**Exploring Social Inequality at Petra through Dental Pathology**

By

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Dental pathologies such as linear enamel hypoplasias (LEHs), periapical lesions (abscesses), dental calculus and caries, and antemortem tooth loss (AMTL) can indicate physiological stress during childhood development as well as reflect biocultural markers of nutrition and oral infection. Combined, they provide a powerful indicator of differential access to resources and dietary variation. This research explores the relationship between the frequencies of these pathologies and social stratification in three samples from the ancient Nabataean capital city of Petra and the surrounding hinterlands. The mortuary repertoire of Petra includes ornate monumental façade tombs surrounding the city center in addition to less elaborate shaft chamber tombs. Previous archaeological research explains these tomb variants as reflecting family groups of higher and lower social status, respectively (Perry, 2016; Schmid, Bienkowski, Fiema, & Kolb, 2012; Wadeson, 2012a, 2012b). Statistical analysis of dental pathology frequencies in 696 teeth from the non-elite tombs, 234 teeth from the elite façade tombs, and 132 teeth from a contemporary non-urban site identified statistically higher frequencies of dental calculus between the façade and shaft chamber tomb samples ($\chi^2 = 30.79$, $p < 0.001$) and the façade and hinterland tomb samples ($\chi^2=5.98$, $p=0.014$). The frequency of LEHs of the selected Polar teeth were also significantly different between the façade and shaft chamber tomb samples ($\chi^2 = 18.13$, $p < 0.001$). Additionally, the data show significantly higher frequencies of AMTL in the non-urban

hinterland tomb sample when compared to both the façade ($\chi^2 = 9.61$, $p = 0.002$) and shaft chamber tomb samples ($\chi^2 = 17.90$, $p < 0.001$). No differences in the frequency of dental caries or abscesses were found. The higher frequency of LEHs suggests that the elite individuals experienced stress during childhood development more often than the non-elite individuals. However, more observations of LEHs point to a higher frequency of childhood stress survival. Unfortunately, the limited subadult remains from both contexts hinders understanding the relationship between LEH frequencies and childhood morbidity and mortality. The difference in dental calculus frequencies indicates either different patterns of protein, dairy, or water consumption between tomb lineages, or differences in taphonomic preservation between tomb types. The higher frequency of AMTL in the hinterland tomb indicates that the non-urban individuals had more dental pathologies that led to AMTL, such as dental caries or calculus, than the urban samples.

# Exploring Social Inequality at Petra through Dental Pathology

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# CHAPTER 1: Introduction

Petra was a bustling capital city of the Nabataean Kingdom and a major trade center in the 1st century B.C.–A.D., The inhabitants of Petra had gained considerable economic power because of the city's strategic role in the trade of spices, incense, and other aromatics (Johnson, 1987). Archaeological explorations at Petra have discovered both lavish villas (Schmid, 2002) and more modest domestic structures (Parker, 2016). The variation seen in the domestic structures is mirrored by the site's well-known, ornate, monumental façade tombs that contrast with simpler rock-cut shaft tombs (Perry, 2016). This difference in domestic and mortuary architecture indicates that social and economic inequality existed at the site, but it is unclear if this inequality resulted in dietary variation or differential access and use of resources. Bioarchaeology can be used to address this question through intra-site comparison of skeletal indicators of inequality and diet, such as dental pathologies. A comparison of developmental dental pathologies, such as linear enamel hypoplasias, can reveal differences in childhood health and development. Additionally, plaque-related dental pathologies, such as dental caries, dental calculus, antemortem tooth loss, and abscesses, can reveal differences in diet and oral heath during life. The frequencies of dental pathologies at Petra were expected to reflect the social stratification implied by funerary architecture, with elite Nabataeans in the façade tombs exhibiting greater frequencies of dental caries, calculus, AMTL and abscesses associated with consumption of carbohydrate rich foods and non-elite individuals in the shaft chamber tombs exhibiting higher frequencies of linear enamel hypoplasias indicative of greater childhood stress. This study seeks to determine if the social inequality implied by house and tomb construction is reflected in individual diet and disease burdens and to establish if social stratification at Petra impacted the health and well-being of city inhabitants.

Human dentition from three different locations within the city of Petra was used in this analysis; the Renaissance tomb located in Wadi Farasa, Khubtha tombs 779 and 781 located near the city center, and shaft tombs from Petra North Ridge on the edge of the urban core. In addition to these sites, a tomb from Petra's hinterland, tomb A.10, was included as a comparative non-urban sample. The Renaissance and two Khubtha tombs contain purported "elite" individuals responsible for construction of the monumental façade tombs, Petra North Ridge consists of shaft chamber tombs of proposed "non-elite" populations, and the hinterland tomb consists of rural individuals. The teeth from these burials were macroscopically analyzed for pathologies indicative of diet and oral disease such as dental caries, linear enamel hypoplasias, dental calculus, antemortem tooth loss, and abscesses. Dental pathology frequencies, which can reflect diet and infectious disease burdens, from the three different tomb types were used to identify social-status-related differences in oral health at Petra.

In contrast with symbols of status based on mortuary architecture, previous bioarchaeological analyses suggests non-elite Nabataeans show few physical or biological markers of stress and that elites may have been under greater physiological stress during childhood than non-elites (Bikai & Perry, 2001; Canipe, 2014). The current study relies on a larger sample size than these earlier studies and examines a more specific set of dental pathologies to assess the impact of social stratification on diet and dental health at Petra.

The following chapter will cover the history of Petra, discuss both the historical and archaeological literature surrounding Petra, and illustrate how dental pathologies can be used to elucidate the relationships between oral health, social stratification, and nutrition. Chapter 3 will explain the methods used to catalogue the skeletal and dental material as well as describe the procedures followed for collecting data on human dental pathologies. An overview of the frequencies of dental pathologies by tomb type and by tomb is presented in Chapter 4. These findings are discussed in Chapter 5, where it is proposed that despite the similarities in plaque related dental disease social stratification can be viewed through differences in dental calculus and linear enamel hypoplasia frequencies. The final chapter summarizes the implications of the dental pathologies observed and suggests areas of future research.

# CHAPTER 2: Background

Petra is a UNESCO world heritage site located in southern Jordan that is known for its unique architecture and semi-desert location. Although the site has been used to tell the extraordinary tales of fictitious characters in movies such as *Indiana Jones and the Last Crusade* and *The Mummy Returns*, relatively little is known about the lives of the Nabataeans who built and inhabited Petra. Archaeological and bioarchaeological information indicate that, by the 1$^{st}$ century B.C.–1$^{st}$ century A. D, the Nabataeans at Petra had a complex society represented by monumental architecture (Al-Muheisen, 2007; Schmid, 2002), intricate funerary rights (Perry, 2016), and a relatively well-fed population showing little evidence of disease (Canipe, 2014). The tomb architecture suggests that those who were entombed within monumental façade tombs were elite individuals with a specialized diet and greater access to resources in contrast to those entombed in simpler shaft chamber tombs. Differences in dental pathologies at Petra were explored following these mortuary indicators of social stratification.

## Historical Background

Prior to the development of Petra, the Nabataeans were a nomadic population believed to have migrated from northeast Arabia to southern Jordan during the middle of the 1$^{st}$ millennium B.C. (Schmid, 2002). Little is known about the Nabataeans prior to 400 B.C. due to the lack of a written history or clear archaeological presence. As a result, most textual sources referencing the Nabataeans come from Nabataean contact with other cultures (Wenning, 2007). The Greek historian Diodorus produced the first written record of the group, describing the 4$^{th}$ century B.C. Nabataeans as nomads who frequently engaged in trade between South Arabia and the Mediterranean (Schmid, 2002).

Petra likely began as a Nabataean storage outpost and religious center around the 3rd or 2nd century B.C. (Wenning, 2007). Petra's location along several major trade routes connecting the Arabian Peninsula with the Mediterranean allowed the Nabataeans to tax goods traveling through the land they controlled as well as participate in trade (Schmid, 2002). This influx of wealth and trade likely contributed to the development of public infrastructure toward the end of the 1st century B.C. such as a massive road through the Siq, multiple temples, an extensive water catchment system, and a large theatre in addition to elaborate funerary monuments and domestic structures (Schmid, 2002). The Nabataeans mastered water management and distribution at Petra, using water they obtained from numerous nearby limestone springs (Al-Farajat & Salameh, 2010) and controlling it using a complex system of clay pipelines, open-faced channels and a network of wells and cisterns. These worked together to maintain a constant water supply throughout the year (Ortloff, 2005). One of the most impressive monumental structures that exemplifies the Nabataean's mastery of water was the pool and ornamental garden complex located in the city center next to the "Great Temple" (Wenning, 2007). Although only a small part of the site has been excavated, it is clear that by the end of the 1st century B.C., Petra was a prosperous and well-administered city (Schmid, 2002).

The city's prosperity, however, may have been experienced only by a small segment of the Petra's inhabitants because signs of inequality often increase with urban growth. This idea is rooted in an archaeological model focused on political economy where development of state level societies often results in increased social stratification (Flannery, 1972). Here, as society develops into a state, social, political, and economic systems increase in complexity and this can be viewed in the archaeological record through the restriction of resources, display of wealth, and the legitimation of the ruling class (Baines & Yoffee, 2000).

Scholars have assumed that the varied nature of tomb architecture at Petra reflects the relative social and political importance of the deceased and, by extension, their access to dietary resources during life. Wadeson (2012b) suggests that individuals within centrally located, highly visible façade tombs are more likely to be members of the elite, whereas individuals found in pit graves with low visibility are probably from non-elite groups in the city. People may have experienced some mobility between social classes, for some shaft tombs were enhanced by later generations with the addition of a decorative façade and others were incorporated into larger funerary complexes (Wadeson, 2012b).

Wadeson's interpretations rely heavily on processual mortuary archaeology, namely the notion that high-status individuals often enjoy specialized mortuary rites to convey their status. Binford (1971) suggests that very high-status individuals may be buried in particular locations, have their body prepared or positioned in a specific manner, and be interred with material symbols of status and other goods. Building on Binford's (1971) observations that the interment of high-status individuals often necessitates greater group involvement and community disruption than typical mortuary rituals, Tainter (1975, 1978) suggested that energy expended in mortuary acts also reflects the status of the deceased. This energy expenditure can be conceptualized in terms of the complexity of body preparation, construction and location of any built monument or mortuary feature, and the extent and duration of ritual mortuary behavior. However, the energy expenditure can only be assessed qualitatively with mortuary rituals requiring diverse levels of energy (Tainter, 1978). However, the expression of status in mortuary practice is highly variable and must include understanding the larger socio-cultural system of the society practicing those mortuary rites (Binford, 1971).

Understanding social stratification using mortuary archaeology is complicated further by the malleable nature of socio-cultural systems, wherein symbolic meaning and structures of power are created and re-created by the individuals living within specific historical contexts (Hodder, 1989). Pearson (1982) directly challenges the processual argument that tomb elaboration directly indicates status of the interred because mortuary rituals and architecture can be an idealized rather than actual expression of status. Here, the ability for tomb constructions to be mutable (Wadeson, 2012b) suggests they may have been used as social platforms to convey and legitimize position and power within Nabataean society or justify new social positions in times of power shifts and cultural turmoil (Pearson, 1982). Additionally, the body of the deceased can be used to express ideas of social position and inheritance (Sofaer, 2006) or posthumously ascribe status to the individual being interred via material funerary goods (Pearson, 1982, Shanks & Tilley 1982). In fact, the commingled nature of burials in mortuary contexts at Petra likely reflects familial and social cohesiveness even after death (Perry, 2017). In general, the living undertake mortuary treatment of the deceased, thus funerary rites and architecture reveals more their goals and desires rather than of the deceased themselves. The status implied by the mortuary treatment of the deceased after death provides a context in which to assess the lived experience of status during life as reflected in skeletal indicators of health.

## Monumental Façade Tombs

Petra is well known for the approximately 628 façade tombs carved into sandstone cliff faces throughout the city and the surrounding mountains (Nehmé, 2003). Façade tombs typically consist of an exterior decorative façade and an internal square chamber containing burial spaces either carved into the walls or floors on the interior (Wadeson, 2012b). The larger façade tombs often have spaces preceding the burial chamber sometimes containing benches and basins associated with funerary ritual and kitchens for feasting. The carved façades themselves have been extensively studied with research suggesting that they reflect socioeconomic status (Schmid, 2007; Wadeson, 2013), political resistance (Anderson, 2002, 2005), and temporal trends (Wadeson 2012a,b). Additional studies have suggested that the façade tombs contain extended ancestral lineages (Perry, 2016; Schmid, 2012; Wadeson, 2012a,b). The façade types are generally divided into eight different styles, with the more complex façade types generally predating the later less complex façade styles (Wadeson, 2012b). This trend may reflect the desire of social climbers during the 1st century A.D. to express high-status social and cultural identity (Wadeson, 2013).

The façade tombs were not merely places of rest but also places of commemoration, where living individuals would host feasts both during and after the burial of the deceased (Sachet, 2010). Paleobotanical, zooarchaeological, and biomolecular analysis have shown that animal and plant remains (Bouchaud et al., 2015) as well as secondary products derived from plants and animals, such as dairy products, vegetal oils, incense, and resin (Garnier, Sachet, Zymla, Tokarski, & Rolando, 2010) likely played a role in these feasts. These feasts were often held in 'banquet halls,' spaces surrounded on two or more sides by stone benches (Healey, 2001) located close to façade tomb complexes. Interestingly, these banquet halls begin increasing in size from the late 1st century B.C. onward (Sachet, 2010), which may indicate funerary feasting became increasingly important over time. Overall, the façade tombs are a complex combination of public and funerary spaces imbued with multiple social, political, and cultural meanings (Anderson, 2002, 2005).

Three monumental tombs are included within this study: the Renaissance tomb located in Wadi Farasa in the city's southern suburbs (Schmid et al., 2008), and tombs 779 and 781, located across from the rock-carved amphitheater and originally identified and labeled during Brünnow and von Domaszewski's survey (Brünnow, Domaszewski, Euting, & Kunze 1904; Wadeson, 2012a, 2014). The Renaissance tomb is located at the entrance of a large tomb complex, pictured in Figure 1, and was excavated in 2003 as part of the International Wadi Farasa project (Schmid et al., 2008). The façade of the tomb, pictured alongside the tomb plan in Figure 2, appears to have minor errors such as warping and some unfinished areas that could indicate that the tomb was abandoned before it was finished, however it is more likely that these errors were the result of stonecutters attempting to avoid weaker parts of the sandstone (Huguenot, Bdool, & Schmid, 2004), a compromise often made in the tomb façade construction (Wadeson, 2012b). Fourteen shaft graves were found within the chamber of the Renaissance tomb that held at minimum 30 individuals. Although much of the tomb was looted, ceramics found within the graves indicate they were in use toward the third quarter of the 1$^{st}$ century A.D. (Schmid et al., 2008). Most of the graves contained single articulated burials and four graves were estimated to contain at least 2 individuals. Burial 12 contained the most individuals with an MNI of 9 (Schmid et al., 2008).

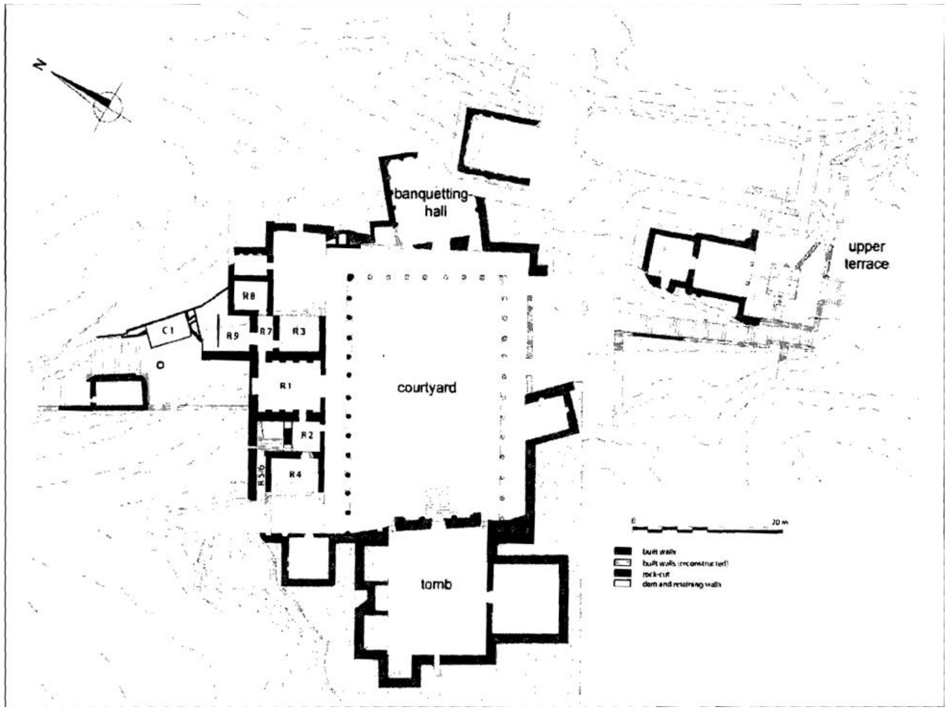


**Figure 1 General plan of the Renaissance tomb and associated structures taken from Schmid 2010.**

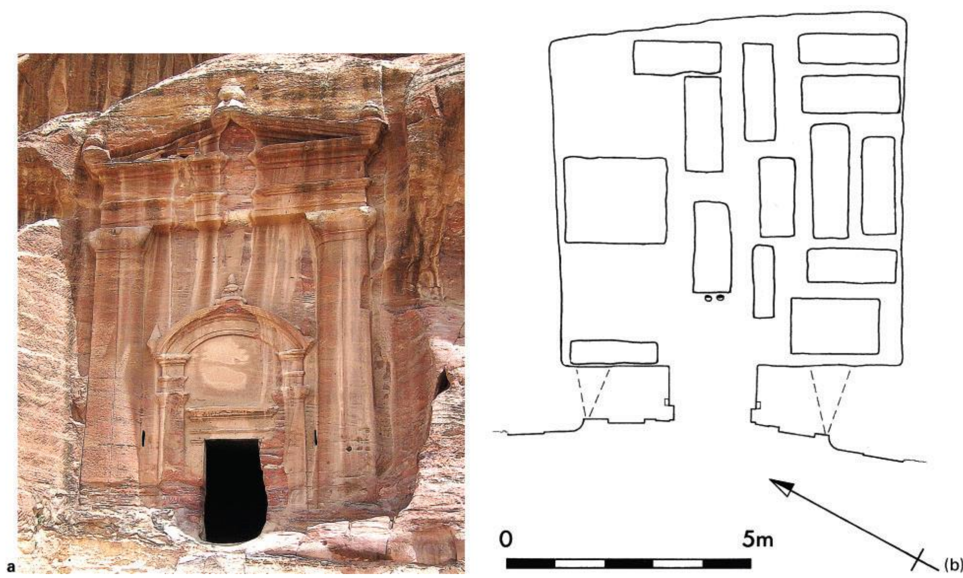


**Figure 2 The Renaissance tomb façade and tomb plan from Wadeson 2010.**

Façade tombs 779 and 781, shown alongside a tomb plan in Figure 3, were excavated in 2010 and 2011 as part of the International Al-Khubtha Tombs Project (Wadeson, 2012a, 2014). These façade tombs are located on the west side of the al-Khubtha mountain across from the

Roman-style amphitheater and belong to the same necropolis as the Royal tombs (Wadeson, 2012a). The tombs are along the main entrance into the city and are highly visible from the center of town. Tomb 779 (MNI = 4) contains one grave located in an arched recess, known as an *arcosolium,* in the back wall and four pit graves in the south-eastern corner of the chamber. The graves in tomb 779 have been dated to the late 1st century A.D. (Wadeson, 2012a). These burials reveal a pattern of placing bodies in wooden coffins atop a layer of lime, after which they are sealed with slabs, stones, and mortar (Wadeson, 2012a). Tomb 781 (MNI = 19) contains 16 architectural compartments that house bodies called *loculi*, carved into the walls of the chamber and an *arcosolium* centrally located in the back wall similar to tomb 779 (Wadeson, 2012a). Four graves located in the north-eastern *loculi* and the burial space within the *arcosolium* have been excavated (Wadeson, 2014). The *arcosolium* contains a unique subsidiary chamber carved into the middle of its back wall that contained human remains and remains of a wooden coffin (Wadeson, 2012a). The pottery identified within tomb 781 indicates it was used during the middle of the 1st century B.C. to early 2nd century A.D. Because of looting and taphonomic disturbance of the burials, it is not known if the burials within tomb 781 were interred within a short timeframe (Wadeson, 2014). Not all of the mortuary features in these tombs have been excavated, the goal of future seasons is to continue clearing and excavating the burial chamber and loculi of Tomb 781 (Wadeson, 2014).

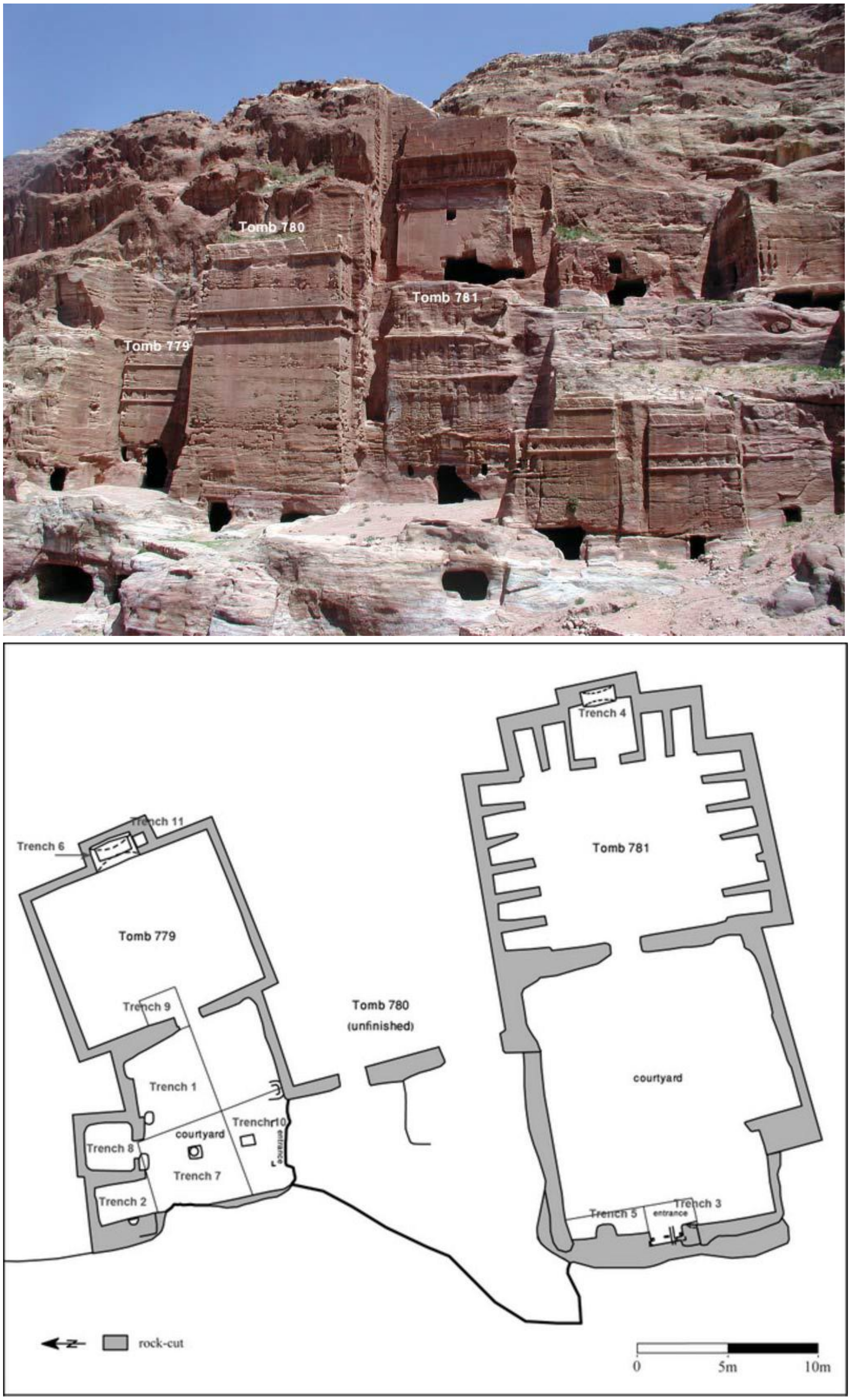


**Figure 3 Façade and plan of tombs 779 and 781 from Wadeson (2012).**

## Petra North Ridge

The North Ridge at Petra contains over 50 documented shaft chamber tombs cut into the bedrock (Parker & Perry, 2013). The tombs under study are located near the northern city wall, seen in Figure 4, and were built in the late 1st or early 2nd century A.D. at the edge of Petra's urban core. The first excavation that focused on the North Ridge's tombs occurred in 1998-1999 with the excavation of Tombs 1 and 2 at the Ridge Church by Bikai and Perry (2001). Overall, the individuals in both tombs show little physical or biological stress aside from degenerative and activity-related conditions possibly related to living in a rugged terrain. Excavations in 2012, 2014, and 2016 by Megan Perry and S. Thomas Parker sought to further explore the findings by Bikai and Perry (Parker & Perry, 2013; Perry, 2016). As of 2017, the Petra North Ridge Project excavations uncovered eight shaft chamber tombs: B.4, B.5, B.6, B.7, B.8, B.9, F.1, and F.2. However, B.8, B.9, and F.2 did not contain any skeletal remains. A preliminary paleopathology study by Canipe (2014) on the health and diet of individuals in tomb B.4 and a portion of B.5 corroborate the observations made by Bikai and Perry (2001) that these individuals showed almost no lesions on their bones indicative of physiological or nutritional stress. Appleton (2015) reconstructed the Nabataean diet using samples from tomb 2 and tombs B.4, B.5, and B.6 and found that the individuals interred there had access to a varied diet characterized by $C_3$ plant sources and animals that consumed $C_3$ plants. In contrast to the 'dirty city' epidemiological model (Larsen, 1997), where instances of disease increase with increased sedentism, the Nabataean population at the North Ridge exhibit healthy, active lives during the 1st century B.C. and 1st century A.D.

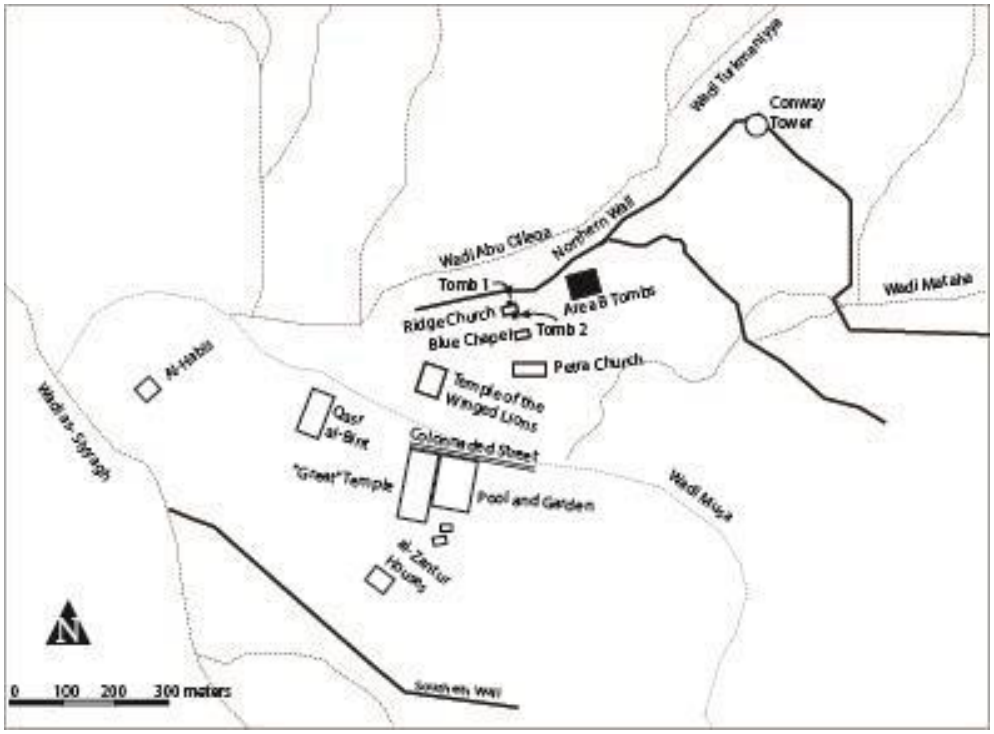


**Figure 4 Petra North Ridge map taken from Appleton 2015.**

## Petra Hinterland Tombs

During the 2012 season of the Petra Hinterland Tombs Project (PHTP), eleven new tombs were recorded in the Jibāl ash-Sharāh mountain range running north to south along the eastern border of Petra (Wadeson & Abudanah, 2016). Some of the tombs, like the one pictured in Figure 5, were unique constructions consisting of subterranean chambers and constructed of ashlars, known as hypogeum, containing loculi (Wadeson & Abudanah, 2016). These tombs were likely family tombs testifying the status and wealth of the owners; they also likely acted as territorial markers of land ownership (Wadeson & Abudanah, 2016). One of these tombs. A.10, was excavated in 2013. The tombs along this mountain range typically date to the 1st century A.D., however this date has yet to be verified for the tomb included in this study, tomb A.10 (Wadeson & Abudanah, 2016). Petra hinterland tomb A.10 had 16 loculi containing human remains, the dental pathology data from these remains were included in this study as a comparative non-urban population.

A comparison of dental pathologies between these three tomb types can reveal differences in the nutrition, diet, and disease burdens of the elite, non-elite, and non-urban individuals interred. Developmental dental pathologies can inform us of childhood inequality, whereas plaque related dental pathologies show evidence of oral disease accumulated during life.

**Figure 5 Petra hinterland tomb A.10 before excavation (Wadeson & Abudanah, 2016).**

## Faunal Assemblages as Indicators of Socioeconomic stratification

Tomb construction is not the only evidence of social stratification at Petra, evidence of social stratification of food resources has also been found. Numerous paleobotanical analyses (Bedal & Schryver, 2007; Jacquat & Martinoli, 1999; Karg, 1996; Ramsay & Bedal, 2015; Ramsay & Smith, 2013; Stucky et al., 1995; Tholbecq, Durand, & Bouchaud, 2008) of Petra and the surrounding hinterland have been done, however little evidence of socially restricted access to plant resources has been found. On the other hand, zooarchaeological explorations at ez-

Zantur, a set of domestic structures south of Petra's city center, have found evidence of social stratification between faunal assemblages (Studer, 2002, 2007). Excavations at ez-Zantur began in 1998 (Jacquat & Martinoli, 1999). Over the course of the excavations, archaeologists uncovered 3 terraces containing a large 1st century B.C. house (EZ I) which was occupied until the 1st century A.D., a mansion (EZ IV) constructed during the 1st century A.D, and other domestic structures (EZ III) (Studer, 2007). The temporal analysis of the faunal assemblage at EZ I shows a decrease in camels and an increase in pigs and donkeys over the 1st century A.D. as well as an increase in imported freshwater catfish. These trends reflect increased levels of wealth over time and the importation of luxury items (Studer, 2002, 2007). Spatial comparisons of two contemporaneous (1st century A.D.) faunal assemblages found at EZ I and EZ IV revealed that the inhabitants of EZ VI consumed a greater quantity of gazelle as well as wild (Chukar partridge and *Rallidae*) and domestic birds (chicken) than the inhabitants of EZ I (Studer, 2007). The architectural complexity and wall decorations at EZ IV may reflect greater wealth, and Studer (2007) suggests that poultry, game birds, and venison were luxury items during this time period. In comparison, the faunal assemblages at Petra North ridge consist predominantly of sheep and goat elements, followed by chicken, equids, camels, and dogs (Lowrey, 2014). The domestic structures of ez-Zantur were likely homes of Nabataean elites, the faunal assemblages at the site show an increase in imported foods over time. Additionally, the more lavish domestic structure (EZ IV) exhibited significantly more gazelle, wild game, and poultry remains than other less ornate buildings (Studer, 2007). This implies that elite individuals not only had the economic ability to regularly consume protein sources outside of the readily available goats and sheep, but also had the ability to buy imported luxury goods to be consumed. While the remains of imported foods, such as freshwater fish, have yet to be found at the North Ridge tombs, chicken, a valued source of protein according to Studer (2007), is associated with the tombs at the North Ridge. Here, poultry may be present as an offering to the deceased or part of a mortuary feast commemorating the dead (Sachet, 2010; Perry, 2017). Food at Petra is not just an economic resource but a cultural resource integral to commemorative feasts for the deceased. Despite the lack of paleobotanical information within the tombs under study, the analysis of faunal assemblages clearly shows the importance of dietary resources in the assessment and interpretation of social, economic, or cultural differences at Petra.

## Dental Pathology as a Means for Reconstructing Past Lifeways

Dental pathology is the study of the diseases and anomalies of the teeth and jaws. The field can be roughly split into two research areas: studying the relationship between cultural factors, diet, and disease, and recording developmental anomalies resulting from genetic and evolutionary factors (Lukacs, 2012). Oral epidemiological research has demonstrated that social, economic, and environmental factors play an integral role in dental health (Newton & Bower, 2005). As a result, dental pathologies have the potential to illustrate discrepancies, if any, in social and economic status within a given population. However, the relationship between diet, dental health, and social status must be explored within a population's cultural context as the above patterns cannot be similarly applied to all populations.

For the purposes of this study, oral pathologies associated with plaque-related dental disease, such as dental caries, calculus, antemortem tooth loss (AMTL), and abscesses, as well as developmental defects such as linear enamel hypoplasias, will be used to illuminate potential health differences between elite individuals interred in monumental façade tombs, non-elite individuals interred in shaft chamber tombs, and the non-urban burials in the hinterland tomb. It was expected that differences in dental pathology frequencies between the elite and non-elite individuals would reflect the differences seen in their mortuary treatment. These dental pathologies in combination with previous archaeological and historical knowledge can aid in understanding the effect of socioeconomic status on diet and oral health at the site of Petra, Jordan.

## Developmental Dental Pathologies

Linear enamel hypoplasias are horizontal lines that form across a tooth crown due to stress during enamel formation. This can take the form of linear pitting or furrows which often deform the crown of the tooth (Hillson, 2008). The enamel of permanent dentition is set down at a constant rate during childhood tooth formation, and if an individual experiences significant stress such as malnutrition, severe sickness, or injury, the amount of enamel deposited during that period is reduced (Hillson, 2008). Once the child survives the period of stress, normal amelogenesis returns, and the period of reduced enamel formation appears as a linear furrow in the crown's surface. Enamel hypoplasias increase the likelihood of carious development on the smooth surfaces of the teeth, as areas of thin enamel are more quickly demineralized by the acids produced by oral bacteria (Hillson, 2008).

The generally canalized process of enamel formation means that the approximate age at which those stressors occurred can be estimated from the distance of a hypoplasia to the cemento-enamel junction (CEJ) (Goodman & Armelagos, 1985, Goodman & Rose, 1990). However, the expression of linear enamel hypoplasias are affected by differences in tooth plasticity between tooth classes, (Goodman & Armelagos, 1985) and tooth crown shape (Hillson & Bond, 1997). While histological or microscopic study of perikymata may provide a more accurate reflection of systematic stress in the dentition (Hillson & Bond, 1997; Ritzman, Baker, & Schwartz, 2008; Temple, Nakatsukasa, & McGroarty, 2012), macroscopic observation of perturbances in dental enamel development using a 10X lens and the methods outlined by Goodman and Rose (1990) yields a more comparative dataset. This is particularly important in terms of the potential for the use of longitudinal studies in living populations explicitly associating instances of childhood stress events with enamel defects such as LEHs, as has been done by Masterson et al. (2017), to tease out the causes of LEHs.

## Plaque-Related Dental Pathologies

Dental caries is among the most well-known dental pathologies. Caries, also known as cavities, form through the progressive demineralization of the tooth enamel, cementum, and dentine by organic acid. This acid is formed by a variety of oral bacteria and is derived from the fermentation of dietary carbohydrates and sugars (Hillson, 2008), so dental caries is often associated with consumption of soft foods high in carbohydrates. The formation of caries is not only impacted by sugar consumption but also genetic variation in amelogenesis, presence of LEHs, saliva composition, and variation in pathogenic microorganisms (or microbiome) present in the oral cavity of the individual (Lukacs, 2012). Caries is typically chronic with various periods of arrest, remineralization, and resorption (Hillson, 1996). Differences in the number of carious lesions within sub-groups of a population have been hypothesized to be the result of unequal access to cariogenic foods or a difference in the consumption of protein (Roberts & Manchester, 2005). Therefore, differences in amounts of carious lesions between populations may reflect dietary differences, particularly in the consumption of carbohydrates and sugars. Alternatively, it is possible that these differences are due to the varied nutritional and metabolic inter-relationships between bacterial cells (Selwitz, Ismail, & Pitts, 2007). Bacteria from the genus *Veillonella* will utilize the acidic byproducts of carbohydrate fermentation by the streptococci as a carbon source (Selwitz et al., 2007) and other oral bacteria produce urease enzymes that reduce the cariogenicity of the oral environment (Clancy, Pearson, Bowen, & Brune, 2000). Typically, the frequency for calculating dental caries frequencies is established by dividing the number of teeth that exhibited caries by the total number of teeth observed within the sample. However, this method of calculation does not factor in antemortem tooth loss due to severe tooth decay or unobservable carious lesions due to postmortem loss. As a result, the caries rate calculated using this method will be lower than the true number of caries within the population (Duyar & Erdal, 2003), but the level of antemortem tooth loss in the different samples will approximate the extent of this discrepancy.

Dental calculus provides another reflection of dental health in a skeletal sample. Dental calculus is the calcified plaque that forms due to the interaction between oral bacteria, salivary enzymes, diet, genetics, and a number of other factors (Hillson, 1996). Archaeological and microbiological research on the formation of dental calculus have yet to find a definitive cause for plaque mineralization, although archaeological literature has linked calculus formation to alkaline water, high protein diets or high carbohydrate diets (Lieverse, 1999; Marsh, 2010), and to the consumption of marine resources (Malde, Maage, Macha, Julshamn, & Bjorvatn, 1997). Intra-population differences in dental calculus could indicate different individual or familial dietary preferences or restricted access to certain foods, in addition to reliance on varied water sources with different mineral contents. The source of the minerals, such as calcium phosphate salts, required for calcification is found in the saliva as well as secreted by bacteria (Hillson, 1996; White, 1997). The proximity of the lingual aspect of mandibular incisors and buccal aspect of the molars to salivary ducts causes these teeth to form dental calculus more readily than other teeth (Hillson, 1996). Studies have indicated that the saliva of individuals who form considerable dental calculus tend to have significantly higher concentrations of urea, protein, calcium, and phosphate than those who form little to no calculus (Mandel, 1974). Additionally, studies have shown increased water consumption dilutes mineral salts within the oral environment reducing the likelihood of developing dental calculus (Lieverse, 1999). Thus a high frequency of calcified dental plaque would indicate that not only were biofilms forming but also that the oral environment was alkaline enough to calcify dental plaque (Hillson, 1996; Rosan & Lamont, 2000; White, 1997).

Antemortem tooth loss (AMTL) describes the loss of a tooth or teeth due to disease, trauma, or cultural modification prior to the onset of death (Hillson, 2008). AMTL thus can be used to document tooth loss due to carious lesions or other periodontal conditions, as well as indicate possible cultural behaviors such as tooth extraction (Cucina & Tiesler, 2003; Hillson, 1996). Alternatively, clinical studies in North America indicate that females have a higher rate of antemortem tooth loss than males, due to both sex- and gender-related factors (Russel, Gordon, Lukacs, & Kaste, 2013). As such, differences in AMTL may reflect the biological stressors of pregnancy or gender-related division of labor (Cucina & Tiesler 2003; Keenleyside, 2008).

Abscesses form when the pulp chamber of the tooth becomes exposed to the oral environment in cases of extreme dental attrition or severe dental caries (Hillson, 2008). The pulp cavity becomes infected, and drainage channels from the apex of the infected tooth form to the surface of the alveolar bone to discharge pus. Periapical abscesses result from periapical granulomas or apical periodontal cysts rather than an acute pyogenic infection of the tooth root (Dias & Tayles, 1997). Acute infections of the tooth pulp are typically due to a bacterial infection or occur after a periapical granuloma or cyst has formed, but these infections typically affect soft tissue and do not result in skeletal lesions (Dias & Tayles, 1997). As such, the lesions being observed within this study are the result of bony remodeling due to chronic infection and the formation periapical granulomas or apical periodontal cysts. Presence of abscesses indicates that dental disease has been affecting an individual for an extended period and can indicate long-term consumption of cariogenic foods.

Both developmental and plaque-related dental pathologies have been used to identify nutritional or oral health differences between groups by sex or social status within other contexts. For example, caries and AMTL were used to identify intra-population status and sex-based inequalities among the Classic-period (AD 250-900) Maya (Cucina & Tiesler, 2003). Social organization during the Classic period consisted of a small number of interrelated, wealthy families ruling over a large population. Cucina and Tiesler (2003) argue that this status was not only reflected in the monumental architecture at the site, but also reflected in unique nutritional and pathological conditions brought about by differences in dietary resources and labor burdens. They found a lower frequency of caries and higher AMTL in the elite individuals, who were interred in a dynastic burial style with an abundance of high quality goods, compared to non-elite populations interred in communal burial areas lacking quality grave goods. Elite females as opposed to males also had a higher caries rate similar to that of the non-elite population, suggesting that female elites did not have equal access to the foods male elites consumed (Cucina & Tiesler, 2003). In addition, the higher frequency of AMTL in the elite populations, likely resulted from the consumption of a softer, more refined diet (Cucina & Tiesler, 2003). This study shows dental pathologies can be used to explore social organization and inequality within the archaeological record.

Another study used a combination of dental pathology and isotopic analysis to assess historically recorded dietary differences between males and females as well as young and old individuals at the Greek colonial site of Apollonia during the 5$^{th}$ to 2$^{nd}$ centuries B.C.

(Keenleyside, 2008). Literary sources had indicated that males were given preferential access to nourishing foods, whereas females had reduced access to such luxuries (Garnsey, 1999). As fish were a highly valued dietary resource in the Greek diet (Dalby, 1996) and contain anti-cariogenic elements such as fluoride and strontium (Siebert & Trautner, 1985), Keenleyside (2008) suggested that this difference in access to resources would result in sex-based differences in dental caries, calculus, and AMTL expression. Both the isotopic analysis and the dental pathology data showed no significant difference between the sexes, a finding that challenged the ancient literary information concerning diet (Keenleyside, 2008). There was a significant difference in dental pathology between age categories, but this was attributed to the progressive nature of oral lesions such as dental caries. This study shows that dental pathology data can be used to assess social inequality through access to dietary resources, or in this case, provide evidence that the historically documented inequality may not have been strictly enforced or may not have resulted in significantly different patterns of oral lesions.

Finally, numerous studies have utilized linear enamel hypoplasias as indicators of childhood health to assess subsistence transitions (Armelagos & Cohen, 1984; Irei et al., 2008; Starling & Stock, 2007), age-related and seasonal stress events (Goodman, Armelagos, & Rose, 1980), weaning-related stress (Blakely, Leslie, & Reidy, 1994; Goodman et al., 1987; Moggi-Cecchi, Pacciani, & Pinto-Cisternas, 1994) and malnutrition associated with low socioeconomic status (Cucina & İşcan, 1997; Goodman et al., 1980). Notably, in their study of LEH prevalence in high status burials at the Fort Center site in south Florida, Cucina and İşcan (1997) found that the high-status individuals at the site exhibited LEHs in 95% of incisors and 98% of the canines. Interestingly, the dietary reconstruction of the site suggests that inhabitants at the site 'ate well,' and this included turtle, fish, deer, turkey, and other fauna as well as corn (Sears, 1982). The data suggest that privileged classes at Fort Center experienced frequent stress events and that high socioeconomic status and access to a variety of dietary resources did not necessarily act as a buffer from other environmental stressors (Cucina & İşcan, 1997). As linear enamel hypoplasias are indicators of general childhood stress, the above studies used multiple lines of archaeological and historical evidence when interpreting theses lesions.

## Limitations of Paleopathology

Frequencies of pathological lesions need to be interpreted understanding the biases inherent in cemetery-based skeletal data. At face value, the relationship between health and pathology follows a simple dichotomy where a healthy population exhibits fewer skeletal lesions than an unhealthy one. However, Wood et al. (1992) described three problems associated with this simplistic view: the creation of cemetery samples is affected by demographic nonstationarity, selective mortality, and hidden heterogeneity. Demographic nonstationarity recognizes that populations are constantly in flux due to changes in immigration and emigration rates, and fertility and mortality rates. For instance, increased fertility within a population may result in more fetuses, babies, and infants in the cemetery than before. In addition, a sudden influx of young individuals of a certain age, for example between 20 and 25 years old, would result in a spike of 20-25 years old in the cemetery since they are represented more in the population than is typical. In the case of age-related conditions such as dental calculus, a sudden increase in mortality of younger adults (and a resulting overrepresentation in the cemetery) would result in a lower frequency of dental calculus than a site not experiencing this mortality pattern.

Selective mortality implies the skeletal samples under study do not represent the living population they represent (Wood et al., 1992). The cemetery sample contains the non-survivors at particular ages, and thus someone who died at 20 years may not share physiological attributes of someone who lived past 20 years and up to 55 years (and then ended up in the cemetery). As a result, the cemetery is inherently biased since it contains only members of that population who are dead. Why someone ends up dead as opposed to someone else raises the issue of hidden heterogeneity, the recognition that numerous unknown variables affect an individual's risk of death, or frailty, and that this can vary within a skeletal sample. These variables include genetics and other host factors, socioeconomic differences, microenvironmental variation, and temporal changes in health over time (Wood et al., 1992). However, assessing the sample as a whole masks any possible heterogeneity in frailty that exists within the population, and thus hides reasons why some people died and ended up in the cemetery population at a particular age vs. someone who remained living.

An example of these problems when interpreting dental pathologies can be seen in Wood and colleagues (1992) where they reflect on a study by Goodman and Armelagos (1988). Goodman and Armelagos found that frequencies of LEH increased through time at Dickson Mounds, and those with LEHs tended to die at younger ages than those without. In addition, mean age at death seemed to decrease between the early and the late samples. Goodman and Armelagos interpret this pattern as increased exposure to LEH-causing stress results in increased frailty, and as a result, individuals tended to die earlier in these populations than ones with low LEH-related stress. Wood and colleagues, however, suggest an alternative scenario: because LEHs can only be documented if an individual survived the stressful event, as outlined above, higher LEHs mean more people are surviving stress. These LEH-bearing survivors went on to have a higher fertility rate, producing offspring that also go on to survive LEH-causing stress, compared to those who perished in childhood from potential LEH-related stress and never reproduced to have non-LEH-bearing children. As a result, this skeletal sample would appear to have more individuals with LEHs than one with fewer survivors. Goodman (1993) criticized this interpretation of LEHs for being mathematically possible but biologically improbable, stating that he had never come across a population where a clearly advantaged group had more hypoplasias than a disadvantaged group.

Despite these challenges, making solid interpretations of paleopathology data can be ameliorated by using multiple indicators of health, identifying whether lesions where healing or not at the time of death as well as using multiple lines of evidence to clarify the cultural context and the biological processes of skeletal lesions and their development (Goodman, 1993; Wood et al., 1992). The samples under study are no exception to the osteological paradox; the lack of subadult remains makes the assessment of demographic representation and selective mortality in the sample difficult. By using the teeth as a representation of the population groups the study also masks hidden heterogeneity. Additionally, these tombs are multi-generational and cover a 200-year time span therefore differences in disease pathologies may be due to tomb samples representing health at Petra over differing periods of time. In order to make interpretations based off these samples, a variety of oral lesions were used to compare the health of the populations under study and the cultural context of the remains were included in the analysis and discussion.

## Hypotheses

The purpose of this study is to use macroscopic dental pathologies to evaluate social inequality between tomb-architecture based elites and non-elites of Petra during the 1$^{st}$ century B.C. through the 1$^{st}$ century A.D. Dental pathologies are a reflection of dietary patterns as well as biocultural markers reflecting access to nutrition and levels of infection. As discussed above, differences in funerary architecture indicate social stratification was present at Petra (Wadeson, 2012b), and one might expect social stratification to be expressed through differences in health and disease burdens of the individuals buried at Petra. However, paleopathological (Bikai & Perry, 2001; Canipe, 2014) and dietary (Appleton, 2015) studies have suggested that the individuals interred in the non-elite shaft graves had varied diets and were not exposed to disease pathogens as reflected in skeletal indicators of disease and malnutrition. The previous research done at Petra can be used to generate hypotheses regarding the frequency of dental pathologies within each tomb type.

> Null Hypothesis 1: The individuals in the non-elite tombs from the North Ridge will show no differences in the frequency of LEHs compared to the elite sample in the monumental tombs.

In this case, non-elite members and elite members of the population had similarly nutritionally beneficial diets and levels of stress resulting in similar frequencies of LEHs. This could mean that urbanization of Petra, influx of trade, and the increased sedentism of the Nabataean population did not result in socioeconomic inequality between elite and non-elite individuals.

> Alternative Hypothesis 1a: The individuals in the non-elite tombs will show greater frequency of LEHs than the elite sample in the monumental tombs.

In this case, non-elite members of the population have a less nutritional diet or more physiological stress in childhood compared to the elite population, resulting in the increased development of linear enamel hypoplasias. This could mean that urbanization of Petra, influx of trade, and the increased sedentism of the Nabataean population resulted in socioeconomic inequality between elite and non-elite individuals.

> Alternative Hypothesis 1b: The individuals in the non-elite tombs will show a lower frequency of LEHs than the elite sample in the monumental tombs.

In this case, elite members of the population have a less nutritional diet or more physiological stress in childhood compared to the non-elite population, resulting in the increased development of linear enamel hypoplasias. This could mean that urbanization of Petra, influx of trade, and the increased sedentism of the Nabataean population resulted in socioeconomic inequality between elite and non-elite individuals. Canipe's (2014) preliminary investigation of LEHs in subsamples from the Petra North Ridge and Tomb 779 monumental tomb found that the elite Tomb 779 individuals had a significantly higher frequency of linear enamel hypoplasia. She suggested the difference in LEH expression between these populations may be a result of dissimilar diet and childrearing practices or perhaps a result of bias introduced by the small sample sizes (Canipe, 2014).

> Null Hypothesis 2: The non-elite and elite populations at Petra will display similar frequencies of dental caries, AMTL, abscesses, and calculus.

It is possible that tomb architecture does not reflect social status or that social status did not result in significant dietary differences. In fact, Appleton (2015) found a statistically significant difference in $\delta^{13}C$ apatite between a few of the non-elite tombs at the Petra North Ridge, which might mean that dietary variability does not necessarily reflect purported social status. Additionally, similar rates of these dental pathologies in the elite and non-elite individuals could have resulted from both groups adhering to cultural practices, such as teeth cleaning. Therefore, dental pathologies alone cannot indicate dietary differences related to social status, if these differences existed at all.

> Alternative Hypothesis 2a: Individuals in the non-elite tombs will show lower frequencies of dental caries, calculus, AMTL, and abscesses than the elite population.

The foods with higher rates of carbohydrates and starches causing dental caries, calculus, ATML, and abscesses could have been luxury items at Petra. Studies of Classical Maya elites found that the elites exhibit greater instances of caries and antemortem tooth loss due to their consumption of soft, sugary foods (Cucina & Tiesler, 2003). Paleobotanical reconstructions indicate the Nabataeans likely had access to a variety of high-sugar fruits such as date palms, plums, and grapes (Ramsay & Bedal, 2015). A higher instance of caries in individuals interred in monumental tombs could indicate that elite Nabataeans had access to and consumed a higher proportion of sugary fruits and their byproducts, such as wine.

> Alternative Hypothesis 2b: Individuals in the non-elite tombs will show higher frequencies of dental caries, calculus, AMTL, and abscesses than the elite population.

A higher instance of caries in individuals interred in shaft chamber tombs could indicate that the diet of non-elite Nabataeans contained more carbohydrate rich foods, such as grains, than the elite Nabataean diet. This could indicate that urbanization of Petra, influx of trade, and the increased sedentism of the Nabataean population resulted in greater socioeconomic inequality between elite and non-elite individuals.

Although the differences in tomb construction imply socioeconomic stratification existed at the site of Petra, it is unclear if this stratification resulted in dietary differences or differences in stress-related pathologies between those interred in monumental façade tombs and those interred in the shaft chamber tombs at Petra North Ridge. In order to address this, the frequency of dental pathologies was assessed in the façade, shaft chamber, and hinterland tombs.

# CHAPTER 3: Materials and Methods

This study explores human dentition recovered from three different sets of tombs at Petra, one consisting of three “elite” carved façade tombs, and one consisting of five shaft chamber tombs of “non-elite” populations, and one from a tomb excavated outside of the city. The non-elite sample comes from the Petra North Ridge that was excavated as part of the Petra North Ridge Project (Parker & Perry, 2013; Perry, 2016). The “elite” samples come from the Renaissance tomb excavated as part of the International Wadi Farasa Project (IWFP) (Huguenot et al., 2004; Schmid, 2007, 2010; Schmid & Barmasse, 2004, 2006) and Brünnow and von Domaszewski’s façade tombs 779 and 781, excavated as part of the International Al-Khubtha Tombs Project (IKTP) (Wadeson, 2012a, 2014). Teeth from the Petra Hinterland Tombs Project were included as a comparative site outside the urban core of Petra (Wadeson & Abudanah, 2016). Dental inventory and pathology data from the façade tombs and the Petra hinterland tomb had been collected previously by Megan Perry.

The Renaissance tomb contained a minimum of 23 individuals represented by 52 adult teeth, the Khubtha tombs contained at least 23 individuals represented by 180 adult teeth, and the tombs at Petra North Ridge contained at least 120 individuals represented by 696 adult teeth. The Petra hinterland tomb contained a minimum of 8 individuals, represented by maxillary right canines, with a total of 132 teeth in the sample (Table 1). The data were analyzed by tomb type, with 234 teeth from the carved façade tombs, 696 teeth from all 5 Petra North Ridge shaft chamber tombs, and 132 teeth from the Petra hinterland tombs. In addition to the tooth count, the percentage of teeth lost postmortem was calculated by tomb type in Table 2 and by tomb in Table 3. The percentage of postmortem losses could be accounted for in the loose teeth were calculated in Table 4. Although it appears that the tomb types reflect similar rates of postmortem loss, when viewed by tomb it is apparent that tomb F.1 exhibits a lower frequency of postmortem loss and 100% of the teeth missing postmortem can be represented by loose teeth. This could be due to the highly fragmented nature of the maxillae and mandibles on which PMTL is recorded in combination with the abundance of loose teeth within this context. Alternatively, the low postmortem loss could be due to the little taphonomic disturbance within this tomb.

Table 1 Adult Tooth Counts by Tomb Type

| *Tooth Type* | *Façade Tombs* | *Shaft Chamber Tombs* | *Petra hinterland* |
|---|---|---|---|
| Maxillary | | | |
| $I^1$ | 15 | 28 | 6 |
| $I^2$ | 9 | 27 | 8 |
| C | 17 | 33 | 13 |
| $P^1$ | 15 | 40 | 7 |
| $P^2$ | 19 | 46 | 13 |
| $M^1$ | 13 | 59 | 12 |
| $M^2$ | 11 | 60 | 10 |
| $M^3$ | 13 | 35 | 6 |
| Mandibular | | | |
| $I_1$ | 14 | 18 | 8 |
| $I_2$ | 11 | 29 | 10 |
| C | 19 | 36 | 9 |
| $P_1$ | 17 | 42 | 10 |
| $P_2$ | 13 | 45 | 5 |
| $M_1$ | 18 | 81 | 4 |
| $M_2$ | 19 | 77 | 8 |
| $M_3$ | 11 | 40 | 3 |
| Total | 234 | 696 | 132 |

Table 2 Percentage of Teeth Lost Postmortem by Tomb Type

| *Tomb Type* | *Total Teeth Present*[1] | *Observed PMTL* | *Relative Frequency* |
|---|---|---|---|
| Façade Tombs | 375 | 115 | 30.7% |
| Shaft Chamber Tombs | 1007 | 250 | 24.8% |
| Petra hinterland | 206 | 41 | 19.9% |

Table 3 Percentage of Teeth Lost Postmortem by Tomb

| *Site* | *Tomb* | *Total Teeth* | *Observed PMTL* | *Relative Frequency* |
|---|---|---|---|---|
| Renaissance | TR | 83 | 25 | 30.1% |
| Khubtha | 779 | 32 | 4 | 12.5% |
| | 781 | 260 | 86 | 33.1% |
| Petra North Ridge | B.4 | 116 | 52 | 44.8% |
| | B.5 | 412 | 127 | 30.8% |
| | B.6 | 206 | 43 | 20.9% |
| | B.7 | 108 | 14 | 13.0% |
| | F.1 | 165 | 14 | 8.5% |
| Petra hinterland | A.10 | 206 | 41 | 19.9% |

Table 4 Percentage of Postmortem Absences that Could Be Represented in Loose Teeth

| *Site* | *Tomb* | *Postmortem Loss Count* | *Number of Postmortem Absences that Could be Represented by Loose Teeth* | *Percentage of Postmortem Absences that Could be Filled by Loose Teeth*[2] |
|---|---|---|---|---|
| Renaissance | TR.1A | 1 | 0 | 0.0% |
| | TR.1B | 1 | 0 | 0.0% |
| | TR.9 | 13 | 0 | 0.0% |
| | TR.12 | 10 | 3 | 30.0% |
| Khubtha | D.779 | 4 | 0 | 0.0% |
| | D.781 | 20 | 1 | 5.0% |
| | C.781 | 66 | 8 | 12.1% |
| Petra North | B.4 | 52 | 9 | 17.3% |

[1] PMTL frequency calculations include the teeth present in addition to the teeth lost antemortem, making the total number of teeth 375 for the façade tombs, 1007 for the shaft chamber tombs, and 206 for the hinterland tomb.
[2] Assumes that a loose tooth that shares the same location as a tooth lost postmortem in a maxilla or mandible can account for that loss, as shown in Appendix C, this may not necessarily be the case.

| | | | | |
|---|---|---|---|---|
| Ridge | B.5 | 127 | 69 | 54.3% |
| | B.6 | 43 | 34 | 79.1% |
| | B.7 | 14 | 11 | 78.6% |
| | F.1 | 14 | 14 | 100.0% |
| Petra hinterland | A.10 | 41 | 7 | 17.1% |

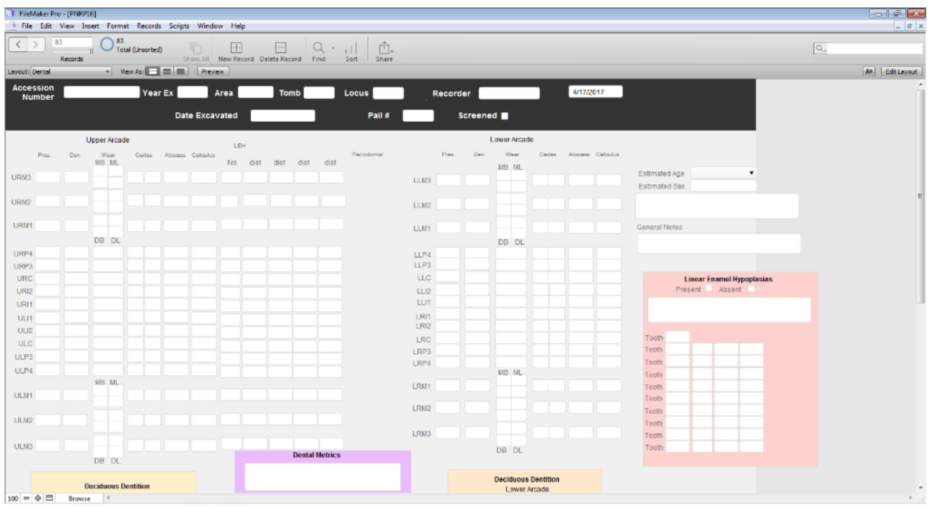


**Figure 6 Dental recording section of the visual recording program.**

The teeth and their associated maxillae and mandibles from the Petra North Ridge Project were recorded in a FileMaker database (Figure 6) using methods outlined in *Standards for Data Collection from Human Skeletal Remains* by Buikstra and Ubelaker (1994). The teeth were recorded in terms of tooth type, side, and whether the tooth is a maxillary or mandibular tooth. Loose teeth each were given a unique accession number in the database, while those associated with a mandible or maxilla were all included on the same form and given the same accession number as the associated bone (which was recorded in the cranial fragments section of the FileMaker database). The presence or absence of the teeth was recorded using numerically coded categories numbered one through eight (Appendix A). When possible, teeth were recorded together with their associated maxillae or mandibles (Appendix B), however given the fragmentary remains present, teeth were most often recorded individually. In addition, the frequency of postmortem losses (Table 2 and Table 3) as well as the percentage of postmortem losses that could be accounted for by loose teeth was calculated by tooth type and by tomb using these categories (Appendix C). This was done by finding where the locations of postmortem losses match the loose teeth found in each tomb. Occlusal surface wear was recorded using methods outlined by Buikstra and Ubelaker in Standards (1994: 52-53) as part of the dental inventory. The commingled nature of the skeletal sample means that most teeth could not be associated with each other or with a particular individual. As a result, age estimations could not be established beyond “adult” or “subadult” (except for some cases of subadults still undergoing dental development) and sex could not be determined.

For each tooth recorded in the inventory, either loose or associated with a dental arcade, observations of dental caries, linear enamel hypoplasias (LEH), and dental calculus were recorded. In addition, any abscesses or antemortem tooth loss (AMTL) noted in maxillae or mandibles were noted together with the dentition they contained. Dental caries was assessed with the aid of a 20X hand-held lens and recorded by tooth or sets of associated dentition. Since dental caries is a progressive pathology preceded by areas of demineralization, discoloration, and occasionally non-carious pitting (Hillson, 2001), only carious lesions that had penetrated the surface of the enamel were recorded. Dental caries was recorded following the methods in *Standards* (Buikstra & Ubelaker, 1994: 54-55). The frequency of dental caries was established by dividing the number of teeth that exhibited caries by the total number of teeth observed within the sample. No correction for AMTL of carious teeth (Lukacs, 1995), postmortem tooth loss of carious teeth (Erdal & Duyar, 1999), or both (Duyar & Erdal, 2003) was used due to the problems of applying these to commingled samples.

Linear enamel hypoplasias (LEHs) were also assessed with the aid of a 20X hand-held lens. LEHs were recorded by the type of hypoplasia, such as organization of the defects and whether the consisted of grooves or pits, in addition to distance of the LEH from the cemento-enamel junction (CEJ) (Buikstra & Ubelaker, 1994: 56-57; Goodman & Rose, 1990). LEH frequencies were determined by dividing the number of teeth that exhibited LEHs by the total number of teeth observed within the sample. This calculation excluded third molars as they rarely form LEHs. The frequency of LEHs was also determined using only maxillary first incisors and mandibular canines, also known as polar teeth (Goodman & Rose, 1990). Additionally, age at LEH formation was calculated using the distance of the LEH from the CEJ using the methods outlined by Goodman and Rose (1990).

Presence or absence of dental calculus was recorded, as well as severity of calculus following the methods in *Standards* (Buikstra & Ubelaker, 1994: 56). Dental calculus frequencies were established by dividing the number of teeth that exhibited calculus by the total number of teeth observed within the sample. It should be noted that dental calculus is often damaged or lost within the archaeological record. As a result, teeth from the PNRP sample may exhibit fewer instances of dental calculus due to the commingled and fragmentary nature of the remains.

As noted above, antemortem tooth loss (AMTL) was entered in the visual recording program as part of the dental inventory describing the presence or absence of dentition. Identification of antemortem tooth loss was based on the absence of the tooth and the remodeling of the alveolar bone within the socket (Buikstra & Ubelaker, 1994: 49). AMTL frequencies were determined by dividing the recorded number of teeth lost before death by the sum of the estimated postmortem tooth loss and the total number of teeth observed within the sample. Due to the possibility that some of the teeth lost postmortem were found as loose teeth, AMTL frequencies also were calculated using a corrected postmortem tooth loss count. Antemortem and postmortem tooth loss can only be observed in association with a maxilla or mandible and is more accurate in samples with fully articulated remains, unlike the PNRP samples. As a result, the frequencies calculated for AMTL within this dataset likely do not reflect the actual rates of AMTL within this sample.

Alveolar abscesses were scored by location (buccal/labial versus lingual surface of the alveolar bone) and the associated tooth as outlined in *Standards* (Buikstra & Ubelaker, 1994:55). Similar to AMTL, abscesses can only be recorded if alveolar bone is present, which is incomplete in this commingled, fragmented sample. Therefore, the method of recording tooth presence in *Standards* (Buikstra & Ubelaker, 1994) resulted in an unforeseen gap in the data. The number "2" is used to record a tooth that is present and fully formed, but it does not distinguish if the tooth is associated with alveolar bone that could be observed for abscesses. To calculate the abscess frequency, only teeth found in association with a mandible or maxilla were used for this calculation (Appendix B, Table 24).

After the dental pathologies for the all tombs were recorded, frequencies of expressed pathologies were calculated by tomb type as well as by individual tomb. Chi-square tests were used to assess whether the frequencies of pathologies varied by tomb type. Fisher's exact test was used to assess differences between the individual tombs because of the smaller sample sizes involved. A Bonferroni-corrected α-value was used to correct for the error that results from multiple comparisons of variables. In addition, distributions of the estimated age of occurrence of LEHs were calculated for each tomb and compared using Kolmogorov-Smirnov tests. The following chapters will explore the relationship between dental pathologies and social stratification in the individuals interred within the “elite” carved façade tombs and “non-elite” shaft chamber tombs.

# CHAPTER 4: Results

As discussed above, the Nabataean city of Petra exhibits a diverse mortuary repertoire including ornate monumental façade tombs surrounding the city center as well as less elaborate shaft chamber tombs within and outside of the urban core. Previous archaeological research suggests these tomb variants reflect family groups of higher and lower social status, respectively (Wadeson, 2012a, b). Whether or not the inequality implied by this mortuary architecture is reflected in the oral health of the individuals interred was determined by examining and comparing the frequency of dental pathologies between the Renaissance tomb and Khubtha carved façade tombs and the shaft chamber tombs found at the Petra North Ridge site, in addition to one tomb excavated in Petra's hinterland.

## Linear Enamel Hypoplasia

Linear enamel hypoplasia frequencies were calculated using all teeth except for the third molars, which rarely form linear enamel hypoplasias. Their inclusion could bias the LEH frequency calculations for contexts with a larger number of third molars, as seen in the Petra North Ridge tombs (Table 23, Appendix A). In addition, LEH frequency was calculated using only two sets of polar teeth, the upper first incisors and the lower maxillary canines following Goodman and Rose (1990). The frequency of linear enamel hypoplasias utilizing all teeth except for the third molar varied greatly across tomb types, with the shaft tombs showing a lower frequency of LEHs than the façade tombs ($\chi^2$ = 40.3, p < 0.001) and the hinterland tombs ($\chi^2$ = 5.86, p = 0.015) (Table 5). When divided by tomb, Fisher's exact test found a significant difference between the Renaissance tomb and tombs B.5, B.6, and F.1; and between tomb B.5 and tombs 779, 781, B.6, B.7, and the hinterland tomb (Table 6). Due to the fact tomb B.5 had the largest sample size and the lowest relative frequency (Figure 10) the tomb was significantly different from several other tombs.

The frequency of LEHs based on two sets of polar teeth, maxillary central incisors and mandibular canines revealed a significant difference between the façade and shaft chamber tomb types ($\chi^2 = 18.62$, $p < 0.001$) with no other tomb type pairs differing significantly from each other (Table 7). Differences in the LEH frequency of the maxillary first incisors and mandibular canines by tomb using Fisher's exact test only found a significant difference between the Renaissance tomb and tomb B.5 (Table 8).

Where possible, estimated age of occurrence was established for each LEH following the method outlined by Goodman and Rose (1990) (Appendix D). The mean age of occurrence across all sites was 3.7 years; with means of 3.6, 3.8, and 3.9 years for the façade, shaft chamber and hinterland tombs respectively. The distributions of ages of occurrence appear to be consistent across tomb types (Figure 11-Figure 14). A Kolmogorov-Smirnov test did not find a significant difference between the façade and shaft chamber tombs ($D = 0.060$, $p = 0.922$), the façade and hinterland tombs ($D = 0.085$, $p = 0.969$), or the shaft chamber and hinterland tombs ($D = 0.104$, $p = 0.777$). Additionally, the estimated amount of time between LEH formation on each tooth was calculated to assess if the stress events were the result of seasonal stressors, such as winter periods or dry-seasons (Figure 15). The mean amount of time between LEHs was 0.72 years with no clear temporal pattern in LEH formation.

Table 5 Percentage of Teeth Affected by LEHs by Tomb Type

| *Tomb Type* | *Total Teeth*[1] | *Observed LEHs* | *Relative Frequency* | *$\chi^2$ Results (Bonferroni corrected $\alpha=0.016$)* |
|---|---|---|---|---|
| Facade Tombs | 210 | 67 | 32% | Façade vs. Shaft: $\chi^2=40.3$, $p<0.001$<br>Façade vs. Hinterland: $\chi^2=3.95$, $p=0.047$<br>Shaft vs. Hinterland: $\chi^2=5.86$, $p=0.015$ |
| Shaft Chamber Tombs | 621 | 77 | 12% | |
| Petra hinterland | 123 | 26 | 21% | |

Table 6 Percentage of Teeth Affected by LEHs by Tomb

| *Site* | *Tomb* | *Total Teeth* | *Observed LEHs* | *Relative Frequency* |
|---|---|---|---|---|
| Renaissance | TR | 49 | 23 | 46% |
| Khubtha | 779 | 25 | 9 | 36% |
| | 781 | 136 | 26 | 19% |
| Petra North Ridge | B.4 | 31 | 3 | 10% |
| | B.5 | 233 | 11 | 5% |
| | B.6 | 140 | 25 | 18% |
| | B.7 | 86 | 18 | 13% |
| | F.1 | 131 | 20 | 15% |
| Petra hinterland | A.10 | 123 | 26 | 21% |

Table 7 Percentage of Selected Polar Teeth ($I^1$ and C,) Affected by LEHs by Tomb Type

| *Tomb Type* | *Polar Teeth* | *Observed LEHs* | *Relative Frequency* | *$\chi^2$ Results (Bonferroni corrected $\alpha$=0.016)* |
|---|---|---|---|---|
| Facade Tombs | 34 | 25 | 74% | Façade vs. Shaft: $\chi^2$=18.13, p<0.001<br>Façade vs. Hinterland: $\chi^2$=3.70, p=0.055<br>Shaft vs. Hinterland: $\chi^2$=0.51, p=0.474 |
| Shaft Chamber Tombs | 64 | 17 | 26% | |
| Petra hinterland | 15 | 6 | 40% | |

Table 8 Percentage of Selected Polar Teeth ($I^1$ and C,) Affected by LEHs by Tomb

| *Site* | *Tomb* | *Total Teeth* | *Observed LEHs* | *Relative Frequency* |
|---|---|---|---|---|
| Renaissance | TR | 7 | 7 | 100% |
| Khubtha | 779 | 4 | 4 | 100% |
| | 781 | 23 | 14 | 61% |
| Petra North Ridge | B.4 | 2 | 0 | 0.0% |
| | B.5 | 30 | 4 | 13% |
| | B.6 | 12 | 3 | 25% |
| | B.7 | 7 | 4 | 57% |
| | F.1 | 13 | 6 | 46% |
| Petra hinterland | A.10 | 15 | 6 | 40% |

Table 9 P-values of Inter-tomb Comparisons of LEH Frequencies of All Teeth Except the M3 Using Fisher's Exact Test (Bonferroni-corrected α=0.00035, significant results noted with *)

| | Façade Tombs | | | Petra hinterland Tomb | Shaft Chamber Tombs | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TR | 779 | 781 | A.10 | B.4 | B.5 | B.6 | B.7 | F.1 |
| TR | -- | | | | | | | | |
| 779 | 0.4595 | -- | | | | | | | |
| 781 | 0.0075 | 0.3307 | -- | | | | | | |
| A.10 | 0.0013 | 0.1253 | 0.4637 | -- | | | | | |
| B.4 | 0.0005 | 0.0235 | 0.0599 | 0.2000 | -- | | | | |
| B.5 | >0.0001* | >0.0001* | >0.0001* | >0.0001* | 0.2180 | -- | | | |
| B.6 | >0.0001* | 0.0574 | 0.1441 | 0.5344 | 0.4202 | 0.0001* | -- | | |
| B.7 | 0.0032 | 0.1835 | 0.5183 | 1.0000 | 0.1859 | >0.0001* | 0.6028 | -- | |
| F.1 | >0.0001* | 0.0232 | 0.0485 | 0.2555 | 0.5720 | 0.0008 | 0.6257 | 0.3613 | -- |

Table 10 P-values of Inter-tomb Comparisons of Selected Polar Teeth ($I^1$ and C,) LEH Frequencies Using Fisher's Exact Test (Bonferroni-corrected α=0.00035, significant results noted with *)

| | *Façade Tombs* | | | *Petra hinterland Tomb* | *Shaft Chamber Tombs* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TR | 779 | 781 | A.10 | B.4 | B.5 | B.6 | B.7 | F.1 |
| TR | -- | | | | | | | | |
| 779 | 1.000 | -- | | | | | | | |
| 781 | 0.0710 | 0.2677 | -- | | | | | | |
| A.10 | 0.0167 | 0.0867 | 0.3201 | -- | | | | | |
| B.4 | 0.0278 | 0.0667 | 0.1833 | 0.5147 | -- | | | | |
| B.5 | >0.0001* | 0.0015 | 0.0004 | 0.0615 | 1.0000 | -- | | | |
| B.6 | 0.0031 | 0.0192 | 0.0750 | 0.6828 | 1.0000 | 0.3873 | -- | | |
| B.7 | 0.1923 | 0.2364 | 1.0000 | 0.6517 | 0.4444 | 0.0271 | 0.3261 | -- | |
| F.1 | 0.0445 | 0.1029 | 0.4932 | 1.0000 | 0.4857 | 0.0441 | 0.4110 | 1.000 | -- |

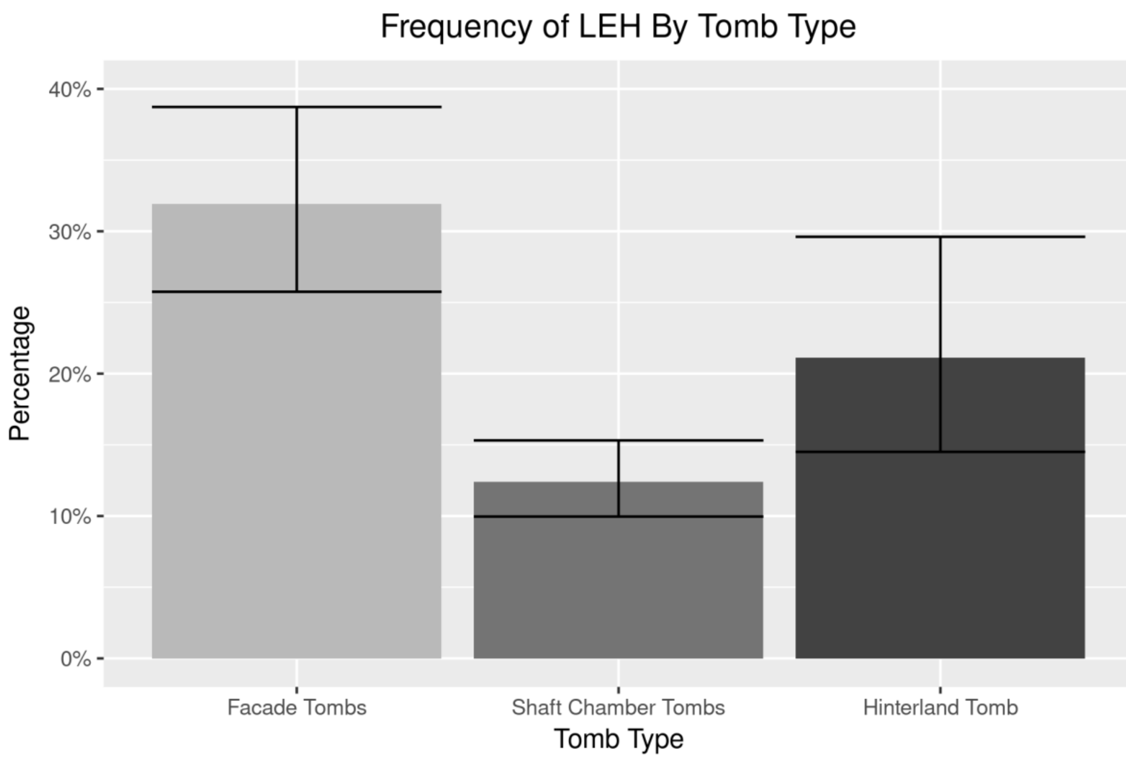


**Figure 7 Frequency of LEHs of all teeth except the M3 by tomb type with 95% confidence intervals. Only the façade tombs and shaft chamber tombs had a significant difference at the α=0.016 level.**

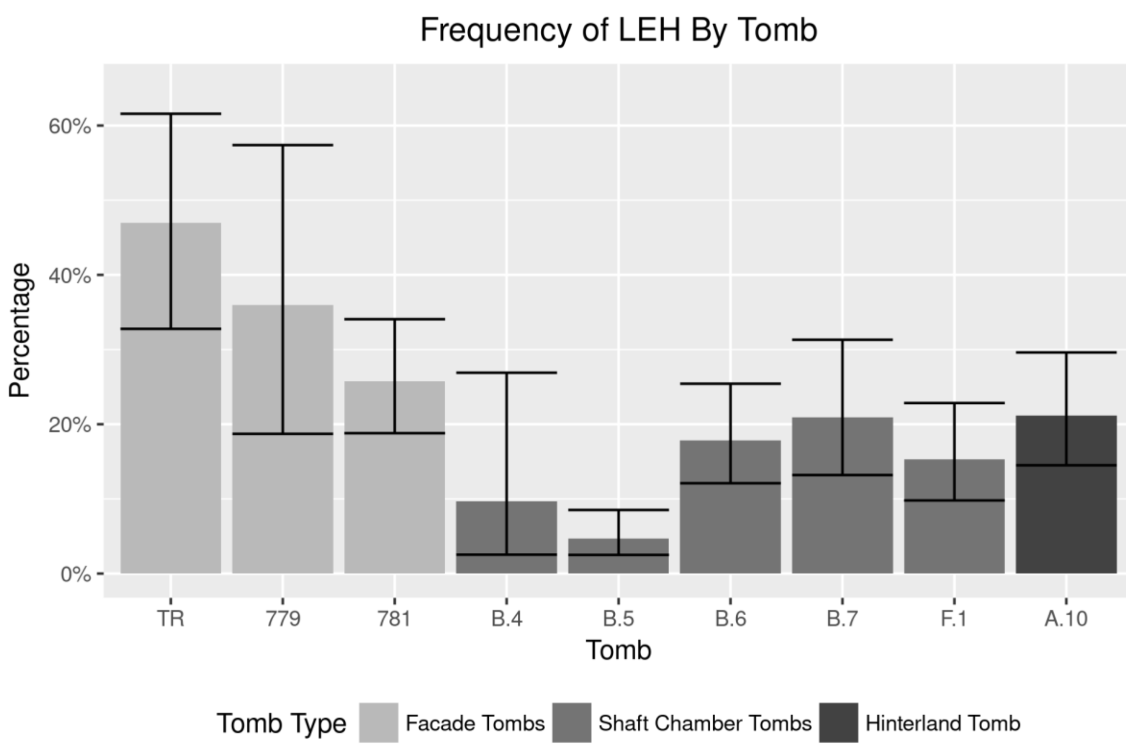


**Figure 8 Frequency of LEH of all teeth except the M3 by tomb with 95% confidence intervals.**

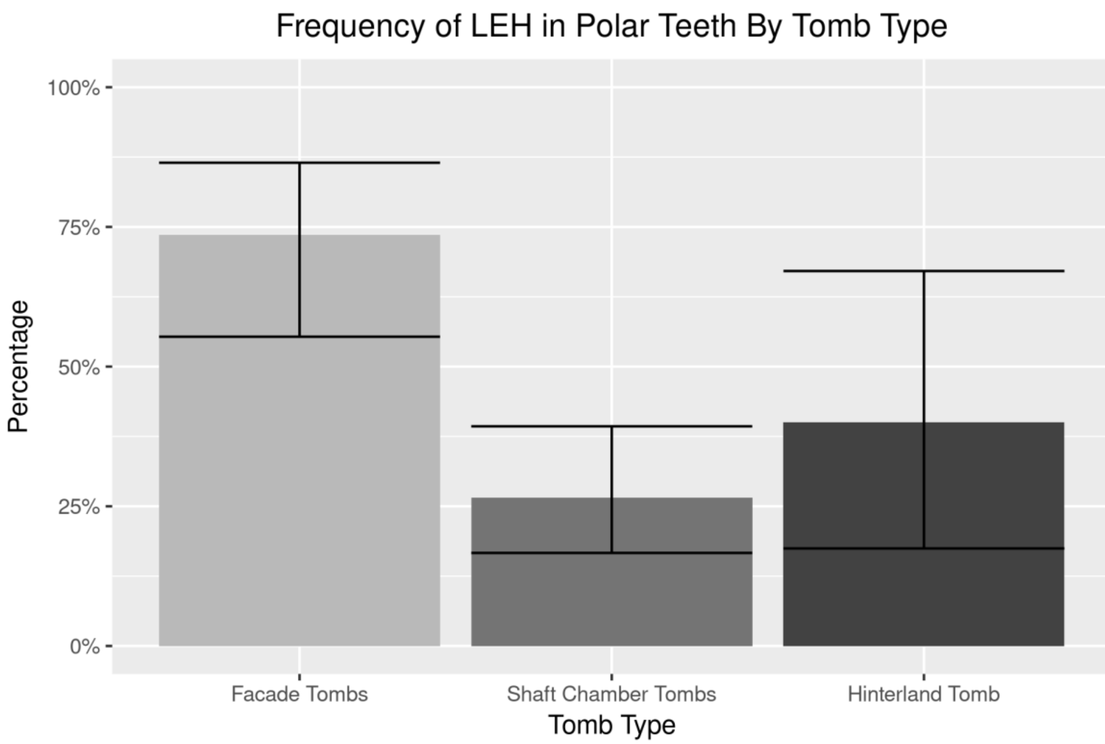


**Figure 9 Frequency of LEHs affecting selected polar teeth ($I^1$ and $C_,$) with 95% confidence intervals. Only the façade tombs and shaft chamber tombs had a significant difference at the α=0.016 level.**

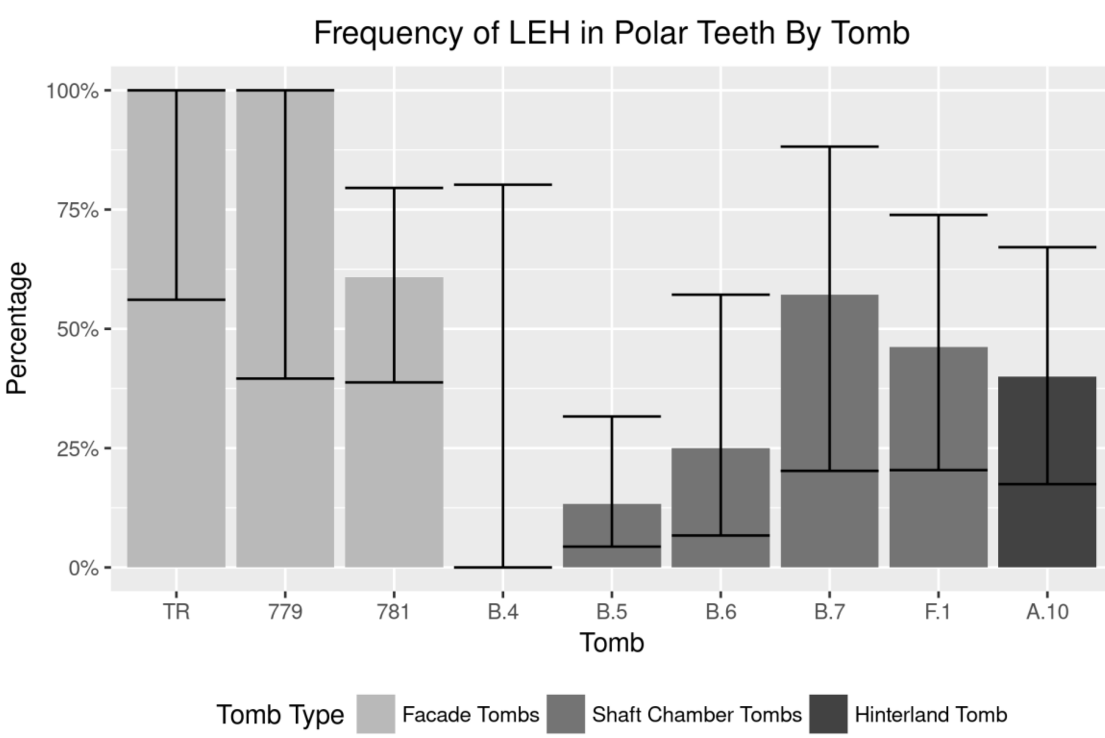


**Figure 10 Frequency of LEH affecting selected polar teeth ($I^1$ and $C_,$) by tomb with 95% confidence intervals.**

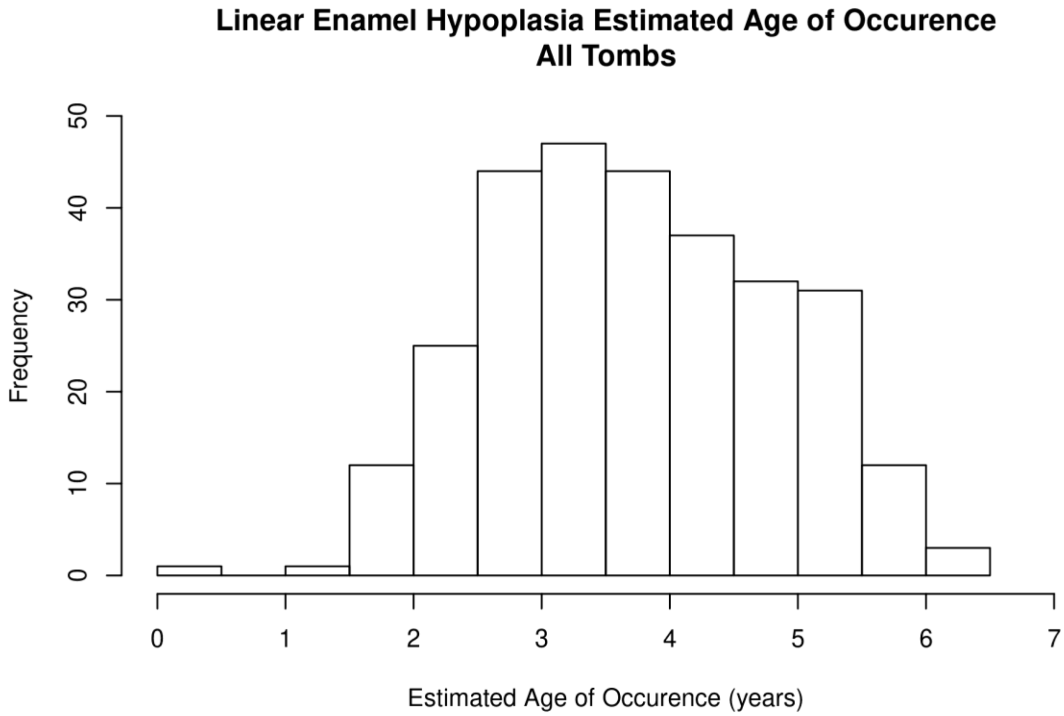


**Figure 11 Estimated age of occurrence of LEHs across all tombs.**

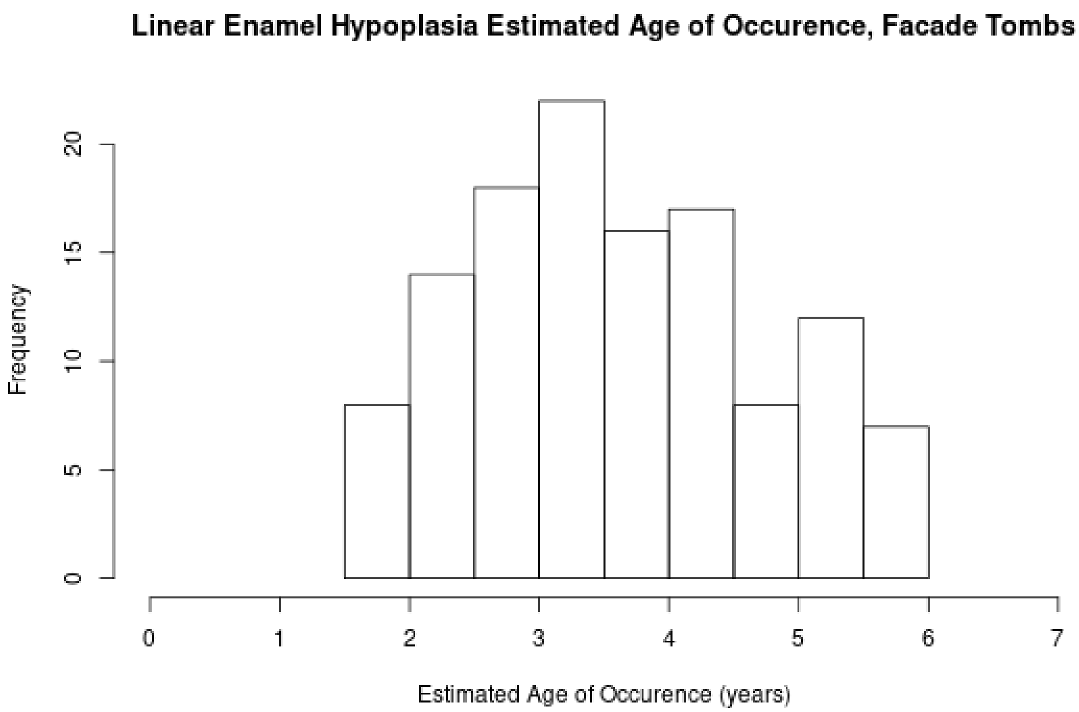


**Figure 12 Estimated age of occurrence of LEHs in façade tombs.**

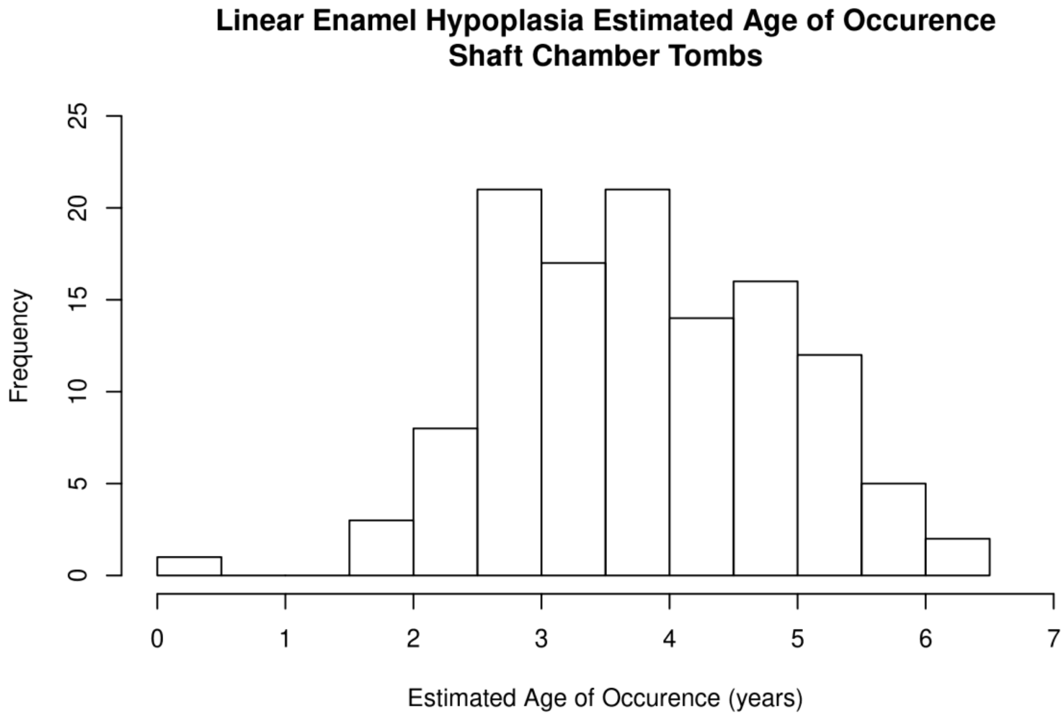


**Figure 13 Estimated age of occurrence of LEHs in shaft chamber tombs**

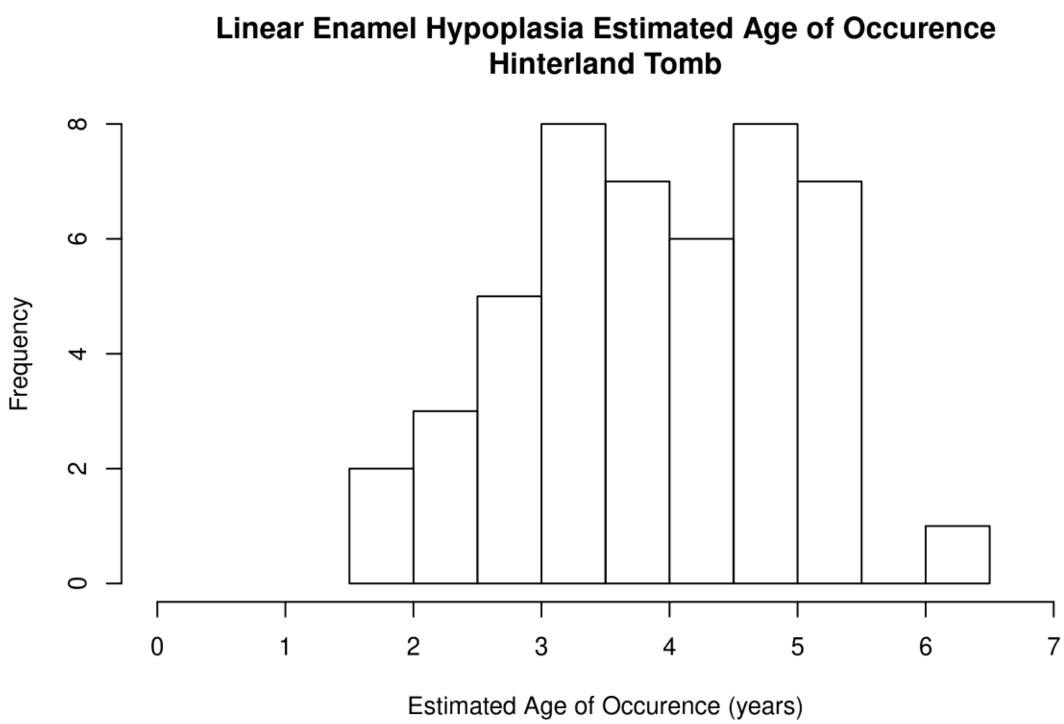


**Figure 14 Estimated age of occurrence of LEHs for the hinterland tomb.**

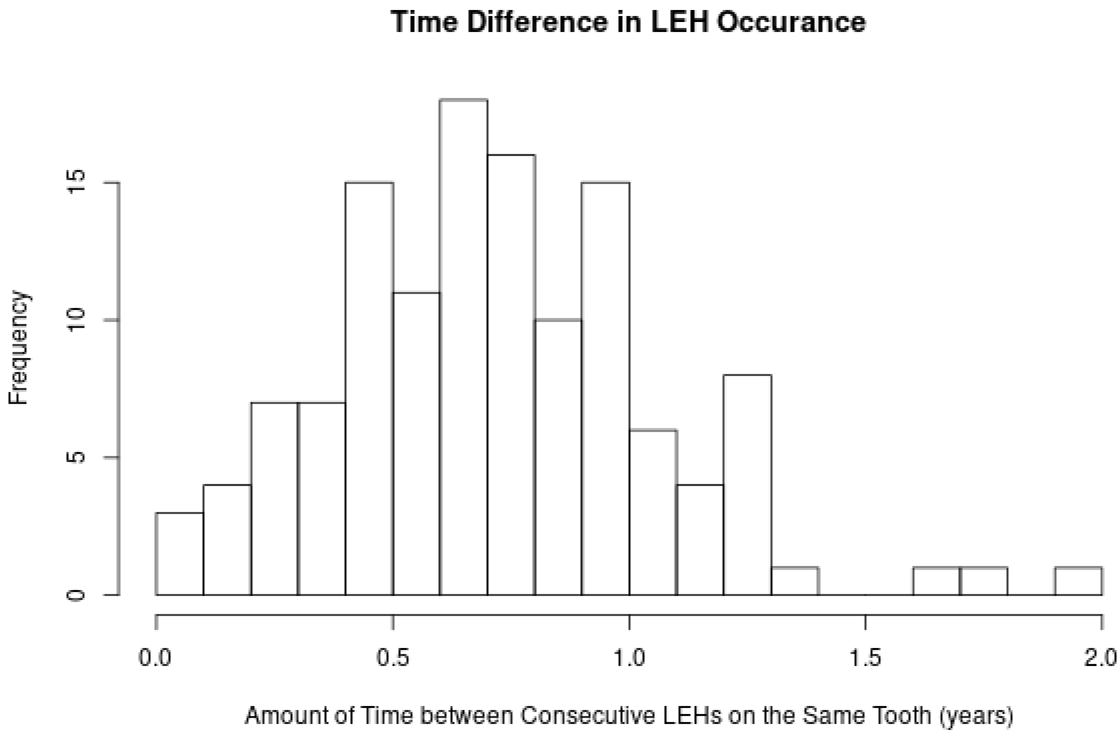


**Figure 15 Time between consecutive LEHs**

## Dental Caries

Despite the differences in sample size, the expression of dental caries seems consistent across all sites, with expression of carious lesions occurring in 3% to 5% of the respective samples (Table 11 and Figure 7). This trend continues when comparing these frequencies by tomb, as seen in Table 6. The lack of variation in caries frequencies also emerged in comparisons between tombs using Fisher's exact test, with no single tomb differing significantly from any other tomb (Table 13). This can be seen in Figure 17, which shows that the confidence intervals for each tomb are large enough to overlap.

Table 11 Percentage of Teeth Affected by Dental Caries by Tomb Type

| *Tomb Type* | *Total Teeth* | *Observed Caries* | *Relative Frequency* | *$\chi^2$ Results (Bonferroni corrected $\alpha=0.016$)* |
|---|---|---|---|---|
| Facade Tombs | 234 | 8 | 3.4% | Façade vs. Shaft: $\chi^2=0.00$, $p=1.000$<br>Façade vs. Hinterland: $\chi^2=0.36$, $p=0.550$<br>Shaft vs. Hinterland: $\chi^2=0.47$, $p=0.491$ |
| Shaft Chamber Tombs | 696 | 25 | 3.6% | |
| Petra hinterland | 132 | 7 | 5.3% | |

Table 12 Percentage of Teeth Affected by Dental Caries by Tomb

| *Site* | *Tomb* | *Total Teeth* | *Observed Caries* | *Relative Frequency* |
|---|---|---|---|---|
| Renaissance | TR | 52 | 2 | 3.8% |
| Khubtha | 779 | 28 | 0 | 0.0% |
| | 781 | 154 | 6 | 3.9% |
| Petra North Ridge | B.4 | 39 | 2 | 5.1% |
| | B.5 | 257 | 9 | 3.5% |
| | B.6 | 157 | 11 | 7.0% |
| | B.7 | 92 | 2 | 2.2% |
| | F.1 | 151 | 1 | 0.7% |
| Petra hinterland | A.10 | 132 | 7 | 5.3% |

Table 13 P-values of Inter-tomb Comparisons of Dental Caries Frequencies Using Fisher's Exact Test

(Bonferroni-corrected α=0.00035 significant results noted with *)

| | *Façade Tombs* | | | *Petra hinterland Tomb* | *Shaft Chamber Tombs* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TR | 779 | 781 | A.10 | B.4 | B.5 | B.6 | B.7 | F.1 |
| TR | -- | | | | | | | | |
| 779 | 0.5392 | -- | | | | | | | |
| 781 | 1.0000 | 0.6925 | -- | | | | | | |
| A.10 | 1.0000 | 0.6068 | 0.5838 | -- | | | | | |
| B.4 | 1.0000 | 0.5061 | 0.6642 | 1.000 | -- | | | | |
| B.5 | 1.0000 | 0.6065 | 1.0000 | 0.4248 | 0.6433 | -- | | | |
| B.6 | 0.5255 | 0.2210 | 0.3190 | 0.6302 | 1.0000 | 0.1545 | -- | | |
| B.7 | 0.6199 | 1.0000 | 0.7137 | 0.3140 | 0.5820 | 0.7344 | 0.1404 | -- | |
| F.1 | 0.1618 | 1.0000 | 0.1208 | 0.0273 | 0.1076 | 0.0992 | 0.0055 | 0.5589 | -- |

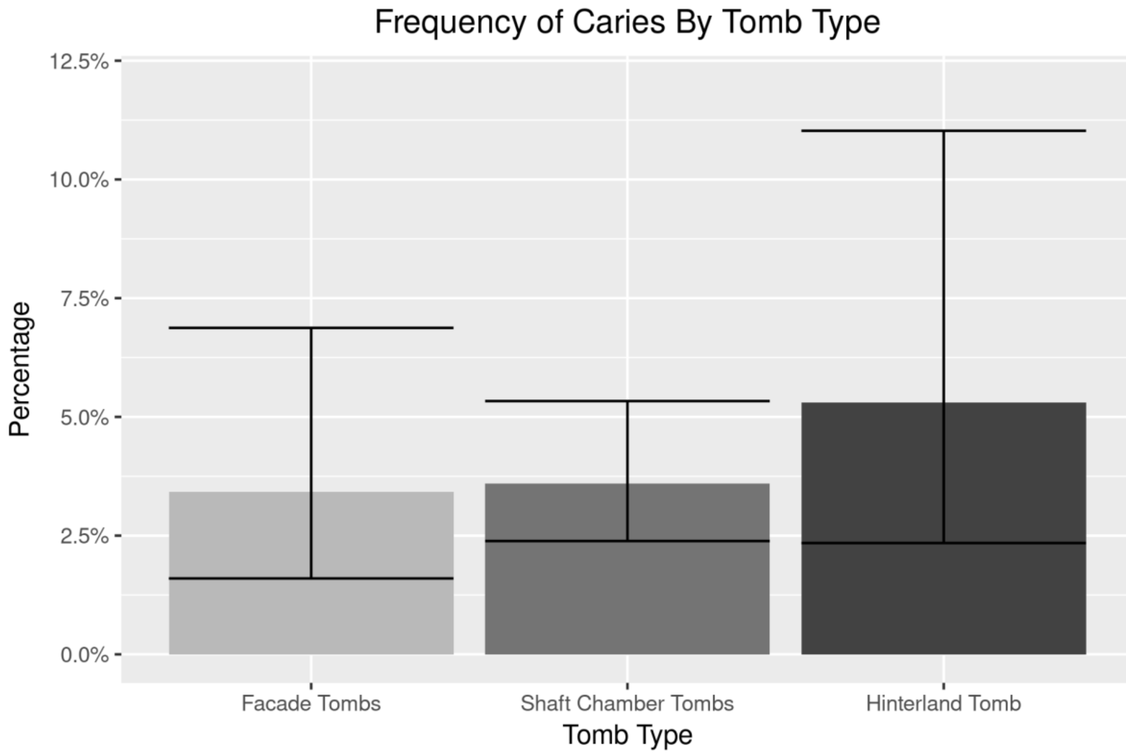


**Figure 16 Frequency of caries by tomb type with 95% confidence intervals. None of the tomb types displayed a significant difference at the α=0.016 level.**

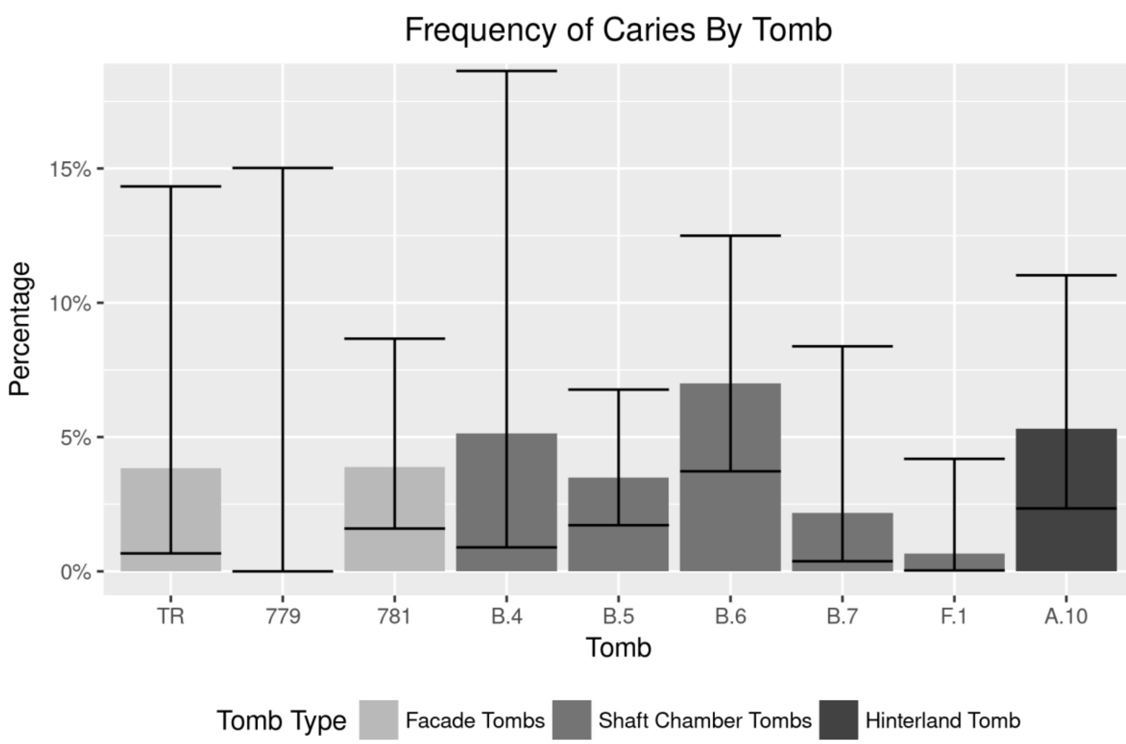


**Figure 17 Frequency of caries by tomb with 95% confidence intervals.**

## Dental Calculus

From the overall sample, 351 teeth, or 33%, exhibited some degree of dental calculus formation and the frequency of dental calculus showed some variation across the sites. The façade tombs exhibited a frequency of 48% with 112 out of 234 teeth observed exhibiting dental calculus. The Petra North Ridge tombs had the lowest frequency of dental calculus at 27.7% (Table 14). When using pairwise Chi-squared tests there was a significant difference between the façade and shaft chamber tombs ($\chi^2$ = 30.79, $p < 0.001$) and the façade and hinterland tombs ($\chi^2$ = 5.98, $p = 0.014$), but no significance between the shaft and hinterland tombs (Table 14).

When divided by tomb type (Figure 18) façade tombs clearly exhibit a higher frequency of dental calculus than the shaft chamber tombs. Fisher's exact test found significant difference between the Renaissance tomb and tombs B.5, B.6, and F.1; tomb 779 and B.5, B.6, and F.1; B.5 and 781, B.7 and the hinterland tomb (Table 16).

Table 14 Percentage of Teeth Affected by Dental Calculus by Tomb Type

| *Tomb Type* | *Total Teeth* | *Observed Calculus* | *Relative Frequency* | *$\chi^2$ Results (Bonferroni corrected α=0.016)* |
|---|---|---|---|---|
| Facade Tombs | 234 | 112 | 48% | Façade vs. Shaft: $\chi^2$=30.8, p<0.001<br>Façade vs. Hinterland: $\chi^2$=5.98, p=0.014<br>Shaft vs. Hinterland: $\chi^2$=1.80, p=0.180 |
| Shaft Chamber Tombs | 696 | 194 | 28% | |
| Petra hinterland | 132 | 45 | 34% | |

Table 15 Percentage of Teeth Affected by Dental Calculus by Tomb

| *Site* | *Tomb* | *Total Teeth* | *Observed Calculus* | *Relative Frequency* |
|---|---|---|---|---|
| Renaissance | TR | 52 | 21 | 40% |
| Khubtha | 779 | 28 | 13 | 46% |
| | 781 | 154 | 27 | 18% |
| Petra North Ridge | B.4 | 39 | 5 | 13% |
| | B.5 | 257 | 5 | 1.9% |
| | B.6 | 157 | 12 | 7.6% |
| | B.7 | 92 | 17 | 18% |
| | F.1 | 151 | 10 | 6.6% |
| Petra hinterland | A.10 | 132 | 23 | 17% |

Table 16 P-values of Inter-tomb Comparisons of Dental Calculus Frequencies Using Fisher's Exact Test

(Bonferroni-corrected α=0.00035, significant results noted with *)

| | *Façade Tombs* | | | *Petra hinterland Tomb* | *Shaft Chamber Tombs* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TR | 779 | 781 | A.10 | B.4 | B.5 | B.6 | B.7 | F.1 |
| TR | -- | | | | | | | | |
| 779 | 0.6412 | -- | | | | | | | |
| 781 | 0.0012 | 0.0020 | -- | | | | | | |
| A.10 | 0.0019 | 0.0021 | 1.0000 | -- | | | | | |
| B.4 | 0.0048 | 0.0044 | 0.6315 | 0.6257 | -- | | | | |
| B.5 | >0.0001* | >0.0001* | >0.0001* | >0.0001* | 0.0048 | -- | | | |
| B.6 | >0.0001* | >0.0001* | 0.0100 | 0.0176 | 0.3399 | 0.0085 | -- | | |
| B.7 | 0.0058 | 0.0053 | 0.8648 | 0.6517 | 0.6099 | >0.0001* | 0.0136 | -- | |
| F.1 | >0.0001* | >0.0001* | 0.0046 | 0.0053 | 0.1970 | 0.0259 | 0.8263 | 0.0059 | -- |

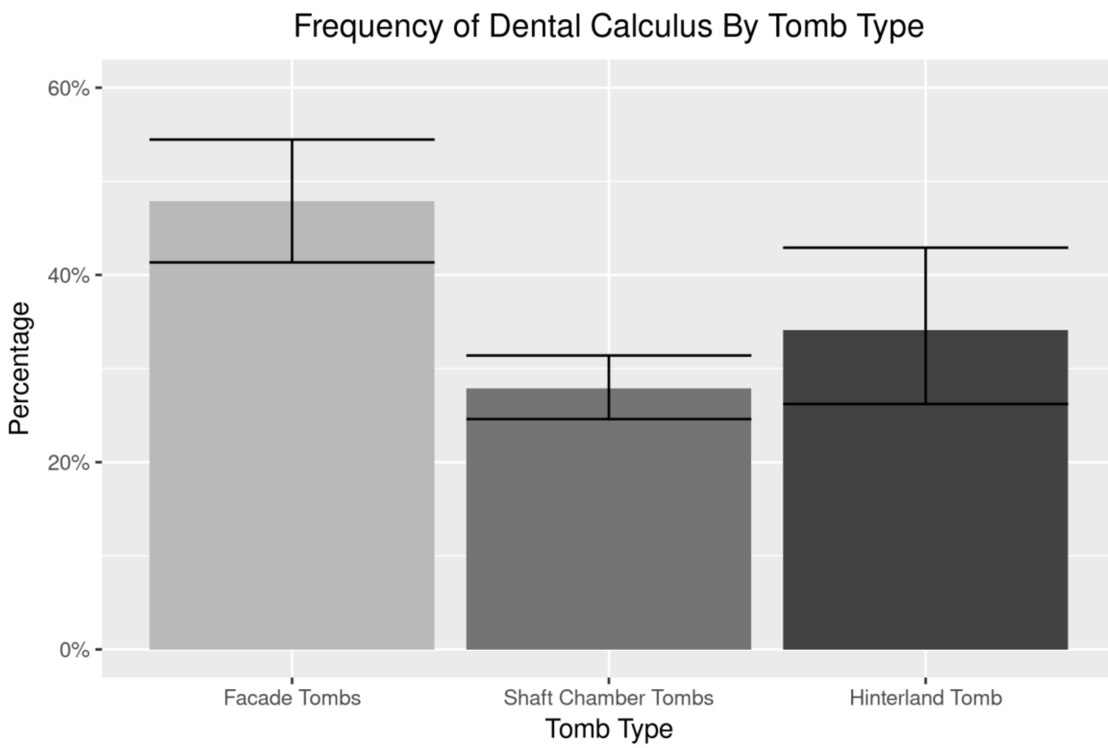


**Figure 18 Percentage of teeth affected by dental calculus by tomb type with 95% confidence intervals. The façade tombs had a significant difference from the and shaft chamber tombs and the hinterland tomb at the α=0.016 level.**

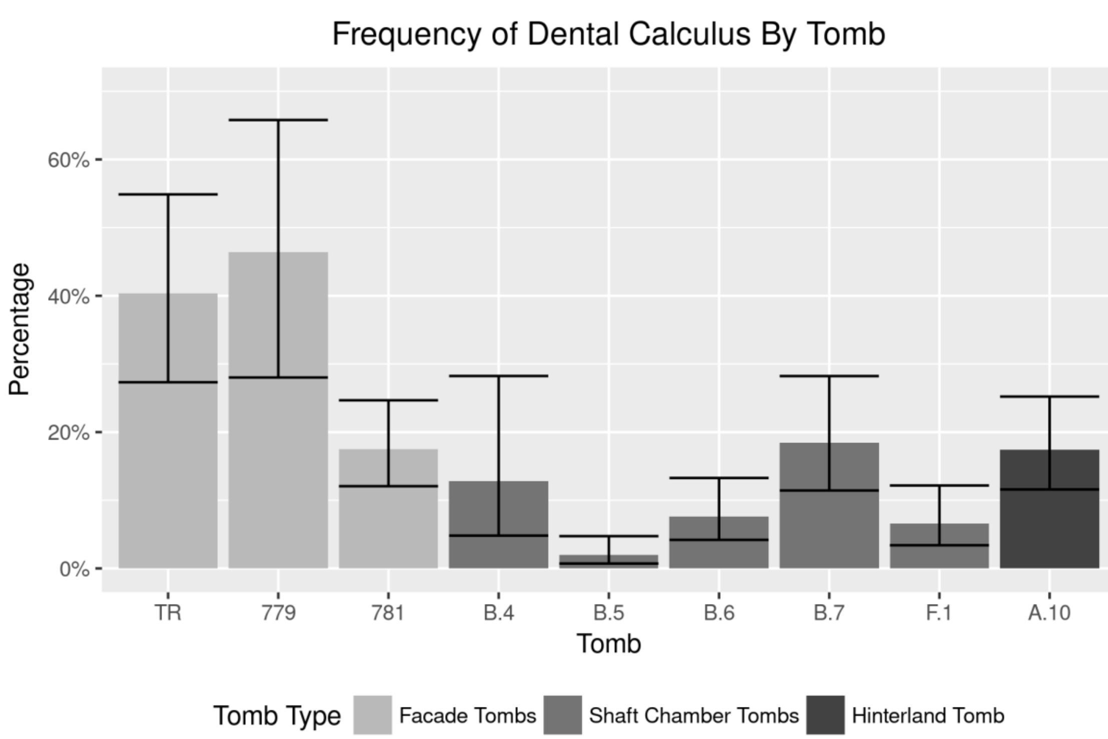


**Figure 19 Percentage of teeth affected by dental calculus by tomb with 95% confidence intervals.**

### Antemortem Tooth Loss

The observed mandibles and maxillae have 120 teeth lost prior to death. The façade and shaft chamber tombs exhibited similar frequencies of AMTL (6% to 7%), however the hinterland tomb exhibited a significantly higher frequency of AMTL (16%) (Table 17). After establishing which teeth lost postmortem could potentially be accounted for within the loose teeth for each tomb, a corrected percentage was calculated resulting in slightly higher frequencies of AMTL across all sites. When divided by tomb type, the hinterland tombs exhibit significantly more AMTL than the façade tombs ($\chi^2 = 9.61$, $p = 0.002$) and shaft chamber tombs ($\chi^2 = 17.90$, $p < 0.001$).

When divided by tomb, two tombs, B.4 and A.10, exhibited high corrected frequencies of AMTL compared to the other tombs under study at 22.3% and 13.8% respectively (Table 18). Fisher's exact test revealed a significant difference between tomb B.4 from tombs 781, B.5, B.6, B.7, and F.1; tomb F.1 and the Renaissance tomb, 781, B.4, B.5, and the hinterland tomb; and the hinterland tomb and tombs B.5, B.6, and B.7 (Table 19).

Table 17 Percentage of Teeth Affected by Antemortem Tooth Loss by Tomb Type

| *Tomb Type* | *Total Teeth*[3] | *Observed AMTL* | *Relative Frequency* | *Corrected Relative Frequency*[4] | *$\chi^2$ Results (Bonferroni corrected α=0.016)* |
|---|---|---|---|---|---|
| Facade Tombs | 373 | 26 | 7.0% | 7.8% | Façade vs. Shaft: $\chi^2$=0.08, p=0.781<br>Façade vs. Hinterland: $\chi^2$=9.61, p=0.002<br>Shaft vs. Hinterland: $\chi^2$=17.90, p<0.001 |
| Shaft Chamber Tombs | 996 | 61 | 6.1% | 7.2% | |
| Petra hinterland | 201 | 33 | 16.4% | 17.0% | |

[3] AMTL frequency includes teeth lost postmortem, making the total number of teeth 373 for the façade tombs, 996 for the shaft chamber tombs, and 201 for the hinterland tombs.
[4] There is a possibility that some of the teeth lost postmortem were found as loose teeth. Where the locations of postmortem losses match the loose teeth found, this column assumes that they are the same, and only counts one of them toward the total count of teeth.

Table 18 Percentage of Teeth Affected by Antemortem Tooth Loss by Tomb

| *Site* | *Tomb* | *Total Teeth*[3] | *Observed AMTL* | *Relative Frequency* | *Corrected Relative Frequency*[4] |
|---|---|---|---|---|---|
| Renaissance | TR | 85 | 6 | 7.2% | 11.3% |
| Khubtha | 779 | 32 | 0 | 0.0% | 0.0% |
| | 781 | 258 | 20 | 7.8% | 8.0% |
| Petra North Ridge | B.4 | 116 | 25 | 21.6% | 23.4% |
| | B.5 | 408 | 28 | 6.9% | 8.3% |
| | B.6 | 203 | 6 | 3.0% | 3.6% |
| | B.7 | 108 | 2 | 1.9% | 2.1% |
| | F.1 | 161 | 0 | 0.0% | 0.0% |
| Petra hinterland | A.10 | 201 | 33 | 16.4% | 17.0% |

Table 19 P-values of Inter-tomb Comparisons of Corrected AMTL Frequencies Using Fisher's Exact Test

(Bonferroni-corrected α=0.00035, significant results noted with *)

| | *Façade Tombs* | | | *Petra hinterland Tomb* | *Shaft Chamber Tombs* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TR | 779 | 781 | A.10 | B.4 | B.5 | B.6 | B.7 | F.1 |
| TR | -- | | | | | | | | |
| 779 | 0.0790 | -- | | | | | | | |
| 781 | 0.4236 | 0.1431 | -- | | | | | | |
| A.10 | 0.3978 | 0.0061 | 0.0048 | -- | | | | | |
| B.4 | 0.0892 | 0.0011 | 0.0002* | 0.2217 | -- | | | | |
| B.5 | 0.4352 | 0.1528 | 1.0000 | 0.0029 | 0.0001* | -- | | | |
| B.6 | 0.0398 | 0.5923 | 0.0665 | >0.0001* | >0.0001* | 0.0582 | -- | | |
| B.7 | 0.0242 | 1.0000 | 0.0485 | 0.0001* | >0.0001* | 0.0384 | 0.7148 | -- | |
| F.1 | 0.0003* | 1.0000 | 0.0001* | >0.0001* | >0.0001* | 0.0001* | 0.0320 | 0.1551 | -- |

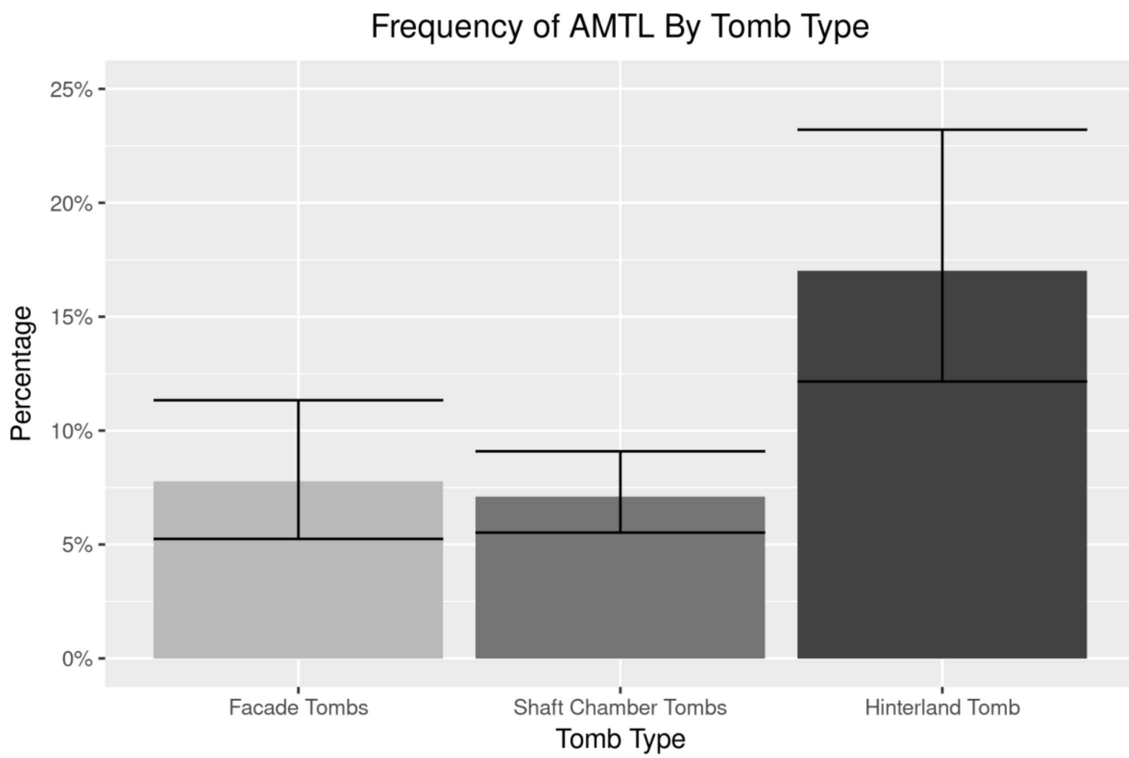


**Figure 20 Frequency of corrected antemortem tooth loss by tomb type with 95% confidence intervals. The hinterland tomb was significantly higher than the façade or shaft chamber tombs at the p=0.016 level.**

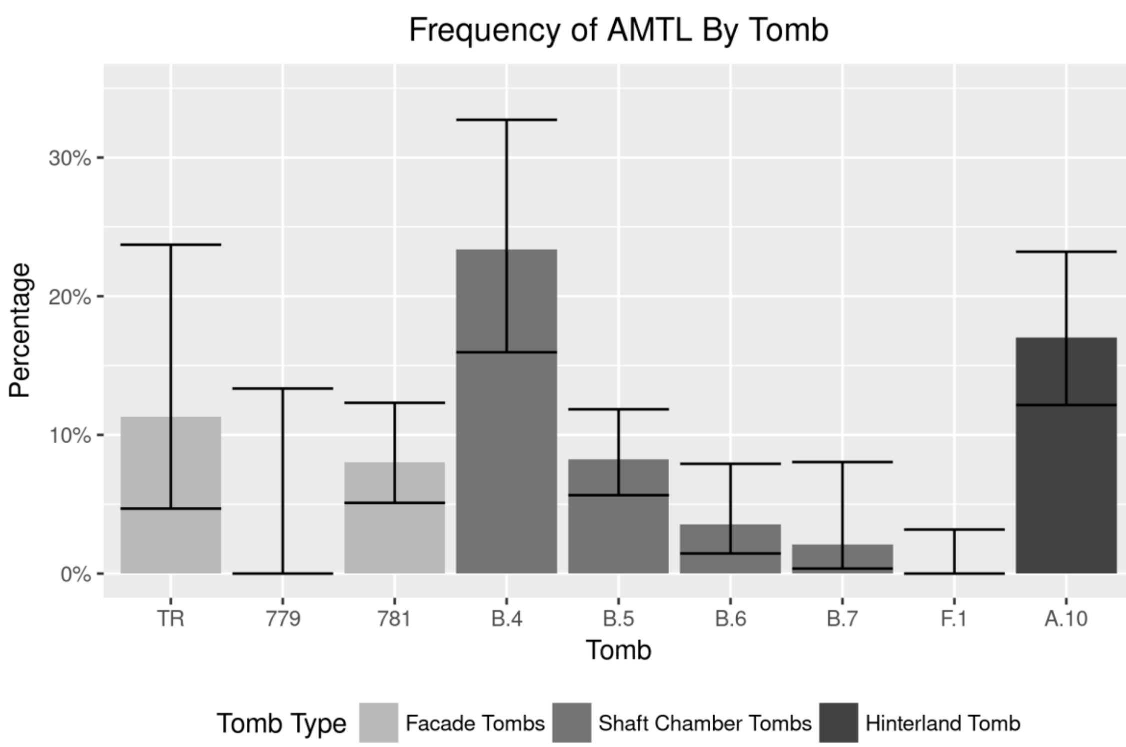


**Figure 21 Frequency of corrected antemortem tooth loss by tomb with 95% confidence intervals**

## Abscesses

Few abscesses were observed across all sites, with only 7 abscesses out of maxillary and mandibular alveolar bone associated with 1,061 teeth. However, as discussed above, some of these teeth have associated alveolar bone, and some do not, and including the entire tooth count artificially deflates the abscess frequencies. In addition, the small number of abscesses could be due to the poor preservation of alveolar bone in the maxillae and mandibles at Petra. No significant differences in the frequencies were found between tomb types (Table 20). Dividing the sample by tomb yielded similar non-significant results with no tombs differing significantly from any other tomb (Table 22).

Table 20 Frequency of Teeth Associated with Abscesses by Tomb Type

| *Tomb Type* | *Total Teeth*[5] | *Observed Abscesses* | *Relative Frequency* | *$\chi^2$ Results (Bonferroni corrected α=0.016)* |
|---|---|---|---|---|
| Façade Tombs | 339 | 4 | 1.2% | Façade vs. Shaft: $\chi^2$=0.39, p=0.533 |
| Shaft Chamber Tombs | 540 | 3 | 0.6% | Façade vs. Hinterland: $\chi^2$=0.84, p=0.359 |
| Petra hinterland | 176 | 0 | 0.0% | Shaft vs. Hinterland: $\chi^2$=0.10, p=0.750 |

Table 21 Frequency of Teeth Associated with Abscesses by Tomb

| *Site* | *Tomb* | *Total Teeth* | *Observed Abscesses* | *Relative Frequency* |
|---|---|---|---|---|
| Renaissance | TR | 60 | 2 | 3.3% |
| Khubtha | 779 | 32 | 0 | 0.0% |
| | 781 | 247 | 2 | 0.8% |
| Petra North Ridge | B.4 | 94 | 0 | 0.0% |
| | B.5 | 290 | 2 | 0.7% |
| | B.6 | 90 | 1 | 1.1% |
| | B.7 | 40 | 0 | 0.0% |
| | F.1 | 26 | 0 | 0.0% |
| Petra hinterland | A.10 | 176 | 0 | 0.0% |

[5] Abscesses calculated using only teeth in association with alveolar bone, making the total number of teeth for the façade tombs 339, shaft chamber tombs 540, and hinterland tomb 176.

Table 22 P-values of Inter-tomb Comparisons of Abscess Frequencies Using Fisher's Exact Test

(Bonferroni-corrected α=0.00035, significant results noted with *)

| | *Façade Tombs* | | | *Petra hinterland Tomb* | *Shaft Chamber Tombs* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TR | 779 | 781 | A.10 | B.4 | B.5 | B.6 | B.7 | F.1 |
| TR | -- | | | | | | | | |
| 779 | 0.5392 | -- | | | | | | | |
| 781 | 0.2648 | 1.0000 | -- | | | | | | |
| A.10 | 0.0638 | 1.0000 | 0.5129 | -- | | | | | |
| B.4 | 0.5048 | 1.0000 | 1.0000 | 1.0000 | -- | | | | |
| B.5 | 0.1331 | 1.0000 | 0.6325 | 0.5289 | 1.0000 | -- | | | |
| B.6 | 0.1535 | 1.0000 | 0.6202 | 0.3383 | 1.0000 | 1.0000 | -- | | |
| B.7 | 0.1288 | 1.0000 | 0.5298 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | -- | |
| F.1 | 0.0647 | 1.0000 | 0.4984 | 1.0000 | 1.0000 | 0.5326 | 1.0000 | 1.0000 | -- |

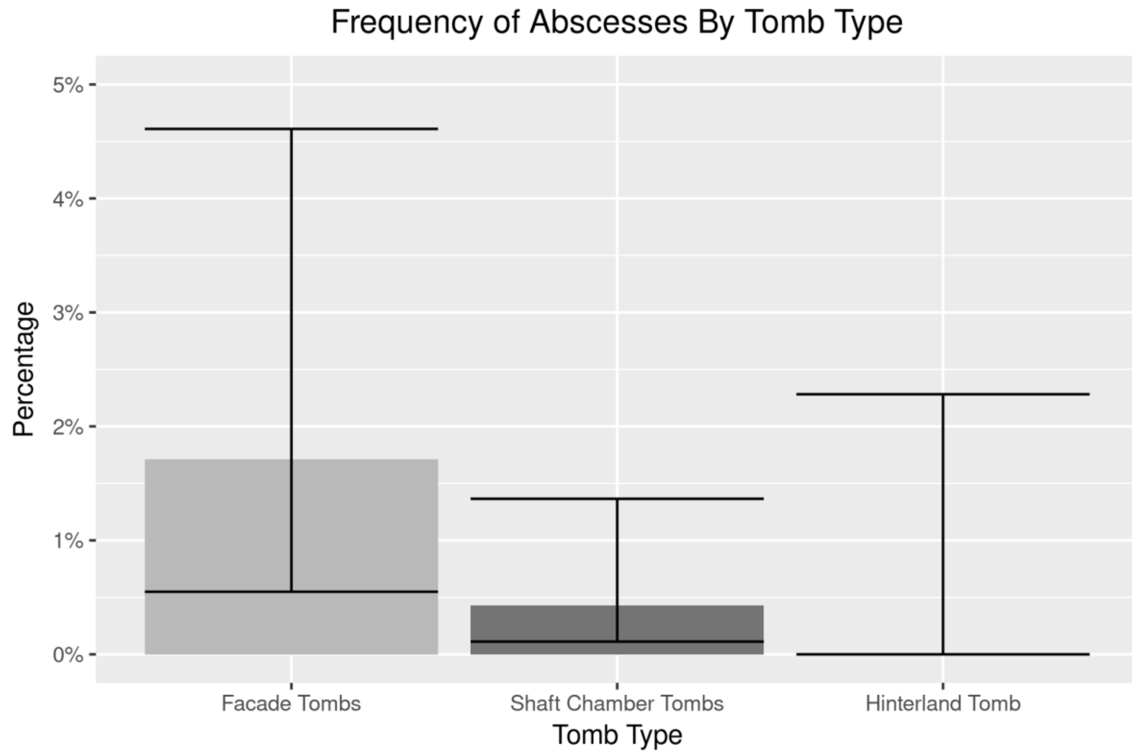


**Figure 22 Percentage of abscesses by tomb type with 95% confidence intervals. No significant differences were found across tomb types at the p=0.016 level.**

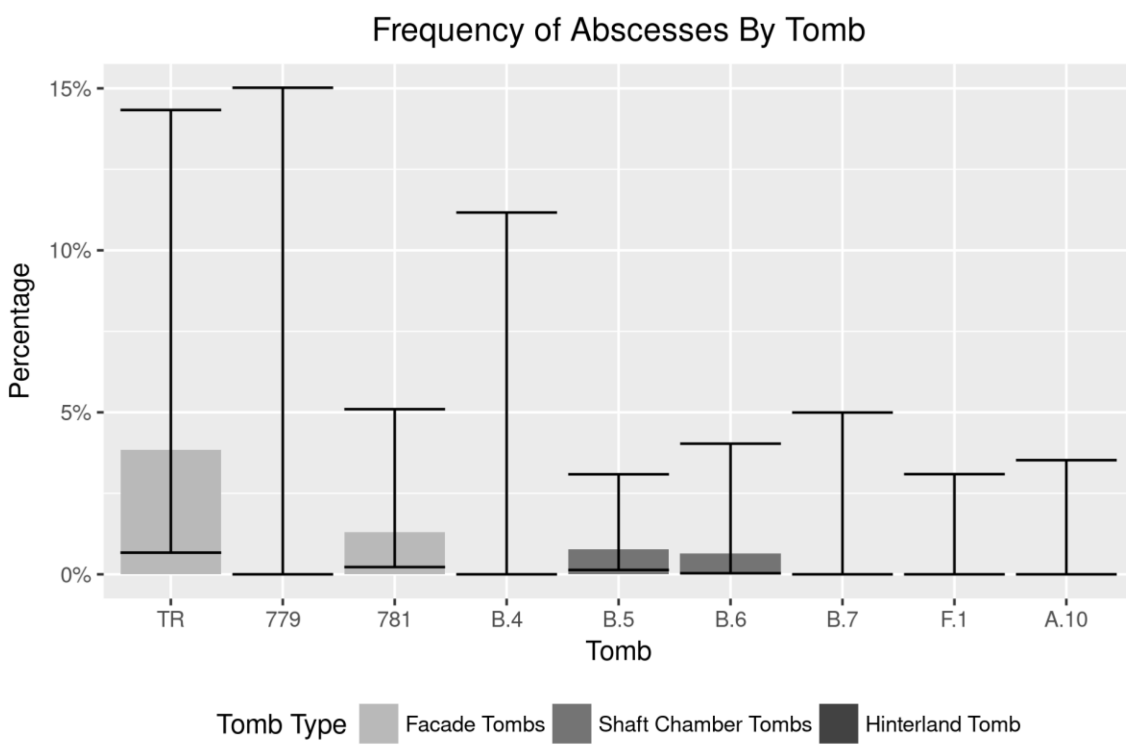


**Figure 23 Percentage of abscesses by tomb with 95% confidence intervals.**

## Summary

Rates of LEHs, dental calculus, and antemortem tooth loss significantly differed between some tomb types. Antemortem tooth loss was significantly different between the hinterland tomb and both the façade and shaft chamber tombs; linear enamel hypoplasias in the selected Polar teeth were significantly different between the façade and shaft chamber tombs; and dental calculus was significantly different between the façade and both the shaft chamber and hinterland tombs. In addition, Fisher's Exact Test was employed to explore inter-tomb differences to identify those with anomalous frequencies that may be driving the overall differences seen between tomb types. No significant differences in dental caries or abscesses were found between tomb types, which is consistent with the Chi-squared analysis by tomb type. The LEH frequencies in tombs B.6 and F.1 were significantly different than those of the Renaissance tomb, additionally Fisher's exact test found a significant difference in LEHs between tomb B.5 and all other tombs except B.4 and F.1. However, when this analysis was done using upper central incisors and mandibular canines, only the B.5 and the Renaissance tombs differed significantly. Tomb B.5 also differed from all tombs apart from B.4, B.6 and F.1 when dental calculus frequencies were tested. The Fisher tests for dental calculus revealed tombs B.6 and F.1 both significantly differed from the Renaissance tomb and tomb 779. The AMTL frequencies for tomb B.4 differed significantly from all of the shaft chamber tombs and tomb 781; F.1 differed from all tombs except 799, B.6, and B.7; finally, the hinterland tomb differed from tombs B.6, B.7, and F.1. Generally, most of the differences found by the fisher tests were between tomb types with fewer differences found within tomb types. Notable exceptions to this pattern are tomb B.4 exhibiting significantly higher frequencies of AMTL when compared to other shaft chamber tombs and tomb B.5 exhibiting significantly fewer LEHs than B.6 and B.7 as well as exhibiting significantly fewer instances of dental calculus than tomb B.7.

These patterns within the data could result not only from different diets and levels of childhood stress, but also environmental and taphonomic factors. The next chapter provides explanations for the differences and similarities seen within oral pathology data at Petra.

# CHAPTER 5: Discussion

The varied nature of funerary architecture at Petra is thought to represent social and economic stratification that should manifest in differences in the health of the individuals buried at Petra. Socio-economic differences between families should impact their access to resources and instances of stress-related disorders in dental enamel and plaque-related oral pathologies (Cucina & Tiesler, 2003; Goodman & Rose, 1991). If this social stratification exists, it should be reflected at the family level within the tombs, which according to epigraphic evidence contain individuals of an extended ancestral lineage (Perry, 2016; Schmid et al., 2012; Wadeson, 2012a,b).

## Developmental Dental Pathologies

Linear enamel hypoplasias develop due to stressors such as malnutrition, micronutrient deficiencies, disease, parasitism, weaning, and localized dental trauma occurring during amelogenesis (Goodman & Rose, 1990; Masterson et al., 2017). Studies of contemporary and archaeological populations have shown a clear relationship between malnutrition, socioeconomic status, and the development of LEHs (Cucina & Tiesler, 2003; Goodman et al., 1980, 1987; Goodman & Rose, 1991). Additionally, there is evidence that receiving adequate nutrition, through nutritional supplements, can significantly reduce the frequency of LEHs within a population (Goodman & Armelagos, 1989). In the case of Petra, the prevalence of LEHs in the façade tombs could imply that the elite population consumed a poorer childhood diet or experienced a higher disease burden than the non-elite individuals, resulting in a significantly higher incidence of LEHs within the façade tomb.

However, as discussed in Chapter 2, enamel hypoplasias can only be observed and recorded if an individual survives the stress event and normal amelogenesis resumes (Goodman & Rose 1990, 1991; Wood et al., 1992). Thus, the significantly higher frequency of LEHs in the façade tombs may indicate that the elites were less frail, perhaps due to lower disease burdens overall and better access to nutritious foods, than the non-elites within the shaft chamber tombs, and therefore survived periods of childhood stress that led to LEH development. The major hindrance for identifying any indicators of frailty during childhood is the underrepresentation of non-adult burials within either the façade tombs or the shaft tombs.  The tomb from Petra's hinterland did not differ in LEH frequency from either the façade tombs or the shaft chamber tombs. This is the only tomb from outside of Petra included in this analysis, but it may indicate no dramatic difference in frailty or exposure to malnutrition and disease between rural and urban populations.

LEH development has been linked specifically to the nutritionally and immunologically stressful period of weaning (Blakey et al., 1994; Goodman et al., 1980, 1987; Moggi-Cecchi et al., 1994). During the weaning period, children transition to an adult diet through gradually replacing breastmilk, containing vital hormones, nutrients, and antibodies, with cereal paste, eggs, honey and non-human milk (Dupras, Schwarcz, & Fairgrieve, 2001) as well we other reported elements of a Mediterranean weaning diet (Prowse et al., 2008). The homogeneity of LEH age distributions across tomb types within Petra and between Petra and the hinterland, with a peak between ages 2 and 3, may indicate when the potentially deleterious effects of weaning began to impact the health of children. Multiple studies (Blakely et al., 1994; Moggi-Cecchi et al., 1994) have shown that an increase in LEHs is seen months or years after the historically recorded beginning of the weaning period, suggesting that gradual nature of weaning results in delayed physiological effects in the body. Initial results from Provan's (2018) isotopic analysis of childhood diet at Petra North Ridge suggest that weaning may have extended past 3 years or that a specialized childhood diet was used after weaning was completed. Additionally, $C_4$ foods such as millet served as supplementary foods during the weaning period more than the generally $C_3$ adult diet. The similarity in LEH age occurrence, if LEHs are primarily related to the stresses of weaning, would suggest individuals regardless of social status or rural-urban residency followed the same practices in terms of the age of weaning. However, the differences in LEH frequency between the façade and shaft chamber tombs indicate that weaning stress differentially impacted different segments of the population.

Interpretations based on LEHs in dental enamel however are limited by differences in tooth plasticity between tooth classes, (Goodman & Armelagos, 1985) and tooth crown shape (Hillson & Bond, 1997), and method used for estimating age of occurrence (Ritzman et al., 2008). LEHs in all teeth, except for the third molars, were recorded in this study, but frequencies in only the maxillary first incisors and mandibular canines, which are more sensitive to perturbations leading to LEH formation (Goodman & Armelagos, 1985), were used for comparison.

## Plaque-Related Dental Pathologies

While explorations of linear enamel hypoplasias can illuminate childhood stressors, such as nutrition, disease, and trauma, explorations of plaque-related diseases aid in understanding the diet, oral disease, and trauma of past populations (Alvarez, 1995; Marsh, 2010; Rosan & Lamont, 2000; Selwitz et al., 2007). The oral cavity is regularly exposed to mechanical, chemical, and bacterial changes that affect not only the health and wellness of an individual but also the hundreds of species of bacteria and millions of cells contained on the teeth (Rosan &

Lamont, 2000; Selwitz et al., 2007). These bacteria form a biofilm covering the mouth and have incredibly complex interactions with the enzymes, minerals, and other bacteria within a single oral cavity (Clancy et al., 2000; Kuramitsu, He, Lux, Anderson, & Shi, 2007; Selwitz et al., 2007). As such, when considering the etiology of plaque-based pathologies, the interactions between the external environment, oral environment, and microflora of the mouth must be considered holistically. This study observed four interrelated indicators of oral cavity health and biology: dental caries, dental calculus, dental abscesses, and antemortem tooth loss (AMTL), with the expectation that frequencies in these variables will reflect status-related dietary differences between the populations. No clear pattern emerged in the data, with dental caries and abscesses showing no differences between any of the tomb types, and dental calculus having a higher frequency in the façade tombs and AMTL a higher frequency in the rural hinterland tomb. Possible explanations for this pattern reflect the complicated relationship between these pathologies and the broader environment.

## Dental Caries

Carious lesions are formed through the progressive localized demineralization of dental enamel by weak organic acids, the byproducts of the metabolism of fermentable carbohydrates by endogenous bacteria (Hillson, 1996; Selwitz et al., 2007). The oral microbiome plays a key role in caries development, notably the presence of cariogenic bacteria such as *Streptococcus mutans*, *Streptococcus sobrinus*, and *Lactobactillus*, but other factors such as inadequate salivary flow, poor oral hygiene, and frequent consumption of fermentable carbohydrates can impact caries development (Marsh, 2010; Selwitz et al., 2007). Paleobotanical evidence from Petra suggests the diet was rich in carbohydrates such as dates, figs, wheat, barley, and alcohol (Bedal & Schryver, 2007; Jacquat & Martinoli, 1999; Karg, 1996; Ramsay & Bedal 2015; Ramsay &

Smith, 2013, Stucky et al., 1995, Tholbecq et al., 2008), something which was confirmed the strong $C_3$ signature in isotopic studies of the shaft chamber tomb adults (Appleton, 2015). The homogeneity in dental caries frequencies between the tombs indicates the elite and non-elite individuals consumed these carbohydrate-rich foods at the same level. In addition, since calcium and lactic acid (lactate) play a role in caries formation, the elite and non-elite populations likely consumed similar amounts of animal byproducts containing these nutrients, such as goat's milk or yogurt (Studer, 2007). Furthermore, the available water sources at Petra are mineral rich (Al-Khashman, 2007), which may have prevented or even reversed early stages of caries formation.

However, observation of dental caries may be biased since extreme dental caries can lead to infections of the pulp chamber, resulting in periapical abscesses and AMTL (Hillson, 1996). Thus, assessing AMTL frequency provides an important component of this analysis, as seen below. In addition, dental caries formation is inhibited by the same factors that limit plaque and dental calculus formation such as regular salivary flow, abrasion by the tongue, foods, and dietary grit (Hillson, 2008; Rosan & Lamont 2000). However, as discussed below, differences were observed in dental calculus frequencies, suggesting other factors may have led to the development of dental calculus but not caries in the façade tomb samples versus the shaft chamber tombs, or vice versa.

## Dental Calculus

Unlike dental caries, differences in dental calculus were observed between the façade tombs and the shaft chamber tombs as well as the façade and hinterland tombs. Dental calculus development is affected by the consumption of dairy and meat products, as well as the level of water intake and the mineral salt concentration of the water. In addition, like dental caries, any abrasive process that would disturb or disrupt the film of dental plaque on the tooth also has the potential to remove pieces of dental calculus (Hillson, 1996, 2008; Rosan & Lamont, 2000). Therefore, the lower levels of dental calculus in the shaft chamber and hinterland populations could result from consuming less water in combination with less dairy and meat products than the façade tombs, or more abrasive foods. The city of Petra has well documented water management and storage systems, including aqueduct systems that tapped local springs, that directed water to most of the city's inhabitants (Al-Muheisen & Tarrier, 2002; Nehmé, 2003; Ortloff, 2005), although elites engaged in conspicuous practices of water consumption and display in the form of pool and garden complexes (Bedal, 2001; Wenning, 2007) and baths (Tholbecq et al., 2008). However, much of the water at Petra is highly saline and alkaline due to minerals from the surrounding rock dissolving into the water (Al-Khashman, 2007). Therefore, differences in calculus development may suggest that those buried in the different tomb types within Petra and in the hinterland tomb relied on different water sources, with the façade tomb families consuming more mineral-rich water than the shaft chamber tomb or hinterland lineages, or simply more water overall. Unlike variation in dairy and meat consumption levels or exposure to abrasives, which may manifest in different frequencies of dental caries between the tomb groups, choice of water source would not necessarily impact caries development, but would result in a difference seen in dental calculus.

## Antemortem Tooth Loss

While the façade and shaft chamber tombs showed no significant difference in antemortem tooth loss, both had significantly lower frequencies than the non-urban hinterland tomb. Antemortem tooth loss is the *in vivo* loss of a tooth as the result of disease, trauma, or cultural modification like tooth extraction (Hillson, 2008). The specific causes of AMTL vary from person to person, however AMTL is often associated with heavy attritional wear and carious lesions (Cucina & Tiesler, 2003; Hillson, 1996). Considering that the hinterland tombs exhibited the highest frequency of AMTL, it is possible that carious teeth may have been lost antemortem (Dias & Tayles, 1997; Lewis, Macfarlane, & McGowan, 1990) and thus the hinterland tomb caries frequency is artificially low. In general, the higher AMTL in the hinterland tomb suggests they had more dental pathologies that led to AMTL, such as dental caries or calculus, than the urban samples. However, cases of AMTL were not necessarily linked to dental abscesses in this sample, which also did not differ between the tomb types.

### Abscesses

The frequencies of periapical lesions, referred to as abscesses, did not differ across the samples. Abscess development is linked to the same bacteria associated with carious lesions (Lewis et al., 1990), and thus the homogeneity in abscesses and caries indicates that the different groups had similar levels of these oral bacteria. However, as discussed below, the frequency of abscesses may be artificially low due to the relatively large number of teeth (many of which were loose and unassociated with alveolar bone) as opposed to tooth sockets and associated alveolar bone that would show abscess development.

### Summary

The façade tombs at Petra were expected to have dental pathologies indicative of less childhood stress and different diet than the shaft chamber tombs and the hinterland tomb. The individuals interred within the façade tombs exhibited significantly higher frequencies of LEHs and dental calculus when compared to the purported non-elites found in the shaft chamber tombs on the North Ridge, with no differences in carious lesions, AMTL, and abscesses. Our data rejected Null Hypothesis 1, instead showing evidence for Alternate Hypothesis 1b, where the non-elite population showed a significantly lower frequency of LEHs than the elite population represented by the façade tombs. This supports Canipe's (2014) observation that the elite individuals from the Khubtha tombs exhibited a significantly higher frequency of LEHs. The prevalence of LEHs in the façade tombs could imply that the elite population consumed a poorer childhood diet or experienced a higher disease burden than the non-elite individuals. These observations are consistent with other analyses of LEHs in high status populations, where high socioeconomic status and dietary variation did not necessarily act as a buffer from environmental stressors (Cucina & İşcan, 1997). A comparison of childhood diet between tomb types using Provan's (2018) reconstruction would aid in our understanding of the cause(s) of LEHs, unfortunately no comparative isotopic data is available for the façade tombs. The lack of difference in carious lesions, AMTL and abscesses support Null Hypothesis 2 which suggests that either tomb architecture does not reflect socioeconomic status and/or that socioeconomic status may not have resulted in significant dietary differences within Petra. Considering the Nabataeans mastery of water management, some of which was allotted for agriculture (Ortloff, 2005), it is possible that Petra maintained a large and steady enough supply of carbohydrate rich agricultural goods that their distribution was not significantly stratified.

The non-urban hinterland tomb only differed from the urban groups in terms of AMTL. AMTL is often the result of carious lesions and the subsequent infection by cariogenic bacteria. Ramsay and Smith (2013) note that the remains of grapes, date palms, and figs have been found in the city of Petra and Petra's hinterland, and suggest that these fruits were grown locally. An increase in AMTL may imply agricultural production and consumption of carbohydrate-rich foods in the hinterland. However, as the hinterland tombs were family tombs, tomb A.10 may not be representative of all hinterland inhabitants (Wadeson & Abudanah, 2016). A number of possibilities explaining these patterns in dental pathologies have been presented, however the complexities of the oral microbiome compound with the poor preservation at the site of Petra make it impossible to come to a definitive singular cause without additional research reconstructing childhood and adult diet in addition to a more nuanced understanding of the social, political, and cultural implications of the façade tombs.

# CHAPTER 6: Conclusions

The social stratification implied by the differences in funerary architecture was expected to predict the frequencies of dental pathologies at Petra, with the façade tomb individuals exhibiting greater frequencies plaque-related dental pathologies associated with consumption of carbohydrate rich foods and shaft chamber tomb individuals exhibiting higher frequencies of linear enamel hypoplasias indicative of greater childhood stress. However, the data reveal a far more complicated picture of oral health, diet, and status at Petra. The lack of difference in dental caries, antemortem tooth loss, and abscesses suggests that socioeconomic status may not have resulted in dietary differences in the consumption of agricultural goods; in this case the mortuary architecture at Petra may not have been reflective of the socioeconomic status of the once living inhabitants, but instead was used to convey and legitimate power within Nabataean society (Wadeson, 2012b). Significant differences between the façade and shaft chamber tombs were found in dental calculus and LEH frequencies. The façade tombs also differed significantly from the hinterland tomb. The differences in dental calculus are attributable to differences in the consumption of dairy and meat, and level of water intake. Considering, both ez-Zantur (Studer, 2007) and the North Ridge site (Lowrey, 2014) faunal assemblages exhibit an abundance of protein sources, specifically goat and sheep, dietary differences in protein consumption may not sufficiently explain the difference in dental calculus frequencies. Alternatively, differences in water consumption, especially the mineral rich water of Petra (Al-Khashman, 2007), more adequately explains the differences seen in dental calculus: the façade tomb individuals may be sourcing their water from different locations with a higher mineral content than the members of the shaft chamber and hinterland tombs. The differences in LEHs between the façade and shaft chamber tomb could imply the elite population experienced a higher disease burden, poorer childhood diet, or differences in weaning stress. Although a thorough analysis has been done, the causes of these LEHs cannot be interpreted alone; they are better understood when considered in conjunction with isotopic reconstructions of childhood diet. Provan (2018) has provided this data for the shaft chamber tombs at Petra North Ridge, however comparative dietary reconstructions for the façade tombs have yet to be done.

The results from this study shed light on the complex interactions between social identities, economic power, dietary resources, and oral lesions at the site of Petra, Jordan during the 1st century B.C-A.D. and have shown that dental pathologies can be used to explore social identities and status in archaeological populations. Although several interpretations have been presented, additional data is necessary to clarify the causes of the differences seen in dental pathology frequencies.

The assumption that tomb architecture at Petra merely reflects the relative social and political importance of the deceased may be an oversimplification. Rather than merely reflecting social status, it is possible the façade tombs play an active role in both establishing the familial or political position of the dead and legitimating the status of the living. In contrast with the shaft chamber tombs, where the dead are intentionally commingled to reify bonds of kinship, the façade tombs may have been used to establish and enforce bonds other than or in addition to family ties. The deceased within the façade tombs tend to be interred in single burials and remained mostly articulated rather than intentionally commingled, this may suggest that the elites retained individual identities and importance after death (Perry, 2017). Rather than to establish kinship, the façade tombs may be used as a form of elite political resistance to express and reaffirm a Nabataean identity in the face of the impending Roman invasion (Anderson, 2002, 2005). As mentioned before, the addition of carved façades to older shaft tombs (Wadeson, 2012b) suggests the façade tombs may have been used as social or political platforms by the living to legitimize position and power within Nabataean society or justify one's social position in times of cultural turmoil (Pearson, 1982). Unlike the single burials of the façade tombs, the shaft chamber tombs at Petra North Ridge were purposely commingled to establish and reaffirm ancestral identities through specialized preparation, interment, feasting, and visitations to the deceased (Perry, 2017). Ultimately, the comparison of shaft chamber tombs to façade tombs may be unfair as they could serve fundamentally different social functions, with one emphasizing important sociopolitical connections or ideologies and the other celebrating the cohesiveness of a family lineage. A paleopathological analysis comparing individuals interred in multiple styles of façade tombs may be more informative of the meaning behind the carved façades and what they imply about social status and health at Petra. The potential differences in social function between the façade and shaft chamber tombs does not diminish the fact that the monumental façade tombs required more time, energy, expertise, and resources to construct than the shaft chamber tombs which indicates some form of inequality was present at Petra even if that inequality was not detrimental to the dental health of the individuals interred within the shaft chamber tombs. Unfortunately, disentangling the status implied by monumental tomb architecture from the lived status of the individuals interred is difficult without knowing the relationship of the individuals within the façade tombs.

In order to understand the meaning of the carved façade tombs and the social identities of those within, the relatedness of the individuals interred within these tombs needs to be established. Epigraphic evidence indicates familial relationships within the tombs (Healey, 2001; Huguenot et al., 2004; Nehmé 2003) but this does not necessarily tell us about the biological relatedness of the individuals interred. Not only is this important for establishing the façade tombs as familial tombs but also it is necessary for assessing issues of hidden heterogeneity within the sample. Biodistance studies would reveal the relatedness within the tombs and possibly provide a better explanation for differences in dental pathology frequencies due to familial dietary preferences or genetic predispositions (Hillson, 2008) than socioeconomic status or other factors. These can be done using non-metric skeletal and dental traits or dental metric analysis on the crown (Buikstra & Ubelaker, 1994) or cervical metrics on the tooth root (Hillson, Fitzgerald, & Flinn, 2005).

Reconstructions of childhood diet using stable isotope analysis can also contribute greatly to the understanding of oral health at Petra. As mentioned above Provan (2018) has already done the dietary reconstruction of childhood diet, however dietary reconstruction has not been done for those interred in façade tombs. Comparisons of childhood diet would not only contribute to our understanding of Nabataean weaning practices and childhood heath, but also hold implications for status and personhood at Petra.

Reassessment of the estimated ages of occurrence for LEHs using the method suggested by Ritzman and colleagues (2008) would likely improve our understanding of childhood stress at the site. The thin sectioning of the teeth would enable the observation of less severe hypoplasias that cannot be easily or reliably assessed with the naked eye. As such, this type of histological analysis of perturbations in dental enamel can provide a more sensitive reflection of stress in ancient childhood as well as a more accurate estimated age of occurrence. Considering that the method outlined by Ritzman and colleagues (2008) often results in older age of occurrence estimations it may show higher instances of childhood stress after the expected weaning period.

Comparative non-dental pathology data for the façade tombs and remainder of the shaft chamber tombs (B.6, B.7, and F.1) is necessary for understanding the effect of socioeconomic status on overall health. Interestingly, the tombs used in Canipe's (2014) study of health at Petra, tombs B.4 and B.5, exhibited significant differences in dental pathology frequencies from the other shaft chamber tombs as well as the façade tombs. Additional paleopathological analysis at the North Ridge may reveal familial differences in skeletal lesions between the shaft chamber tombs. Comparisons of the skeletal lesions in the façade tombs and shaft chamber tombs would be useful in assessing socioeconomic stratification.

Recent innovations in paleomicrobiology can help assess the ancient microbiome, microflora, and diet through the analysis of dental calculus which preserves the imprint of bacterial forms (Arsenburg, 1996; Linossier. Gajardo, & Olavarria, 1996), dietary microfossils (Dobney & Brothwell, 1986, 1988), water and airborne environmental pollutants (Warinner et al., 2014) and starch granules (Hardy et al., 2009). Additionally, the advent of high-throughput next generation sequencing (NGS) allowed for genetic analysis of oral bacteria (Adler et al., 2013; De La Fuente, Flores, & Moraga, 2012). Seeing as all tombs exhibited some level of dental calculus, the analysis of dietary microfossils may provide the necessary assessment of the botanicals consumed by the Nabataeans interred and elucidate possible consumption patterns related to socioeconomic status. Seeing as the microbes that make up human microbiota coevolved and are vertically transmitted within specific human groups, bacteria and bacterial evolution could be used as a marker of ancestry and migrations (Dominguez-Bello, Blaser, Ley, & Knight, 2011).

Despite the unclear implication of the carved façades, this study has found significant differences in the lived experiences of the purported elite and non-elite individuals at Petra.The analysis of LEHs indicates that the purported elite individuals at Petra experienced higher frequencies of childhood stress than non-elite population, which could be attributed to different childhood disease burdens, childhood diets, or different weaning stressors. Although the dental caries, AMTL, and abscess data indicated no difference in consumption of carbohydrate rich foods between the urban social classes, the elite population did exhibit significantly higher frequencies of dental calculus than the non-elite and non-urban populations, which could indicate social differences in the consumption of dairy and meat, or differences in water sourcing. The hinterland tomb exhibited significantly higher frequencies of AMTL, which suggests the non-urban population had more dental pathologies, such as dental caries or calculus, that lead to AMTL. Although the full implications of the façade tombs remain unknown, the data provide insight into the lived experiences of those interred within and indicate that the purported elite individuals experienced more stress during childhood as well as differences in diet and water sources compared to the non-elite population. The data from this study will ideally help bridge the gap in knowledge between the experienced status of the elite and non-elite populations during life and the status implied by their mortuary treatment after death, as well as provide a baseline for future studies concerning social stratification at Petra.

# Bibliography


Adler, C. J., Dobney, K., Weyrich, L. S., Kaidonis, J., Walker, A. W., Haak, W., … others. (2013). Sequencing ancient calcified dental plaque shows changes in oral microbiota with dietary shifts of the neolithic and industrial revolutions. *Nature Genetics*, *45*(4), 450.

Al-Farajat, M., & Salameh, E. (2010). Vulnerability of the drinking water resources of the nabataeans of petra–jordan. *Jordan Journal of Civil Engineering*, *4*.

Al-Khashman, O. A. (2007). Study of water quality of springs in petra region, jordan: A three-year follow-up. *Water Resources Management*, *21*(7), 1145–1163.

Al-Muheisen, Z. (2007). Water engineering and irrigation system of the nabateans: A regional vision. *The Annual of the Department of Antiquities of Jordan*, *51*, 471–486.

Al-Muheisen, Z., & Tarrier, D. (2002). Water in the nabatean period. *ARAM Periodical*, *14*, 515–524.

Alvarez, J. O. (1995). Nutrition, tooth development, and dental caries. *The American Journal of Clinical Nutrition*, *61*(2), 410S–416S.

Anderson, B. (2002). Imperial legacies, local identities: References to achaemenid persian iconography on crenelated nabataean tombs. *Ars Orientalis*, 163–207.

Anderson, B. P. (2005). *Constructing nabataea: Identity, ideology, and connectivity.* (PhD thesis). University of Michigan.

Appleton, L. (2015). *Dietary reconstruction of urban inhabitants of the 1St century ad petra* (Master's thesis). East Carolina University.

Arensburg, B. (1996). Ancient dental calculus and diet. *Human Evolution*, *11*(2), 139–145.

Armelagos, G. J., & Cohen, M. N. (1984). *Paleopathology at the origins of agriculture*. Academic Press Orlando (FL).

Baines, J., & Yoffee, N. (2000). Order, legitimacy and wealth: Setting the terms. *Order, Legitimacy and Wealth in Ancient States*, 13–17.

Bedal, L.-A. (2001). A pool complex in petra's city center. *Bulletin of the American Schools of Oriental Research*, 23–41.

Bedal, L.-A., & Schryver, J. G. (2007). Nabataean landscape and power. *Crossing Jordan: North American Contributions to the Archaeology of Jordan*, 375.

Bikai, P. M., & Perry, M. A. (2001). Petra north ridge tombs 1 and 2: Preliminary report. *Bulletin of the American Schools of Oriental Research*, 59–78.

Binford, L. R. (1971). Mortuary practices: Their study and their potential. *Memoirs of the Society for American Archaeology*, 6–29.

Blakey, M. L., Leslie, T. E., & Reidy, J. P. (1994). Frequency and chronological distribution of dental enamel hypoplasia in enslaved african americans: A test of the weaning hypothesis. *American Journal of Physical Anthropology*, *95*(4), 371–383.

Bouchaud, C., Sachet, I., Dal Prà, P., Delhopital, N., Douaud, R., & Leguilloux, M. (2015). New discoveries in a nabataean tomb. Burial practices and 'plant jewellery'in ancient hegra (madâ'in sâlih, saudi arabia). *Arabian Archaeology and Epigraphy*, *26*(1), 28–42.

Brünnow, R.-E., Domaszewski, A. von, Euting, J., & Kunze, M. F. (1904). *Die provincia arabia auf grund zweier in den jahren 1897 und 1898 unterommenen reisen und der berichte früherer reisender beschrieben von rudolf ernst brünnow und alfred v. Domaszewski: Bd. Die römerstrasse von mâdebâ über petra und oddruh bis el-'akaba, unter mitwirkung von julius euting. 1904* (Vol. 1). KJ Trübner.

Buikstra, J. E., & Ubelaker, D. H. (1994). Standards for data collection from human skeletal remains. *Arkansas Archaeological Survey Research Series*, *44*.

Canipe, C. (2014). *Exploring quality of life at petra through paleopathology* (Master's thesis). East Carolina University.

Clancy, K. A., Pearson, S., Bowen, W. H., & Burne, R. A. (2000). Characterization of recombinant, ureolytic streptococcus mutans demonstrates an inverse relationship between dental plaque ureolytic capacity and cariogenicity. *Infection and Immunity*, *68*(5), 2621–2629.

Cucina, A., & İşcan, M. Y. (1997). Assessment of enamel hypoplasia in a high status burial site. *American Journal of Human Biology: The Official Journal of the Human Biology Association*, *9*(2), 213–222.

Cucina, A., & Teisler, V. (2003). Antemortem tooth loss in the northern peten area, mexico: A biocultural perspective on social status differences among the classic maya. *American Journal of Physical Anthropology*, *122*(1), 1–10.

Dalby, A. (1996). *Siren feasts: A history of food and gastronomy in greece*. Routledge.

De La Fuente, C., Flores, S., & Moraga, M. (2013). DNA from human ancient bacteria: A novel source of genetic evidence from archaeological dental calculus. *Archaeometry*, *55*(4), 767–778.

Dias, G., & Tayles, N. (1997). "Abscess cavity"—a misnomer. *International Journal of Osteoarchaeology*, *7*(5), 548–554.

Dobney, K., & Brothwell, D. (1986). Dental calculus: Its relevance to ancient diet and oral ecology. *Teeth and Anthropology*, *291*, 55–81.

Dobney, K., & Brothwell, D. (1988). A scanning electron microscope study of archaeological dental calculus. In *Scanning electron microscopy in archaeology* (pp. 372–385). British Archaeological Reports.

Dominguez-Bello, M. G., Blaser, M. J., Ley, R. E., & Knight, R. (2011). Development of the human gastrointestinal microbiota and insights from high-throughput sequencing. *Gastroenterology*, *140*(6), 1713–1719.

Dupras, T. L., Schwarcz, H. P., & Fairgrieve, S. I. (2001). Infant feeding and weaning practices in roman egypt. *American Journal of Physical Anthropology*, *115*(3), 204–212.

Duyar, I., & Erdal, Y. S. (2003). A new approach for calibrating dental caries frequency of skeletal remains. *HOMO-Journal of Comparative Human Biology*, *54*(1), 57–70.

Erdal, Y. S., & Duyar, I. (1999). A new correction procedure for calibrating dental caries frequency. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, *108*(2), 237–240.

Flannery, K. V. (1972). The cultural evolution of civilizations. *Annual Review of Ecology and Systematics*, *3*(1), 399–426.

Garnier, N., Sachet, I., Zymla, A., Tokarski, C., & Rolando, C. (2010). Biomolecular archaeology and analysis of artefacts found in nabataean tombs in petra. *Death and Burial in Arabia and Beyond. Multidisciplinary Perspective. Society for Arabian Studies Monographs*, *10*, 263–274.

Garnsey, P. (1999). *Food and society in classical antiquity*. Cambridge University Press.

Goodman, A. H. (1993). On the interpretation of health from skeletal remains. *Current Anthropology*, *34*, 281–288.

Goodman, A. H., Allen, L. H., Hernandez, G. P., Amador, A., Arriola, L. V., Chavez, A., & Pelto, G. H. (1987). Prevalence and age at development of enamel hypoplasias in mexican children. *American Journal of Physical Anthropology*, *72*(1), 7–19.

Goodman, A. H., & Armelagos, G. J. (1985). Factors affecting the distribution of enamel hypoplasias within the human permanent dentition. *American Journal of Physical Anthropology*, *68*(4), 479–493.

Goodman, A. H., & Armelagos, G. J. (1988). Childhood stress and decreased longevity in a prehistoric population. *American Anthropologist*, *90*(4), 936–944.

Goodman, A. H., & Armelagos, G. J. (1989). Infant and childhood morbidity and mortality risks in archaeological populations. *World Archaeology*, *21*(2), 225–243.

Goodman, A. H., Armelagos, G. J., & Rose, J. C. (1980). Enamel hypoplasias as indicators of stress in three prehistoric populations from illinois. *Human Biology*, 515–528.

Goodman, A. H., & Rose, J. C. (1990). Assessment of systemic physiological perturbations from dental enamel hypoplasias and associated histological structures. *American Journal of Physical Anthropology*, *33*(S11), 59–110.

Goodman, A. H., & Rose, J. C. (1991). Dental enamel hypoplasias as indicators of nutritional status. *Advances in Dental Anthropology*, *5*, 225–240.

Hardy, K., Blakeney, T., Copeland, L., Kirkham, J., Wrangham, R., & Collins, M. (2009). Starch granules, dental calculus and new perspectives on ancient diet. *Journal of Archaeological Science*, *36*(2), 248–255.

Healey, J. F. (2001). *The religion of the nabataeans: A conspectus* (Vol. 136). Brill.

Hillson, S. (1996). *Dental anthropology*. Cambridge University Press.

Hillson, S. (2001). Recording dental caries in archeological human remains. *International Journal of Osteoarcheology*, *11*(4), 249–289.

Hillson, S. (2008). Dental pathology. In M. A. Katzenburg & S. R. Saunders (Eds.), *Biological anthropology of the human skeleton* (Second, pp. 301–340). John Wiley; Sons.

Hillson, S., & Bond, S. (1997). Relationship of enamel hypoplasia to the pattern of tooth crown growth: A discussion. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, *104*(1), 89–103.

Hillson, S., Fitzgerald, C., & Flinn, H. (2005). Alternative dental measurements: Proposals and replationships with other measurements. *American Journal of Physical Anthroplogy*, *126*(4), 413–426.

Hodder, I. (1989). Writing archaeology: Site reports in context. *Antiquity*, *63*(239), 268–274.

Hughuenot, C. N., Bdool, M., & Schmid, S. (2004). Cleaning and excavation of the renaissance tomb at petra. *Annual of the Department of Antiquities of Jordan*, *48*, 203–210.

Irei, K., Doi, N., Fukumine, T., Nishime, A., Hanihara, T., Yoneda, M., & Ishida, H. (2008). Dental diseases of human skeletal remains from the early-modern period of kumejima island, okinawa, japan. *Anthropological Science*, *116*(2), 149–159.

Jacquat, C., & Martinoli, D. (1999). Vitis vinifera l.: wild or cultivated? Study of the grape pips found at petra, jordan; 150 bc–ad 40. *Vegetation History and Archaeobotany*, *8*(1-2), 25–30.

Johnson, D. J. (1987). *Nabataean trade: Intensification and culture change* (PhD thesis). University of Utah.

Karg, S. (1996). Pflanzenreste aus den nabäischen und spätrömischen schichten. In petra ez zantur i. Ergebnisse der schweiserisch-liechtensteinischen ausgrabungen 1998-1992. *Copenhagan-Terra Archaeologoca*, *2*, 355–357.

Keenleyside, A. (2008). Dental pathology and diet at apollonia, a greek colony on the black sea. *International Journal of Osteoarchaeology*, *18*(3), 262–279.

Kuramitsu, H. K., He, X., Lux, R., Anderson, M. H., & Shi, W. (2007). Interspecies interactions within oral microbial communities. *Microbiology and Molecular Biology Reviews*, *71*(4), 653–670.

Larsen, C. S. (1997). *Bioarchaeology interpreting behavior from the human skeleton*. Cambridge University Press.

Lewis, M. A. O., Macfarlane, T. W., & McGowan, D. A. (1990). A microbiological and clinical review of the aute dentoalveolar abscess. *British Journal of Oral and Maxillofacial Surggery*, *28*(6), 359–366.

Lieverse, A. R. (1999). Diet and aetiology of dental calculus. *International Journal of Osteoarcheology*, *9*(4), 219–232.

Linossier, A., Gajardo, M., & Olavarria, J. (1996). Paleomicrobiological study in dental calculus: Streptococcus mutans. *Scanning Microscopy*, *10*(4), 1005–1013.

Lowrey, D. (2014). *Faunal summary report*.

Lukacs, J. (1995). Caries correction factor: A new method of calibrating dental caries rates to compensate for antemortem loss of teeth. *International Journal of Osteoarchaeology*, *5*, 151–156.

Lukacs, J. (2012). Oral health in past populations: Context, concepts and controversies. In A. L. Grauer (Ed.), *A companion to paleopathology* (pp. 553–581).

Malde, M. K., Maage, A., Macha, E., Julshamn, K., & Bjorvatn, K. (1997). Fluoride content in selected food items from five areas in east africa. *Journal of Food Composition and Analysis*, *10*(3), 233–245.

Mandel, I. D. (1974). Relation of saliva and plaque to caries. *Journal of Dental Research*, *53*(2), 246–266.

Marsh, P. D. (2010). Microbiology of dental plaque biofilms and their role in oral health and caries. *Dental Clinics*, *54*(3), 441–454.

Masterson, E. E., Fitzpatrick, A. L., Equobahrie, D. A., Mancl, E., L A adn Conde, & Hujoel, D. A. (2017). Malnutrition-related early childhood exposures and enamel defects in the permanent dentition: A longitudinal study from the bolivian amazon. *American Journal of Physical Anthropology*, *164*(2), 416–423.

Moggi-Cecchi, J., Pacciani, E., & Pinto-Cisternas, J. (1994). Enamel hypoplasia and age at weaning in 19th-century florence, italy. *American Journal of Physical Anthropology*, *93*(3), 299–306.

Nehme, L. (2003). The petra survey project. In C. Markoe (Ed.), *Petra rediscovered* (pp. 145–163).

Newton, J. T., & Bower, E. J. (2005). The social determinants of oral health: New approaches to conceptualizing and researching complex causal networks. *Community Dentistry and Oral Epidemiology*, *33*(1), 25–34.

Ortloff, C. R. (2005). The water supply and distribution system of the nabataean city of petra (jordan), 300 bc–ad 300. *Cambridge Archaeological Journal*, *15*(1), 93–109.

Parker, S. T. (2016). The petra north ridge project: Domestic structures and the cuty wall. *Studies in the History and Archeology of Jordan XII*, 587–595.

Parker, S. T., & Perry, M. A. (2013). Petra north ridge project: The 2012 season. *Annual of the Department of Antiquities of Jordan*.

Parker, S. T., & Perry, M. A. (2018). *Petra north ridge project: The 2014 season*.

Pearson, M. P. (1982). Mortuary practices, society and ideology: Anethnoarchaeological study. *Symbolic and Structural Archaeology*, *1*, 99–113.

Perry, M. A. (2016). A new light on nabataean mortuary rituals in petra. *Studies in the History and Archaeology of Jordan*, *12*, 385–398.

Perry, M. A. (2017). Sensing the dead: Mortuary ritual and tomb visitation at nabataean petra. *Syria. Archéologie, Art et Histoire*, *94*, 99–106.

Provan, M. E. (2018). *Stable isotope analysis of childhood diet at 1st century b.c./A.D. Petra, jordan* (Master's thesis). East Carolina University.

Prowse, T. L., Saunders, S. R., Schwarcz, H. P., Garnsey, P., Macchiarelli, R., & Bondioli, L. (2008). Isotopic and dental evidence for infant and young child feeding practices in an imperial roman skeletal sample. *American Journal of Physical Anthropology*, *137*(3), 294–308.

Ramsay, J., & Bedal, L. A. (2015). Garden variety seeds? Botanical remains from the petra garden and pool complex. *Vegetation History and Archaeobotany*, *24*(5), 621–634.

Ramsay, J., & Smith II, A. M. (2013). Desert agriculture at bir madhkur: The first archaeobotanical evidence to support the timing and scale of agriculture during the late roman/byzantine period in the hinterland of petra. *Journal of Arid Environments*, *99*, 51–63.

Ritzman, T. B., Baker, B. J., & Schwartz, G. T. (2008). A fine line: A comparison of methods for estimating ages of linear enamel hypoplasia formation. *American Journal of Physical Anthropology*, *135*(3), 348–361.

Roberts, C. A., & Manchester, K. (2005). *The archaeology of disease*. Cornell University Press.

Rosan, B., & Lamont, R. J. (2000). Dental plaque formation. *Microbes and Infection*, *2*(13), 1599–1607.

Russell, S. L., Gordon, S., Lukacs, J. R., & Kaste, L. M. (2013). Sex/gender differences in tooth loss and edentulism: Historical perspectives, biological factors and sociologic reasons. *Dental Clinics*, *57*(2), 317–337.

Sachet, I. (2010). Feasting with the dead: Funerary marzeah in petra. *Multidisciplinary Perspective. Society for Arabian Studies Monographs*, *10*, 249–262.

Schmid, S., Amour, A., Barmasse, A., Duchesne, S., Huguenot, C., & Wadeson, L. (2008). New insights into nabataean funerary practices. *Proceedings of the 5th International Congress of the Ancient Near East*, 135–160.

Schmid, S. G. (2002). From aretas to the annexation: Petra nd the nabataeans. In J. Frösen & Z. Fiema (Eds.), *Petra a city forgotten and rediscovered* (pp. 44–59). The Amos Anderson Art Museum.

Schmid, S. G. (2007). The international wadi farasa project (iwfp) preliminary report on the 2006 season. *Annual of the Department of Antiquities of Jordan*, *51*, 141–150.

Schmid, S. G. (2010). The international wadi farasa project (iwfp) preliminary report on the 2009 season. *Annual of the Department of Antiquities of Jordan*, *54*, 221–235.

Schmid, S. G., & Barmasse, A. (2004). The international wadi farasa project (iwfp) preliminary report on the 2003 season. *Annual of the Department of Antiquities of Jordan*, *48*, 333–346.

Schmid, S. G., & Barmasse, A. (2006). The international wadi farasa project (iwfp) preliminary report on the 2005 season. *Annual of the Department of Antiquities of Jordan*, *50*, 520–528.

Schmid, S. G., Bienkowski, P., Fiema, Z. T., & Kolb, B. (2012). The palaces of the nabataean kings at petra. *Proceedings of the Seminar for Arabian Studies*, *42*, 73–98.

Sears, W. H. (1982). *Fort center: An archaeological stie in the lake okeechobee basin*. University Presses of Florida.

Selwitz, R. H., Ismail, A. I., & Pitts, N. B. (2007). Dental caries. *The Lancet*, *369*(9555), 51–59.

Shanks, M., & Tilley, C. (1982). Ideology, symbolic power and ritual communication: A reinterpretation of neolithic mortuary practices. *Symbolic and Structural Archaeology*, *1*, 129–154.

Siebert, G., & Trautner, K. (1985). Fluoride content of selected human food, pet food and related materials. *Zeitschrift Für Ernährungswissenschaft*, *24*(1), 54–66.

Sofaer, J. R. (2006). *The body as material culture: A theoretical osteoarchaeology* (Vol. 4). Cambridge University Press.

Starling, A. P., & Stock, J. T. (2007). Dental indicators of health and stress in early egyptian and nubian agriculturalists: A difficult transition and gradual recovery. *American Journal of Physical Anthropology*, *134*(4), 520–528.

Stucky, R. A., Kolb, B., Schmid, S. G., Gerber, Y., Bellwald, U., & Jacquat, C. (1995). Swiss-liechtenstein excavations at az-zantur in petra 1994: The sixth campaign. *Annual of the Department of Antiquities in Jordan*, *39*(1), 297–315.

Studer, J. (2002). Dietary differences at ez zantur petra, jordan (1st century bc-ad 5th century). In H. Buitenhuis, A. M. Choyke, M. Mashkour, & A. H. Al-Shiyab (Eds.), *Archaeozoology of the near east v* (pp. 273–281). Archaeological Research; Consultancy.

Studer, J. (2007). Animal exploitation in the nabataean world. In K. D. Politis (Ed.), *In the world of the nabataeans* (pp. 252–272).

Tainter, J. A. (1975). Social inference and mortuary practices: An experiment in numerical classification. *World Archaeology*, *7*(1), 1–15.

Tainter, J. A. (1978). Mortuary practices and the study of prehistoric social systems. In *Advances in archaeological method and theory, volume 1* (pp. 105–141). Elsevier.

Temple, D. H., Nakatsukasa, M., & McGroarty, J. N. (2012). Reconstructing patterns of systemic stress in a jomon period subadult using incremental microstuctures of enamel. *Journal of Archaeological Science*, *39*(5), 1634–1641.

Tholbecq, L., Durand, C., & Bouchaud, C. (2008). A nabataean rock-cut sanctuary in petra: Second preliminary report on the "obodas chapel" excavation project, jabal numayr (2005-2007). *Annual of the Department of Antiquities of Jordan*, *52*, 235–254.

Wadeson, L. (2012a). Excavations at petra: The international al-khubtha tombs project (iktp). *Palestine Exploration Quarterly*, *144*, 208–218.

Wadeson, L. (2012b). The funerary landscape of petra: Results from a new study. *Supplement to Proceedngs of the Seminar for Arabian Studies*, *42*, 99–126.

Wadeson, L. (2013). Nabataean façade tombs: A new chronology. *Studies in the History and Archaeology of Jordan*, *11*, 507–528.

Wadeson, L. (2014). Excavations at petra: The international al-khubtha tombs project (iktp) 2013. *Palestine Exploration Quarterly*, *146*, 1–7.

Wadeson, L., & Abudanah, F. (2016). Newly discovered tombs in the hinterland of petra. *Studies in the History and Archaeology of Jordan*, *12*, 83–100.

Warinner, C., Rodrigues, J. F. M., Vyas, R., Trachsel, C., Shved, N., Grossmann, J., … others. (2014). Pathogens and host immunity in the ancient human oral cavity. *Nature Genetics*, *46*(4), 336.

Wenning, R. (2007). The nabataeans in history. In K. D. Politis (Ed.), *The world of the nabataeans. Volume 2 of the internation conference the world of the herods and the nabataeans held at the british museum 17-19 april 2001* (pp. 25–44). Franz Steiner Verlag.

White, D. J. (1997). Dental calculus: Recent insights into occurrence, formation, prevention, removal and oral health effects of supragingival and subgingival deposits. *European Journal of Oral Science*, *105*(5), 508–522.

Wood, J. W., Milner, G. R., harpending, H. C., Weiss, K. M., N, C. M., Eisenberg, L. E., … Katzenberg, M. A. (1992). The osteological paradox: Problems of inferring prehistoric health from skeletal samples [and comments and reply]. *Current Anthropology*, *33*(4), 343–370.

# Appendix A: Adult Tooth Counts by Tomb

Table 23 Adult Tooth Counts by Tomb

| Tooth Type | Renaissance Tomb (TR) | 779 | 781 | B.4 | B.5 | B.6 | B.7 | F.1 | Hinterland Tomb (A.10) |
|---|---|---|---|---|---|---|---|---|---|
| Maxillary | | | | | | | | | |
| I1 | 5 | 2 | 9 | 0 | 8 | 7 | 3 | 10 | 6 |
| I2 | 2 | 2 | 6 | 0 | 10 | 8 | 2 | 7 | 8 |
| C | 3 | 2 | 13 | 2 | 4 | 15 | 5 | 7 | 13 |
| P1 | 4 | 2 | 9 | 1 | 10 | 9 | 9 | 11 | 7 |
| P2 | 2 | 2 | 12 | 3 | 14 | 10 | 7 | 12 | 13 |
| M1 | 6 | 2 | 8 | 1 | 24 | 12 | 8 | 14 | 12 |
| M2 | 5 | 2 | 6 | 4 | 20 | 17 | 4 | 15 | 10 |
| M3 | 2 | 2 | 10 | 3 | 8 | 11 | 2 | 11 | 6 |
| Mandibular | | | | | | | | | |
| I1 | 5 | 2 | 7 | 0 | 5 | 5 | 6 | 2 | 8 |
| I2 | 2 | 1 | 8 | 1 | 14 | 2 | 7 | 5 | 10 |
| C | 3 | 2 | 14 | 2 | 22 | 5 | 4 | 3 | 9 |
| P1 | 4 | 2 | 11 | 2 | 18 | 6 | 9 | 7 | 10 |
| P2 | 5 | 2 | 9 | 5 | 22 | 6 | 2 | 10 | 5 |
| M1 | 3 | 1 | 11 | 2 | 35 | 18 | 9 | 17 | 12 |
| M2 | 3 | 1 | 13 | 8 | 27 | 20 | 11 | 11 | 10 |
| M3 | 1 | 1 | 8 | 5 | 16 | 6 | 4 | 9 | 6 |
| Total | 52 | 28 | 154 | 39 | 257 | 157 | 92 | 151 | 132 |

# Appendix B. Maxillae and Mandibles with Associated Teeth

Table 24 List of Maxillae and Mandibles with Associated Teeth

| Accession Number | Tooth | Presence Score |
|---|---|---|
| 781:248.a | RC1 | 2 |
| | LP2 | 2 |
| | RM2 | 2 |
| | LP2 | 2 |
| | RP1 | 2 |
| | RP1 | 2 |
| | LM2 | 2 |
| | RM1 | 2 |
| | LC1 | 2 |
| 781:248.b | RC1 | 2 |
| | RI1 | 2 |
| | RP2 | 2 |
| | LI1 | 2 |
| | RI2 | 2 |
| | LC1 | 2 |
| | LC1 | 2 |
| 781:254 | LM1 | 2 |
| | RM3 | 2 |
| | RC1 | 2 |
| | LI1 | 2 |
| | RI1 | 2 |
| | LP1 | 2 |
| | RM2 | 2 |
| | LP1 | 2 |
| | RP2 | 2 |
| | LM3 | 2 |
| | LM2 | 2 |
| | LI1 | 2 |
| | RP2 | 2 |
| | LI2 | 2 |
| | RI2 | 2 |
| | LM1 | 7 |
| | RM3 | 2 |
| | LP2 | 2 |
| | RM1 | 2 |
| | RI1 | 2 |
| | LM3 | 2 |
| | LI2 | 2 |
| | RM1 | 2 |

| | | |
|---|---|---|
| | LC1 | 2 |
| | RC1 | 2 |
| | LM2 | 7 |
| 781:263.a | RP2 | 2 |
| | RC1 | 7 |
| | LI2 | 7 |
| | RM1 | 2 |
| | LM1 | 2 |
| | LP2 | 7 |
| | RM1 | 2 |
| | RP1 | 2 |
| | LC1 | 7 |
| | LM3 | 2 |
| | RI2 | 7 |
| | LI1 | 7 |
| | RP2 | 2 |
| | LP2 | 2 |
| | LP1 | 7 |
| 781:279 | RP2 | 2 |
| | RI2 | 2 |
| | RP2 | 2 |
| | LP1 | 2 |
| | LM2 | 2 |
| | LM3 | 2 |
| | RM1 | 2 |
| | LI1 | 2 |
| | RC1 | 2 |
| | RM2 | 2 |
| | LM1 | 2 |
| | RP1 | 2 |
| | RI1 | 2 |
| | RM2 | 2 |
| | LI2 | 2 |
| | RP1 | 2 |
| | LM1 | 2 |
| | LM2 | 2 |
| 781:282 | LM3 | 2 |
| | LC1 | 2 |
| | RM3 | 2 |
| | LM1 | 2 |
| | RM1 | 2 |
| | LP1 | 2 |
| | LM2 | 2 |
| | RM2 | 2 |

| | | |
|---|---|---|
| | LP2 | 2 |
| 781:286 | RM1 | 2 |
| | RM2 | 2 |
| | RM3 | 2 |
| 781:288.a | RI2 | 2 |
| | LP2 | 2 |
| | LC1 | 2 |
| | RP2 | 2 |
| | RC1 | 2 |
| | LM3 | 2 |
| | LC1 | 2 |
| | RC1 | 2 |
| | LM1 | 2 |
| | LP1 | 2 |
| | RM3 | 2 |
| | RM2 | 2 |
| | RI1 | 2 |
| | LP1 | 2 |
| | LI1 | 2 |
| | RP1 | 2 |
| | LM2 | 2 |
| | LP2 | 2 |
| | LI1 | 2 |
| 781:288.b | RM1 | 2 |
| | RM3 | 8 |
| | RM3 | 8 |
| 781:288.c | LC1 | 2 |
| | RI2 | 2 |
| | RM3 | 1 |
| | LP2 | 7 |
| | RC1 | 2 |
| | LI2 | 2 |
| | RI1 | 2 |
| | RP1 | 2 |
| 781:288.d | LI1 | 2 |
| | RP2 | 2 |
| | LP1 | 2 |
| | LC1 | 2 |
| | RC1 | 2 |
| | LI2 | 2 |
| | RI1 | 2 |
| | RC1 | 2 |
| | RP1 | 2 |
| | LC1 | 2 |

| | | |
|---|---|---|
| | RI2 | 2 |
| 781:304b | RM3 | 2 |
| C.781:73 | LM3 | 2 |
| | LM1 | 2 |
| | RI2 | 2 |
| | LM2 | 2 |
| | RP1 | 2 |
| C.781:75 | LM1 | 2 |
| | RC1 | 2 |
| | LP1 | 2 |
| | LM2 | 2 |
| | RM2 | 2 |
| | LP2 | 2 |
| | LM3 | 2 |
| | LC1 | 2 |
| | RM3 | 2 |
| D.779:229 | LI1 | 2 |
| | RI1 | 2 |
| | LI1 | 2 |
| | RP2 | 2 |
| | LP1 | 2 |
| | RP1 | 2 |
| | LP1 | 2 |
| | RM3 | 2 |
| | LM2 | 2 |
| | RM2 | 2 |
| | RC1 | 2 |
| | LI2 | 2 |
| | RI2 | 2 |
| | LI2 | 2 |
| | RM1 | 2 |
| | LP2 | 2 |
| | RP2 | 2 |
| | LP2 | 2 |
| | LM3 | 2 |
| | RM3 | 2 |
| | RP1 | 2 |
| | LC1 | 2 |
| | RC1 | 2 |
| | LC1 | 2 |
| | RM2 | 2 |
| | LM1 | 2 |
| | RM1 | 2 |
| A.10:53 | LI1 | 8 |

| | | |
|---|---|---|
| | RI2 | 8 |
| | LP1 | 8 |
| | RP2 | 8 |
| | LM3 | 8 |
| | LM2 | 1 |
| | LI2 | 8 |
| | RC1 | 8 |
| | LP2 | 8 |
| | RM2 | 1 |
| | RI1 | 8 |
| | LC1 | 8 |
| | RP1 | 1 |
| | LM2 | 1 |
| | RM3 | 8 |
| A.10:55.a | RI2 | 7 |
| | LM2 | 2 |
| | RC1 | 1 |
| | RC1 | 2 |
| | LM1 | 2 |
| | RP2 | 7 |
| A.10:55.b | LP1 | 2 |
| | LC1 | 1 |
| A.10:57 | LP1 | 2 |
| | RM2 | 2 |
| | RP2 | 1 |
| | RC1 | 2 |
| | LC1 | 2 |
| | LC1 | 2 |
| | RM1 | 2 |
| | RP2 | 2 |
| | LP1 | 2 |
| A.10:59.a | LM1 | 1 |
| | LP2 | 2 |
| | RM2 | 2 |
| | RP1 | 2 |
| | RI1 | 2 |
| | RI1 | 2 |
| | RM1 | 1 |
| | RI2 | 2 |
| | RI2 | 2 |
| A.10:6.a | LP1 | 2 |
| | LM2 | 2 |
| | LI2 | 2 |
| | RM2 | 2 |

| | | |
|---|---|---|
| | LP2 | 2 |
| | RM1 | 2 |
| | LC1 | 2 |
| | LM1 | 2 |
| | RM1 | 2 |
| A.10:6.b | LM2 | 1 |
| | LC1 | 2 |
| | RP2 | 2 |
| | RI2 | 2 |
| | LI1 | 2 |
| | RP2 | 1 |
| | LM3 | 2 |
| | LP1 | 2 |
| | RM1 | 2 |
| | RC1 | 7 |
| | LP2 | 2 |
| | LI2 | 2 |
| | RC1 | 2 |
| | RI1 | 2 |
| | RM2 | 1 |
| | RP1 | 2 |
| A.10:60.a | RM1 | 2 |
| | LC1 | 7 |
| | RM2 | 2 |
| | LM1 | 7 |
| A.10:60.b | LI1 | 7 |
| | LC1 | 7 |
| | RP1 | 2 |
| | RI2 | 2 |
| | LI1 | 7 |
| | RP2 | 2 |
| | LC1 | 7 |
| | LP1 | 2 |
| | RP2 | 2 |
| | RC1 | 2 |
| | LI2 | 2 |
| | RC1 | 2 |
| | RI1 | 7 |
| | RM1 | 2 |
| | RP1 | 1 |
| A.10:7 | LM3 | 2 |
| | RC1 | 2 |
| | RP2 | 2 |
| | RP1 | 2 |

| | | |
|---|---|---|
| | LP2 | 2 |
| | RI2 | 2 |
| A.10.58 | RI1 | 2 |
| | RI2 | 7 |
| | RC1 | 2 |
| B.10:11 | LM3 | 2 |
| | LM3 | 1 |
| | RM2 | 7 |
| | RM3 | 2 |
| | RI1 | 2 |
| | RM1 | 2 |
| | LM2 | 1 |
| | LM1 | 7 |
| | RM1 | 1 |
| | RM2 | 1 |
| B.10:41 | RP1 | 2 |
| | RM2 | 1 |
| | LM1 | 1 |
| | RP2 | 2 |
| | LI1 | 2 |
| | LM3 | 2 |
| | RC1 | 7 |
| | RM1 | 1 |
| | LI2 | 2 |
| B.4:10.b | LP2 | 2 |
| B.4:10.c | LM2 | 7 |
| | LM3 | 7 |
| B.4:10.d | RM3 | 2 |
| B.4:10.e | LM2 | 7 |
| | LM3 | 7 |
| B.4:10.f | LP2 | 7 |
| B.4:10.h | RM3 | 2 |
| | RP1 | 7 |
| | RM2 | 7 |
| B.4:10.i | RM2 | 7 |
| | RP2 | 7 |
| B.4:16.e | LP2 | 7 |
| | RP1 | 7 |
| | RP2 | 7 |
| B.4:16.f | RM2 | 7 |
| | RM3 | 7 |
| B.4:23.b | LM3 | 2 |
| | LM1 | 2 |
| B.4:23.c | LM2 | 2 |

| | | |
|---|---|---|
| | LP2 | 2 |
| B.4:23.d | LM1 | 2 |
| | LM2 | 7 |
| B.4:23.e | RM3 | 7 |
| | RM2 | 7 |
| B.4:23.f | LP2 | 7 |
| | LM2 | 2 |
| B.5:15.c | LI1 | 7 |
| | RC1 | 7 |
| | RI1 | 7 |
| | RP2 | 7 |
| | RI2 | 7 |
| | RM1 | 7 |
| B.5:15.e | LC1 | 7 |
| | LM1 | 7 |
| | LI1 | 7 |
| | LP1 | 7 |
| | RM3 | 7 |
| | LI2 | 7 |
| | LP2 | 7 |
| B.5:15.f | LP2 | 7 |
| | LM3 | 7 |
| | LC1 | 7 |
| | LM1 | 7 |
| | RI2 | 7 |
| | LP1 | 7 |
| | LM2 | 7 |
| | LI2 | 7 |
| B.5:15.g | RM3 | 7 |
| | RM1 | 7 |
| | RM2 | 7 |
| | RP2 | 7 |
| B.5:15.o | RP2 | 7 |
| | RM1 | 7 |
| B.5:15.q | RP2 | 7 |
| | RM3 | 7 |
| B.5:17.b | LM1 | 7 |
| | RC1 | 7 |
| B.5:31.e | RC1 | 7 |
| | RM3 | 7 |
| | RI1 | 7 |
| | RP1 | 7 |
| | RI2 | 7 |
| | RM2 | 7 |

| | | |
|---|---|---|
| | LM2 | 7 |
| | LM1 | 7 |
| B.5:34.43.d | LP1 | 7 |
| | LP2 | 7 |
| | LC1 | 7 |
| B.5:34.47.a | RP1 | 2 |
| | RC1 | 2 |
| B.5:34.53.c | LP2 | 7 |
| | LM3 | 7 |
| | LM1 | 7 |
| | LM2 | 7 |
| B.5:34.53.d | RP1 | 2 |
| | RM2 | 2 |
| | RP2 | 2 |
| | RM3 | 2 |
| | RC1 | 7 |
| | RM1 | 7 |
| B.5:34.c | RI1 | 7 |
| | RI2 | 7 |
| | LM1 | 2 |
| | RC1 | 7 |
| B.5:34.e | RI2 | 7 |
| | RM1 | 7 |
| | RC1 | 7 |
| | RM2 | 7 |
| | RP1 | 7 |
| B.5:34.f | RI2 | 7 |
| | RP2 | 7 |
| | RM3 | 2 |
| | RC1 | 7 |
| | RM1 | 7 |
| | RP1 | 7 |
| | RM2 | 7 |
| B.5:34.g | RM2 | 7 |
| | RM3 | 7 |
| | RM1 | 7 |
| B.5:34.h | LM2 | 7 |
| B.5:34.i | RM2 | 7 |
| | RM3 | 7 |
| B.5:34.j | LP1 | 7 |
| | LI2 | 7 |
| B.5:35.120.b | RC1 | 7 |
| | LP2 | 7 |
| | RP1 | 7 |

| | | |
|---|---|---|
| | LM1 | 7 |
| | RM2 | 7 |
| | LI2 | 7 |
| B.5:35.122.a | RI2 | 7 |
| | RP2 | 7 |
| | LC1 | 7 |
| | RC1 | 7 |
| | RM1 | 7 |
| | LP1 | 7 |
| | RP1 | 7 |
| | RM2 | 7 |
| B.5:35.122.c | RP2 | 7 |
| | RM2 | 7 |
| B.5:35.125.a | RM1 | 7 |
| | RM2 | 7 |
| | LP1 | 8 |
| | LP2 | 8 |
| | LC1 | 8 |
| B.5:35.128.c | LM3 | 2 |
| | LM1 | 7 |
| | LM2 | 7 |
| B.5:35.128.d | LC1 | 7 |
| B.5:35.128.e | LM1 | 7 |
| | LM2 | 7 |
| | LP2 | 7 |
| | LM3 | 7 |
| B.5:35.128.f | RM2 | 7 |
| | RP2 | 7 |
| | RM1 | 7 |
| B.5:35.128.g | RM2 | 2 |
| | RP2 | 7 |
| | RM1 | 7 |
| B.5:35.135.a | LM1 | 7 |
| B.5:35.137.b | RM1 | 7 |
| | RM2 | 7 |
| B.5:35.140.17.a | LP2 | 7 |
| B.5:35.140.17.b | LP1 | 7 |
| B.5:35.141.a | LC1 | 7 |
| | LP2 | 7 |
| B.5:35.141.b | RM1 | 7 |
| | RC1 | 7 |
| | RM3 | 7 |
| | RP2 | 7 |
| B.5:35.27.a | RP2 | 7 |

| | | |
|---|---|---|
| | RM3 | 2 |
| | RC1 | 7 |
| | RM1 | 7 |
| | RP1 | 7 |
| | RM2 | 2 |
| | RI2 | 7 |
| B.5:35.f | RP1 | 7 |
| | RM2 | 7 |
| B.5:35.g | LM3 | 7 |
| | LP1 | 7 |
| | RM1 | 7 |
| | LM2 | 7 |
| | RM3 | 7 |
| B.5:35.h | RP2 | 7 |
| | RM1 | 7 |
| | RM2 | 7 |
| B.6:28.250.c | RM3 | 2 |
| | RM2 | 2 |
| B.6:28.255.b | RM3 | 7 |
| | RM1 | 7 |
| | RM2 | 7 |
| B.6:28.255.c | RM2 | 7 |
| | RM1 | 7 |
| B.6:28.262.a | LI2 | 8 |
| | LC1 | 8 |
| B.6:28.262.c | RP1 | 7 |
| B.6:31.343.a | RP1 | 7 |
| | RI2 | 2 |
| | RP2 | 7 |
| | RC1 | 7 |
| B.6:43.435.d | LM1 | 7 |
| B.6:43.435.f | LC1 | 7 |
| B.6:43.435.g | LP2 | 7 |
| | LC1 | 7 |
| | LP1 | 7 |
| B.6:43.435.h | RM2 | 7 |
| B.6:44.446.d | RM2 | 7 |
| B.6:44.446.e | RM2 | 7 |
| | RM1 | 2 |
| B.6:44.446.f | RC1 | 7 |
| | RM2 | 7 |
| | RP2 | 7 |
| | RM1 | 7 |
| B.6:44.447.b | LM2 | 2 |

| | | |
|---|---|---|
| B.6:44.447.h | RC1 | 7 |
| | RI1 | 7 |
| | RP1 | 7 |
| | RI2 | 7 |
| | RP2 | 7 |
| B.6:44.447.i | LM2 | 2 |
| B.6:44.447.j | RM2 | 7 |
| B.6:44.447.k | RM1 | 7 |
| | RM2 | 7 |
| B.6:44.447.l | LI2 | 7 |
| | RI2 | 7 |
| | LC1 | 7 |
| | LI1 | 7 |
| | RI1 | 7 |
| B.6:44.448.a | LM2 | 7 |
| B.7:31.c | LI1 | 7 |
| | LP1 | 2 |
| | LM3 | 2 |
| | LI2 | 7 |
| | LP2 | 7 |
| | RI1 | 7 |
| | LC1 | 7 |
| | LM2 | 2 |
| B.7:31.i | LP1 | 7 |
| | RP2 | 7 |
| | LP2 | 7 |
| | RP1 | 2 |
| B.7:31.j | LM2 | 7 |
| | LM3 | 7 |
| B.7:32.b | RP1 | 7 |
| | RM2 | 7 |
| | RI2 | 7 |
| | RP2 | 7 |
| | RM3 | 7 |
| | RC1 | 7 |
| | RM1 | 7 |
| B.7:34.c | RP2 | 7 |
| | RC1 | 7 |
| | RP1 | 7 |
| F.1:28.115.35.f | LC1 | 2 |
| | RM1 | 2 |
| | LP2 | 2 |
| | RM2 | 2 |
| | RP2 | 2 |

| | | |
|---|---|---|
| F.1:28.97.69.a | LM2 | 2 |
| | LP2 | 7 |
| | LM3 | 2 |
| | LM1 | 2 |
| | RI2 | 7 |
| | LI2 | 7 |
| F.1:30.134.2.a | LI1 | 8 |
| | LM1 | 1 |
| | LI2 | 8 |
| | RM2 | 8 |
| | LP2 | 8 |
| TR03.T.1A=ST.18_squelettegauche_502 | RP2 | 2 |
| | RM1 | 2 |
| | LM2 | 2 |
| TR03.T.1A=ST.18_squelettegauche_503 | LI1 | 2 |
| | RI2 | 2 |
| | LP1 | 2 |
| | RP2 | 2 |
| | LM3 | 7 |
| | LI2 | 2 |
| | RC1 | 7 |
| | LP2 | 2 |
| | RM2 | 2 |
| | RI1 | 2 |
| | LC1 | 2 |
| | RP1 | 2 |
| | LM1 | 7 |
| | RM3 | 2 |
| TR03.T.1A2=ST.18_659 | LI1 | 2 |
| | RI1 | 2 |
| TR03.T.1B=St.18_partiesupremblaisujectT1B_671 | LI1 | 7 |
| | RI1 | 7 |
| | RP1 | 7 |
| | LP2 | 2 |
| | RI2 | 2 |
| | LM1 | 2 |
| | RC1 | 2 |
| TR03.T.8_757 | RI1 | 1 |
| | RP1 | 1 |
| | LM1 | 1 |
| | RM1 | 1 |
| Accession Number | Tooth | Presence |
| 781:248.a | RC1 | 2 |
| | LP2 | 2 |

| | | |
|---|---|---|
| | RM2 | 2 |
| | LP2 | 2 |
| | RP1 | 2 |
| | RP1 | 2 |
| | LM2 | 2 |
| | RM1 | 2 |
| | LC1 | 2 |
| 781:248.b | RC1 | 2 |
| | RI1 | 2 |
| | RP2 | 2 |
| | LI1 | 2 |
| | RI2 | 2 |
| | LC1 | 2 |
| | LC1 | 2 |
| 781:254 | LM1 | 2 |
| | RM3 | 2 |
| | RC1 | 2 |
| | LI1 | 2 |
| | RI1 | 2 |
| | LP1 | 2 |
| | RM2 | 2 |
| | LP1 | 2 |
| | RP2 | 2 |
| | LM3 | 2 |
| | LM2 | 2 |

# Appendix C. Postmortem Tooth Loss and Loose Teeth of the Same Tooth Type

Table 25 Comparison of Postmortem Tooth Loss Locations and Loose Teeth

| Area | Tomb | Tooth | Absent | Loose Tooth Count |
|---|---|---|---|---|
| F | 1 | RM1 | 1 | 10 |
| F | 1 | LC1 | 1 | 4 |
| F | 1 | LI1 | 2 | 4 |
| F | 1 | LI2 | 1 | 3 |
| F | 1 | LP1 | 2 | 6 |
| F | 1 | RC1 | 2 | 2 |
| F | 1 | RI1 | 2 | 6 |
| F | 1 | RI2 | 1 | 2 |
| F | 1 | RM3 | 1 | 2 |
| F | 1 | RP1 | 1 | 5 |
| A | 10 | LC1 | 2 | 0 |
| A | 10 | LP1 | 3 | 0 |
| A | 10 | LP2 | 2 | 0 |
| A | 10 | RM3 | 1 | 0 |
| A | 10 | RP2 | 1 | 2 |
| A | 10 | LC1 | 1 | 0 |
| A | 10 | LI1 | 2 | 0 |
| A | 10 | LI2 | 2 | 0 |
| A | 10 | LM1 | 2 | 0 |
| A | 10 | LM2 | 1 | 0 |
| A | 10 | LM3 | 1 | 0 |
| A | 10 | LP1 | 3 | 0 |
| A | 10 | LP2 | 2 | 1 |
| A | 10 | RC1 | 3 | 1 |
| A | 10 | RI1 | 3 | 1 |
| A | 10 | RI2 | 3 | 2 |
| A | 10 | RM1 | 2 | 0 |
| A | 10 | RM2 | 1 | 1 |
| A | 10 | RP1 | 3 | 0 |
| A | 10 | RP2 | 3 | 0 |
| TR | 12 | LC1 | 1 | 1 |
| TR | 12 | LI1 | 1 | 0 |
| TR | 12 | LI2 | 1 | 0 |
| TR | 12 | LM2 | 1 | 0 |

| | | | | |
|---|---|---|---|---|
| TR | 12 | LM3 | 1 | 0 |
| TR | 12 | LP1 | 1 | 1 |
| TR | 12 | RC1 | 1 | 0 |
| TR | 12 | RI1 | 1 | 0 |
| TR | 12 | RI2 | 1 | 0 |
| TR | 12 | RP1 | 1 | 1 |
| TR | 1A | LM2 | 1 | 0 |
| TR | 1B | RM3 | 1 | 0 |
| B | 4 | LC1 | 3 | 1 |
| B | 4 | LI1 | 2 | 0 |
| B | 4 | LI2 | 2 | 1 |
| B | 4 | LM1 | 1 | 0 |
| B | 4 | LP1 | 3 | 0 |
| B | 4 | RC1 | 2 | 1 |
| B | 4 | RI1 | 2 | 0 |
| B | 4 | RI2 | 2 | 0 |
| B | 4 | RM1 | 2 | 0 |
| B | 4 | RM2 | 1 | 1 |
| B | 4 | RP1 | 1 | 1 |
| B | 4 | LC1 | 2 | 1 |
| B | 4 | LI1 | 1 | 0 |
| B | 4 | LI2 | 1 | 0 |
| B | 4 | LM1 | 2 | 0 |
| B | 4 | LM2 | 2 | 0 |
| B | 4 | LM3 | 2 | 0 |
| B | 4 | LP1 | 2 | 0 |
| B | 4 | LP2 | 2 | 1 |
| B | 4 | RC1 | 4 | 1 |
| B | 4 | RI1 | 3 | 0 |
| B | 4 | RI2 | 4 | 0 |
| B | 4 | RM1 | 2 | 1 |
| B | 4 | RM3 | 1 | 0 |
| B | 4 | RP1 | 1 | 0 |
| B | 4 | RP2 | 2 | 0 |
| B | 5 | LC1 | 9 | 3 |
| B | 5 | LI1 | 9 | 1 |
| B | 5 | LI2 | 8 | 1 |
| B | 5 | LM1 | 4 | 10 |
| B | 5 | LM2 | 3 | 3 |
| B | 5 | LM3 | 4 | 1 |
| B | 5 | LP1 | 8 | 3 |
| B | 5 | LP2 | 7 | 6 |
| B | 5 | RC1 | 3 | 5 |
| B | 5 | RI1 | 9 | 1 |

| | | | | |
|---|---|---|---|---|
| B | 5 | RI2 | 4 | 3 |
| B | 5 | RM2 | 1 | 7 |
| B | 5 | RM3 | 3 | 3 |
| B | 5 | RP1 | 5 | 3 |
| B | 5 | RP2 | 5 | 5 |
| B | 5 | LC1 | 2 | 0 |
| B | 5 | LI1 | 4 | 4 |
| B | 5 | LI2 | 2 | 2 |
| B | 5 | LM2 | 2 | 8 |
| B | 5 | LP1 | 2 | 3 |
| B | 5 | LP2 | 1 | 1 |
| B | 5 | RC1 | 7 | 0 |
| B | 5 | RI1 | 5 | 4 |
| B | 5 | RI2 | 7 | 2 |
| B | 5 | RM1 | 3 | 6 |
| B | 5 | RM3 | 2 | 3 |
| B | 5 | RP1 | 6 | 4 |
| B | 5 | RP2 | 2 | 3 |
| B | 6 | LC1 | 2 | 1 |
| B | 6 | LI1 | 2 | 1 |
| B | 6 | LI2 | 3 | 0 |
| B | 6 | LM2 | 1 | 9 |
| B | 6 | LM3 | 1 | 1 |
| B | 6 | LP1 | 1 | 4 |
| B | 6 | LP2 | 1 | 2 |
| B | 6 | RC1 | 1 | 2 |
| B | 6 | RI1 | 3 | 2 |
| B | 6 | RI2 | 3 | 0 |
| B | 6 | RM3 | 3 | 4 |
| B | 6 | RP1 | 2 | 2 |
| B | 6 | RP2 | 1 | 3 |
| B | 6 | LI2 | 1 | 3 |
| B | 6 | LM1 | 3 | 6 |
| B | 6 | LM3 | 2 | 5 |
| B | 6 | RC1 | 1 | 5 |
| B | 6 | RI1 | 2 | 4 |
| B | 6 | RI2 | 1 | 2 |
| B | 6 | RM1 | 3 | 3 |
| B | 6 | RM3 | 3 | 5 |
| B | 6 | RP2 | 3 | 3 |
| B | 7 | LC1 | 1 | 1 |
| B | 7 | LI2 | 1 | 1 |
| B | 7 | RI1 | 1 | 2 |
| B | 7 | RI2 | 1 | 4 |

| | | | | |
|---|---|---|---|---|
| B | 7 | LC1 | 1 | 2 |
| B | 7 | LI1 | 1 | 1 |
| B | 7 | LI2 | 1 | 0 |
| B | 7 | RC1 | 1 | 2 |
| B | 7 | RI1 | 2 | 2 |
| B | 7 | RI2 | 2 | 1 |
| B | 7 | RM1 | 2 | 1 |
| D | 779 | LM1 | 1 | 0 |
| D | 779 | LM2 | 1 | 0 |
| D | 779 | LM3 | 1 | 0 |
| D | 779 | RI2 | 1 | 0 |
| | 781 | LC1 | 3 | 0 |
| | 781 | LI1 | 4 | 0 |
| | 781 | LI2 | 3 | 0 |
| | 781 | LM1 | 1 | 0 |
| | 781 | LM2 | 2 | 1 |
| | 781 | LM3 | 2 | 0 |
| | 781 | LP1 | 5 | 0 |
| C | 781 | LP2 | 2 | 0 |
| | 781 | RC1 | 4 | 0 |
| | 781 | RI1 | 4 | 0 |
| | 781 | RI2 | 4 | 0 |
| C | 781 | RM1 | 3 | 1 |
| C | 781 | RM2 | 4 | 0 |
| C | 781 | RM3 | 2 | 1 |
| | 781 | RP1 | 3 | 0 |
| | 781 | RP2 | 4 | 0 |
| | 781 | LC1 | 2 | 0 |
| | 781 | LI1 | 3 | 0 |
| | 781 | LI2 | 3 | 0 |
| | 781 | LM1 | 2 | 0 |
| | 781 | LM2 | 2 | 1 |
| | 781 | LP1 | 2 | 1 |
| | 781 | LP2 | 2 | 0 |
| | 781 | RC1 | 5 | 2 |
| | 781 | RI1 | 2 | 1 |
| | 781 | RI2 | 2 | 0 |
| | 781 | RM1 | 2 | 0 |
| | 781 | RM2 | 3 | 0 |
| | 781 | RP1 | 4 | 0 |
| | 781 | RP2 | 2 | 1 |
| TR | 9 | LC1 | 1 | 0 |
| TR | 9 | LI1 | 1 | 0 |
| TR | 9 | LI2 | 1 | 0 |

| | | | | |
|---|---|---|---|---|
| TR | 9 | LM2 | 1 | 0 |
| TR | 9 | LM3 | 1 | 0 |
| TR | 9 | LP1 | 1 | 0 |
| TR | 9 | LP2 | 1 | 0 |
| TR | 9 | RC1 | 1 | 0 |
| TR | 9 | RI1 | 1 | 0 |
| TR | 9 | RI2 | 1 | 0 |
| TR | 9 | RM3 | 1 | 0 |
| TR | 9 | RP1 | 1 | 0 |
| TR | 9 | RP2 | 1 | 0 |

# Appendix D: Cases of Linear Enamel Hypoplasia and Estimated Age of Occurrence

Table 26 Recorded Linear Enamel Hypoplasias and Estimated Age of Occurrence

| Accession Number | Tooth | Distance from CEJ(mm) | Estimated Age |
|---|---|---|---|
| D.779:229 | LI1 | 4.9 | 2.3 |
| | LC1 | 2.1 | 4.7 |
| | | 3.4 | 3.9 |
| | RI1 | 2.3 | 3.5 |
| | | 2.5 | 3.4 |
| | RI2 | 4.1 | 2.9 |
| | RC1 | 2.1 | 4.7 |
| | | 3.2 | 4.0 |
| | LI1 | 3.9 | 2.2 |
| | LC1 | 4.4 | 3.9 |
| | RC1 | 2.2 | 5.2 |
| | | 3.9 | 4.2 |
| | RM1 | 2.1 | 2.6 |
| C.781:75 | LC1 | 1.5 | 5.6 |
| | | 4.3 | 4.0 |
| | | 7.2 | 2.3 |
| | RC1 | 1.6 | 5.6 |
| | | 4.9 | 3.6 |
| | | 6.6 | 2.6 |
| | RP1 | 1.3 | 5.2 |
| C.781:74 | RC1 | 1.7 | 4.9 |
| 781:248.a | LC1 | 2.2 | 5.2 |
| | RC1 | 2.4 | 5.1 |
| | | 4.6 | 3.8 |
| 781:248.b | LI1 | 1 | 4.0 |
| | | 1.5 | 3.8 |
| | | 2.3 | 3.5 |
| | LC1 | 2.9 | 4.2 |
| | | 4.2 | 3.4 |
| | RI1 | 1.8 | 3.7 |
| | | 4.3 | 2.5 |
| | RI2 | 2.3 | 3.6 |
| | | 3.1 | 3.3 |
| | | 5.7 | 2.2 |

| | | | |
|---|---|---|---|
| | RC1 | 2.9 | 4.2 |
| | | 4.4 | 3.2 |
| | RP2 | 1.9 | 5.1 |
| | RM1 | 1 | 3.1 |
| | LC1 | 3.8 | 4.3 |
| 781:254 | LI1 | 2.4 | 3.4 |
| | | 4.4 | 2.5 |
| | LI2 | 3 | 3.3 |
| | LC1 | 1.7 | 4.9 |
| | | 3.1 | 4.1 |
| | LP1 | 2.8 | 4.6 |
| | RI1 | 2.3 | 3.5 |
| | | 4.4 | 2.5 |
| | RI2 | 4.4 | 2.7 |
| | | 2.3 | 3.6 |
| | RC1 | 2.4 | 4.5 |
| | | 3.4 | 3.9 |
| | LI1 | 1.7 | 3.2 |
| | | 4.4 | 2.0 |
| | LI2 | 3.9 | 2.4 |
| | | 4.5 | 2.1 |
| | RI1 | 1.8 | 3.2 |
| | | 3.4 | 2.4 |
| | RC1 | 2.4 | 5.1 |
| | | 3.8 | 4.3 |
| | | 4.8 | 3.7 |
| 781:278 | RC1 | 2.8 | 4.2 |
| | | 4.5 | 3.2 |
| 781:279 | RP1 | 3.2 | 4.4 |
| | RP2 | 0.9 | 5.6 |
| | RM1 | 1 | 3.1 |
| 781:288.a | LI1 | 2.1 | 3.5 |
| | | 4.3 | 2.5 |
| | | 5.4 | 2.0 |
| | | 6.3 | 1.6 |
| | LC1 | 7.2 | 1.5 |
| | LP1 | 1.1 | 5.5 |
| | | 3.2 | 4.4 |
| | RI1 | 1.9 | 3.6 |
| | | 4.6 | 2.4 |
| | | 6.6 | 1.5 |
| | LC1 | 5.2 | 3.4 |
| | | 6.5 | 2.7 |
| | | 3.5 | 4.4 |

| | | | |
|---|---|---|---|
| | RC1 | 1.4 | 5.7 |
| | | 2.7 | 4.9 |
| | | 4.2 | 4.0 |
| TR03.T.12=ST.9_NE_163 | RP1 | 1.5 | 5.3 |
| TR03.T.12=ST.9_squellette1_323 | LP1 | 3.1 | 4.5 |
| | | 1.9 | 5.1 |
| TR03.T.12=ST.9_squellette1_324 | LP2 | 6.8 | 2.8 |
| | | 7.7 | 2.4 |
| TR03.T.12=ST.9_squellette1_325 | LC1 | 3.2 | 4.0 |
| TR03.T.12=ST.9_squellette1_326 | LC1 | 2 | 5.3 |
| | | 4 | 4.1 |
| TR03.T.1A=ST.18_squelettegauche_502 | RP2 | 2.4 | 4.9 |
| TR03.T.1A=ST.18_squelettegauche_503 | LI2 | 2.3 | 3.0 |
| | | 3.5 | 2.5 |
| | LC1 | 3.9 | 4.2 |
| | | 1.2 | 5.8 |
| | | 2.4 | 5.1 |
| | LP1 | 2.7 | 4.3 |
| | LP2 | 1.9 | 5.8 |
| | RI1 | 2.1 | 3.0 |
| | RC1 | 4.5 | 3.9 |
| TR03.T.1Bea1A2=ST.18_squelettedroite_653 | RI1 | 2.6 | 3.3 |
| | | 3.8 | 2.8 |
| | | 5.2 | 2.1 |
| TR03.T.1A2=ST.18_656 | RP1 | 1.6 | 5.2 |
| TR03.T.1A2=ST.18_657 | LI1 | 5.5 | 2.0 |
| | | 2.3 | 3.5 |
| | | 4.3 | 2.5 |
| TR03.T.1A2=ST.18_659 | LI1 | 2.5 | 2.8 |
| | | 3.9 | 2.2 |
| | | 4.4 | 2.0 |
| | RI1 | 1.5 | 3.3 |
| | | 2.8 | 2.7 |
| TR03.T.1B=St.18_partiesupremblaisujectT1B_671 | LI1 | 2.9 | 3.2 |
| | | 5.1 | 2.2 |
| | | 6.5 | 1.5 |
| | LP2 | 0.9 | 5.6 |
| | | 2.3 | 4.9 |
| | LM1 | 3.9 | 1.8 |
| | RI1 | 5.6 | 2.0 |
| | | 3.8 | 2.8 |
| | RI2 | 2.5 | 3.5 |
| | | 4.6 | 2.7 |
| | RC1 | 5.2 | 2.8 |

| | | | |
|---|---|---|---|
| A.10:3 | RP1 | 2.3 | 4.5 |
| A.10:6.a | LI2 | 1.7 | 3.8 |
| | | 2.3 | 3.6 |
| | | 3.5 | 3.1 |
| | LP2 | 2.5 | 4.8 |
| | LC1 | 3.3 | 4.6 |
| | RC1 | 2.3 | 5.1 |
| | | 3.6 | 4.4 |
| A.10:7 | LP1 | 2.1 | 5.0 |
| | | 3.1 | 4.5 |
| | | 4.3 | 3.9 |
| | RP2 | 1.1 | 5.5 |
| | | 2 | 5.1 |
| | | 2.8 | 4.7 |
| A.10:9 | LI2 | 3.4 | 2.6 |
| A.10:54 | RI1 | 3 | 3.1 |
| | | 3 | 3.1 |
| A.10:55.a | RI2 | 1.8 | 3.8 |
| | | 3.6 | 3.1 |
| | | 5.3 | 2.4 |
| | | 7 | 1.7 |
| A.10:57 | LC1 | 4.2 | 3.4 |
| | LP1 | 2.7 | 4.7 |
| | | 1.3 | 5.4 |
| | RC1 | 1 | 5.4 |
| | | 2.7 | 4.3 |
| | | 4.4 | 3.2 |
| | LC1 | 2.8 | 4.9 |
| A.10:59.a | RI1 | 1.5 | 3.8 |
| | | 3.6 | 2.9 |
| | | 5.3 | 2.1 |
| | RI1 | 2.2 | 3.0 |
| | | 3.2 | 2.5 |
| | | 4.2 | 2.1 |
| | RI2 | 1.8 | 3.2 |
| A.10:60.b | LI1 | 2.8 | 3.2 |
| | | 4.4 | 2.5 |
| | | 5.8 | 1.9 |
| | RC1 | 1.4 | 5.1 |
| | | 2.2 | 4.6 |
| | | 3.4 | 3.9 |
| | RP1 | 3.8 | 4.1 |
| | RM1 | N/A | N/A |
| | LP1 | 1.3 | 5.2 |

| | | | |
|---|---|---|---|
| | | 2.4 | 4.5 |
| | RP1 | 4.1 | 3.4 |
| | RP2 | 1.2 | 6.2 |
| A.10:60.c | RC1 | 3.6 | 3.8 |
| | RP1 | 3 | 4.1 |
| B.5:13.a | RM1 | 1 | 3.1 |
| B.4:10.d | RM3 | 0.9 | N/A |
| B.4:10.m | LP2 | 1.5 | 5.3 |
| B.4:17.d | LC1 | 1.6 | 5.0 |
| | | 2.8 | 4.2 |
| | | 4.8 | 3.0 |
| B.4:22.a | RC1 | 1.8 | 4.9 |
| | | 2.7 | 4.3 |
| | | 3.8 | 3.6 |
| | | 5.2 | 2.8 |
| B.5:4.b | RC1 | 3.5 | 4.4 |
| | | 5.7 | 3.1 |
| B.5:9.g | LM3 | N/A | N/A |
| B.5:9.h | RI1 | 3.3 | 3.0 |
| | | 5 | 2.2 |
| | | 1.2 | 4.0 |
| B.5:11.b | RI2 | N/A | N/A |
| B.6:0.d | RC1 | 1.9 | 5.4 |
| | | 3 | 4.7 |
| | | 4.3 | 4.0 |
| B.6:0.g | LC1 | 2.2 | 4.6 |
| | | 3.2 | 4.0 |
| B.6:0.h | RC1 | 2.2 | 4.6 |
| B.6:0.i | LC1 | 4 | 3.5 |
| B.6:0.k | LP1 | 2.4 | 4.5 |
| B.6:0.u | LM1 | 2.9 | 2.2 |
| B.6:0.an | RI2 | N/A | N/A |
| B.6:10.31.b | RI1 | 5.4 | 2.0 |
| | | 6.1 | 1.7 |
| | | 6.5 | 1.5 |
| B.6:36.42.a | LP1 | N/A | N/A |
| B.6:28.250.a | RM1 | 0.8 | 3.1 |
| B.6:28.250.a | RM1 | 1.3 | 2.9 |
| B.6:44.447.d | LP2 | 2 | 5.1 |
| B.6:28.255.101.a | LM1 | 2.4 | 2.4 |
| B.6:44.446.b | LM1 | N/A | N/A |
| B.6:28.250.b | RM1 | 1.6 | 2.8 |
| B.6:42.a | RM1 | 1.7 | 2.7 |
| B.6:23.a | LP2 | 1.3 | 5.4 |

| | | | |
|---|---|---|---|
| B.7:33.j | LM1 | 2.0 | 2.6 |
| B.7:35.a | LP1 | 0.9 | 5.6 |
| B.5:35.b | RP1 | 2.1 | 4.7 |
| B.5:34.55.a | RP1 | 1.5 | 5.3 |
| | | 1.8 | 5.1 |
| | | 4.4 | 3.8 |
| B.5:34.b | RP1 | 2.4 | 4.5 |
| B.6:43.435.c | LM2 | N/A | N/A |
| B.7:31.a | RP1 | 1.9 | 5.1 |
| B.7:27.76.a | RM2 | 1.8 | 6.4 |
| B.7:33.499.a | RM2 | 1.8 | 6.0 |
| B.5:35.118.a | LM1 | 1.5 | 2.8 |
| | | 1.4 | 2.9 |
| | | 1.9 | 2.6 |
| | | 2.7 | 2.3 |
| B.7:19.56.a | RM2 | 1.9 | 5.9 |
| B.7:19.56.b | RP1 | 2.6 | 4.7 |
| | | 3.9 | 4.1 |
| | | 6.4 | 2.8 |
| B.7:19.56.c | | N/A | N/A |
| B.7:33.499.c | LM2 | 1.7 | 6.0 |
| B.7:33.499.c | | 2.5 | 5.6 |
| B.5:32.3.115.e | RC1 | 3.1 | 4.7 |
| | | 4.4 | 3.9 |
| | | 6.4 | 2.7 |
| B.5:33.c | RI2 | 2.4 | 3.5 |
| B.5:34.47.a | RC1 | 3.5 | 4.4 |
| | | 4.6 | 3.8 |
| B.6:6.g | RC1 | N/A | N/A |
| B.6:28.250.c | RM2 | 2.5 | 5.9 |
| | RM3 | 1.7 | N/A |
| B.6:31.343.110.a | | 3.9 | N/A |
| B.6:36.370.c | LP1 | 3.1 | 4.0 |
| B.6:37.a | LC1 | 2.7 | 4.3 |
| B.6:44.447.e | RP2 | 1.8 | 5.2 |
| B.6:44.447.f | LI1 | 1.7 | 3.7 |
| | | 3.7 | 2.8 |
| B.6:44.446.e | RM1 | 1.9 | 2.6 |
| | | 2.7 | 2.3 |
| B.6:44.447.i | LM2 | 5.2 | 4.2 |
| B.7:19.56.d | RI1 | 0.9 | 4.1 |
| | | 1.6 | 3.8 |
| | | 1.9 | 3.6 |
| B.7:19.56.e | RI1 | 1.3 | 3.9 |

| | | | |
|---|---|---|---|
| | | 2.3 | 3.5 |
| B.7:19.56.e | RI1 | 2.4 | 3.4 |
| B.7:19.56.f | LI1 | 1.1 | 4.0 |
| B.7:19.56.g | LC1 | 3.9 | 3.6 |
| B.7:19.56.h | LI2 | 1.3 | 3.5 |
| B.7:19.56.i | RI1 | 1.1 | 3.5 |
| B.7:33.a | RC1 | 1.4 | 5.1 |
| | | 2.3 | 4.6 |
| | | 3.8 | 3.6 |
| B.7:33.c | LC1 | 2.3 | 4.6 |
| | | 4.3 | 3.3 |
| | | 2 | 4.8 |
| B.7:33.e | LC1 | 2.1 | 5.3 |
| | | 2.6 | 5.0 |
| B.7:33.h | RI2 | 2.9 | 2.8 |
| F.1:22.89.S1.an | RI1 | 4.2 | 2.6 |
| F.1:28.94.S1.ar | LM1 | 2.1 | 2.6 |
| F.1:28.94.S1.ah | LM2 | N/A | N/A |
| F.1:28.115.6 | RI1 | 3 | 3.1 |
| | | 5.1 | 2.2 |
| F.1:28.115.35.f | LC1 | 2 | 4.8 |
| F.1:28.97.69.ad | RI2 | 1.7 | 3.8 |
| | | 3.6 | 3.1 |
| F.1:28.97.69.af | LI2 | 1.4 | 3.9 |
| | | 2.8 | 3.4 |
| F.1:29.143.1.ak | RC1 | 3.6 | 3.8 |
| | | 5.3 | 2.7 |
| | | 7.1 | 1.6 |
| | | 9.2 | 0.3 |
| F.1:23.99.S1.l | RI1 | 1.9 | 3.6 |
| | | 3 | 3.1 |
| F.1:30.134.1.ag | RI1 | 1.2 | 4.0 |
| F.1:26.121.S1.hd | LI2 | N/A | N/A |
| F.1:28.116.1.bq | RI1 | 3.5 | 2.9 |
| | | 4.6 | 2.4 |
| F.1:28.116.1.bp | RI2 | 4.6 | 2.7 |
| F.1:28.98.S1.fx | LI1 | 2.5 | 3.4 |
| | | 3.6 | 2.9 |
| F.1:28.144.S2.af | LC1 | 3.6 | 3.8 |
| F.1:28.130.1.bm | LI2 | 1.7 | 3.3 |
| | | 3.5 | 2.5 |
| F.1:28.130.1.bo | RI2 | 1.8 | 3.2 |
| F.1:29.143.S2.hj | LC1 | 1.1 | 5.3 |
| | | 1.8 | 4.9 |

| | | |
|---|---|---|
| | 2.8 | 4.2 |
| | 3.9 | 3.6 |