral nomads were consuming more animal products, including cheese and meat, than individuals from Khirbet Qazone, who may have been more focused on plant-based dietary resources. Additionally, $\delta^{13}C_{enamel\_ap}$ values were significantly higher than $\delta^{13}C_{bone\_ap}$ values for both sites, demonstrating variability between the adult and subadult diets. One possible explanation for this is that children consumed greater amounts of milk or C_4 resources such as sorghum or millet than their adult counterparts. Children at both sites also consumed similar amounts of protein, as evidenced by $\delta^{13}C_{enamel\_coll}$ and $\delta^{15}N_{enamel\_coll}$ values, and had relatively similar mean $\delta^{13}C_{enamel\_ap}$ values by age at sample formation. These similarities support the use of similar weaning micronutrients and childhood diets, although the exact types of foods or milk used may have varied. The consistency of a C_3-based diet and the probable consumption of milk for children in both populations, accords with the symbiosis between agricultural and pastoral communities hypothesized for the region and the importance of agricultural cultivation and grazing animals to both sedentary and semi-nomadic communities (Rosen 2007, Banning 1986, Levy 1983, Oleson 2010). Animal products and agricultural goods along with jewelry and other valuable items produced in the towns and cities of the region were likely exchanged through trade between communities and resulted in the dietary similarities observed. Zabayir's location at the edge of the Roman *limes* would have necessitated interaction with at least those communities associated with the Roman military (Ibrahim and Gordon 1987). Although traditional explanations for the increased fortification of the *limes* assume tension between nomadic or semi-nomadic and sedentary communities (Parker 2000, 1987a, Parker and Betlyon 2006, Parker 1987b), the data presented for Zabayir suggest a more synergistic model of cooperation between pastoralist and sedentary communities in line with archaeological data for the Nabataean kingdom.

It is also possible that the individuals from Zabayir engaged in supplemental cultivation, although the arid conditions at the site would have made this unlikely on a large scale or for large portions of the year (Ibrahim and Gordon 1987), similarly, some residents of Khirbet Qazone may have raised animals or elected to engage in a more pastoral nomadic existence at times. Ethnographic and historical observations suggest that pastoral nomadic groups in the Middle East supplemented their diet with small scale cultivation, wild gathering, and trade (Barth 1956, Musil 1928, Barth 1961).

Communities are often divided into distinct categories based on subsistence modes; however, subsistence practices fall along a spectrum (Sellen and Smay 2001). In reality most communities utilize and depend upon resources from multiple subsistence patterns to sustain their lifestyles and these patterns may also change through time. Barth (1961) suggests that sedentarization among pastoralists increases with growing herds, which are a proxy for increased wealth. An examination of the $\delta^{18}O$ data suggests that the community members were closely aligned and moved as a group. This agrees with previous isotopic analyses of strontium, which also suggest relatively little variability between individuals within the population (Perry 2002a). The relative wealth of burial items included with the Zabayir graves compared to the Khirbet Qazone burials indicate that community mobility may have served the population in different ways (Ibrahim and Gordon 1987, Politis 1998, Politis, Kelly, and Usman 2005). The items included with the Zabayir burials, such as coins, jewelry, figurines, and tools, fit more closely with other

Nabataean and Early/Middle Roman burials in the region, which were often richly supplied with personal items (Perry and Walker 2018, Lenoble, Al-Muheisen, and Villeneuve 2001). The Zabayir community supports the idea of specialized pastoralism proposed by Levy (1983) in which pastoral and agricultural communities split the risks and benefits of each lifestyle through primary specialization in plant agriculture or animal husbandry and trade between groups of differing subsistence modes. Since sedentary communities are often more limited in space and grazing resources, which can lead to reduced animal yields as well as greater human exposure to zoonoses, having a proportion of the population specifically devoted to herding would be sustainable and even valuable for the larger regional community. However, the Zabayir community may also have found other ways to support their community by trading services, and not just goods, as *foederati* or local support for the Roman army (Ibrahim and Gordon 1987).

Episodes of urbanism and abatement have been studied at Tell Hesban and Tell ‘Umayri via food systems and the interaction between ecological and social factors that influence subsistence economies (LaBianca 1991). In the Near East, periods of depopulation often occurred on a regional rather than site specific scale and may be related to more general patterns of settlement growth and declining influenced by the centralization of state power or changes in the ecological factors behind food production. This model relates sedentism and nomadism to political mechanisms, since households may resist exploitation by state governments through more mobile subsistence strategies. Similarly they may choose to engage more consistently in systems that benefit them economically through sedentarization (Barth 1961). This suggests that the Zabayir community was benefitting significantly from the continued use of a unified group identity, which may have reinforced community cohesion and ties with other former Nabataean communities in the new Roman sociopolitical landscape. This may have allowed them to better leverage their influence to accumulate goods and wealth afforded by connections in this changed political landscape.

11.3 DIVERSITY IN THE NABATAEAN/ROMAN EXPERIENCE

While the data suggest significant similarities in the activities, stresses, and diet for both agricultural and pastoral communities, the differences observed may speak to a broader diversity or resource discrepancy between communities regionally. Subsistence intensification and social stratification are related, although the directionality of the relationship is unique to the circumstances of a given community (Sheehan et al. 2018). Social stratification via the success of some community members may ultimately lead to subsistence intensification as with the example of increased sedentism among successful pastoralists. Alternatively, subsistence intensification could lead to a greater focus on a less diverse array of agricultural resources and increased specialization and social stratification within a community. In any case, social stratification increases privatization and inter-group differentiation. At the Nabataean capital, Petra, privatization has been explored in the tombs. Although the monuments themselves remained public, over time the nature of the sacred became more private via the construction of burial chambers and dining halls enclosed behind elaborate stone facades with wooden doors (Schmid 2013, Wadeson 2012). Schmid (2013) applies Foucault's principle of *hetertopia*[9] to discuss the special implications of Nabataean mortuary architectural design that restricts access to tombs. This is the case for the Soldier Tomb in the Wadi Farasa East. Unlike most other façade tombs in Petra,

[9] A geographic principle used to describe the relationship between space and location for non-political structures.

the visibility of the façade itself is restricted to those individuals permitted access through the courtyard gate. Similarly, multigenerational burial plots in the Early Bronze Age cemetery at Bab edh-Drah, located near the Khirbet Qazone cemetery, demonstrate the construction of a large wall that has been interpreted as evidence of increased social privatization as the economic commitment to sedentism grew and the community expanded "illustrating the importance of kinship and social, political, and economic differentiation" (Chesson 1999; Sheridan et al. 2014:135). As a society or community becomes more specialized and sociopolitical divisions within the population increase, privatization of space and other resources, increase as well.

At Khirbet Qazone, inter-group differences were also evidenced in burial practices. Material culture inclusions except for burial shrouds and clothing were rare in all burials. In contrast, tombs at Petra and Khirbet edh-Dharih contained a variety of grave goods and personal adornments, such as stone tiles with carved reliefs; bone hair ornaments or kohl sticks, copper and bronze bracelets and rings, and gold jewelry with semi-precious stone inlays accompany many burials (Lenoble, Al-Muheisen, and Villeneuve 2001, Perry and Walker 2018, Perry 2017). All graves within the cemetery were public and easily accessible, but the types of burials provide some evidence that multiple corporate or familial social groups or classes could be identified from a complete examination of the archaeological data (Politis 2005, 1998, Politis, Kelly, and Usman 2005). These divisions may influence or prescribe access to certain resources within the community through socioeconomic status, social capital, and community influence, reducing individual choices regarding nutritional resources and ultimately health outcomes. A variety of sociocultural factors including socioeconomic factors, class, urbanization, and mobility can have drastic impacts on diet, health, and growth (Steckel 1995, Tanner 1987, Smith et al. 2003, Stillman, Gibson, and McKenzie 2012, Franzen and Smith 2009). Broader comparisons between individuals to examine intra-community relationships was difficult since the publication of the cemetery excavations, including grave material goods and detailed tomb descriptions, has not yet been finalized. However, future studies integrating the archaeological data in concert with the stress, activity, and isotope data from the current study may provide additional information about individual identities and marginalization or empowerment among individuals within the community.

This study identified evidence for differences in cooking practices and activity specialization, which could indicate a trend toward increasing social differentiation within the Khirbet Qazone community. The small sample sizes and the lack of collagen at Khirbet Qazone compromised the ability to perform more detailed analyses of diet and inter-group variation. The continued application of isotopes to examine diet and mobility throughout the region could reveal additional information about subsistence patterns and social differences within and between communities. Similarly, additional research examining MSM use by side combined with osteoarthritis data may shed more light on activity patterns and specialization within the population.

When examined regionally, diet was generally similar in terms of the types of foods available; however, the variety and focus of each diet was clearly different. The paleobotanical and stable isotope data for several communities indicate a central focus on primarily C_3 food resources, but included cereal grains, such as barley and wheat, fruits, and legumes (peas, lentils fava beans, and bitter vetch) as well as terrestrial mammals (sheep/goat, pigs, and camels), along with chicken, wild fowl, and marine proteins (Ramsay and Smith 2013, Ramsay and Parker 2016, Ramsay and Bedal 2015, Studer 2007, Oleson 2004). Olives, dates, and wine have also been found in sedentary communities (Schmid 2001, Dolinka 2003, Politis 2004). However, these resources may not have been utilized equally across the Nabataean territory. At Khirbet Qazone and Zabayir, the data suggest that some communities relied more on seasonal availability and wild supplementation for animals indicating that the flow of food was unidirectional into urban centers rather than out to more marginalized communities. The Dead Sea littoral has been documented as a trade center for Dead Sea mineral exploitation and agricultural production (Politis 2007). However, in agricultural communities, trade can sometimes lead to intensification and decreased crop diversity (Laparidou and Rosen 2015). Like technological revolutions and political transitions, economic change may also precipitate social change (Levy and Najjar 2007).

The variety of foods available to the Khirbet Qazone community may have been like larger urban centers, but the actual quantities in which these were available or consumed may have varied greatly by individual. The evidence for substantial rates of non-specific stress indicators, possibly related to diet, also suggests that individuals may have been more reliant on relatively low nutrient food resources. Despite this, the relationship between communities with differing subsistence foci may have impacted each community favorably, allowing for the provision of dietary resources that would not otherwise be available. While adult dental caries rates at Khirbet Qazone were consistent with some of the highest rates observed for other Nabataean and Early/Middle Roman groups, the incidence of caries recorded for deciduous teeth was much higher than other communities. CO was also more prevalent with the most severe cases concentrated among subadults. These data suggest that overall stress may have been more intense at Khirbet Qazone. Within the population, a greater amount of variance was observed in $\delta^{13}C$ and $\delta^{18}O$ values indicating differences in diet and cooking that may reflect individual limitations or diversity of choice at Khirbet Qazone.

Petra also demonstrated possible evidence for variable cooking practices in bulk $\delta^{18}O_{enamel\_ap}$ values. While at Petra, no clear differences were observed in the experience of stress between the middle and upper class groups defined by the elaboration of tomb construction, however, the individuals at Khirbet Qazone experienced greater stress as indicated by CO and dental caries rates than individuals at Petra (Canipe 2014, Lieurance 2018). The relatively marginal location of the Khirbet Qazone community may have impacted their dietary resources. Marginalization can also lead to increased discrimination in resource access and social divisions, which may account for some of the variation at Khirbet Qazone in diet and cooking patterns, as well as burial practices.

Identity, like the human skeleton, is mutable and can change as life progresses and individual behaviors change or the environment around a person or community shifts. The picture described by Khirbet Qazone and Zabayir is one of malleable subsistence communities that interacted with and benefited from populations with different subsistence modes. Whether this was a direct response to the challenges posed by the climactic growth of the Nabataean kingdom at Khirbet Qazone prior to Roman annexation or the transition into a new system of governance and social landscape at Zabayir, subsistence lifestyles played a key role in the behaviors, health, and identity of the individuals involved. The current study demonstrates the utility of human skeletal remains as one component of a broader integrative archaeological model to address questions of individual, community, and state-level identities and relationships. Ultimately, subsistence economy is one community attribute that may define both an individual’s and group’s identity. Future bioarchaeological research examining life course health, diet, mobility and activity from a larger number of individuals and sites throughout the region may continue to shed light on the nuanced process of community subsistence change along a spectrum and the sociocultural and socioeconomic implications for individuals and communities that drive and arise from these decisions to better understand the formative process of identity in ancient communities.

11.4 CONSIDERATIONS FOR FUTURE RESEARCH

Future research exploring the relationship between pastoral nomadic groups and agriculturalists using human skeletal remains is needed to further refine our understanding of the relationships between subsistence groups and the ways in which subsistence and community structures may have fluctuated through time. While important, this study represents only two relatively small communities. Research including other contemporaneous sites would provide a greater understanding of the variability throughout the region. Diachronic comparisons for sites representing different temporal periods could create a better understanding of how these systems changed or created stability in the local social landscape through time. Finally, the inclusion of burial data, such as grave construction, artifacts, and communal versus individual burial contexts, may provide additional information about social relationships or socioeconomic status within the cemeteries to look at individual and group identities within each of the study communities in greater detail.

While mobility was not specifically addressed in the current study, $\delta^{18}O_{bone\ ap}$ and $\delta^{18}O_{enamel\ ap}$ variability at each site provided some evidence for community movement at Zabayir and also for the possibility of immigrants or more mobile individuals within the Khirbet Qazone population. Given the ancient documents available for the Dead Sea region, which indicate strong relationships between communities on either side of the Dead Sea, some mobility within this population would be expected (Esler 2019, Isaac 1992). However, $\delta^{18}O$ data alone cannot provide definitive evidence for mobility. Future studies using strontium isotopes, or perhaps even sulphur isotopes, may provide a clearer picture of individual mobility and the movement of people to and from the site. Finally, future research exploring the relationship between the early life stress indicators included in this study and later life disease or aging conditions, including osteoporosis and osteoarthritis, may provide a more complete picture of how stress impacted individual life histories at each site.

APPENDIX A: DEMOGRAPHIC DATA

Table A-1. Demographic summary of Khirbet Qazone skeletons.

Skeleton	***Sex***[1]	***Total Age Range***[2]	***Cohort***
A1	U	3 – 9 m	3
A2	U	8 m – 2 y	3
A3.1	U	3.6 y – 6.3 y	4
A3.2	U	6 m – 2 y	3
A3.3	U	Adult	12
H1	U	6 – 10 y	5
H2	M	22 – 29 y	9
I1	U	4 – 8 y	5
K1	U	3 y – 6 y 4 m	5
K2	M	50 – 60+ y	11
K3	F	30 – 39 y	10
K4	M	50 – 60+ y	11
K5	M	40 – 49 y	10
K6	F	40 – 45 y	10
K7	F	40 – 44 y	10
K7B	F	50+ y	11
K8.1	F	40 – 49 y	10
K8.2	U	< birth	1
K9	F	50+ y	11
K10	F	40 – 49 y	10
M1	M	40 – 49 y	10
M2	M	18 – 24 y	8
N1	M	12 – 18 y	7
R1.1	U	12 – 18 y	7
R1.1A	M	21+ y	12
R1.2	F	40 – 44 y	10
R1.3	U	40 – 44 y	10
R1.3A	U	20 – 50+ y	12
R1.4A	F	20 – 50+ y	12
R2.1	U	6 – 10 y	5
R2.2	U	25 – 29 y	9
R2.3	U	5 – 9 y	5
R2.4	M	30 – 45 y	10
R2.5	U	1 – 5 y	4
R2.6	U	4.5 – 5 y	4

Table A-1. Continued

Skeleton	***Sex[1]***	***Total Age Range[2]***	***Cohort***
T1	F	40 – 49 y	10
T2	M	20 – 24 y	8
U1	F	45 – 50+ y	10
W1	F	27 – 30 y	9
W2	U	2 – 4 y	4
Y1	M	30 – 44 y	10
Z1	F	25 – 29 y	9
Z2	U	8 m – 1.5 y	3
θ1	M	30 – 39 y	10
θ2	F	30 – 35 y	9
θ3	F	30 – 39 y	10

[1]F=female; M=male; U=unidentified
[2]m=months; y=years

Table A-2. Demographic summary of Zabayir skeletons.

Skeleton	*Sex*[1]	*Total Age Range*[2]	*Cohort*
AP-3/1	M	30 – 35 y	9
AP-3/2	M	22 – 26 y	8
AP-5	F	Adult	12
AP-7/1	U	25 – 29 y	9
AP-7/2	U	2 – 6 y	3
AP-7/3	U	Adult	12
AP-8/1-1	U	Adult	12
AP-8/1-2	U	Adult	12
AP-9	M	Adult	12
AP-13	M	30 – 35 y	9
AP-17	U	Adult	12
AP-21/1	M	Adult	12
AP-21/2	U	3 – 5 y	4
AP-23/2	F	60+ y	11
AP-24	M	23 – 29 y	8
AP-25B	F	Adult	12
AP-28A/1	U	30 – 34 y	9
AP-28B/1-1	U	14 – 18 y	6
AP-28B/1-2	U	40 – 44 y	10
AP-28B/1-3	F	50+ y	11
AP-28B/2	M	Adult	12
AP-28B/3	U	Adult	12
AP-28B/4	U	Adult	12
R-2	F	18 – 23 y	7
R-6	F	60+ y	11
R-7	U	Adult	12
R-9	U	Adult	12
R-11	U	16 – 24 y	7
R-12	U	8 – 11 y	5
R-13	F	25 – 29 y	9
R-21	M	30 – 35 y	9
R-25	F	Adult	12
R-26	U	40 – 44 y	10
R-27	F	Adult	12
R-30	U	5 – 6 y	5
R-35	M	18 – 20 y	7

Table A-2. Continued

Skeleton	*Sex*[1]	*Total Age Range*[2]	*Cohort*
R-36	U	Adult	12
R-37	F	Adult	12
R-38	U	Adult	12
R-44	M	50 – 59 y	11
R-46	F	50+ y	11
R-47	M	35 – 39 y	10
R-50/1	F	40 – 45 y	10
R-50/2	U	6 – 14 y	5
R-53	M	30 – 35 y	9
R-54	F	25 – 29 y	9
R-55	M	40 – 44 y	10
R-69	F	35 – 39 y	10
R-71	U	7 – 11 y	5
R-73	M	30 – 39 y	9
R-75/1	F	20 – 24 y	8
R-75/2	U	25 – 29 y	9
R-75/3	U	Subadult	0
R-76	F	25 – 34 y	9
R-77	F	40 – 49 y	10
R-82	M	Adult	12
R-86	M	50+ y	11
R-88	F	50+ y	11
R-89/1	F	25 – 29 y	9
R-89/2	U	Adult	12
R-89/3	U	Adult	12
R-91	M	Adult	12
R-95	U	4 – 6 y	4
R-96	U	6 – 10 y	5
R-97	U	12 – 18 y	6
R-99/1[3]	M	Adult	12
R-99/2[3]	F	Adult	12
R-100/1	F	50+ y	11
R-100/2	F	22 – 24 y	8
R-101	F	30 – 34 y	9
R-105/1	U	40 – 44 y	10
R-105/2	U	Adult	12

Table A-2. Continued

Skeleton	*Sex*[1]	*Total Age Range*[2]	*Cohort*
R-105/3	U	4 – 6 y	4
R-109	F	30 – 34 y	9
R-111/1	M	20 – 24 y	8
R-111/2	U	2 – 6 y	4
R-112	U	14 – 18 y	6
R-114	M	40 – 44 y	10
R-117	F	60+ y	11
R-122	U	Adult	12
R-123	U	4 – 8 y	4
R-124	F	30 – 39 y	9
R-131	M	40 – 45 y	10
R-141	U	Adult	12
R-143	F	25 – 29 y	9
R-146	M	Adult	12
R-151/1	U	30 – 34 y	9
R-151/2	U	1 – 2 y	3
UK-1/3A-1	F	50+ y	11
UK-1/3A-2	U	Subadult	0
UK-1/3A-3	U	Adult	12
UK-1/3A-4	U	Adult	12
UK-1/3B-1	U	≤15 y	6
UK-1/3B-2	U	Adult	12
UK-1/3B-3	U	Adult	12
UK-1/3B-4	U	Adult	12
UK-6/1	U	50 – 59 y	11

[1]F=female; M=male; U=unidentified

[2]m=months; y=years; path=pathology

[3]These are labeled as “99 or 22” but are listed here as R-99/1 and R-99/2 following Perry 2001.

Table A-3. Khirbet Qazone overall adult skeletal completeness scores.

Skeleton	*Cranial*		*Axial*		*Upper Limb*		*Lower Limb*		*Skeleton Total*	
	Total	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
A3.3	0	0.00	0	0.00	17	20.24	0	0.00	17	5.88
H2	54	100.00	62	82.67	69	82.14	69	90.79	254	87.89
K2	53	98.15	72	96.00	82	97.62	27	35.53	234	80.97
K3	53	98.15	63	84.00	79	94.05	68	89.47	263	91.00
K4	53	98.15	75	100.00	82	97.62	76	100.00	286	98.96
K5	54	100.00	74	98.67	84	100.00	75	98.68	287	99.31
K6	54	100.00	75	100.00	81	96.43	76	100.00	286	98.96
K7	51	94.44	72	96.00	80	95.24	27	35.53	230	79.58
K7B	54	100.00	75	100.00	81	96.43	76	100.00	286	98.96
K8.1	54	100.00	75	100.00	80	95.24	73	96.05	282	97.58
K9	53	98.15	69	92.00	79	94.05	74	97.37	275	95.16
K10	54	100.00	66	88.00	60	71.43	45	59.21	225	77.85
M1	40	74.07	55	73.33	61	72.62	65	85.53	221	76.47
M2	0	0.00	75	100.00	79	94.05	56	73.68	210	72.66
N1	54	100.00	75	100.00	81	96.43	72	94.74	282	97.58
R1.1	22	10.74	43	57.33	28	33.33	16	21.05	109	37.72
R1.1A	13	24.07	0	0.00	20	23.81	17	22.37	50	17.30
R1.2	10	18.52	28	37.33	3	3.57	0	0.00	41	14.19
R1.3	9	16.67	34	45.33	3	3.57	0	0.00	46	15.92
R1.3A	10	18.52	0	0.00	0	0.00	0	0.00	10	3.46
R1.4A	19	35.19	5	6.67	0	0.00	0	0.00	24	8.30
R2.2	45	83.33	42	56.00	36	42.86	55	72.37	178	61.59
R2.4	40	74.07	58	77.33	64	76.19	50	65.79	212	73.36
T1	38	70.37	60	80.00	69	82.14	74	97.37	241	83.39
T2	52	96.30	57	76.00	68	80.95	63	82.89	240	83.04
U1	33	61.11	55	73.33	68	80.95	49	64.47	205	70.93
W1	54	100.00	75	100.00	84	100.00	49	64.47	262	90.66
Y1	38	70.37	60	80.00	71	84.52	72	94.74	241	83.39
Z1	54	100.00	54	72.00	60	71.43	70	92.11	184	63.67
Ө1	54	100.00	60	80.00	46	54.76	39	51.32	199	68.86
Ө2	43	79.63	62	82.67	75	89.29	66	86.84	246	85.12
Ө3	54	100.00	51	68.00	73	86.90	63	82.89	241	83.39

Table A-4. Khirbet Qazone subadult overall completeness scores.

Skeleton	***Cranial***		***Axial***		***Upper Limb***		***Lower Limb***		***Skeleton Total***	
	Subtotal	**%**	**Subtotal**	**%**	**Subtotal**	**%**	**Subtotal**	**%**	**Total**	**%**
A1	54	100	75	100	30	100	18	100	177	100
A2	52	96.30	75	100	30	100	18	100	175	98.87
A3.1	45	83.33	0	0.00	0	0.00	0	0.00	45	25.42
A3.2	51	94.44	0	0.00	0	0.00	0	0.00	51	28.81
H1	54	100	68	90.67	30	100	18	100	170	96.05
I1	53	98.15	71	94.67	30	100	18	100	172	97.18
K1	52	96.30	59	78.67	28	93.33	15	83.33	154	87.01
K8.2	24	44.44	30	40.00	28	93.33	18	100	100	56.50
R2.1	42	77.78	54	72.00	19	63.33	8	44.44	123	69.49
R2.3	42	77.78	31	41.33	16	53.33	4	22.22	93	52.54
R2.5	0	0.00	36	48.00	4	13.33	6	33.33	46	25.99
R2.6	0	0.00	0	0.00	3	10.00	9	50.00	12	6.78
W2	54	100	75	100	21	70.00	18	100	168	94.92
Z2	33	61.11	47	62.67	24	80.00	16	88.89	120	67.80

Table A-5. Zabayir overall adult skeletal completeness scores.

Skeleton	*Cranial*		*Axial*		*Upper Limb*		*Lower Limb*		*Skeleton Total*	
	Total	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
AP-3/1	0	0.00	16	21.33	0	0.00	2	2.63	18	6.23
AP-3/2	0	0.00	56	74.67	44	52.38	20	26.32	120	41.52
AP-9	11	20.37	8	10.67	11	13.10	6	7.89	36	12.46
AP-13	0	0.00	23	30.67	35	41.67	17	22.37	75	25.95
AP-5	15	27.78	0	0.00	0	0.00	0	0.00	15	5.19
AP-17	4	7.41	34	45.33	30	35.71	24	31.58	92	31.83
AP-21/1	54	100.00	42	56.00	19	22.62	28	36.84	143	49.48
AP-23/2	10	18.52	50	66.67	12	14.29	11	14.47	83	28.72
AP-24	42	77.78	52	69.33	30	35.71	10	13.16	134	46.37
AP-25B	24	44.44	33	44.00	20	23.81	10	13.16	87	30.10
AP-28A/1	4	7.41	26	34.67	19	22.62	3	3.95	52	17.99
AP-28B/2	17	31.48	4	5.33	6	7.14	11	14.47	38	13.15
AP-28B/3	0	0.00	7	9.33	11	13.10	10	13.16	28	9.69
AP-28B/4	37	68.52	0	0.00	0	0.00	4	5.26	41	14.19
R-2	17	31.48	20	26.67	7	8.33	6	7.89	50	17.30
R-6	5	9.26	4	5.33	2	2.38	12	15.79	23	7.96
R-7	0	0.00	9	12.00	13	15.48	0	0.00	22	7.61
R-9	8	14.81	7	9.33	8	9.52	4	5.26	27	9.34
R-11	32	59.26	43	57.33	19	22.62	4	5.26	98	33.91
R-13	10	18.52	50	66.67	19	22.62	4	5.26	83	28.72
R-21	0	0.00	18	24.00	25	29.76	17	22.37	60	20.76
R-25	25	46.30	21	28.00	15	17.86	3	3.95	64	22.15
R-26	6	11.11	12	16.00	16	19.05	10	13.16	44	15.22
R-27	9	16.67	31	41.33	22	26.19	31	40.79	93	32.18
R-35	2	3.70	48	64.00	33	39.29	22	28.95	105	36.33
R-36	3	5.56	32	42.67	11	13.10	2	2.63	48	16.61
R-37	7	12.96	15	20.00	3	3.57	3	3.95	28	9.69
R-38	9	16.67	25	33.33	5	5.95	20	26.32	59	20.42
R-44	31	57.41	49	65.33	34	40.48	16	21.05	130	44.98
R-46	27	50.00	15	20.00	26	30.95	14	18.42	82	28.37
R-47	50	92.59	57	76.00	25	29.76	25	32.89	157	54.33
R-50	10	18.52	10	13.33	0	0.00	3	3.95	23	7.96
R-53	3	5.56	46	61.33	32	38.10	27	35.53	108	37.37
R-54	26	48.15	27	36.00	22	26.19	25	32.89	100	34.60
R-55	3	5.56	33	44.00	17	20.24	13	17.11	66	22.84
R-69	16	29.63	22	29.33	1	1.19	0	0.00	39	13.49
R-73	21	38.89	54	72.00	28	33.33	28	36.84	131	45.33
R-75/1	21	38.89	30	40.00	15	17.86	9	11.84	75	25.95

Table A-5. Continued

Skeleton	*Cranial*		*Axial*		*Upper Limb*		*Lower Limb*		*Skeleton Total*	
	Total	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
R-75/2	8	14.81	34	45.33	16	19.05	10	13.16	68	23.53
R-76	34	62.96	42	56.00	37	44.05	40	52.63	153	52.94
R-77	7	12.96	34	45.33	16	19.05	2	2.63	59	20.42
R-82	21	38.89	8	10.67	9	10.71	1	1.32	39	13.49
R-86	8	14.81	43	57.33	20	23.81	5	6.58	76	26.30
R-88	1	1.85	38	50.67	10	11.90	11	14.47	60	20.76
R-89/1	0	0.00	24	32.00	11	13.10	15	19.74	50	17.30
R-91	32	59.26	1	1.33	6	7.14	7	9.21	39	13.49
R-97	4	7.41	19	25.33	1	1.19	7	9.21	31	10.73
R-100/1	27	50.00	20	26.67	10	11.90	7	9.21	64	22.15
R-100/2	20	37.04	4	5.33	0	0.00	0	0.00	24	8.30
R-101	52	96.30	54	72.00	33	39.29	20	26.32	159	55.02
R-105/1	6	11.11	24	32.00	16	19.05	2	2.63	48	16.61
R-105/2	45	83.33	31	41.33	14	16.67	15	19.74	105	36.33
R-109	36	66.67	29	38.67	36	42.86	17	22.37	106	36.68
R-111/1	0	0.00	46	61.33	20	23.81	16	21.05	82	28.37
R-114	14	25.93	48	64.00	47	55.95	34	44.74	143	49.48
R-117	0	0.00	29	38.67	14	16.67	16	21.05	59	20.42
R-122	13	24.07	13	17.33	18	21.43	4	5.26	48	16.61
R-124	0	0.00	35	46.67	19	22.62	10	13.16	64	22.15
R-131	53	98.15	43	57.33	28	33.33	15	19.74	139	48.10
R-141	16	29.63	43	57.33	28	33.33	24	31.58	111	38.41
R-143	11	20.37	34	45.33	14	16.67	5	6.58	64	22.15
R-146	28	51.85	12	16.00	10	11.90	5	6.58	55	19.03
R-151/1	17	31.48	20	26.67	27	32.14	16	21.05	80	27.68
UK-6/1	0	0.00	6	8.00	8	9.52	8	10.53	22	7.61

Table A-6. Zabayir overall subadult skeletal completeness scores.

Skeleton	*Cranial*		*Axial*		*Upper Limb*		*Lower Limb*		*Skeleton Total*	
	Total	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
AP-7/2	6	11.11	8	10.67	6	20.00	9	50.00	29	16.38
AP-21-2	12	22.22	61	81.33	18	60.00	17	94.44	108	61.02
R-12	0	0.00	56	74.67	23	76.67	5	27.78	84	47.46
R-30	2	3.70	2	2.67	5	16.67	14	77.78	23	12.99
R-50	10	18.52	3	4.00	0	0.00	1	5.56	14	7.91
R-71	2	3.70	12	16.00	4	13.33	4	22.22	22	12.43
R-75/3	0	0.00	5	6.67	2	6.67	0	0.00	7	3.95
R-95	2	3.70	25	33.33	9	30.00	0	0.00	36	20.34
R-96	10	18.52	27	36.00	0	0.00	4	22.22	41	23.16
R-105/3	7	12.96	12	16.00	2	6.67	9	50.00	30	16.95
R-111/2	2	3.70	8	10.67	3	10.00	0	0.00	13	7.34
R-112	16	29.63	14	18.67	10	33.33	9	50.00	49	27.68
R-123	19	35.19	16	21.33	4	13.33	0	0.00	39	22.03
R-151/2	6	11.11	0	0.00	0	0.00	0	0.00	6	3.39

APPENDIX B: DIET AND WEANING

Table B-1. Khirbet Qazone subadult (cohort 0-6) dentition summary.

Skeleton	Cohort	Sex	Permanent Teeth Present[1]	Deciduous Teeth Present[1]	Alveoli Present	# Caries	# Abscess	# AMTL	# LEH[2]	High Calculus Score	High Wear Score
A1	3	U	0	2	20	0	0	0	n/a	n/a	n/a
A2	3	U	0	14	20	0	0	0	n/a	0	1.00
A3.1	4	U	0	6	10	0	0	0	n/a	0	1.00
A3.2	3	U	0	16	20	0	0	0	n/a	0	1.00
H1	5	U	10	10	20	1	0	0	0	0	3.00
I1	5	U	4	18	20	7	0	0	4	0	3.00
K1	5	U	0	20	20	0	0	0	n/a	0	2.25
R2.1	5	U	12	6	13	1	1	0	8	0	3.50
R2.3	5	U	14	9	15	1	0	0	16	0	4.00
W2	4	U	0	5	12	0	0	0	n/a	0	1.00
Z2	3	U	0	1	15	0	0	0	n/a	0	1.00

[1]Includes only partially erupted teeth or those in occlusion. Teeth scored as “8” (unerupted/in the crypt) on the dental inventory are excluded from counts.
[2]LEH recorded on permanent teeth only.

Table B-2. Khirbet Qazone adult (cohorts 7-12) dentition summary.

Skeleton	Cohort	Sex	Permanent Teeth Present	Alveoli Present	# Caries	# Abscess	# AMTL	# LEH	High Calculus Score	High Wear Score
H2	9	M	30	32	2	1	n/a	21	2	4.50
K2	11	M	21	32	1	0	12	0	2	7.00
K3	10	F	15	29	1	3	13	20	1	6.00
K4	11	M	17	32	2	6	14	5	3	8.00
K5	10	M	19	32	0	0	9	20	2	8.25
K6	10	F	32	32	1	0	0	1	2	6.00
K7	10	F	10	25	1	0	15	0	3	7.00
K7B	11	F	24	32	0	0	8	3	2	8.25
K8.1	10	F	21	32	2	0	7	22	3	8.00
K9	11	F	18	32	2	8	14	4	2	10.00
K10	10	F	10	32	2	2	9	9	0	5.00
M1	10	M	0	26	n/a	0	15	n/a	3	6.50
N1	7	M	28	32	0	0	0	3	2	3.5
R1.1	7	U	6	—	0	n/a	n/a	3	0	3.50
R1.1A	12	M	5	0	0	n/a	n/a	3	0	5.00
R1.3	10	U	7	4	0	n/a	n/a	1	0	5.25
R1.3A	12	U	8	0	0	n/a	n/a	23	1	4.00
R1.4A	12	F	11	0	0	n/a	n/a	6	1	4.00
R2.2	9	U	14	16	0	0	1	4	3	2.00
R2.4	10	M	4	30	1	0	13	12	0	4.00
T1	10	F	0	16	n/a	0	10	n/a	—	—
T2	8	M	13	31	0	0	5	15	0	3.00
U1*	10	F	1	0	n/a	n/a	n/a	n/a	0	7.00
Y1	10	M	13	26	1	0	10	18	1	5.00
Z1	9	F	4	32	0	0	7	n/a	0	4.00
Θ1	10	M	30	32	3	2	0	24	3	5.00
Θ2	9	F	21	32	3	0	1	3	2	5.75
Θ3	10	F	17	32	0	0	13	16	2	7.00

*Skeleton excluded from analyses due to poor tooth and alveolar preservation.

Table B-3. Zabayir subadult (cohort 0-6) dentition summary.

Skeleton	Cohort	Sex	Permanent Teeth Present	Deciduous Teeth Present	Alveoli Present	# Caries	# Abscess	# AMTL	# LEH[1]	High Calculus Score	High Wear Score
AP-21/2	4	U	1	5	10	0	0	0	0	0	2.00
R-71	5	U	3	0	0	n/a	n/a	n/a	n/a	n/a	n/a
R-96	5	U	2	2	1	0	0	0	3	0	4.40
R-97	6	U	15	0	10	0	0	0	6	0	3.50
R-123	4	U	8	2	6	0	0	0	0	0	4.00
R-151/2	3	U	0	3	12	0	0	0	0	0	2.00

[1]LEH recorded on permanent teeth only.

Table B-4. Zabayir adult (cohort 7-12) dentition summary.

Skeleton	Cohort	Sex	Permanent Teeth Present	Alveoli Present	# Caries	# Abscess	# AMTL	# LEH	High Calculus Score	High Wear Score
AP-9	12	M	1	5	n/a	0	0	n/a	0	—
AP-21/1	12	M	2	32	n/a	1	16	n/a	0	—
AP-24	8	M	10	28	0	0	0	8	2	3.80
AP-25B	12	F	5	21	0	0	0	0	0	6.20
AP-28A/1	9	U	4	3	0	0	0	0	1	3.00
R-11	7	U	4	24	0	0	0	n/a	0	1.00
R-13	9	F	0	2	n/a	n/a	1	n/a	—	—
R-25	12	F	8	21	0	0	7	0	2	—
R-27	12	F	1	3	0	1	3	n/a	1	6.00
R-38	12	U	12	0	2	n/a	n/a	1	2	4.50
R-44	11	M	0	24	n/a	0	23	n/a	—	—
R-46	11	F	0	25	n/a	0	25	n/a	—	—
R-47	10	M	8	31	0	1	6	0	1	9.00
R-50/1	10	F	1	3	n/a	0	0	n/a	0	—
R-73	9	M	3	15	0	0	1	0	2	3.00
R-75/1	8	F	0	14	n/a	0	3	n/a	—	—
R-75/2	9	U	0	10	n/a	0	3	n/a	—	—
R-82	12	M	11	13	0	0	0	11	0	2.75
R-89[1]	12	U	0	13	n/a	0	7	n/a	—	—
R-89/98/97 (OA)[1]	12	U	5	17	0	0	5	n/a	0	8.00
R-89/98/97 (MA/YA)[1]	12	U	4	16	0	0	1	n/a	0	3.75
R-91	12	M	4	15	n/a	n/a	n/a	5	0	—
R-100/1	11	F	15	8	1	0	1	0	2	4.00
R-101	9	F	6	32	0	0	0	3	3	6.40
R-105/1	10	U	5	12	n/a	0	0	n/a	0	—
R-105/2	12	U	4	16	0	0	0	0	0	3.75
R-109	9	F	12	31	2	1	6	n/a	3	7.00
R-114	10	M	10	16	0	0	1	0	2	5.75
R-122	12	U	6	7	0	0	0	n/a	2	5.00
R-131	10	M	5	32	0	0	27	n/a	0	—
R-141	12	U	2	0	n/a	n/a	n/a	n/a	0	—
R-143	9	F	5	3	0	0	1	3	2	4.50
R-146	12	M	7	18	0	0	3	8	2	8.00
R-151/1	9	U	9	15	0	0	3	2	2	7.75

[1]Note that the three R-89 dentitions observed could not be definitively assigned to R-89/1, 89/2, or 89/3. All were reported as indeterminate sex and unknown age adult.

Table B-5. Observed permanent dentition by site.

Tooth	Khirbet Qazone (n=25)			Zabayir (n=22)		
	Expected	*Observed*	*%*	*Expected*	*Observed*	*%*
I1	100	62	62.00	88	10	11.36
I2	100	62	62.00	88	10	11.36
C	100	61	61.00	88	22	25.00
P1	100	59	59.00	88	21	23.86
P2	100	51	51.00	88	23	26.14
M1	100	46	46.00	88	18	20.45
M2	100	44	44.00	88	27	30.68
M3	100	27	27.00	88	15	17.05
Total	**800**	**412**	**51.50**	**704**	**146**	**20.74**

Table B-6. Khirbet Qazone inventory of deciduous dentition.

Skeleton	A1	A2	A3.1	A3.2	H1	I1	K1	R2.1	R2.3	W2	Z2
Right Maxillary											
i1	8	2	5	5	—	5	2	3	5	2	5
i2	8	2	2	2	5	2	2	3	5	2	1
C	8	2	2	1	5	2	2	2	2	5	5
m1	8	1	2	2	2	2	2	3	5	5	5
m2	8	8	2	1	2	2	2	3	5	5	5
Left Maxillary											
i1	8	2	5	5	—	2	2	—	5	3††	3
i2	8	2	5	2	5	2	2	—	5	3††	3
C	8	2	5	1	5	2	2	2	2	3††	3
m1	8	1	2	2	2	2	2	2	2	3††	3
m2	8	8	2	1	2	2	2	2	2	3††	3
Right Mandibular											
i1	1	2	3	2	—	2	2	—	5	5	5
i2	8	2	3	2	—	2	2	—	5	5	5
C	8	2	3	5	2	2	2	—	2	5	5
m1	8	8	3	2	2	2	2	—	2	2	8
m2	8	8	3	1	2	2	2	—	2	2	8
Left Mandibular											
i1	1	2	3	2	—	2	2	2	5	3††	5
i2	5	2	3	2	—	5	2	2	5	3††	5
C	8	2	3	5	2	2	2	—	5	3††	5
m1	8	8	3	2	2	2	2	—	2	2	8
m2	8	8	3	1	2	2	2	—	2	5	5

††Elements are presumed present, but further observations were either partially or completely obscured by textiles.

Table B-7. Khirbet Qazone inventory of permanent dentition.

Skeleton	A2*	A3.1*	A3.2*	H1*	H2	I1*	K1*	K2	K3	K4	K5	K6	K7	K7B	K8.1
	Right Maxillary														
I1	—	8	8	2	2	8	8	2	2	2	2	2	4	2	2
I2	—	8	8	8	2	—	8	2	2	2	2	2	3	2	2
C	—	8	—	—	2	—	—	2	7	2	2	2	3	2	2
P1	—	—	—	—	2	8	—	2	2	2	4	2	3	2	4
P2	—	—	—	—	2	—	—	2	2	2	4	2	3	2	2
M1	8	8	8	2	7	2	8	2	2	4	4	2	3	2	2
M2	—	—	—	8	2	8	—	4	3	4	4	2	3	2	2
M3	—	—	—	—	2	—	—	6	3	4	4	2	3	4	6
	Left Maxillary														
I1	—	8	8	2	2	8	8	2	2	2	2	2	4	2	2
I2	—	8	8	8	2	—	8	2	2	4	5	2	4	2	2
C	—	8	—	—	2	—	—	2	4	2	7	2	4	2	2
P1	—	—	—	—	2	—	—	2	7	2	7	2	4	2	2
P2	—	—	—	—	2	—	—	2	4	4	7	2	4	2	2
M1	8	8	8	2	7	2	8	2	4	4	4	2	4	2	2
M2	—	—	—	8	2	8	—	2	4	4	4	2	4	2	2
M3	—	—	—	—	2	—	—	6	4	4	4	2	4	4	6
	Right Mandibular														
I1	—	3	—	2	2	—	—	4	2	4	2	2	2	2	2
I2	—	3	—	2	2	—	—	2	2	2	2	2	2	2	2
C	—	3	8	—	2	—	—	2	2	2	2	2	2	2	2
P1	—	3	—	—	2	—	—	2	2	2	2	2	2	2	2
P2	—	3	—	—	2	—	—	2	4	5	2	2	2	4	4
M1	8	3	8	2	2	2	8	4	4	4	2	2	4	2	4
M2	—	3	—	8	2	8	—	4	4	4	2	2	4	4	4
M3	—	3	—	—	2	—	—	4	4	4	2	2	2	4	6?
	Left Mandibular														
I1	—	3	—	2	2	—	—	4	2	4	2	2	2	4	2
I2	—	3	—	2	2	—	—	4	2	2	2	2	4	2	2
C	—	3	8	—	2	—	—	2	2	2	2	2	2	2	2
P1	—	3	—	—	2	—	—	2	2	2	2	2	2	2	2
P2	—	3	—	—	2	—	—	2	4	2	2	2	2	4	4
M1	8	3	8	2	2	2	8	4	4	2	4	2	4	2	4
M2	—	3	—	8	2	8	—	2	4	2	2	2	4	2	4
M3	—	3	—	—	2	—	—	4	4	4	2	2	4	4	6?

*Indicates subadult

Table B-7. Continued

Skeleton	K9	K10	M1	N1*	R1.1*	R1.1A	R1.3	R1.3A	R1.4A	R2.1*
Right Maxillary										
I1	2	5	3	2	3	3	3	2	3	1
I2	2	5	3	2	3	3	2	2	3	1
C	4	5	3	2	3	3	3	2	3	3
P1	4	2	3	2	3	3	3	2	3	3
P2	4	2	3	2	2	3	3	5	3	3
M1	4	4	7	2	2	3	3	3	2	3
M2	4	4	4	2	7	3	2	3	2	3
M3	4	4	4	8	8	3	3	3	2	3
Left Maxillary										
I1	2	2	7	2	3	3	3	2	3	1
I2	2	5	7	2	2	3	3	2	3	1
C	4	5	4	2	3	3	3	2	3	8
P1	4	5	4	2	3	3	3	3	2	8
P2	4	2	4	2	3	3	3	3	2	8
M1	4	4	7	2	2	2	3	3	3	1
M2	4	4	3	2	3	3	2	3	3	1
M3	4	4	2	8	3	2	2	3	2	1
Right Mandibular										
I1	2	5	5	2	3	3	5	3	7	7
I2	2	2	5	2	3	3	5	3	7	8
C	2	2	5	2	3	3	7	3	7	8
P1	2	5	5	2	3	2	7	3	2	8
P2	2	2	4	2	3	3	4	3	2	8
M1	2	4	4	2	2	3	7	3	2	1
M2	2	4	4	2	2	3	2	3	2	8
M3	2	4	4	8	3	3	3	3	3	8
Left Mandibular										
I1	2	5	5	2	3	3	3	3	7	1
I2	2	2	4	2	3	2	3	2	5	1
C	2	2	4	2	5	2	2	3	3	8
P1	2	5	5	2	7	3	2	3	3	8
P2	2	2	4	2	7	3	3	3	3	8
M1	4	4	4	2	7	3	3	3	3	5
M2	2	4	4	2	7	3	3	3	3	1
M3	4	4	4	8	1	3	3	3	2	1

*Indicates subadult

Table B-7. Continued

Skeleton	R2.2	R2.3*	R2.4	T1	T2	U1	W2*	Y1	Z1	θ1	θ2	θ3
Right Maxillary												
I1	5	2	2	3	3	3	8	2	5	2	2	2
I2	5	1	5	3	5	3	8	2	7	2	5	2
C	5	8	2	3	2	3	8	2	2	2	5	2
P1	2	1	2	3	2	3	8	7	7	2	5	4
P2	2	8	4	3	2	3	8	2	7	2	5	4
M1	2	5	4	3	4	3	8	3	4	2	2	4
M2	2	1	4	3	2	3	3	7	7	2	2	4
M3	2	—	4	3	1	3	3	7	7	2	5	2
Left Maxillary												
I1	5	2	3	3	2	3	3††	2	5	5	5	2
I2	5	1	3	3	5	3	3††	2	7	2	5	2
C	7	8	3	3	2	3	3††	5	5	2	5	2
P1	7	8	2	3	7	3	3††	4	2	2	5	2
P2	7	8	3	3	7	2	3††	4	7	2	5	4
M1	5	1	3	3	7	3	3††	2	2	2	4	4
M2	3	1	3	3	7	3	3††	3	2	2	2	4
M3	3	—	3	3	5	3	3††	3	4	2	2	4
Right Mandibular												
I1	2	1	7	5	5	3	3††	2	5	2	2	2
I2	7	5	5	5	2	3	3††	5	5	2	2	2
C	7	5	5	5	2	3	3††	2	5	2	2	2
P1	2	1	4	4	2	3	3††	7	5	2	2	4
P2	2	1	4	4	2	3	3††	4	5	2	2	2
M1	4	1	4	4	4	3	3††	4	4	2	2	4
M2	2	8	4	4	4	3	3††	4	4	2	2	2
M3	5	—	4	4	1	3	3††	4	5	5	2	2
Left Mandibular												
I1	2	1	7	5	5	3	3††	2	5	2	2	5
I2	2	5	5	5	5	3	3††	2	5	2	2	5
C	2	5	7	5	5	3	3††	5	5	2	2	2
P1	2	5	7	4	7	3	3††	2	5	2	2	2
P2	5	5	4	4	4	3	3††	2	4	2	2	2
M1	5	1	4	4	5	3	3††	4	5	2	2	4
M2	2	8	4	4	4	3	3††	4	4	2	2	4
M3	5	—	4	4	1	3	3††	4	4	2	2	4

*Indicates subadult

††Elements are presumed present, but further observations were either partially or completely obscured by textiles.

Table B-8. Zabayir inventory of deciduous dentition.

Skeleton	AP-21/2	R-71	R-96	R-123	R-151/2
Right Maxillary					
i1	3	3	3	3	3
i2	3	3	3	3	3
C	3	3	3	3	3
m1	3	3	3	3	3
m2	3	3	3	3	3
Left Maxillary					
i1	3	3	3	3	3
i2	3	3	3	3	3
c	3	3	3	3	3
m1	3	3	3	3	3
m2	1	3	3	3	3
Right Mandibular					
i1	5	3	3	5	5
i2	5	3	3	5	5
c	5	3	3	5	5
m1	2	3	3	2	2
m2	2	3	3	2	8
Left Mandibular					
i1	5	3	3	5	5
i2	5	3	3	3	5
c	5	3	3	3	5
m1	2	3	3	3	2
m2	2	3	2	3	8

Table B-9. Zabayir inventory of permanent dentition.

Skeleton	AP-9	AP-21/1	AP-21/2*	AP-24	AP-25B	AP-28A/1	R-11	R-13	R-25	R-27	R-38	R-44
Right Maxillary												
I1	3	5	3	5	3	3	3	3	3	3	3	4
I2	3	7	3	5	3	3	3	3	3	3	3	4
C	5	5	3	5	3	3	3	3	3	3	3	4
P1	5	4	3	5	3	3	3	3	3	3	2	4
P2	5	4	3	5	3	3	3	3	5	3	3	4
M1	7	4	1	5	3	3	3	3	4	3	3	4
M2	†	5	3	2	3	3	†?	3	4	3	3	4
M3	3	5	3	3	3	3	3	3	4	3	3	4
Left Maxillary												
I1	3	5	3	5	5	3	5	3	5	3	3	3
I2	3	5	3	5	5	3	5	3	5	3	3	3
C	3	4	3	2	5	3	5	3	4	3	2	3
P1	3	4	3	2	5	3	5	3	5	3	3	3
P2	3	7	3	2	5	3	5	3	2	3	3	3
M1	3	4	3	3	2	2	5	3	7	4	3	3
M2	3	4	3	3	2	2	†?	3	4	4	2	3
M3	3	4	3	3	5	3	2	3	5	4	2	3
Right Mandibular												
I1	3	4	—	5	5	3	5	3	3	3	3	4
I2	3	5	—	5	5	3	5	3	3	3	3	4
C	3	3	—	2	5	3	5	3	2	3	2	4
P1	3	5	—	5	5	3	5	3	3	3	3	4
P2	3	5	—	5	2	3	5	3	3	3	3	4
M1	3	5	8	2	5	3	5	3	2	3	3	4
M2	3	4	8	5	3	3	5	4	†	3	3	4
M3	3	4	—	2	3	3	5	5	5	3	2	4
Left Mandibular												
I1	3	4	—	2	5	3	5	3	3	2	2	4
I2	3	4	—	2	5	3	5	3	3	3	2	4
C	3	5	—	5	5	3	5	3	7	3	2	4
P1	3	5	—	5	5	3	5	3	7	3	3	5
P2	3	4	—	5	5	3	2	3	7	7	2	4
M1	3	4	8	2	2	5	7	3	4	3	2	4
M2	3	4	8	2	2	2	7	3	4	3	2	4
M3	3	5	—	5	6	2	5	3	2	3	3	4

†=Previously sampled
†?=One upper M2 previously sampled, side unknown

Table B-9. Continued

Skeleton	R-46	R-47	R-50/1	R-71*	R-73	R-75/1	R-75/2	R-82	R-89[1]	R-89/ 98/97 (OA)[1]	R-89/ 98/97 (MA/YA)[1]
Right Maxillary											
I1	4	5	3	3	3	3	3	3	3	3	3
I2	3	5	3	3	3	3	3	3	3	3	3
C	3	5	3	3	2	3	3	3	3	3	3
P1	3	5	3	3	2	3	3	2	3	3	3
P2	3	5	3	3	3	3	3	3	3	3	3
M1	3	2	3	3	3	3	3	3	3	3	3
M2	3	4	3	3	†	3	3	3	3	3	3
M3	3	4	3	3	3	3	3	3	3	3	3
Left Maxillary											
I1	4	5	3	1	5	3	3	3	3	5	3
I2	4	5	3	1	5	3	3	3	3	5	3
C	4	2	3	1	5	3	3	3	3	5	3
P1	4	5	3	3	5	3	3	3	3	5	3
P2	4	2	3	3	5	3	3	3	3	2	3
M1	4	5	3	3	3	3	3	3	3	4	3
M2	4	5	3	†	3	3	3	3	3	2	3
M3	4	5	3	3	3	3	3	3	3	5	3
Right Mandibular											
I1	4	5	3	3	5	5	4	3	5	5	2
I2	4	5	3	3	5	5	5	3	5	5	5
C	4	5	3	3	2	5	5	2	5	2	5
P1	4	7	3	3	3	5	3	2	4	3	2
P2	4	2	3	3	3	5	3	5	4	3	4
M1	4	4	3	3	3	4	3	5	4	3	4
M2	4	7	3	3	3	3	3	2	4	3	2
M3	4	4	3	3	3	3	3	2	4	2	2
Left Mandibular											
I1	4	5	3	3	5	5	4	5	5	5	5
I2	4	2	3	3	5	5	5	3	5	5	5
C	4	5	3	3	5	5	5	2	5	5	5
P1	4	2	3	3	5	5	5	2	4	5	5
P2	4	4	3	3	5	5	5	2	4	5	5
M1	4	4	7	3	4	4	4	2	3	5	4
M2	4	5	5	3	5	4	5	2	3	2	4
M3	4	3	5	3	5	6	3	2	3	5	4

*=Indicates subadult; †=Previously sampled; †?=One upper M2 previously sampled, side unknown

[1]Note that the three R-89 dentitions observed could not be definitively assigned to R-89/1, 89/2, or 89/3. All were reported as indeterminate sex and unknown age adult.

Table B-9. Continued

Skeleton	R-91	R-96*	R-97	R-100/1	R-101	R-105/1	R-105/2	R-109/91	R-114	R-122	R-123*
Right Maxillary											
I1	*3*	*3*	*5*	*2*	*5*	*3*	*5*	*2*	*3*	*3*	*3*
I2	*3*	*3*	*5*	*2*	*5*	*3*	*5*	*5*	*3*	*3*	*1*
C	*3*	*3*	*2*	*2*	*5*	*3*	*5*	*2*	*3*	*3*	*1*
P1	*3*	*3*	*2*	*7*	*5*	*3*	*2*	*4*	*3*	*3*	*1*
P2	*3*	*3*	*2*	*2*	*5*	*3*	*5*	*5*	*3*	*3*	*1*
M1	*3*	*3*	*3*	*4*	*5*	*3*	*5*	*5*	*3*	*3*	*3*
M2	*3*	*3*	*2*	*†*	*7†?*	*3*	*5*	*2*	*3*	*3*	*3*
M3	*3*	*3*	*2*	*2*	*5*	*3*	*5*	*3*	*3*	*3*	*3*
Left Maxillary											
I1	*3*	*3*	*5*	*2*	*5*	*3*	*5*	*5*	*3*	*5*	*3*
I2	*3*	*3*	*5*	*3*	*5*	*3*	*5*	*5*	*3*	*5*	*3*
C	*3*	*3*	*5*	*3*	*5*	*3*	*5*	*2*	*3*	*5*	*8*
P1	*3*	*3*	*2*	*2*	*5*	*3*	*5*	*4*	*3*	*5*	*3*
P2	*3*	*3*	*2*	*2*	*5*	*3*	*5*	*2*	*3*	*2*	*1*
M1	*3*	*2*	*2*	*3*	*5*	*3*	*2*	*2*	*3*	*5*	*3*
M2	*3*	*3*	*3*	*2*	*†?*	*3*	*2*	*4*	*3*	*5*	*3*
M3	*2*	*3*	*3*	*3*	*5*	*3*	*2*	*4*	*3*	*5*	*3*
Right Mandibular											
I1	*5*	*3*	*5*	*5*	*5*	*5*	*3*	*5*	*7*	*3*	*5*
I2	*5*	*3*	*2*	*5*	*5*	*5*	*3*	*2*	*4*	*3*	*5*
C	*5*	*2*	*5*	*5*	*5*	*5*	*3*	*5*	*2*	*7*	*5*
P1	*7*	*3*	*2*	*5*	*5*	*7*	*3*	*5*	*5*	*3*	*1*
P2	*5*	*3*	*2*	*5*	*5*	*3*	*3*	*2*	*2*	*3*	*5*
M1	*7*	*3*	*2*	*5*	*5*	*3*	*3*	*4*	*2*	*3*	*1*
M2	*5*	*3*	*2*	*2*	*2*	*3*	*3*	*2*	*2*	*3*	*5*
M3	*5*	*3*	*8*	*5*	*2*	*3*	*3*	*5*	*5*	*3*	*5*
Left Mandibular											
I1	*5*	*3*	*5*	*5*	*5*	*5*	*3*	*5*	*2*	*3*	*3*
I2	*5*	*3*	*5*	*2*	*5*	*5*	*3*	*2*	*5*	*7*	*3*
C	*5*	*3*	*1*	*2*	*2*	*5*	*3*	*5*	*5*	*3*	*8*
P1	*5*	*3*	*5*	*2*	*5*	*7*	*3*	*5*	*5*	*7*	*3*
P2	*5*	*3*	*1*	*2*	*5*	*7*	*3*	*2*	*2*	*3*	*3*
M1	*7*	*3*	*5*	*5*	*2*	*7*	*3*	*4*	*2*	*7*	*3*
M2	*3*	*3*	*5*	*5*	*2*	*7*	*3*	*2*	*2*	*2*	*1*
M3	*5*	*3*	*5*	*5*	*2*	*6*	*3*	*5*	*2*	*3*	*3*

*=Indicates subadult
†=Previously sampled
†?=One upper M2 previously sampled, side unknown

Table B-9. Continued

Skeleton	R-131	R-141	R-143	R-146	R-151/1	R-151/2
Right Maxillary						
I1	4	3	3	7	3	3
I2	4	3	3	5	3	3
C	4	3	3	5	3	3
P1	4	3	3	2	3	3
P2	4	3	3	2	3	3
M1	4	3	3	5	2	3
M2	4	3	3	3	3	3
M3	4	3	3	3	3	3
Left Maxillary						
I1	4	3	3	5	3	3
I2	4	3	3	5	3	3
C	4	3	3	2	3	3
P1	4	3	2	2	3	3
P2	4	3	3	4	3	3
M1	4	3	3	5	3	3
M2	4	3	3	4	*	3
M3	4	3	3	3	3	3
Right Mandibular						
I1	4	3	3	5	5	5
I2	7	3	3	5	2	5
C	7	3	3	5	2	8
P1	4	3	3	2	2	5
P2	4	3	3	4	2	5
M1	4	3	3	3	2	8
M2	4	†?	†	3	4	—
M3	4	3	3	3	4	—
Left Mandibular						
I1	7	3	3	2	2	5
I2	7	3	2	3	5	5
C	7	3	3	3	2	8
P1	4	3	2	3	2	5
P2	4	7	3	3	5	5
M1	4	7	7	3	4	8
M2	4	†?	2	3	5	—
M3	4	5	4	3	3	—

†=Previously sampled
†?=One upper M2 previously sampled, side unknown

Table B-10. Khirbet Qazone and Zabayir teeth processed for dental analysis by author.

Site[1]	Skeleton	Tooth[1]	Max/Mand[1]	R/L[1]	Sample Type/#	# of Samples
KQ	H1	M1	Mand	L	Enamel	3
KQ	H2	M1	Mand	R	Enamel	4
KQ	H2	M2	Mand	L	Enamel	2
KQ	I1	M1	Max	L	Enamel	3
KQ	K2	M1	Max	L	Enamel	3
KQ	K2	M2	Mand	L	Enamel	3
KQ	K5	M1	Mand	R	Enamel	1
KQ	K5	M1	Mand	R	Dentine	1
KQ	K5	M2	Mand	L	Enamel	1
KQ	K6	M1	Mand	R	Enamel	1
KQ	K6	M2	Mand	L	Enamel	3
KQ	K7	C	Mand	L	Enamel	3
KQ	K7	C	Mand	L	Dentine	1
KQ	K8	M2	Max	L	Enamel	3
KQ	K9	M1	Mand	R	Enamel	1
KQ	K9	M2	Mand	L	Enamel	2
KQ	N1	M1	Mand	R	Enamel	3
KQ	N1	M2	Max	L	Enamel	4
KQ	R1.2A	M1	Mand	L	Enamel	1
KQ	R1.4A	M1	Mand	R	Enamel	3
KQ	R2.1	M1	Max	R	Enamel	1
KQ	R2.2	M1	Max	R	Enamel	2
KQ	R2.2	M2	Mand	L	Enamel	2
KQ	R2.3	M1	Mand	L	Enamel	1
KQ	T2	M1	Max	L	Enamel	3
KQ	T2	M2	Max	L	Enamel	3
KQ	Θ1	M1	Mand	R	Enamel	3
KQ	Θ1	M2	Mand	R	Enamel	3
KQ	Θ2	M1	Max	R	Dentine	1
KQ	Θ3	M2	Mand	R	Dentine	1
QAIA	AP-1	C	Max	R	Enamel	2
QAIA	AP-21-2	M1	Max	L	Enamel	2
QAIA	AP-24	M1	Mand	L	Enamel	2
QAIA	AP-25B	M1	Max	L	Enamel	1
QAIA	AP-25B	M2	Max	L	Enamel	2
QAIA	AP-28A-1	M1	Max	L	Enamel	2
QAIA	AP-28A-1	M2	Max	L	Enamel	2

[1]KQ=Khirbet Qazone; QAIA=Zabayir; Mand=mandibular; max=maxillary; M1=first molar; M2=second molar; C=canine; R=right; L=left

Table B-10. Continued

Site	Skeleton	Tooth	Max/Mand	R/L	Sample Type/#	# of Samples
QAIA	R-47	M1	Max	R	Enamel	2
QAIA	R-71	C	Max	L	Enamel	4
QAIA	R-73	C	Max	R	Enamel	3
QAIA	R-76	M1	Max	R	Enamel	2
QAIA	R-76	M2	Max	L	Enamel	3
QAIA	R-82	C	Mand	L	Enamel	1
QAIA	R-82	M2	Mand	L	Enamel	1
QAIA	R-89/98/97 (MA)	C	Mand	L	Enamel	3
QAIA	R-89/98/97 (YA)	M1	Mand	R	Enamel	2
QAIA	R-89/98/97 (YA)	M2	Mand	R	Enamel	3
QAIA	R-96	M1	Max	R	Enamel	3
QAIA	R-146	C	Max	L	Enamel	1
QAIA	R-151	C	Mand	L	Enamel	2

[1]KQ=Khirbet Qazone; QAIA=Zabayir; Mand=mandibular; max=maxillary; M1=first molar; M2=second molar; C=canine R=right; L=left

Table B-11. Khirbet Qazone and Zabayir bone apatite samples processed by author.

Site[1]	Skeleton	Material	Sample Type
KQ	A3.2	Bone	Apatite
KQ	H2	Bone	Apatite
KQ	K1	Bone	Apatite
KQ	K2	Bone	Apatite
KQ	K3	Bone	Apatite
KQ	K4	Bone	Apatite
KQ	K5	Bone	Apatite
KQ	K6	Bone	Apatite
KQ	K7	Bone	Apatite
KQ	K7B	Bone	Apatite
KQ	K8.1	Bone	Apatite
KQ	K9	Bone	Apatite
KQ	M1	Bone	Apatite
KQ	M2	Bone	Apatite
KQ	N1	Bone	Apatite
KQ	R2.4	Bone	Apatite
KQ	T1	Bone	Apatite
KQ	T2	Bone	Apatite
KQ	U1	Bone	Apatite
KQ	Y1	Bone	Apatite
KQ	Z1	Bone	Apatite
KQ	Ɵ1	Bone	Apatite
KQ	Ɵ3	Bone	Apatite
KQ	H1	Bone	Apatite
KQ	R2.1	Bone	Apatite
QAIA	AP-21-2	Bone	Apatite
QAIA	AP-24	Bone	Apatite
QAIA	AP-25B	Bone	Apatite
QAIA	AP-28A-1	Bone	Apatite
QAIA	R-101	Bone	Apatite
QAIA	R-11	Bone	Apatite
QAIA	R-111/1	Bone	Apatite
QAIA	R-114	Bone	Apatite
QAIA	R-13	Bone	Apatite
QAIA	R-143	Bone	Apatite
QAIA	R-146	Bone	Apatite
QAIA	R-151/1	Bone	Apatite
QAIA	R-26	Bone	Apatite

Table B-11. Continued

Site[1]	Skeleton	Material	Sample Type
QAIA	R-35	Bone	Apatite
QAIA	R-44	Bone	Apatite
QAIA	R-47	Bone	Apatite
QAIA	R-53	Bone	Apatite
QAIA	R-54	Bone	Apatite
QAIA	R-55	Bone	Apatite
QAIA	R-71	Bone	Apatite
QAIA	R-73	Bone	Apatite
QAIA	R-75[2]	Bone	Apatite
QAIA	R-76	Bone	Apatite
QAIA	R-77	Bone	Apatite
QAIA	R-82	Bone	Apatite
QAIA	R-86	Bone	Apatite
QAIA	R-88	Bone	Apatite
QAIA	R-89[3]	Bone	Apatite
QAIA	R-96	Bone	Apatite

[1]KQ=Khirbet Qazone; QAIA=Zabayir

[2]Note that the specimen could have come from either R-75/1 or R-75/2

[3]Note that the specimen could have come from R-89/1, 89/2, or 89/3

Table B-12. Site and demographic information for $\delta^{13}C$ and $\delta^{15}N$ samples from dentine collagen.

USF #	Site	Skeleton	Age Cohort	Sex	Tooth Type[1]	$\delta^{13}C$	$\delta^{15}N$
37878	Khirbet Qazone	K5	10	M	LRM1	-17.9	13.4
37881	Khirbet Qazone	K7	10	F	LRC	-13.8	17.0
37897	Khirbet Qazone	θ2	9	F	URM1	-19.0	9.3
37898	Khirbet Qazone	θ3	10	F	LRM2	-18.3	10.1
—	Zabayir	AP-24	8	M	LRM2	-19.2	10.8
—	Zabayir	AP-28B	12	F	LRM2	-18.2	13.0
—	Zabayir	R-25	12	F	LRM3	-17.2	13.5
—	Zabayir	R-36	12	U	ULM2	-18.6	9.3
—	Zabayir	R-37	12	F	LLM2	-18.2	11.9
—	Zabayir	R-53	9	M	LRM3	-18.5	9.3
—	Zabayir	R-73	9	M	LRM3	-18.4	10.9
—	Zabayir	R-76	9	F	LRM1	-18.2	11.6
—	Zabayir	R-97	6	U	ULM1	-18.7	11.3
—	Zabayir	R-99	—	—	ULM3	-18.2	10.7
—	Zabayir	R-100	—	—	ULM2	-18.5	11.5
—	Zabayir	R-105	—	—	URM1	-18.3	11.6
—	Zabayir	R-146	12	M	URM1	-17.7	11.5

[1]Tooth types abbreviations include four letters: 1) Lower/Upper (L/U), Left/Right (L/R), Canine/First Molar/Second Molar/Third Molar (C/M1/M2/M3)

Table B-13. Site and demographic information for $\delta^{13}C$ and $\delta^{18}O$ samples from bone carbonate and dental enamel.

USF #	Site	Skeleton[1]	Age Cohort	Sex	Material[2]	Subsample	$\delta^{13}C$	$\delta^{18}O$
36307	Khirbet Qazone	H2	9	M	Bone	n/a	-14.0	-1.6
36309	Khirbet Qazone	K2	11	M	Bone	n/a	-13.9	0.6
36310	Khirbet Qazone	K3	10	F	Bone	n/a	-14.5	-1.8
36311	Khirbet Qazone	K4	11	M	Bone	n/a	-14.8	-1.6
36312	Khirbet Qazone	K5	10	M	Bone	n/a	-12.7	1.0
36313	Khirbet Qazone	K6	10	F	Bone	n/a	-13.8	-0.5
36314	Khirbet Qazone	K7	10	F	Bone	n/a	-11.2	3.0
36315	Khirbet Qazone	K7B	11	F	Bone	n/a	-14.7	0.9
36316	Khirbet Qazone	K8.1	10	F	Bone	n/a	-14.1	-0.7
36317	Khirbet Qazone	K9	11	F	Bone	n/a	-13.6	-1.1
36318	Khirbet Qazone	M1	10	M	Bone	n/a	-14.1	-0.7
36319	Khirbet Qazone	M2	8	M	Bone	n/a	-13.4	3.8
36320	Khirbet Qazone	N1	7	M	Bone	n/a	-14.2	-2.0
36321	Khirbet Qazone	R2.4	10	M	Bone	n/a	-14.5	-2.0
36322	Khirbet Qazone	T1	10	F	Bone	n/a	-14.7	-1.4
36323	Khirbet Qazone	T2	8	M	Bone	n/a	-13.9	-0.6
36324	Khirbet Qazone	U1	10	F	Bone	n/a	-14.3	1.8
36325	Khirbet Qazone	Y1	10	M	Bone	n/a	-14.3	-1.6
36326	Khirbet Qazone	Z1	9	F	Bone	n/a	-14.8	-2.0
36327	Khirbet Qazone	Θ1	10	M	Bone	n/a	-12.8	1.1
36328	Khirbet Qazone	Θ3	10	F	Bone	n/a	-13.5	-1.9
37910	Zabayir	AP-24	8	M	Bone	n/a	-12.9	-1.9
37911	Zabayir	AP-25B	12	F	Bone	n/a	-12.7	-2.6
37912	Zabayir	AP-28A-1	9	U	Bone	n/a	-12.7	-2.8
37914	Zabayir	R-11	7	U	Bone	n/a	-12.7	-1.3
37916	Zabayir	R-13	9	F	Bone	n/a	-12.3	-1.7
37918	Zabayir	R-26	10	U	Bone	n/a	-12.4	-2.2
37919	Zabayir	R-35	7	M	Bone	n/a	-11.7	-1.6
37920	Zabayir	R-44	11	M	Bone	n/a	-12.7	-1.9
37899	Zabayir	R-47	10	M	Bone	n/a	-12.6	-3.0
37921	Zabayir	R-53	9	M	Bone	n/a	-12.9	-2.1
37922	Zabayir	R-54	9	F	Bone	n/a	-13.3	-2.1
37923	Zabayir	R-55	10	M	Bone	n/a	-13.1	-2.8
37901	Zabayir	R-73	9	M	Bone	n/a	-12.6	-2.3
37924	Zabayir	R-75	12	U	Bone	n/a	-12.8	-2.4

[1]MA=middle adult; YA=young adult

[2]Tooth types abbreviations include four letters: 1) Lower/Upper (L/U), Left/Right (L/R), Canine/First Molar/Second Molar/Third Molar (C/M1/M2/M3)

Table B-13. Continued

USF #	Site	Skeleton[1]	Age Cohort	Sex	Material[2]	Subsample	δ13C	δ18O
37902	Zabayir	R-76	9	F	Bone	n/a	-12.1	-1.5
37925	Zabayir	R-77	10	F	Bone	n/a	-12.2	-2.3
37903	Zabayir	R-82	12	M	Bone	n/a	-12.0	-2.5
37926	Zabayir	R-86	11	M	Bone	n/a	-13.2	-2.4
37927	Zabayir	R-88	11	F	Bone	n/a	-12.6	-2.1
37904	Zabayir	R-89	12	U	Bone	n/a	-12.9	-1.0
37913	Zabayir	R-101	9	F	Bone	n/a	-12.3	-2.9
37915	Zabayir	R-111/1	8	M	Bone	n/a	-13.7	-1.5
37906	Zabayir	R-114	10	M	Bone	n/a	-12.7	-1.7
37917	Zabayir	R-143	9	F	Bone	n/a	-12.9	-2.7
37907	Zabayir	R-146	12	M	Bone	n/a	-12.3	-1.4
37908	Zabayir	R-151	9	U	Bone	n/a	-12.2	-2.4
36268A	Khirbet Qazone	H1	5	U	LLM1	Sample A	-12.5	-1.5
36268B	Khirbet Qazone	H1	5	U	LLM1	Sample B	-13.0	-1.6
36268C	Khirbet Qazone	H1	5	U	LLM1	Sample C	-13.2	-1.6
36281A	Khirbet Qazone	H2	9	M	LRM1	Sample A	-12.6	-0.9
36281B	Khirbet Qazone	H2	9	M	LRM1	Sample B	-12.8	-0.9
36281C	Khirbet Qazone	H2	9	M	LRM1	Sample C	-13.0	-1.4
36281D	Khirbet Qazone	H2	9	M	LRM1	Sample D	-13.3	-1.4
36282A	Khirbet Qazone	H2	9	M	LLM2	Sample A	-12.4	-1.7
36282B	Khirbet Qazone	H2	9	M	LLM2	Sample B	-12.7	-1.6
36269A	Khirbet Qazone	I1	5	U	ULM1	Sample A	-12.0	-1.5
36269B	Khirbet Qazone	I1	5	U	ULM1	Sample B	-12.5	-1.3
36269C	Khirbet Qazone	I1	5	U	ULM1	Sample C	-13.0	-1.3
36273A	Khirbet Qazone	K2	11	M	ULM1	Sample A	-11.4	-0.5
36273B	Khirbet Qazone	K2	11	M	ULM1	Sample B	-11.9	-0.6
36273C	Khirbet Qazone	K2	11	M	ULM1	Sample C	-12.1	-0.7
36274A	Khirbet Qazone	K2	11	M	LLM2	Sample A	-11.8	1.0
36274B	Khirbet Qazone	K2	11	M	LLM2	Sample B	-12.1	-0.6
36274C	Khirbet Qazone	K2	11	M	LLM2	Sample C	-12.3	-0.8
36267	Khirbet Qazone	K6	10	F	LRM1		-12.3	-1.3
37928	Khirbet Qazone	K6	10	F	LLM2	Sample A	-11.2	-1.7
37929	Khirbet Qazone	K6	10	F	LLM2	Sample B	-11.4	-2.9
37930	Khirbet Qazone	K6	10	F	LLM2	Sample C	-11.3	-2.9
37941	Khirbet Qazone	K7	10	F	LRC	Sample A	-8.2	3.8
37942	Khirbet Qazone	K7	10	F	LRC	Sample B	-7.8	4.6
37943	Khirbet Qazone	K7	10	F	LRC	Sample C	-8.5	3.8

[1]MA=middle adult; YA=young adult

[2]Tooth types abbreviations include four letters: 1) Lower/Upper (L/U), Left/Right (L/R), Canine/First Molar/Second Molar/Third Molar (C/M1/M2/M3

Table B-13. Continued

USF #	Site	Skeleton[1]	Age Cohort	Sex	Material[2]	Subsample	δ13C	δ18O
37931	Khirbet Qazone	K8.1	10	F	ULM2	Sample A	-12.6	-2.2
37932	Khirbet Qazone	K8.1	10	F	ULM2	Sample B	-12.8	-2.2
37933	Khirbet Qazone	K8.1	10	F	ULM2	Sample C	-12.3	-2.7
36279A	Khirbet Qazone	K9	11	F	LRM1	Sample A	-12.5	-0.6
36280A	Khirbet Qazone	K9	11	F	LLM2	Sample A	-12.1	-0.6
36280B	Khirbet Qazone	K9	11	F	LLM2	Sample B	-12.3	-1.3
36277A	Khirbet Qazone	N1	7	M	LRM1	Sample A	-12.5	-1.7
36277B	Khirbet Qazone	N1	7	M	LRM1	Sample B	-13.7	-1.5
36277C	Khirbet Qazone	N1	7	M	LRM1	Sample C	-12.9	-1.3
36278A	Khirbet Qazone	N1	7	M	ULM2	Sample A	-11.8	-1.1
36278B	Khirbet Qazone	N1	7	M	ULM2	Sample B	-12.6	-1.7
36278C	Khirbet Qazone	N1	7	M	ULM2	Sample C	-12.4	-1.3
36278D	Khirbet Qazone	N1	7	M	ULM2	Sample D	-12.6	-1.7
37934	Khirbet Qazone	R1.4A	12	F	LRM1	Sample A	-11.9	-1.9
37935	Khirbet Qazone	R1.4A	12	F	LRM1	Sample B	-12.0	-2.6
37936	Khirbet Qazone	R1.4A	12	F	LRM1	Sample C	-12.4	-2.4
37937	Khirbet Qazone	R2.2	9	U	URM1	Sample A	-12.7	-2.1
37938	Khirbet Qazone	R2.2	9	U	URM1	Sample B	-13.0	-2.3
37939	Khirbet Qazone	R2.2	9	U	LLM2	Sample A	-12.2	-2.0
37940	Khirbet Qazone	R2.2	9	U	LLM2	Sample B	-12.3	-2.5
36275A	Khirbet Qazone	T2	8	M	ULM1	Sample A	-11.4	-1.3
36275B	Khirbet Qazone	T2	8	M	ULM1	Sample B	-12.9	0.2
36275C	Khirbet Qazone	T2	8	M	ULM1	Sample C	-12.3	-1.4
36276A	Khirbet Qazone	T2	8	M	ULM2	Sample A	-12.6	-0.4
36276B	Khirbet Qazone	T2	8	M	ULM2	Sample B	-12.7	0.0
36276C	Khirbet Qazone	T2	8	M	ULM2	Sample C	-12.3	-1.5
36265A	Khirbet Qazone	θ1	10	M	LRM1	Sample A	-11.9	0.3
36265B	Khirbet Qazone	θ1	10	M	LRM1	Sample B	-12.1	0.1
36265C	Khirbet Qazone	θ1	10	M	LRM1	Sample C	-12.4	1.2
36266A	Khirbet Qazone	θ1	10	M	LRM2	Sample A	-11.4	0.8
36266B	Khirbet Qazone	θ1	10	M	LRM2	Sample B	-11.3	1.0
36266C	Khirbet Qazone	θ1	10	M	LRM2	Sample C	-11.9	0.5
37978	Zabayir	AP-21-2	4	U	ULM1	Sample A	-11.9	-4.1
37979	Zabayir	AP-21-2	4	U	ULM1	Sample B	-12.4	-3.1
37982	Zabayir	AP-25B	12	F	ULM1		-12.0	-1.3
37983	Zabayir	AP-25B	12	F	ULM2	Sample A	-11.6	-2.8
37984	Zabayir	AP-25B	12	F	ULM2	Sample B	-11.8	-3.0

[1]MA=middle adult; YA=young adult
[2]Tooth types abbreviations include four letters: 1) Lower/Upper (L/U), Left/Right (L/R), Canine/First Molar/Second Molar/Third Molar (C/M1/M2/M3)

Table B-13. Continued

USF #	Site	Skeleton[1]	Age Cohort	Sex	Material[2]	Subsample	$\delta^{13}C$	$\delta^{18}O$
37985	Zabayir	AP-28A-1	9	U	ULM1	Sample A	-11.2	-2.9
37986	Zabayir	AP-28A-1	9	U	ULM1	Sample B	-11.8	-1.9
37987	Zabayir	AP-28A-1	9	U	ULM2	Sample A	-11.3	-2.6
37988	Zabayir	AP-28A-1	9	U	ULM2	Sample B	-11.9	-2.8
37948	Zabayir	R-71	5	U	ULC	Sample A	-11.3	-3.1
37949	Zabayir	R-71	5	U	ULC	Sample B	-11.5	-2.7
37950	Zabayir	R-71	5	U	ULC	Sample C	-12.0	-2.1
37951	Zabayir	R-71	5	U	ULC	Sample D	-11.7	-2.0
37952	Zabayir	R-73	9	M	URC	Sample A	-11.1	-1.6
37953	Zabayir	R-73	9	M	URC	Sample B	-11.5	-3.0
37954	Zabayir	R-73	9	M	URC	Sample C	-12.1	-2.4
37955	Zabayir	R-76	9	F	ULM1	Sample A	-11.6	-1.4
37956	Zabayir	R-76	9	F	ULM1	Sample B	-11.8	-1.2
37957	Zabayir	R-76	9	F	ULM2	Sample A	-11.7	-1.2
37958	Zabayir	R-76	9	F	ULM2	Sample B	-11.5	-1.6
37959	Zabayir	R-76	9	F	ULM2	Sample C	-11.7	-2.1
37960	Zabayir	R-89/98/97 (MA)	12	U	LLC	Sample A	-11.4	-2.2
37961	Zabayir	R-89/98/97 (MA)	12	U	LLC	Sample B	-12.1	-2.6
37962	Zabayir	R-89/98/97 (MA)	12	U	LLC	Sample C	-11.9	-2.3
37963	Zabayir	R-89/98/97 (YA)	12	U	LRM1	Sample A	-12.1	-2.1
37964	Zabayir	R-89/98/97 (YA)	12	U	LRM1	Sample B	-11.9	-2.7
37965	Zabayir	R-89/98/97 (YA)	12	U	LRM2	Sample A	-11.0	-3.4
37966	Zabayir	R-89/98/97 (YA)	12	U	LRM2	Sample B	-11.5	-3.4
37967	Zabayir	R-89/98/97 (YA)	12	U	LRM2	Sample C	-9.2	-2.5
37970	Zabayir	R-96	5	U	URM1	Sample A	-11.3	-1.5
37971	Zabayir	R-96	5	U	URM1	Sample B	-11.8	-3.3
37972	Zabayir	R-96	5	U	URM1	Sample C	-11.4	-3.0

[1]Tooth types abbreviations include four letters: 1) Lower/Upper (L/U), Left/Right (L/R), Canine/First Molar/Second Molar/Third Molar (C/M1/M2/M3)
[2]MA=middle adult; YA=young adult

APPENDIX C: STRESS AND WEANING

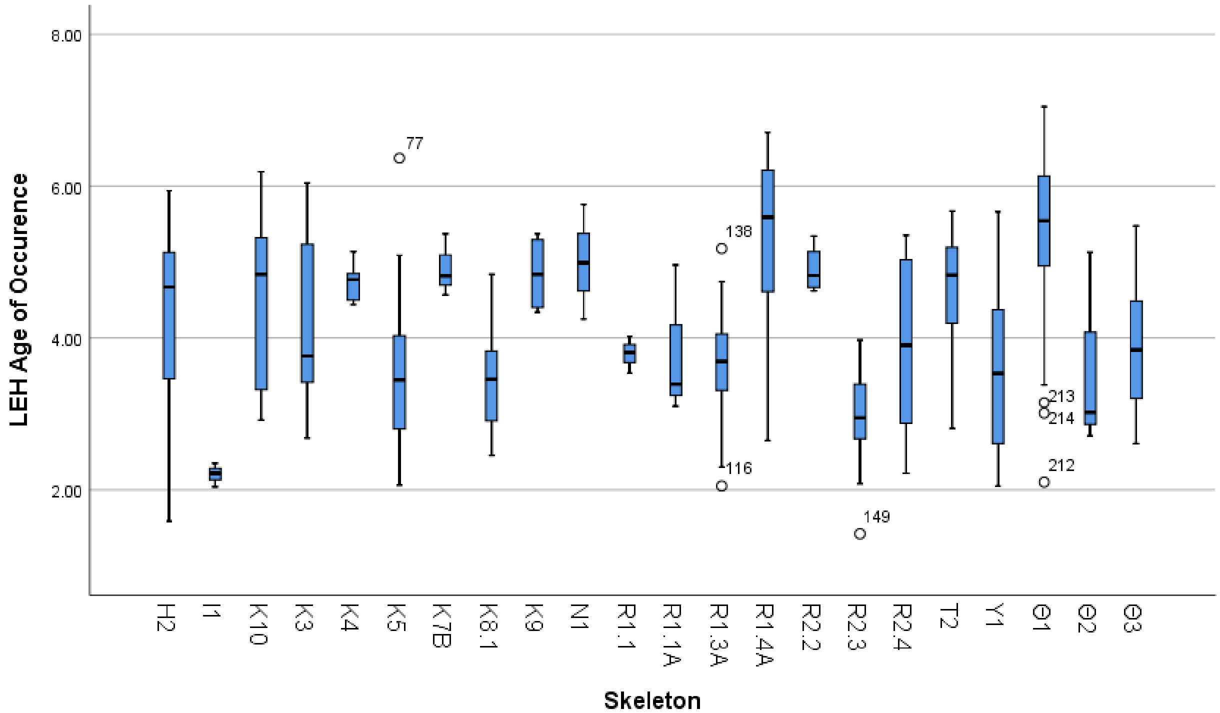

Figure C-1. Individual distribution of LEH by age for Khirbet Qazone skeletons.

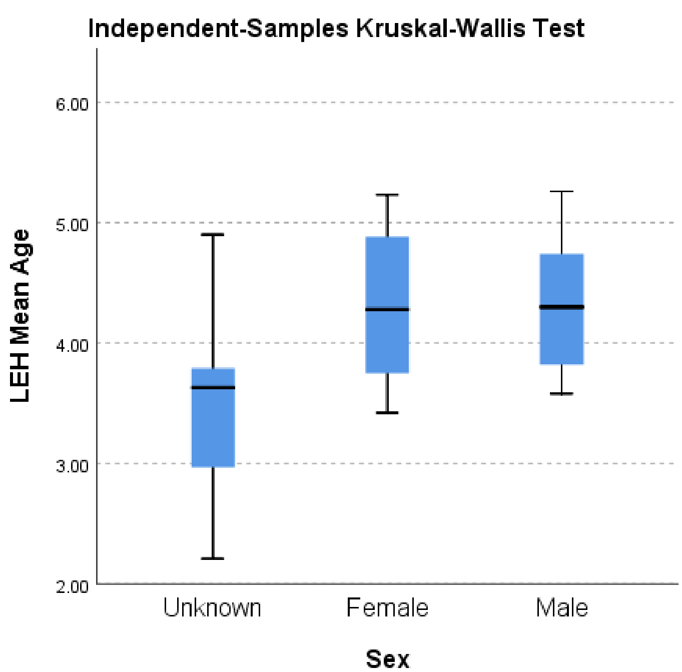

Figure C-2. Khirbet Qazone LEH mean age by sex.

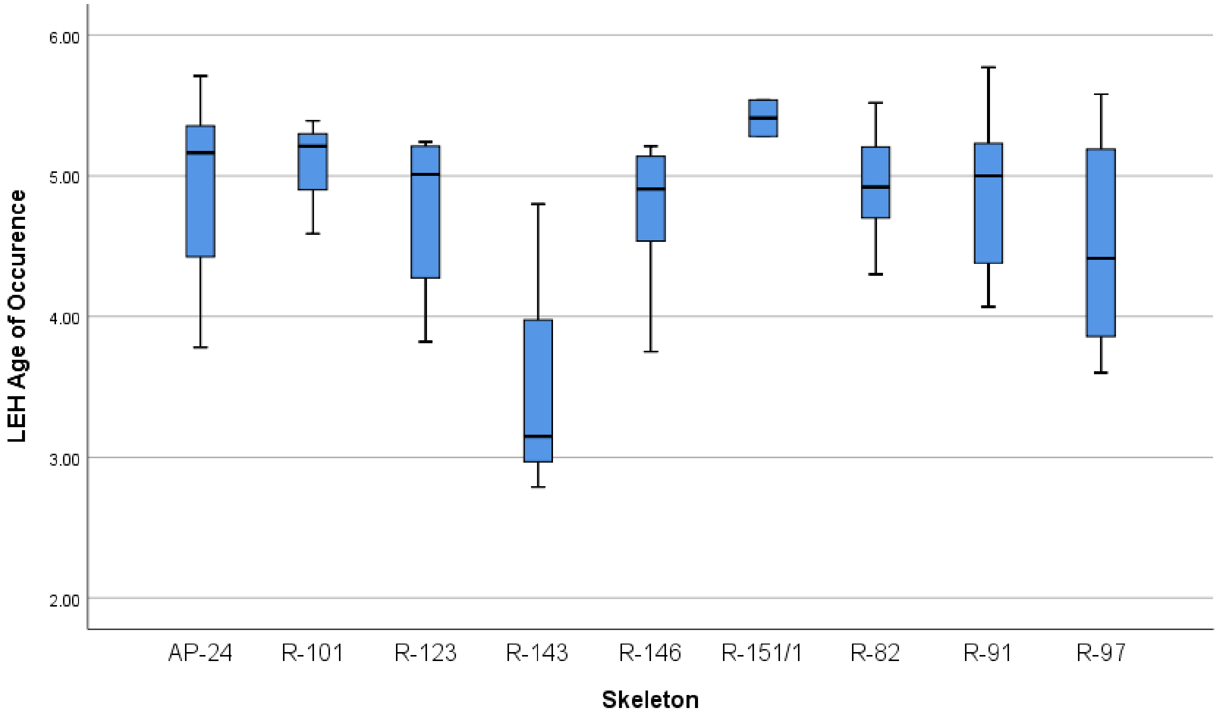

Figure C-3. Individual distribution of LEH by age for Zabayir skeletons.

APPENDIX D: ACTIVITY

Table D-1. Khirbet Qazone upper extremity MSM robusticity scores by individual.

Skeleton	**H2**		**K2**		**K3**		**K4**		**K5**		**K6**		**K7**		**K7B**		**K8.1**		**K9**	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula																				
Triceps brachii	3	3	3	3	1	1	3	3	3	3	1	1	2	2	2	2	2	2	3	3
Clavicle																				
Costoclavicular ligament	2	1	2	1	1	1	4	3	3	†	3	3	1	1	2	1	†	†	2	1
Subclavius	—	—	2	2	1	1	2	2	2	3	2	2	2	2	1	1	1	2	2	2
Trapezoid ligament	—	1	2	1	1	1	2	2	3	3	3	2	1	1	4	4	1	2	2	2
Humerus																				
Supraspinatus/ Infraspinatus	—	—	3	3	1	1	3	3	3	3	3	2	—	1	2	1	2	2	2	—
Subscapularis	2	—	3	3	1	1	3	3	3	3	3	2	—	3	3	3	3	3	2	—
Teres minor	—	1	2	2	1	1	3	3	3	3	2	2	—	3	1	1	1	1	2	—
Common extensor tendon	—	—	3	3	1	1	3	3	3	3	2	2	3	3	3	3	2	2	3	—
Common flexor tendon	2	2	2	2	1	1	3	3	3	3	2	2	3	3	3	3	2	2	3	—
Deltoideus	—	—	1	1	1	1	2	2	3	3	2	2	3	3	2	2	3	2	2	—
Teres major/ latissimus dorsi	2	1	1	1	1	1	2	2	3	3	1	1	—	2	3	2	2	2	1	—
Pectoralis major	4	2	2	2	2	2	3	3	3	3	2	2	—	2	3	3	2	2	3	—
Ulna																				
Triceps brachii	2	2	3	2	2	2	3	3	3	3	2	2	1	1	2	2	1	1	3	3
Brachialis	2	2	2	2	2	2	3	3	3	3	2	1	1	1	2	2	2	2	3	2
Supinator	2	2	3	3	1	1	3	3	3	3	2	2	2	1	3	3	2	2	2	2
Radius																				
Biceps brachii	1	1	2	—	1	1	2	2	2	2	2	1	2	2	2	2	2	2	2	3
Brachioradialis	—	2	3	3	2	2	3	3	—	3	3	3	3	3	3	2	1	1	—	3
Interosseus membrane	1	1	1	1	1	1	3	3	2	2	1	1	3	3	2	2	2	2	3	3
Supinator	1	1	1	1	1	1	3	3	3	3	1	1	3	3	2	2	1	1	3	2
Pronator teres	1	1	2	2	1	1	3	3	3	3	1	1	1	1	3	3	1	1	3	3
Pronator quadratus	—	2	3	†	1	1	3	3	—	3	2	2	3	3	3	3	2	2	2	2
Average Score	1.92	1.56	2.19	2.00	1.19	1.19	2.81	2.76	2.84	2.90	2.00	1.76	2.13	2.10	2.43	2.24	1.75	1.80	2.40	2.38
Combined R & L Aggregate Score	1.72		2.10		1.19		2.79		2.87		1.88		2.11		2.33		1.78		2.39	

Table D-1. Continued

Skeleton	M1		M2		N1		R1.1		R1.2		R1.3		R2.2		R2.4		T1		T2	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula																				
Triceps brachii	3	3	2	2	1	1	—	—	—	—	—	—	2	—	3	3	3	3	1	—
Clavicle																				
Costoclavicular ligament	3	†	3	3	1	1	—	—	—	2	—	—	1	1	2	—	2	1	2	2
Subclavius	3	3	2	2	2	1	—	—	—	—	—	—	2	2	3	—	2	2	—	2
Trapezoid ligament	3	4	3	2	1	1	—	—	—	—	—	2	2	2	2	2	3	3	1	1
Humerus																				
Supraspinatus/ Infraspinatus	3	4	1	1	1	1	—	—	—	—	—	—	—	—	1	—	2	1	1	1
Subscapularis	3	3	2	2	1	1	—	—	—	—	—	—	—	—	2	—	2	2	2	1
Teres minor	3	3	1	1	1	1	—	—	—	—	—	—	—	—	2	—	2	1	1	1
Common extensor tendon	3	3	2	2	1	1	—	—	—	—	—	—	—	2	—	—	3	3	2	1
Common flexor tendon	3	3	2	2	2	2	—	—	—	—	—	—	—	2	3	—	3	3	1	1
Deltoideus	2	†	2	2	2	2	—	—	—	—	—	—	2	2	2	—	3	3	2	2
Teres major/ latissimus dorsi	5	4	2	2	1	1	1	1	—	—	—	—	1	2	—	—	2	2	1	1
Pectoralis major	6	6	6	4	4	2	1	1	—	—	—	—	3	3	—	—	3	2	1	1
Ulna																				
Triceps brachii	3	3	1	1	1	1	—	—	—	—	—	—	—	—	—	—	3	2	1	1
Brachialis	3	3	2	2	1	1	2	—	—	—	—	—	—	—	—	—	3	4	1	1
Supinator	3	3	2	2	1	1	1	—	—	—	—	—	—	—	—	—	3	3	1	1
Radius																				
Biceps brachii	3	3	1	1	1	1	—	—	—	—	—	—	—	1	3	—	3	3	1	1
Brachioradialis	2	2	—	1	1	1	—	—	—	—	—	—	—	—	—	—	3	3	—	—
Interosseus membrane	3	3	1	1	1	1	—	—	—	—	—	—	—	1	—	—	2	2	1	1
Supinator	3	3	2	1	2	2	—	—	—	—	—	—	—	1	—	—	2	2	2	2
Pronator teres	2	2	1	1	1	1	—	—	—	—	—	—	—	1	—	—	2	2	1	1
Pronator quadratus	3	—	1	2	1	1	—	—	—	—	—	—	—	—	—	—	3	3	0	0
Average Score	3.10	3.22	1.95	1.76	1.33	1.19	1.25	1.00	—	2.00	—	2.00	1.86	1.67	2.30	2.50	2.57	2.38	1.21	1.16
Combined R & L Aggregate Score	3.15		1.85		1.26		1.17		2.00		2.00		1.74		2.33		2.48		1.18	

Table D-1. Continued

Skeleton	U1		W1		Y1		Z1		01		03	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula												
Triceps brachii	1	1	—	—	1	1	3	3	3	3	3	3
Clavicle												
Costoclavicular ligament	1	1	—	—	—	1	—	—	2	3	1	1
Subclavius	1	1	—	—	2	2	—	—	3	3	3	3
Trapezoid ligament	1	2	—	—	2	3	—	—	2	2	1	1
Humerus												
Supraspinatus/ Infraspinatus	1	—	—	—	2	1	2	2	3	3	2	2
Subscapularis	2	1	—	—	3	3	3	3	3	3	3	3
Teres minor	1	1	—	—	3	3	2	3	3	3	2	2
Common extensor tendon	2	2	—	—	3	3	3	2	3	3	3	3
Common flexor tendon	2	2	—	—	3	3	2	2	3	3	2	2
Deltoideus	2	2	—	—	1	1	2	2	3	3	2	2
Teres major/ latissimus dorsi	2	2	—	—	2	2	3	3	2	2	2	2
Pectoralis major	2	2	—	—	3	3	4	3	5	3	2	3
Ulna												
Triceps brachii	2	2	—	1	3	2	3	2	3	3	2	2
Brachialis	3	3	—	3	2	2	3	3	3	3	2	2
Supinator	2	2	—	2	2	2	3	3	2	2	2	2
Radius												
Biceps brachii	2	1	—	—	2	2	2	2	3	3	2	3
Brachioradialis	3	3	—	—	2	3	2	2	—	3	3	3
Interosseus membrane	3	3	—	1	1	1	2	2	3	2	2	3
Supinator	2	3	—	2	1	1	3	3	2	2	3	3
Pronator teres	2	2	—	—	2	2	2	2	3	3	2	2
Pronator quadratus	3	3	—	1	1	2	2	3	3	3	3	3
Average Score	1.90	1.95	—	1.67	2.05	2.05	2.56	2.50	2.85	2.76	2.24	2.38
Combined R & L Aggregate Score	1.93		1.67		2.05		2.53		2.80		2.31	

Table D-2. Khirbet Qazone lower extremity MSM robusticity scores by individual.

Skeleton	H2		K2		K3		K4		K5		K6		K7		K7B		K8		K9	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																				
Semimembranosus/ semitendinosus/ biceps femoris	2	2	3	3	3	3	3	3	3	3	3	3	2	3	3	3	2	2	3	—
Femur																				
Gluteus maximus	1	1	3	—	2	2	3	3	3	3	3	3	3	—	3	3	4	4	5	5
Gluteus medius	1	2	3	3	2	2	3	3	3	3	2	2	—	—	2	2	3	3	3	3
Gluteus minimus	2	1	3	3	2	2	3	3	3	3	2	2	2	—	3	3	3	3	—	3
Psoas	2	2	3	—	1	1	3	3	3	3	3	3	—	—	3	3	2	2	—	3
Gastrocnemius	2	2	4	4	2	2	3	3	3	3	3	3	—	—	2	2	3	5	3	3
Quadratus femoris	2	2	3	—	1	1	2	2	—	3	2	—	—	—	3	3	2	2	—	—
Vastus medialis	1	2	2	1	1	1	3	3	3	3	2	2	2	—	3	3	2	2	3	3
Patella																				
Quadriceps tendon	1	1	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2
Tibia																				
Patellar ligament/ quadriceps tendon	1	1	3	3	2	2	3	3	3	—	2	2	—	—	2	3	2	3	3	3
Popliteus	1	1	3	3	—	—	3	3	3	—	2	2	—	—	1	1	2	3	3	4
Soleus	2	1	3	3	2	2	3	5	3	3	3	3	1	1	3	2	2	2	3	3
Calcaneus																				
Calcaneal tendon	2	2	3	3	2	2	3	3	3	3	2	2	2	2	3	3	2	2	3	3
Aggregate Score	1.54	1.54	2.92	2.80	1.83	1.83	2.92	3.08	2.92	2.91	2.38	2.42	2.00	2.00	2.54	2.54	2.38	2.69	3.10	3.18
Combined R & L Aggregate Score	1.54		2.87		1.83		3.00		2.91		2.40		2.00		2.54		2.54		3.14	

Table D-2. Continued

Skeleton	M1		M2		N1		R1.1		R1.2		R2.2		R2.4		T1		T2		U1	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																				
Semimembranosus/ semitendinosus/ biceps femoris	3	3	1	1	—	—	—	—	—	—	1	1	1	1	3	3	1	—	2	2
Femur																				
Gluteus maximus	3	3	2	2	1	1	—	1	—	—	—	—	3	—	3	3	2	—	2	2
Gluteus medius	3	3	2	1	1	1	—	—	—	—	—	—	2	2	3	3	1	1	2	—
Gluteus minimus	3	3	2	1	1	1	—	—	—	—	—	—	3	—	3	3	1	1	2	—
Psoas	3	3	2	2	—	—	—	—	—	—	—	—	2	2	2	2	—	—	2	—
Gastrocnemius	3	3	1	1	1	1	—	—	—	3	—	—	—	—	3	3	—	—	3	3
Quadratus femoris	3	3	1	1	1	1	—	—	—	—	—	—	2	—	2	2	1	—	2	2
Vastus medialis	3	3	1	1	1	1	—	—	—	—	—	—	—	—	3	3	1	—	2	2
Patella																				
Quadriceps tendon	3	3	1	1	1	1	—	—	—	—	—	—	2	2	3	3	1	1	2	2
Tibia																				
Patellar ligament/ quadriceps tendon	—	3	2	2	1	1	—	—	—	—	—	—	—	—	3	3	1	—	—	—
Popliteus	—	3	1	1	1	1	—	—	—	—	—	—	—	—	3	4	1	1	—	—
Soleus	—	3	2	2	2	2	—	—	—	—	—	—	—	—	3	3	—	1	—	2
Calcaneus																				
Calcaneal tendon	3	3	—	1	1	1	—	—	—	—	2	2	3	3	3	3	1	1	2	—
Aggregate Score	3.00	3.00	1.50	1.31	1.09	1.09	0.00	1.00	0.00	3.00	1.50	1.50	2.25	2.00	2.85	2.92	1.10	1.00	2.10	2.14
Combined R & L Aggregate Score	3.00		1.40		1.09		1.00		3.00		1.50		2.15		2.88		1.06		2.12	

Table D-2. Continued

Skeleton	W1		Y1		Z1		θ1		θ3	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa										
Semimembranosus/ semitendinosus/ biceps femoris	—	—	2	2	2	2	4	4	3	3
Femur										
Gluteus maximus	—	—	3	3	3	3	3	3	3	2
Gluteus medius	—	—	3	3	3	3	3	3	—	2
Gluteus minimus	—	—	3	3	3	3	3	3	2	2
Psoas	—	—	3	—	2	2	3	3	2	2
Gastrocnemius	—	—	3	4	2	2	3	3	3	3
Quadratus femoris	—	—	3	3	3	3	2	2	—	2
Vastus medialis	—	—	3	4	3	3	3	3	2	2
Patella										
Quadriceps tendon	—	—	2	2	3	—	—	3	2	—
Tibia										
Patellar ligament/ quadriceps tendon	2	2	2	2	2	2	3	3	2	2
Popliteus	1	1	3	3	2	2	3	3	2	2
Soleus	2	2	2	3	3	3	3	3	2	2
Calcaneus										
Calcaneal tendon	3	3	3	3	3	3	3	3	2	2
Aggregate Score	2.00	2.00	2.69	2.92	2.62	2.58	3.00	3.00	2.27	2.17
Combined R & L Aggregate Score	2.00		2.80		2.60		3.00		2.22	

Table D-3. Zabayir upper extremity MSM robusticity scores by individual (highlighted entries indicate single or no MSM scores).

Skeleton	**R-9**		**R-11**		**R-13**		**R-21**		**R-25**		**R-26**		**R-27**		**R-35**		**R-36**		**R-38**	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula																				
Triceps brachii	—	—	2	2	2	—	3	2	2	—	—	—	—	—	1	1	—	—	—	—
Clavicle																				
Costoclavicular ligament	—	3	—	—	—	—	4	2	1	2	—	1	4	—	2	2	—	—	—	—
Subclavius	—	—	—	—	—	—	—	2	2	2	—	—	—	—	0	0	—	—	—	—
Trapezoid ligament	—	—	—	—	2	—	—	1	—	—	—	2	3	—	1	1	—	—	—	—
Humerus																				
Supraspinatus/ Infraspinatus	—	—	1	1	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—
Subscapularis	—	—	1	1	—	—	3	2	—	—	—	—	—	—	—	—	—	—	—	—
Teres minor	—	—	1	1	—	—	3	2	—	—	—	—	—	—	—	1	—	—	—	—
Common extensor tendon	—	3	2	1	2	—	3	—	—	—	—	3	—	—	—	—	—	—	—	—
Common flexor tendon	—	—	1	1	1	—	3	3	—	—	—	—	—	—	—	—	—	—	—	—
Deltoideus	—	3	1	1	—	—	3	3	—	—	—	3	—	—	1	2	—	3	—	—
Teres major/ latissimus dorsi	—	—	1	1	—	—	4	4	—	—	—	—	—	—	0	0	—	3	—	—
Pectoralis major	—	—	2	2	—	—	3	3	—	—	—	3	—	—	1	2	—	—	—	—
Ulna																				
Triceps brachii	3	—	—	1	—	1	2	2	—	—	2	2	—	—	—	—	—	—	—	—
Brachialis	3	—	—	1	1	1	3	3	—	—	2	3	3	3	1	1	—	—	—	—
Supinator	3	—	—	1	2	2	2	2	—	—	1	1	2	2	2	—	—	—	—	—
Radius																				
Biceps brachii	—	—	1	1	2	—	3	—	—	3	2	—	3	—	1	1	—	2	—	—
Brachioradialis	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—
Interosseus membrane	—	—	1	1	—	—	2	—	—	—	—	—	3	—	1	1	—	—	—	—
Supinator	—	—	0	0	—	—	2	—	—	—	—	—	2	—	1	1	—	—	—	—
Pronator teres	—	—	1	1	1	—	3	—	—	2	—	1	2	2	1	1	—	—	—	3
Pronator quadratus	—	—	—	—	—	—	3	—	—	—	—	—	—	—	0	0	—	—	—	—
Aggregate Score	3.00	3.00	1.15	1.06	1.63	1.33	2.79	2.29	1.67	2.25	1.75	2.11	2.75	2.33	0.93	1.00	0.00	2.67	0.00	3.00
Combined R & L Aggregate Score	3.00		1.10		1.55		2.58		2.00		2.00		2.64		0.96		2.67		3.00	

Table D-3. Continued

Skeleton	R-44		R-46		R-47		R-53		R-54		R-55/1		R-73		R-75/1		R-76		R-77	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula																				
Triceps brachii	3	3	3	3	2	3	3	3	3	3	3	3	—	—	2	—	—	—	—	—
Clavicle																				
Costoclavicular ligament	4	—	—	1	2	2	2	2	—	—	—	—	—	1	2	—	1	—	3	—
Subclavius	3	—	—	2	2	2	—	3	—	—	—	—	—	1	2	—	2	—	3	—
Trapezoid ligament	3	—	2	2	2	2	—	2	—	—	—	—	—	2	2	—	2	—	3	—
Humerus																				
Supraspinatus/ Infraspinatus	—	—	—	—	1	—	4	4	4	—	—	2	—	—	—	—	1	1	—	—
Subscapularis	—	—	—	—	3	—	4	3	3	—	—	—	—	—	—	—	1	—	—	—
Teres minor	—	3	—	—	—	—	3	3	2	—	—	3	—	—	—	—	1	1	—	—
Common extensor tendon	3	—	3	—	2	—	3	—	3	3	—	—	—	—	—	—	2	2	—	—
Common flexor tendon	3	—	3	—	3	—	3	3	3	3	—	2	—	—	—	—	1	1	—	—
Deltoideus	3	—	—	3	2	—	3	3	3	3	—	—	—	3	—	—	—	—	—	—
Teres major/ latissimus dorsi	3	—	—	—	—	—	3	3	1	1	—	—	—	—	—	—	1	1	—	—
Pectoralis major	3	—	—	3	3	—	3	3	2	2	—	—	—	—	—	—	—	—	—	—
Ulna																				
Triceps brachii	3	2	—	—	—	—	2	2	—	3	3	—	—	2	—	—	—	2	—	—
Brachialis	2	2	—	3	—	3	—	—	3	3	3	—	—	—	—	—	2	2	—	2
Supinator	1	1	—	2	—	3	2	—	3	3	3	—	—	—	—	—	2	2	—	3
Radius																				
Biceps brachii	3	—	3	3	—	3	—	—	—	—	—	—	—	2	—	—	1	1	—	2
Brachioradialis	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	2	2	—	—
Interosseus membrane	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1	1	3	—
Supinator	3	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	0	0	—	—
Pronator teres	3	2	3	—	—	2	3	4	—	—	—	—	—	—	—	—	1	1	2	—
Pronator quadratus	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	1	1	—	—
Aggregate Score	2.75	2.17	2.83	2.44	2.20	2.20	2.92	2.92	2.73	2.67	3.00	2.67	0.00	1.83	2.00	0.00	1.29	1.29	2.80	2.33
Combined R & L Aggregate Score	2.59		2.60		2.20		2.92		2.70		2.80		1.83		2.00		1.29		2.63	

Table D-3. Continued

Skeleton	R-82		R-86		R-88		R-89		R-100/1		R-100/2		R-101		R-105/1		R-105/2		R-109/91/112	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula																				
Triceps brachii	—	—	3	3	—	—	3	—	—	—	2	—	3	3	2	1	—	—	—	—
Clavicle																				
Costoclavicular ligament	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Subclavius	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Trapezoid ligament	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Humerus																				
Supraspinatus/ Infraspinatus	—	—	—	—	3	2	2	—	—	—	—	—	—	—	1	—	—	—	—	—
Subscapularis	—	—	—	3	3	—	—	—	4	—	—	—	2	2	—	—	—	—	—	—
Teres minor	—	—	3	3	3	3	3	—	2	—	—	—	2	2	2	—	—	—	—	—
Common extensor tendon	—	—	—	3	3	3	3	—	—	—	2	—	—	—	1	1	—	—	3	—
Common flexor tendon	—	—	3	3	3	—	—	—	—	—	—	—	—	—	3	—	—	—	3	—
Deltoideus	—	1	3	3	3	2	2	—	—	—	1	1	1	1	1	2	—	—	3	—
Teres major/ latissimus dorsi	—	—	2	2	2	2	2	—	2	—	2	1	2	2	1	1	—	—	3	—
Pectoralis major	—	—	3	3	3	3	3	—	—	—	3	3	3	3	2	2	—	—	3	—
Ulna																				
Triceps brachii	—	—	—	—	—	2	2	—	—	—	—	—	—	—	—	—	3	—	—	—
Brachialis	—	—	—	2	—	3	3	—	3	3	—	—	3	3	—	—	3	—	—	—
Supinator	—	—	—	3	—	3	3	—	3	—	—	—	3	3	—	—	3	—	—	—
Radius																				
Biceps brachii	—	—	3	—	—	—	3	3	3	—	—	—	—	2	—	—	—	—	—	—
Brachioradialis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Interosseus membrane	—	—	—	—	—	—	2	2	3	3	—	—	3	1	—	—	—	—	—	—
Supinator	—	—	—	—	—	—	1	1	2	2	—	—	—	1	—	—	—	—	—	—
Pronator teres	—	—	—	—	—	—	2	2	1	1	—	—	2	2	—	—	—	—	—	—
Pronator quadratus	—	—	—	—	3	—	1	—	—	—	—	—	2	2	—	—	—	—	—	—
Aggregate Score	0.00	1.00	2.86	2.80	2.89	2.64	2.33	2.00	2.56	2.25	2.00	1.67	2.36	2.08	1.63	1.40	3.00	0.00	3.00	3.00
Combined R & L Aggregate Score	1.00		2.82		2.75		2.26		2.46		1.88		2.21		1.54		3.00		3.00	

Table D-3. Continued

Skeleton	R-109/91/112		R-111/1		R-114/1		R-117		R-122		R-124		R-131		R-141		R-143		R-146	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula																				
Triceps brachii	—	—	3	—	—	3	—	—	—	3	—	—	—	—	—	2	3	3	3	—
Clavicle																				
Costoclavicular ligament	—	2		2	4	2	—	—	—	—	—	3	—	2	—	1	3	—	—	—
Subclavius	—	2		2	2	2	—	—	—	—	3	2	—	2	—	3	3	—	—	—
Trapezoid ligament	—	—		1	2	2	—	—	—	—	—	2	—	2	—	3	3	—	—	—
Humerus																				
Supraspinatus/ Infraspinatus	2	2	1	—	1	1	—	—	—	—	—	3	—	2	—	2	3	—	—	—
Subscapularis	—	—	1	—	2	2	—	—	—	—	3	3	—	1	—	4	3	—	—	—
Teres minor	2	2	1	—	3	3	—	—	—	—	3	3	—	2	—	2	3	—	—	—
Common extensor tendon	—	—	2	2	3	3	—	—	—	—	—	3	—	3	—	—	—	3	—	—
Common flexor tendon	—	—	2	1	3	3	—	—	—	—	—	3	—	3	—	—	—	3	—	—
Deltoideus	2	2	2	2	2	2	1	2	—	—	3	3	2	3	—	3	3	3	3	3
Teres major/ latissimus dorsi	2	2	2	2	2	2	—	1	—	—	3	3	2	1	—	3	2	—	—	3
Pectoralis major	3	3	3	2	3	3	—	2	—	—	3	3	2	2	—	3	3	—	—	3
Ulna																				
Triceps brachii	—	3	—	2	—	2	—	—	—	—	—	2	—	—	—	—	2	—	—	—
Brachialis	3	2	—	3	—	2	—	—	2	—	3	3	3	—	3	3	3	—	—	—
Supinator	3	3	—	3	—	—	—	—	3	—	3	3	3	3	—	2	3	—	—	—
Radius																				
Biceps brachii	3	2	3	—	3	—	—	1	—	—	—	—	3	—	—	4	—	—	—	—
Brachioradialis	—	3	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Interosseus membrane	—	2	2	—	—	—	—	2	—	—	—	—	1	1	—	2	—	—	—	—
Supinator	—	1	2	—	3	—	—	1	—	—	—	—	3	3	—	2	—	—	—	—
Pronator teres	—	1	2	—	—	—	—	1	—	—	—	—	3	3	—	2	—	—	—	—
Pronator quadratus	—	3	3	—	—	—	—	1	—	—	—	—	2	2	—	—	—	—	—	—
Aggregate Score	2.50	2.19	2.13	2.00	2.54	2.29	1.00	1.38	2.50	3.00	3.00	2.79	2.40	2.19	3.00	2.56	2.85	3.00	3.00	3.00
Combined R & L Aggregate Score	2.29		2.08		2.41		1.33		2.67		2.86		2.27		2.59		2.88		3.00	

Table D-3.Continued

Skeleton	R-151		UK-6/1																	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Scapula																				
Triceps brachii	—	—	—	—																
Clavicle																				
Costoclavicular ligament	2	1	3	—																
Subclavius	3	1	1	—																
Trapezoid ligament	2	—	3	—																
Humerus																				
Supraspinatus/ Infraspinatus	—	—	—	—																
Subscapularis	—	—	—	—																
Teres minor	—	—	—	—																
Common extensor tendon	—	—	—	—																
Common flexor tendon	—	—	—	—																
Deltoideus	—	—	—	—																
Teres major/ latissimus dorsi	—	—	—	—																
Pectoralis major	—	—	—	—																
Ulna																				
Triceps brachii	—	—	—	—																
Brachialis	—	—	—	—																
Supinator	—	3	—	—																
Radius																				
Biceps brachii	—	—	3	3																
Brachioradialis	—	—	3	—																
Interosseus membrane	1	—	1	1																
Supinator	3	—	3	3																
Pronator teres	—	—	3	3																
Pronator quadratus	—	—	3	—																
Aggregate Score	2.20	1.67	2.56	2.50																
Combined R & L Aggregate Score	2.00		2.54																	

Table D-4. Zabayir lower extremity MSM robusticity scores by individual (highlighted entries indicate single or no MSM scores).

Skeleton	**AP-3/1**		**AP-3/2**		**AP-9**		**AP-13**		**AP-17**		**AP-21/1**		**AP-23/2**		**AP-24**		**AP-25B**	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																		
Semimembranosus/ semitendinosus/ biceps femoris	—	2	1	—	—	—	3	3	3	3	—	—	—	—	—	—	—	—
Femur																		
Gluteus maximus	—	—	—	—	—	—	—	3	3	3	—	—	3	3	—	—	3	—
Gluteus medius	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	2
Gluteus minimus	—	—	—	—	—	—	3	3	—	—	—	—	—	—	—	2	—	2
Psoas	—	—	—	—	—	—	—	3	—	3	—	—	—	2	—	2	—	—
Gastrocnemius	—	—	—	—	—	2	5	3	2	2	—	—	—	—	2	2	—	—
Quadratus femoris	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vastus medialis	—	—	—	—	—	—	2	2	3	3	—	—	2	2	—	3	—	—
Patella																		
Quadriceps tendon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tibia																		
Patellar ligament/ quadriceps tendon	—	—	—	1	2	—	3	3	3	3	—	—	—	—	—	—	—	—
Popliteus	—	—	—	1	1	—	4	3	2	2	—	—	—	—	—	—	—	—
Soleus	—	—	—	2	3	—	3	—	4	4	—	—	2	2	—	—	—	—
Calcaneus																		
Calcaneal tendon	1	—	—	—	—	—	—	—	2	2	2	2	—	—	—	—	2	2
Aggregate Score	1.00	2.00	1.00	1.33	2.00	2.00	3.29	2.67	2.75	2.78	2.00	2.00	2.33	2.25	2.00	2.25	2.50	2.00
Combined R & L Aggregate Score	1.50		1.25		2.00		2.94		2.76		2.00		2.29		2.20		2.20	

Table D-4. Continued

Skeleton	AP-28B/2		R-2		R-6		R-9		R-11		R-13		R-21		R-25		R-26	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																		
Semimembranosus/ semitendinosus/ biceps femoris	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—
Femur																		
Gluteus maximus	3	3	—	—	—	—	—	3	2	2	1	1	—	3	—	3	3	3
Gluteus medius	—	—	—	—	—	—	—	—	1	1	—	—	—	2	—	—	—	—
Gluteus minimus	—	—	—	—	—	—	—	—	1	1	2	2	—	3	—	—	2	—
Psoas	3	—	—	—	2	—	—	—	2	—	1	—	—	2	—	—	3	—
Gastrocnemius	2	2	—	—	1	—	—	—	—	—	—	—	—	2	—	—	—	—
Quadratus femoris	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
Vastus medialis	2	2	—	—	2	—	—	3	1	1	1	1	—	2	—	2	3	3
Patella																		
Quadriceps tendon	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—
Tibia																		
Patellar ligament/ quadriceps tendon	3	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Popliteus	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Soleus	3	3	4	4	—	—	—	—	—	—	—	—	—	—	—	—	2	2
Calcaneus																		
Calcaneal tendon	—	—	—	—	2	2	—	—	—	—	—	—	—	—	—	—	—	—
Aggregate Score	2.57	2.50	4.00	4.00	1.75	2.00	0.00	3.00	1.40	1.25	1.25	1.50	2.00	2.13	0.00	2.50	2.60	2.67
Combined R & L Aggregate Score	2.54		4.00		1.80		3.00		1.33		1.38		2.10		2.50		2.63	

Table D-4. Continued

Skeleton	R-27		R-35		R-36		R-38		R-44		R-46		R-47		R-53		R-54	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																		
Semimembranosus/ semitendinosus/ biceps femoris	—	3	1	1	—	—	—	—	—	—	—	—	3	3	—	3	2	2
Femur																		
Gluteus maximus	3	3	2	2	—	—	3	3	3	—	3	3	—	2	—	3	3	3
Gluteus medius	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	4	4	3
Gluteus minimus	—	—	—	1	—	—	—	—	3	—	—	—	—	3	—	3	2	2
Psoas	—	2	—	1	—	—	—	—	3	—	—	3	—	3	—	3	1	1
Gastrocnemius	—	4	1	1	—	—	—	—	3	—	—	3	2	2	4	4	3	3
Quadratus femoris	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	3	3	3
Vastus medialis	2	2	—	—	—	2	2	3	3	—	2	2	—	2	—	3	2	2
Patella																		
Quadriceps tendon	2	2	—	—	—	—	2	—	2	—	—	—	—	—	—	—	—	—
Tibia																		
Patellar ligament/ quadriceps tendon	—	1	1	1	—	—	3	—	—	—	—	—	—	2	3	3	3	3
Popliteus	—	2	1	1	—	—	—	—	—	—	—	—	2	2	3	3	—	3
Soleus	—	1	1	1	—	—	—	—	—	—	3	3	2	2	3	3	3	3
Calcaneus																		
Calcaneal tendon	—	—	—	—	—	—	—	—	—	—	—	—	3	3	—	3	—	—
Aggregate Score	2.33	2.22	1.17	1.13	0.00	2.00	2.50	3.00	2.83	0.00	2.67	2.80	2.40	2.42	3.25	3.17	2.60	2.55
Combined R & L Aggregate Score	2.25		1.14		2.00		2.67		2.83		2.75		2.41		3.19		2.57	

Table D-4. Continued

Skeleton	R-55/1		R-73		R-75/1		R-76		R-77		R-82		R-86		R-88		R-89	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																		
Semimembranosus/ semitendinosus/ biceps femoris	3	—	—	—	—	—	1	1	—	—	—	—	3	—	3	3	2	2
Femur																		
Gluteus maximus	3	3	—	3	3	2	2	1	3	—	—	—	—	3	—	3	4	4
Gluteus medius	2	—	—	—	—	—	1	1	—	—	—	—	—	—	—	3	—	—
Gluteus minimus	3	—	—	—	—	3	2	2	—	—	—	—	—	—	—	3	2	2
Psoas	2	2	—	3	—	3	2	2	—	—	—	—	—	—	—	3	1	—
Gastrocnemius	—	3	—	—	—	—	1	1	—	—	—	—	—	—	—	3	2	2
Quadratus femoris	1	—	—	—	—	—	1	1	—	—	—	—	—	—	—	2	—	—
Vastus medialis	2	2	—	3	3	2	1	2	2	2	—	—	—	3	—	2	2	2
Patella																		
Quadriceps tendon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
Tibia																		
Patellar ligament/ quadriceps tendon	—	—	—	—	—	—	1	1	—	—	—	—	—	—	2	2	2	2
Popliteus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	3
Soleus	—	—	—	—	—	—	1	—	—	—	—	—	—	3	2	2	2	2
Calcaneus																		
Calcaneal tendon	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Aggregate Score	2.29	2.50	0.00	3.00	3.00	2.50	1.30	1.33	2.50	2.00	0.00	1.00	3.00	3.00	2.00	2.42	2.13	2.38
Combined R & L Aggregate Score	2.36		3.00		2.67		1.32		2.33		1.00		3.00		2.31		2.25	

Table D-4. Continued

Skeleton	R-100/1		R-100/2		R-101		R-105/1		R-109/91/112		R-109/91/112		R-111/1		R-114		R-117	
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																		
Semimembranosus/ semitendinosus/ biceps femoris	—	1	—	—	—	1	—	—	—	—	—	—	—	3	—	—	1	—
Femur																		
Gluteus maximus	—	1	3	—	3	3	3	3	3	3	3	3	2	2	3	3	1	1
Gluteus medius	—	—	—	—	—	—	3	3	—	—	—	—	—	—	3	3	—	—
Gluteus minimus	—	1	3	—	—	—	3	3	—	—	2	2	2	2	2	2	—	—
Psoas	—	1	2	—	—	—	3	2	—	—	—	—	3	3	3	2	—	—
Gastrocnemius	—	1	2	—	2	2	—	—	—	—	—	4	—	2	—	2	—	—
Quadratus femoris	—	—	2	—	—	—	—	2	—	—	—	—	—	—	2	2	—	—
Vastus medialis	—	1	3	—	2	2	1	2	3	3	—	3	2	2	1	1	3	3
Patella																		
Quadriceps tendon	—	—	—	—	—	—	—	—	—	—	1	1	2	2	2	1	—	—
Tibia																		
Patellar ligament/ quadriceps tendon	1	—	3	3	3	2	—	—	—	—	—	—	—	—	2	2	—	—
Popliteus	—	1	3	3	—	—	—	—	—	—	—	—	—	—	1	1	—	—
Soleus	1	1	4	3	1	1	—	1			—	—	—	3	3	—	—	2
Calcaneus																		
Calcaneal tendon	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	3	—	—
Aggregate Score	1.00	1.00	2.78	3.00	2.20	1.83	2.60	2.29	3.00	3.00	2.00	2.60	2.20	2.33	2.27	2.00	1.67	2.00
Combined R & L Aggregate Score	1.00		2.83		2.00		2.42		3.00		2.38		2.29		2.14		1.83	

Table D-4. Continued

Skeleton	R-122		R-124		R-131		R-141		R-143		R-146		R-151		UK-6/1			
MSM	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Os Coxa																		
Semimembranosus/ semitendinosus/ biceps femoris	—	—	3	—	—	—	—	—	3	—	—	—	—	—	—	—		
Femur																		
Gluteus maximus	—	—	4	4	3	3	3	3	3	—	3	3	3	—	—	2		
Gluteus medius	—	—	—	—	—	—	2	2	2	—	—	—	—	—	—	—		
Gluteus minimus	—	—	3	—	3	3	2	—	3	—	3	—	—	—	—	—		
Psoas	—	—	3	3	—	3	—	—	2	—	—	—	—	—	—	—		
Gastrocnemius	—	—	3	3	4	4	—	—	—	—	—	—	—	—	—	—		
Quadratus femoris	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—		
Vastus medialis	—	—	3	2	2	—	1	1	2	—	3	3	3	—	—	1		
Patella																		
Quadriceps tendon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
Tibia																		
Patellar ligament/ quadriceps tendon	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	1		
Popliteus	—	—	—	—	3	2	—	—	—	—	—	—	—	—	—	—		
Soleus	—	—	—	3	3	3	2	—	—	—	3	—	—	—	2	1		
Calcaneus																		
Calcaneal tendon	—	2	—	—	—	—	2	2	—	—	—	—	—	—	—	—		
Aggregate Score	0.00	2.00	3.17	3.00	3.00	3.00	2.00	2.00	2.43	0.00	3.00	3.00	3.00	0.00	2.00	1.25		
Combined R & L Aggregate Score	2.00		3.09		3.00		2.00		2.43		3.00		3.00		1.40			

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