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Dental Pathology and Morphology of the Pre-Contact Chamorro, Guam

by

Kellie R. Cayer

A thesis

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Dedication

To all those who have helped me along the way.

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Abstract

The objective here is to provide the dental characterization of the pre-contact Chamorro. Here, the dental pathology and morphology from casts of the pre-contact Chamorro are analyzed. Caries, ante-mortem tooth loss (AMTL), and attrition are documented. Morphology was examined to assess the likely geographic relatedness of the sample and the relationship between attrition and morphology. These traits were then recorded for absence/presence or degree and then statistically analyzed.

This study indicated that dental pathology in this sample does not obscure the analysis of dental morphology. Additionally, it was found that attrition affected the anterior dentition more than the posterior dentition in the sample. Caries and AMTL were observed to be representative of a larger population. This may demonstrate how dental anatomy can be impacted by environmental and cultural factors versus the effects one might see on an individual of different tooth morphologies.

Key words: dental attrition; caries; AMTL; Chamorro; Guam

Chapter 1

Introduction and Research Questions

Purpose of Research

The purpose of this thesis is to expand our understanding of dietary behavior, dental health, and biological affinities of the pre-contact Chamorro people of Guam and correlate the possible impact that pathologies have on the observation and analysis of morphological traits. Specifically, the oral health focus looks at the patterns of attrition, caries, and ante-mortem tooth loss (AMTL) found within the sample, including their frequency and severity. By analyzing morphological traits alongside dental pathologies, it may be possible to observe the potential obscuring effects dental pathology has on said traits.

Documenting the severity and frequency of dental morphological and pathological traits contributes to broader anthropological knowledge since such data can be used to hypothesize about a population's diet and dietary changes, subsistence strategies, human-environmental interaction, and cultural activities relating to broader sociocultural factors evidenced in archeology. Similarly, information about past dental health may be informative to modern practices or in understanding sociocultural behaviors tied to modern dental health issues. Overall, descriptive studies such as these provide baseline data for holistic and biocultural approaches, particularly for populations like the ancient Chamorro of Guam, for which we have limited knowledge.

As Euber (2012) indicates, there is a general lack of skeletal databases or collections available for the study of the bioarchaeology of Guam. Skeletal remains recovered in Guam are reburied or left in place to comply with Executive Orders 89-24 and 89-9 (Euber 2012). This means that most remains are not analyzed or are hastily recorded. Such is the case with the remains used in this thesis. Since 1924, of the 11 research categories of Guam bioarchaeology that Euber (2012) designated, 52% of the work presenting bioarchaeological data from Guam were from site reports, not publications. Studies focused on pathology consisted of 19%, while categories such as osteobiography, diet, and biodistance accounted for less than 30% of all publications combined. This may impact the conclusions that can be drawn from this current thesis as there is little comparative data with which to build broader social and anthropological theory. Having said that, this thesis also represents the value of using dental casts from remains otherwise reburied and the overall value and limitations of understanding broader cultural themes from dental data alone. The overall objective of the thesis is to provide the dental characterization of pre-contact Chamorro as proxy indicators of oral behavior and dental health.

Dental Pathologies

As discussed above, analysis of dental wear can aid in understanding what ancient peoples ate, their subsistence strategies, non-dietary uses of their teeth, and what their environment was like. Subsistence strategy and diet are related. For example, occlusal dental wear can be used to study subsistence strategy by studying mastication patterns associated with wear, which can indicate the individuals' diet (Forshaw 2014). Hunter-gatherer dentitions typically reflect a hard, fibrous diet, while agriculturalist dentitions show a more oblique wear angle, indicating mastication of softer, highly-processed plant foods (Forshaw 2014; Forshaw 2015). Dental wear for these subsistence strategies differs in occlusal angle, as hunt er-gatherers have flatter molars than agriculturalists (Forshaw 2015). For agriculturalists, whose diet consists of softer processed foods, the type of mastication related to their subsistence strategy is associated with dental contact, giving the teeth a steeper occlusal wear angle (Forshaw 2014). It is seen that dental wear can indicate the diet as well as the subsistence strategy of archeological individuals and populations (Forshaw 2014).

Dental wear can also indicate properties of diet and the environment which an individual or group occupied. Non-food particles can get into food (and therefore dental calculus), such as grit and sand, as well as phytoliths, which may or may not be dietary (Burnett, Irish and Fong 2013; Forshaw 2014; Neumann, Chevalier and Vrydaghs 2017). This can cause rapid tooth wear (Forshaw 2014), and additionally point to the type of food and other elements present in the oral and external environment. Aspects relating to the type of food may include the consistency of foods and how they have been prepared, which varies based on subsistence strategy and can be seen in the angle of wear patterns in different populations (Forshaw 2015). Additionally, foodstuffs may be affected by the environment in that holding gritty particles may assist in attrition through their own hardness and toughness (Forshaw 2015).

Aside from diet and subsistence strategies, researchers can learn about cultural practices through dental wear. For example, teeth can be used as tools, causing abrasive wear patterns (Burnett, Irish and Fong 2013; Kaifu et al. 2003; Mahajan 2019). Burnett, Irish, and Fong (2013) give the example of Greenlanders, some of whom follow the traditional diet of that group and others who eat a European diet, resulting in differences in wear patterns as measured by age. In addition to chewing tougher foods. the inclusion of non-dietary materials led to further tooth wear (Kaifu et al. 2003). These non-dietary materials may be hygiene tools, such as a toothpick (Burnett, Irish, and Fong 2013; Emmanuel, Couture, and Maureille 2011).

An example of the cultural use of teeth is the chewing of non-dietary objects over a long time to supplement the diet, which can lead to severe tooth wear (Molnar 1972). There are multiple possibilities as to why ancient individuals did this. Chewing objects may have medicinal properties that improve the individual's physical health (Molnar 1972). Such habits have also been seen in foragers, especially females, who sampled plants during foraging (Molnar 1972). Another possibility is that individuals who did this did it to pass the time (Molnar 1972). All these activities resulted in dental wear, which can indicate to researchers the practice of chewing for non-dietary reasons in archeological populations. Further, the wear patterns and other pathologies that will be researched in this thesis may potentially lead to a more thorough understanding of the above aspects of the pre-contact Chamorro's lives. It can be seen here that understanding dental pathologies such as attrition are imperative to understanding other concepts such as the culture and environment of pre-contact peoples.

Morphological Traits

In this study, morphological traits are also analyzed from each dental cast. Most of these traits come from the upper and lower incisors and molars, as well as one from the upper and lower premolars. Dental morphology can indicate not only anatomical traits of an individual's teeth, but also their biogeographic ancestry.

In addition to being useful for estimating biogeographic ancestry, dental morphology has the potential to examine past population structure through an archeological viewpoint (Rathmann and Reyes-Centeno 2020). Dental morphology can also provide information on hominin phylogenies (Rathmann and Reyes-Centeno 2020). It is important to note that this study uses dental morphology solely to estimate biogeographic ancestry.

Research Questions

The research questions for this study focus on the patterns in which dental pathologies (attrition, caries, AMTL) and morphologies occur in the sample of pre-contact Chamorro individuals. Additionally, how those pathologies affect the observation and analysis of dental morphological traits is explored.

Research questions:

1. What are the patterns of dental wear/attrition in this sample?
2. What are the frequencies and patterns of caries and AMTL in this sample?
3. How does dental wear obscure crown morphology and affect biogeographic ancestry estimation?

The way the pre-contact Chamorro used their teeth may potentially be reflected by dental wear patterns seen in this sample. Different use of the anterior and posterior dentitions may indicate types of food and food preparation used by the pre-contact Chamorro. Pietrusewsky et al. (2010) discuss the impact diet had on archeological specimens in the area and the bioarchaeological information made available through dental pathology. The connection between diet and dental use could lead to further knowledge regarding cultural aspects of Chamorro life. Additionally, demographic differences in sex and age may be seen through how the teeth were worn in different individuals given different access to dietary resources.

Another aspect regarding dental health and diet in this sample involves other pathologies, including AMTL and caries. Both pathologies are related to diet in that cariogenic foods lead to caries and eventually tooth loss, and harder or more brittle foods can also result in premature tooth loss. Understanding the distribution of these dental pathologies from a demographic perspective may indicate differences in pathology regarding age, sex, and ancestry, which has the potential to shed light on cultural practices that may affect dental health.

Biogeographic ancestry can be estimated through the analysis of morphological dental traits. Dental morphology from this sample may indicate the locations of individuals' origins in said sample. These biogeographic ancestry clusters include the American Arctic and Northeast Siberia; Australo-Melanesia and Micronesia; East Asia; American Indian; Southeast Asia and Polynesia; Sub-Saharan Africa; and Western Eurasia. However, dental wear can affect the observation of those traits and influence the results of tests conducted to estimate said ancestry. Additionally, individuals from Micronesia, where Guam is located and the specimens for this sample were excavated from, may not be adequately represented in the rASUDAS, the system used in this study to process information on dental morphological traits and estimate biogeographic ancestry.

Thesis Outline

Once the overall purpose of this thesis and the research questions have been introduced in this chapter, Chapter 2 will summarize the background history of the bioarchaeological and modern health data of the Chamorro and Guam, tying together the modern application of data from archeological populations. Next, Chapter 3 will present the specific sample used in this thesis and systematically outline the methodological and analytical components of the project. Results of the materials and methods are presented in Chapter 4, along with tables and associated figures. Finally, Chapter 5 will return to the research questions presented in this first chapter and apply the results and contextual information to interpret answers to those questions.

Chapter Summary

In this chapter, the biological approach to this study was discussed, including a description of the dental pathologies of focus. Additionally, the biocultural aspects that could be applied to this research were explored, with an emphasis on the influence of dental attrition, caries, and AMTL on understanding Chamorro dietary- and dental-related activities. Furthermore, the importance of studying dental morphology alongside those pathologies was addressed, as well as the potential such research has for estimating biogeographic ancestry. Finally, the methodology and hypotheses were also discussed, with an emphasis on how diet affects dental health and how dental pathologies affect the observation and analysis of tooth morphology.

Chapter 2: Cultural and Methodological Background

In this chapter, the geographic area from which the archeological remains inthis sample were found is discussed. Additionally, an overview of the pre-contact Chamorro is given, including information on the cultural, biological, and dental anthropology of that group. Information on modern Chamorro dental pathology and oral health is included, as well as an overview of the dental pathology of an historic Chamorro individual.

Guam and the Chamorro

The Chamorro remains used in this study are from archeological sites in Guam. Guam is an island in Micronesia, the largest in the region at 30 miles long, four to eight miles wide, and 209 square miles total (Athens 1986; Lawrence 1996). A map containing Guam's location can be seen in Figure 2.1. Within the island, the terrain types are split between the north and the south (Athens 1986). In northern Guam, limestone plateaus are abundant, as well as volcanism, fringing reefs, and freshwater wells (Athens 1986). The southern terrain consists of deformed volcanic rocks and a small barrier reef, as well as freshwater sources mainly originating from streams and rivers (Athens 1986). These terrains are affected by a wet season from July to November and a dry season from January to May with transitional seasons in between (Athens 1986). The dry season may receive less than one inch of rainfall per month, but in the wet season between 12 to 15 inches of rainfall may occur (Athens 1986).

Figure 2.1. Map showing the location of Guam (Coddington et al. 2012: 32).

The sample for this study consists of remains from two temporal periods ranging from A.D. 200 – A.D. 1650 and includes the pre-*latte* and *latte* periods (Carson 2012). The pre-*latte* period ranges from 1500 BC to A.D. 900 (Carson 2012) and is primarily associated with pottery (Athens 1986). The *latte* period began in A.D. 900 and ended in A.D. 1700 (Carson 2012) and is associated with a type of architecture using large stones (*lattes*) that were the base for houses and other types of structures (Athens 1986; Peterson 2012). In both periods, women gathered food, fished with hand nets, made herbal medicines, and cooked (Salas and Tolentino 2021). Pre-*latte* and *latte* men did a majority of the fishing, tended to gardens, and built houses and canoes (Salas and Tolentino 2021). Prior to contact, the Chamorro diet included tree roots, starches, fruits, and plant leaves (Salas and Tolentino 2021). Post-contact, foods such as rice were imported to Guam (Leon Guerrero et al. 2008) from the West due to an increased demand that could not be filled by those living in Guam (Solenberger 1967). However, given the rush for analysis and making casts prior to repatriation, specific skeletal and mortuary information for each burial used in this thesis is unknown (Lawrence 1996).

At the point of contact, the Spanish described the Chamorro, who were in the *latte* period at that time, as “robust, corpulent, and strong” and considered them tall and physically fit by contemporary standards (Salas and Tolentino 2021: n.pag.). The reportedly good health of the *latte* Chamorro may be due to their nutritious diets and a subsistence strategy consisting of gathering and cultivating foods, as well as fishing (Salas and Tolentino 2021). The pre-contact Chamorro did, however, experience periods of famine resulting in nutritional stress, which can be seen archeologically (Salas and Tolentino 2021).

While the lack of skeletal data for this thesis dictates that results will only be interpreted using dental remains, there have been a few studies summarizing skeletal data from sites in Guam. The physical labor associated with building *latte* structures isthought to have resulted in the skeletal indicators of stress among the Chamorro (Salas and Tolentino 2021). This is indicated by stress markers on Chamorro individuals’ backs, ankles, knees, and shoulders, potentially a result of heavy lifting or repeated behavior necessary for moving the large latte stones (Salas and Tolentino 2021). For example, this includes stress lesions and robusticity markers found on a Chamorro individual's upper limbs and clavicles (Heathcote et al. 2012). Additionally, other diseases affected the Chamorro in pre-*latte* and *latte* periods, including yaws, arthritis, and osteoarthritis (Douglas, Pietrusewsky and Ikehara-Quebral 1997; Salas and Tolentino 2021). At the archeological site of Gognga-Gun Beach, 19% of individuals were found to have yaws-related diseases (Rothschild and Heathcote 1993). Yaws relates to dental disease as the pathology affects the oral cavity (Bush 2020). This may be useful as there is limited archeological skeletal evidence of yaws, as seen in the study by Rothschild and Heathcote (1993), noted above. In terms of joint disease, osteoarthritis was a common condition in the ancient world, including that of pre-contact Guam (Heathcote et al. 2012). Osteoarthritis was accompanied by other forms of arthritis in pre-contact Guam as well (Heathcote et al. 2012).

Healed fractures were more common in males than females in a sample of 51 non-adults and 101 adults from Guam (Douglas, Pietrusewsky and Ikehara-Quebral 1997). It should be noted that females were underrepresented in that sample (Douglas, Pietrusewsky and IkeharaQuebral 1997). In that sample, the average age of death for non-adults ranged between two and 10 years old, and the average age at death of adults was 43.5 years (Douglas, Pietrusewsky and Ikehara-Quebral 1997). The diet reflected by examinations of the dentitions in the sample was varied and balanced, with implied differential access to resources based on sex (Douglas, Pietrusewsky and Ikehara-Quebral 1997).

Chamorro Dental Anthropology

The Chamorro dentition is described as sundadont (Lawrence 1996). This term indicates a less complex dental morphology that is found in the Pacific and differs from the more complex sinodont morphology found further north of Guam (Lawrence 1996; Pugach et al. 2021). These different dental morphologies are considered to be the result of a split in Asian populations as some groups migrated north and developed changes in their dentitions (sinodont) while other groups traveled east and did not exhibit significant changes in their morphologies (sundadont) (Lawrence 1996).

Dental pathologies found in the Chamorro for this study (dental attrition, caries, antemortem tooth loss) were likely influenced by a highly cariogenic diet including taro, breadfruit, yams, coconut, bananas, fish, shellfish, and possibly rice, as well as foods obtained through hunting and gathering including birds, crabs, and fruit bats (Pietrusewsky et al. 2010). However, caries in the pre-contact Chamorro occurred rarely according to the literature (Pietrusewsky, Douglas and Ikehara-Quebral 1997). Additionally, compared to neighboring Saipan, the people of Guam historically had less caries (Pietrusewsky, Douglas and Ikehara-Quebral 1997). In a sample of individuals from Guam (N = 968) originating from the sites Matapang, Fujita, Rightof-Way, Apurguan, Leo Palace, and Academy Gym, 10.1% of those sampled (98) exhibited caries (Pietrusewsky, Douglas and Ikehara-Quebral 1997). In a sample of individuals from Saipan (N = 451) originating from the sites San Antonio, Hafa Dai, Tanapag, and Oleai, 11.8% of those sampled (53) exhibited caries (Pietrusewsky, Douglas and Ikehara-Quebral 1997). This demonstrates that, according to the literature, caries was rare in the region throughout several sites on both islands, including areas inhabited by the pre-contact Chamorro of Guam.

Ante-mortem tooth loss in Guam and the pre-contact Chamorro is reported to have occurred rarely (less than or equal to 30% of premortem loss per tooth, except for 51% of AMTL of third molars) (Leigh 1930), with 2% of the sample from Pietrusewsky et al. (2010) exhibiting AMTL. It was reported that AMTL was more prevalent in pre-contact Chamorro women than men, however this may be due to biological reasons such as a longer life expectancy for females in that population, and therefore more opportunities to lose teeth throughout life (Douglas, Pietrusewsky and Ikehara-Quebral 1997).

Betel nut staining, discussed more below, can cover all teeth buccally and lingually with a reddish-brown to orangish-red coating (Pietrusewsky et al. 2010; Pietrusewsky et al. 2016), and can cause an increase in dental calculus (Pietrusewsky, Douglas and Ikehara-Quebral 1997; Pietrusewsky et al. 2016), as well as severe attrition of the occlusal plane (Pietrusewsky et al. 2010). Such attrition can obliterate caries in the process of wearing down the surface of the tooth, possibly accounting for the rareness of caries found in pre-contact Guam in the literature (Pietrusewsky et al. 2016). Continued betel nut chewing may also result in dentin exposure followed by accelerated attrition, as well as root fractures from the heavy masticatory load (Trivedy, Craig and Warnakulasuriya 2002). This will also be discussed further below.

Linear enamel hypoplasia (LEH) has also been reported in samples from pre-contact Guam (Pietrusewksy et al. 2010; Pietrusewsky et al. 2016). These LEH have been documented in remains throughout the world as non-specific stress indicators (physiological, psychological, or both) (Pietrusewsky, Douglas and Ikehara-Quebral 1997; Pietrusewsky et al. 2016). Linear enamel hypoplasia represents interruptions during enamel growth due to stress and appear as permanent linear accentuations on enamel (Pietrusewsky et al. 2016). Physiological stressors such as malnourishment or chronic illness can create such accentuations (Guatelli-Steinberg, Ferrell and Spence 2012), as well as psychological stress from the environment during childhood (Temple 2019). In looking at archeological specimens, LEH can sometimes be masked by betel nut staining and crown attrition (Pietrusewsky et al. 2010). In the current sample, it was not possible to view LEH, so comparison will not be made here.

Dental Health and Betel Nut Chewing in Modern Guam

According to Baiju, Varghese, and Sivaram (2017: 21), “oral health is integral to general health and well-being.” This includes factors that potentially lead to dental attrition, cancer, premature tooth loss, and caries. The Chamorro are generally more at risk than other Pacific populations for those and other health issues due to lifestyle risk factors affecting oral health (Leon Guerrero et al. 2020). Lifestyle factors include the chewing of betel nut, such as the type of chewing (Chamorro style, involving ingestion of betel nut and its juices, or Yapese style, where the betel nut and juices are spit out) (Murphy and Herzog 2015). Supplementing those issues are limited awareness and education about oral cancer, as well as difficulties in receiving treatment due topoor access to screening, late-stage diagnoses, and limited treatment options (Leon Guerrero et al. 2020) for general and oral health. For example, data from 2018 found that 41.8% of adults in Guam do not regularly see a dentist (Centers for Disease Control and Prevention 2018). Comparatively, in 2019 in the mainland U.S. 34.5% of adults did not see a dentist (Reinberg 2021). Accessibility of dental health care in Guam can lead to negative treatment outcomes for various oral diseases, discussed further below. Those outcomes can be associated with betel nut chewing, a common and socially acceptable practice in Guam and among the modern-day Chamorro. While the staining associated with betel nut chewing is not observable from the sample used in this thesis since they are dental casts, as betel nuts are significant to modern oral health in the region and staining is visible on archeological teeth, their impact on the overall dental health discussed in this thesis cannot be overlooked, even if not specified. Therefore, I discuss related issues using modern data in this section.

Worldwide, approximately 700 million people chew betel nut (Gupta and Ray 2004). It is sold in Guam at gas stations, grocery stores, and roadside stands, and grown at home (HRSA

2017). Betel nut has a user-dependence level comparable to cigarettes (Moss et al. 2015), and the Chamorro usually chew it by itself and ingest it (Murphy and Herzog 2015; Paulino et al. 2011), with Micronesia having a higher prevalence of chewing betel nut than other places in the region (Oakley, Demaine and Warnakulasuriya 2005).

In a study on betel nut chewing in schools throughout Micronesia, Oakley, Demaine and Warnakulasuriya (2005) found that 63.4% of minors in the area chew betel nut regularly. Additionally, the same study found that roughly 25% of both sexes smoke tobacco. Tobacco chewing and/or snuff dipping was also reported (Oakley, Demaine and Warnakulasuriya 2005). These habits can lead to oral diseases (Giri et al. 2014; Hernandez et al. 2017b; Lee 2017; Moss et al. 2015; Paulino et al. 2017; Paulino et al. 2020) and are addictive (Moss et al. 2015), indicating the potential for continued use and an increased chance for the development of cancer, discussed below. Furthermore, there are different social norms surrounding betel nut chewing and sex in Micronesia, such as the practice being considered unladylike (Paulino et al. 2011).

Chewing betel nut alters the oral microbiome overall. Those who chew it over many years may experience irreversible effects to the makeup of their oral flora by increasing factors that influence antibacterial properties within the oral cavity and possibly increasing the risk of oral diseases, including cancer (Hernandez et al. 2017a). The need for dental care is increased with prolonged use of betel nut, including crowns, root canals, and fillings (Lee 2017) due to the hard, fibrous nature of the nut (Anand et al. 2014). Attrition and abrasion following use of betel nut, as well as chipping, affect the structure of the tooth, potentially leading to severe dental wear (Frost 1972; Priyadarshini et al. 2019). Betel nut chewing also results in dental fractures, tooth staining, periodontitis, and the buildup of calculus followed by gum disease and premature tooth loss (Lee 2017; Trivedy, Craig and Warnakulasuriya 2002). Heavy incisal and occlusal wear can also be caused by continuous betel nut chewing (Giri et al. 2014; Leu-Wai-See 2014; Trivedy, Craig and Warnakulasuriya 2002). The process of dental wear through betel nut chewing is dependent on the consistency of the betel nut, as well as the frequency and duration of an individual's chewing habit (Anand et al. 2014). Over time, the anterior teeth will wear down and the crowns will lose their form, and the incisors will become shortened (Anand et al. 2014).

Individuals choose to chew or not chew for various reasons. Surveyed non-chewing minors report that the bad breath, dental staining, and subsequent poor appearance from those factors lead them to avoid chewing betel nut (Oakley, Demaine and Warnakulasuriya 2005). However, there are many social and cultural reasons for continuing to chew betel nut long-term, including benefits from other medicinal properties, beautification, ceremonial reasons, and peer pressure or a desire for social acceptance (Murphy and Herzog 2015). For example, chewing betel nut results in copious amounts of red saliva, which stains the teeth, gingival, and oral mucosa (Anand et al. 2014). The staining of the teeth has biological effects, but in Chamorro history there are also cultural implications regarding betel nut staining.

The blackening of teeth using plant-based materials was recorded by the Spanish upon their arrival and subsequent conquest of Guam (Zumbroich 2015). This was especially prevalent among Chamorro women, who would stain their teeth intentionally to comply with beauty standards for women at the time (Zumbroich 2015). Teeth blackening may have been ritualistic, as it was associated with feasting and considered a status symbol (Zumbroich 2015). The practice disappeared as the Spanish conquest of Guam was carried out (Zumbroich 2015). It is also a cultural norm among the Chamorro to prepare betel nut by chewing and softening it for elders who have lost their teeth, leading to regular use by younger individuals (Murphy and Herzog 2015).

While betel nut is readily available in Chamorro culture (Murphy and Herzog 2015) there are serious drawbacks to chewing it. Betel nut is a Group 1 carcinogen (Moss et al. 2015; Paulino et al. 2020). It is known to cause oral cancer, oropharyngeal cancer, oral lesions, submucous fibrosis, gum disease, cancer of the pharynx and esophagus, and oral leukoplakia (Moss et al. 2015). Oral leukoplakia has been found in higher amounts in individuals who chew betel nut regularly (Oakley, Demaine and Warnakulasuriya 2005). It is characterized by a white patch on the oral mucosa and has a high potential for becoming malignant (Trivedy, Craig and Warnakulasuriya 2002). Oral leukoplakia is not associated with any other clinical or pathological diagnosis and is solely linked to tobacco, which may be mixed with betel nut (Anand et al. 2014). There are four types of oral leukoplakia: homogenous (white); speckled (red and white); nodular; and verrucous. The speckled type of oral leukoplakia is the more pathological of the group (Trivedy, Craig and Warnakulasuriya 2002).

Submucous fibrosis is another oral pathology linked to betel nut chewing and cancer, resulting in stiffness of the gums and the eventual loss of jaw movement (Talmage-Bowers 2018). These pathologies can be caused by smoking cigarettes or chewing tobacco or betel products (Traub 2020), and the most common cause of submucous fibrosis is betel nut chewing (Rao et al. 2020). Chewing betel nut has a high morbidity rate when it comes to submucous fibrosis with little progress having been made in treatment (Rao et al. 2020).

There are multiple types of oral lesions that are associated with betel nut chewing. These include quid-induced lesions, betel nut-related lesions, and betel nut quid lesions (Anand et al. 2014). These lesions manifest in two ways. An oral mucosal lesion can have a thin border and affect multiple areas of the oral cavity, or it can be localized in the mouth where the betel nut or quid is usually placed by the chewer (Anand et al. 2014). Specific lesions resulting from those categories will be discussed here.

Betel nut-related lesions mainly affect the buccal mucosa, either bilaterally or unilaterally (Anand et al. 2014). It is characterized by a whitish gray discoloration and is not removable (Anand et al. 2014). This type of lesion also has a rough texture (Anand et al. 2014). The betel quid lichenoid lesion is exclusive to betel nut chewers, never being present in non-chewers (Anand et al. 2014). This lesion has fine, white, wavy lines that are parallel to each other and not elevated (Anand et al. 2014). It is localized in the oral cavity atthe placement site of the betel nut (Anand et al. 2014). If a chewer consistently places his or her betel nut quid in the same spot within the mouth, this lesion will form in that area and nowhere else within the oral cavity (Anand et al. 2014).

Of the multiple ethnic groups found in Guam and the surrounding region, Chamorros have higher incidences of cancer (Hernandez et al. 2017b). In a study on mouth cancer rates from 1997-2003, 8.1 per 1,000 Chamorro individuals studied were found to suffer from oral cancer (Paulino et al. 2017). Additionally, in a 1998-2002 study, the mortality rate of the Chamorro due to oral cancer per 1,000 individuals was found to be 6.4 (Paulino et al. 2017). Occurrences of oral cancer are increasing throughout Micronesia (Bhandary and Bhandary 2003).

In 2009, Haddock et al. conducted another study on cancer prevalence in ethnic groups in Guam and the surrounding region. It was found that the Chamorro at that time had an incidence of mouth and pharynx cancer of 24.4 per 100,000 individuals, which is more than twice that of the U.S. rate of 10.7 per 100,000 individuals (Haddock et al. 2009). Compared to other ethnic groups in the area, Chamorros also had a significantly higher rate of mouth cancer, with Filipinos exhibiting these cancer rates at 9.9 cases per 100,000 individuals, Caucasians at 9.6 per 100,000 individuals, Asians at 6.9 per 100,000 individuals, and Micronesians at 6.3 cases per 100,000 individuals (Haddock et al. 2009). These high incidences of betel nut chewing in the Chamorro result in a disparity between that group and other racial or ethnic groups in the development of oral cancer (Paulino et al. 2017). In addition to oral cancer, betel nut chewing is also associated with other, non-communicable diseases among the Chamorro, including cardiovascular disease, diabetes, obesity, and hypertension (Paulino et al. 2017). It may be possible in other collections from Guam to assess broader oral health, including cancers, but in this study the adjacent boney oral structures were not cast.

Another oral disease found in the modern Chamorro is caries. Understandings of oral health are often related to caries prevalence (Doherty, Blinkhorn and Vane 2010). In terms of caries in Guam, it is considered an endemic disease, especially among children, and is commonly left untreated (APIA 2006). Formerly, the caries rate in Guam was twice that of the mainland U.S. (Sterritt, Frew and Rozier 1994). Sterritt, Frew and Rozier (1994) conducted a thirteen-year study that implemented a school-based fluoride mouth rinse program, a clinic-based pit and fissure sealant program, and community water fluoridation in Guam. This study resulted in a decline of caries by 72.8% and an overall improvement in oral health in the area (Sterritt, Frew and Rozier 1994).

Caries is also affected by betel nut chewing. The habit may act as a protector against this oral disease because of some of the factors discussed above. Staining, previously mentioned as a deterrent for many young people in a community where chewing betel nut is common, can act as a protective varnish around the surface of the teeth, preventing caries from forming on the enamel (Trivedy, Craig and Warnakulasuriya 2002). The heavy incisal and occlusal attrition associated with long-term chewing can, by wearing away the surface of the tooth, also wear away areas at risk for or already affected by caries (Trivedy, Craig and Warnakulasuriya 2002). Furthermore, chewing betel nut increases saliva production, which prevents acids from forming in the oral microbiome and plaque from forming on the teeth, leading to the development of caries (Trivedy, Craig and Warnakulasuriya 2002).

Traditionally, the Chamorro believed that diseases such as the ones discussed above were related to spiritual beliefs (Balajadia et al. 2008). If spiritual creatures known as the *taotaomo'na* were not given proper respect, illnesses in humans could develop (Balajadia et al. 2008). Postcontact with the western world, some individuals in Guam still hold these beliefs, and the Chamorro address dental and other pathologies with both traditional and western medicine (Balajadia et al. 2008).

Bioarchaeological Evidence of Dental Pathology in Guam

Archeological evidence demonstrates that many of the above dental diseases and conditions are not modern phenomena in Guam. In an osteobiography of an individual found in Guam from the sixteenth or seventeenth century, Heathcote et al. (2012) describe the skeletal condition of a man called TaoTao Tagga'. In the osteobiography, it is observed that TaoTao Tagga' lost 14 teeth ante-mortem, nine of them being mandibular and the other five maxillary (Heathcote et al. 2012). This could possibly be due to extreme dental wear and periodontal disease, which can be observed on the remaining teeth, which exhibit dentin exposure and periapical caries (Heathcote et al. 2012).

Pathologies like periodontal disease in TaoTao Tagga' led to significant alveolar bone loss. As discussed above, chewing betel nut affects the makeup of the oral microbiome

(Hernandez et al. 2017a). By changing the pH in the oral cavity, dental plaque can accumulate and further periodontal disease, as occurred with TaoTao Tagga' (Heathcote et al. 2012). However, the practice of chewing betel nut also had benefits, mainly the deterrence of caries by wearing down carious lesions on the teeth and destroying caries in the process, with TaoTao Tagga' exhibiting no dental caries whatsoever (Heathcote et al. 2012). Both these oral health phenomena occur today in Guam, and even the method of chewing has not changed (Heathcote et al. 2012). Betel nut staining on TaoTao Tagga's teeth suggests that when he chewed, the betel quid was placed in the retromolar space, a common practice in modern and archeological betel nut chewers (Heathcote et al. 2012).

TaoTao Tagga's dentition showed little room for the eruption of third molars (Heathcote et al. 2012). However, prior to death he lost a lower second molar, allowing an impacted lower third molar to attempt to erupt mesially in the newly available space, which supposedly caused TaoTao Tagga' great pain (Heathcote et al. 2012). This pain may have been treated through betel nut chewing (Heathcote et al. 2012), which further demonstrates the history of betel nut being an important cause and remedy for pathology in Guam.

Understanding the influence dental pathologies have had in Guam and the impact they currently have can help researchers understand societal attitudes towards them. For example, betel nut is a significant factor in oral health in Guam, so documenting the background of its use can shed light on why it is culturally important even with the health risks it poses. Looking at the archeological origins of oral diseases, their causes, and the response to any related illnesses by the individual and the society can assist in understanding the diseases of the past and the attitudes towards those diseases in the present. Such knowledge is important when looking at samples such as the one for the current study, as seeing pathologies like those of TaoTao Tagga' can put into context what an individual may have been doing or experiencing to lead to conditions such as lost teeth, severe dental wear, and caries (or lack thereof).

There are many cultural and environmental factors that go into the population-wide susceptibility of oral diseases. In Guam, social pressures and lack of education play a significant role in the ongoing development of wear, periodontal disease, caries, and oral cancer. Due to individuals in Guam not receiving proper dental hygiene treatment and not being educated on itsimportance, practices such as betel nut chewing continue, subsequently causing the effects described above.

While the sample for this thesis does not allow for collection of evidence of betel nut chewing, processing, or the associated oral cancers in these archeological peoples, other archeological studies suggest that betel nut chewing was prominent pre-contact (Zumbroich 2015) and impacted the color (Pietrusewsky et al. 2016; Pietrusewsky et al. 2010) and attrition (Giri et al. 2014; Leu-Wai-See 2014; Trivedy, Craig and Warnakulasuriya 2002) of teeth, and therefore likely other unknown conditions of the oral soft tissue (Moss et al. 2015; Paulino et al. 2020), though specifics can only be speculated here. Similarly, the long history and deep cultural use of betel nut among the archeological peoples of Guam clearly impact patterns of modern health in the region and in future studies may serve as preventative health information for modern peoples.

Chapter Summary

In this chapter, the pre-contact Chamorro's surroundings, bioarchaeological health, and dental anthropology was discussed. Here, the dental anthropology of the pre-contact group mainly focused on dental health pertaining to caries, AMTL, betel nut staining, and enamel hypoplasia. Additionally, the morphology of Chamorro individuals was briefly mentioned. Modern dental health, including the health effects of chewing betel nut, oral cancer, caries, and periodontal disease, outlined the cultural background and state of oral health for the current population in Guam. An osteobiography from Guam was also discussed, highlighting dental pathologies of past Chamorro individuals. This chapter demonstrates the dental health of both the past and present Chamorro.

Chapter 3: Materials and Methods

The materials used in this study will be discussed in this chapter. Additionally, the methods for analyzing and recording these materials will be discussed, including scales for numerically scoring wear and caries, as well as identification of ante-mortem tooth loss. Morphological dental traits are also considered and have been observed and ranked numerically or scored on presence/absence. Finally, the methods for statistical analysis of pathological and morphological dental traits will be discussed.

Materials

The Collection

For this study, the maxillary and mandibular dental arcades of 63 individuals (consisting of 1,967 observable teeth) from Guam prior to European colonization (A.D. 200 - A.D. 1650) were examined. Dental plaster casts used in this study were made by Lawrence in 1993 from randomly selected skeletons housed in the Paul H. Rosendahl Institute in Guam just after repatriation of a larger collection of remains was underway (Lawrence 1996). Casts were made by pouring yellow labstone into impressions of upper and lower dentitions obtained from the sample (Lawrence 1996). The collection includes 33 males, 26 females, and four non-adults whose sex is unknown, ranging in age from 5 to 60+ years. Of these individuals, 45 are adults and 18 are non-adults. The demographics for the sites from which this sample originates are listed in Table 3.1. Individuals of unknown sex and/or age were not accounted for in this table.

These individuals came from eight sites throughout Guam (Table 3.2). These sites are mapped out in Figure 3.1. Only teeth in good condition and not exhibiting extreme dental wear or extreme ante-/post-mortem tooth loss were included in the sample by Lawrence (1996). This is problematic for this study because the focus is partially on those pathologies and the availability of data on that subject is limited in this sample.

Table 3.1 Demographics for this sample.

Site	Males	Females	Adults	Non-adults	Total individuals per site
89-780	10	9	18	1	19
90-882	5	2	6	1	7
AZ140	6	2	3	6	8
91-1040	3	1	3	2	4
92-1256	1	0	1	0	1
89-757	4	4	6	2	18
89-744N	2	0	2	0	2
89-744	0	1	1	0	1
90-797	2	2	4	0	4

90-796	0	0	0	3	3
89-737	0	0	0	1	1
89-661	0	0	0	1	1

Table 3.2. The latitude and longitude of each site and the percentage of those individuals from the entire sample included from each site (Anonymous 2012). Three individuals from the sample were not included in this table as the only information regarding the site they were found at was "Guam" with no further indication of their origins.

Site name	**Latitude and longitude**	**Number of individuals found at site**	**Percentage of individuals in collection**
Agana	(13.465600, 144.746384)	21	33.87%
Sandcastle, Mocha, Hyatt	(13.443740, 144.777670)	15	24.19%

Maitas Chiribaya	(13.500090, 144.775940)	9	14.52%
Camp Watkins	(13.496870, 144.774010)	9	14.52%
Mangilao	(13.449750, 144.802902)	1	1.61%
Sue Hiro	(13.47861, 144.81834)	1	1.61%
Gun Beach	(13.521590, 144.807300)	3	4.83%
Saipan	(15.185048, 145.746719)	3	4.83%

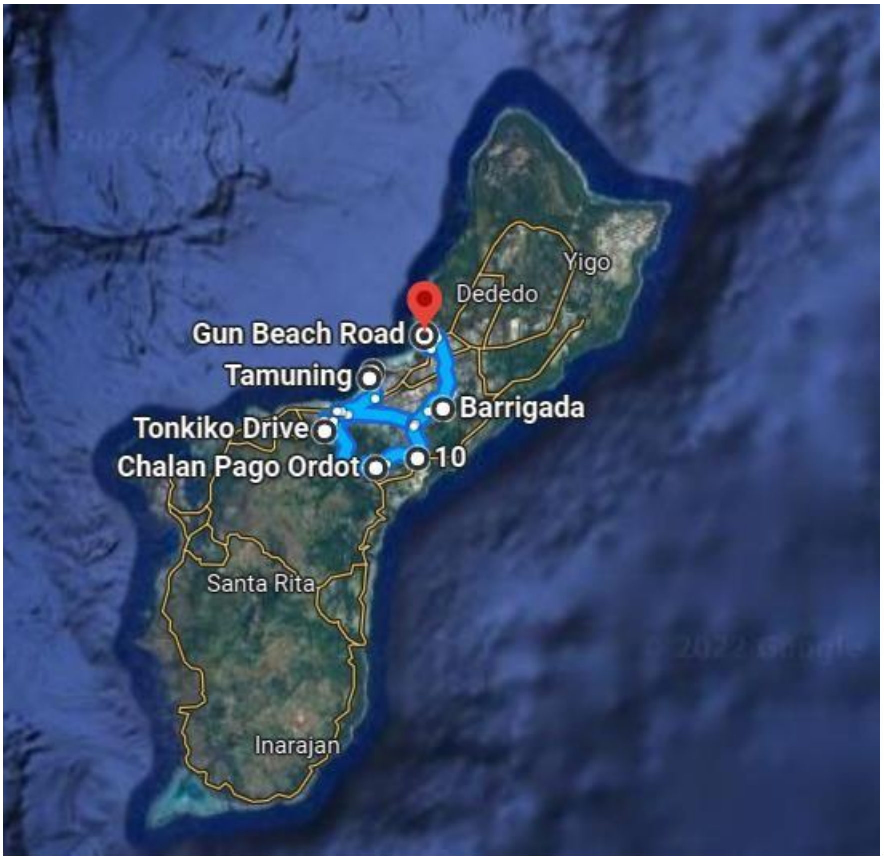

Figure 3.1. Map of locations of archeological sites in modern day Guam (Google Maps 2022).

Methods

Sex and Age Estimations

Unfortunately, Lawrence (1996) does not describe the methods involved in estimating age and sex of the individuals in this collection and the author was unable to be contacted. Therefore, we are left to assume that the more common anthropomorphic methods of that era were used. This would include age estimation for nonadults focusing on dental eruption and maturation, and age estimation of adults including degenerative scoring of the auricular surface and pubic symphysis (Buikstra and Ubelaker 1994). It is also assumed that common anthropomorphic methods described by Buikstra and Ubelaker (1994) were applied to estimate sex from the cranial and pelvic remains for adults. Lawrence (1996) did mention that nonadults were not sexed. Only adult individuals in which sex was estimated were used in this study.

Inventory and Odontometrics

All dental casts were digitally photographed with a scale from the occlusal, buccal/labial, and lingual views. Ultimately, these photographs will be made available to outside researchers for study and linked to a collection database. Dental inventory of each individual and cast was then recorded (Beck and Smith 2018). Each tooth was scored with an inventory code for tooth class (tooth type, mandibular or maxillary), tooth number, pathology (dental attrition, caries, AMTL), and crown morphology (anterior and posterior) traits.

Standard measurements, including mesiodistal length, buccolingual breadth, and crown height of the teeth were taken using Mitutoyo dental calipers (mm) (McClelland 2003). Teeth were measured even when displaying wear, but this was noted as a contributing factor to metric results with the associated wear scores. The mesiodistal length was measured to the maximum distance parallel to the occlusal and labial surfaces (McClelland 2003). Buccolingual breadth was measured as the maximum length perpendicular to the mesiodistal diameter and parallel to the occlusal surface (McClelland 2003). Crown height was measured from the cemento-enamel junction to the highest point of the crown. All measurements were recorded to the closest 0.1 mm to account for intra-observer error (Hillson 1996; Buikstra and Ubelaker 1994).

Pathological Traits

Multiple pathologies were assessed to estimate patterns of dental disease within the sample. These include dental attrition, caries, and AMTL. Dental attrition was explored through the scales put forth by Smith (1984), Scott (1979), and Lagan and Ehrlich (2021). The extent of caries was addressed using a numerical scale from Towle et al. (2021). AMTL was marked for presence or absence. Studying these traits can lead to information regarding diet (Forshaw 2014; Rivals, Schulz and Kaiser 2009), subsistence strategy (Forshaw 2015), cultural activities (Burnett, Irish and Fong 2013; Kaifu et al. 2003; Mahajan 2019), and a group's relationship with the surrounding environment (Forshaw 2014; Forshaw 2015; Rivals, Schulz and Kaiser 2009).

Dental Wear

Teeth located on the buccal side of the mandible and the lingual side of the maxilla have the heaviest bite when masticating, typically resulting in more attrition, or dental wear that results from contact between the teeth without the presence of food (i.e., tooth grinding) (Kaidonis 2008), than other areas in the mouth. Therefore, these are selected for study more often than other areas of the mouth (Mays, de la Rua and Molleson 1995). Furthermore, molars experience attrition more than other teeth from mastication, with special attention paid to upper molars that tend to have thicker enamel, which slows attrition compared to other teeth (Bas et al. 2021; Kim et al. 2018). Molars also have the greatest consistency in wear patterns, making them likely to be analyzed for attrition (Santini, Land and Raab 1990). Attrition tends to be mirrored on the right and left sides of the maxilla and mandible, so in some studies the attrition on only one side of the dentition is analyzed (Santini, Land and Raab 1990).

For this study, attritional macrowear of dental antimeres of the mandible and maxilla were scored (Petraru, Groza and Bejenaru 2018). Smith's (1984) system for anterior teeth was used to score attrition of incisors, canines, and premolars (Table 3.3). This system describes eight stages of wear (1-8) based on dentin exposure and horizontal reduction of the enamel crown (Hillson 1996). Smith's (1984) scale scores anterior dental attrition by the extent of the destruction of the crown and the changes in the tooth's shape as it is worn down, from a complete lack of dental wear (score of 1) to total destruction of the crown (score of 8).

Scoring of severity and location of attrition of molars followed Scott's (1979) and Lagan and Ehrlich's (2021) scales (Tables 3.4 and 3.5, respectively). Scott's (1979) scale consists of a ranked scale of four arbitrarily divided quadrants (buccal-distal, buccal-mesial, lingual-distal, lingual-mesial) per tooth with each quadrant receiving a separate score of one through 10 which are then added together to yield a final composite score ranging from four to 40, indicating the total severity of the attrition on each tooth. Scott (1979) considers a score of 0 for teeth that cannot be observed due to ante-mortem or post-mortem tooth loss, unerupted, or congenitally missing teeth. However, since this study used a separate coding system for inventory, the score of "0" was not employed. The primary concern in this scale is to score the amount of remaining enamel per quadrant per tooth (Scott 1979). The MolWear method developed by Lagan and Ehrlich (2021) also analyzes four quadrants of a molar, but instead of looking for enamel destruction the focus is on dentin exposure.

An average dental wear score was calculated for each individual. This was used as an arbitrary index to compare abrasion and attrition across individuals. The calculation combines all dental wear grades from one individual or tooth class to produce an overall average score (Eshed et al. 2006; Hubbe et al. 2012). Even though the data are ordinal and this measure of central tendency is not recommended for categorical variables (Sokal and Rohlf 1995), it is commonly employed in dental anthropological studies because a standard index has not been established for dental wear. Ten percent of the individuals scored for health data were re-scored using the same methods to test intra-observer error.

Table 3.3. Smith's scale for scoring dental wear for canines and premolars (Buikstra and Ubelaker 1994; Smith 1984).

Stages of wear	**Description**
1	Unworn to polished or small facets (no dentin exposure)
2	Canine: point/hairline of dentin exposed Premolar: moderate cusp removal
3	Canine: dentin line of distinct thickness Premolar: full cusp removal and/or moderate dentin patches
4	Canine: moderate dentin exposure Premolar: at least 1 large dentin exposure on 1 cusp
5	Canine: large dentin area with enamel rim complete Premolar: 2 large dentinal areas
6	Canine: large dentin area with enamel loss on 1 side or thin enamel Premolar: dentinal areas coalesced, enamel rim still complete
7	Canine: enamel rim lost on 2 sides or small remnants of enamel remain Premolar: full dentin exposure, rim loss on at least one side
8	Complete loss of crown, no enamel remaining, crown surface takes on shape of roots

Table 3.4. The first five scores and their descriptions in Scott's scale (Scott 1979: 214).

Score	Description
0	No information available (tooth not occluding, unerupted, antemortem or postmortem loss, etc.)
1	Wear facets invisible or very small
2	Wear facets large, but large cusps still present and surface features (crenulations, noncarious, pits) very evident. It is possible to have pinprick size dentin exposures or "dots" which should be ignored. This is a quadrant with *much* enamel.
3	Any cusp in the quadrant area is rounded rather than being clearly defined as in 2. The cusp is becoming obliterated but is not yet worn flat.
4	Quadrant area is worn flat (horizontal) but there is no dentin exposure other than a possible pinprick sized "dot"

Table 3.5. Scale for measuring dentin exposure on molars (Lagan and Ehrlich 2021).

Score	Description	% Dentin Exposed
1	Little to no wear; tooth just in occlusion	0
1	Enamel worn, no dentin exposed	0
2	"Pinprick" to small dot	<1
3	Moderate dentin patch	1-24
4	Large dentin patch, likely still surrounded on all sides by enamel	25-50
5	Some inter-cuspal coalescence	45-60
6	Extreme inter-cuspal coalescence	50-75

7	Thick enamel ring	60-85
8	Thin enamel ring	85-99
9	Full dentin exposure	100

Caries

Caries is a dental disease that originates in the enamel (American Dental Association Division of Science 2013). Although there may be a color change on the tooth's surface, not observable in this sample, lesions do not qualify as caries without cavitation into the enamel (Towle et al. 2021). Caries is the result of tooth-adherent bacteria - especially *Streptococcus mutans* - metabolizing sugars from dietary materials, creating acids that eventually lead to tooth decay (American Dental Association Division of Science 2013; Rathee and Sapra 2021). The development of caries relies on the presence of these materials, namely highly cariogenic foods, as well as factors relating to the individual and the environment (Rathee and Sapra 2021).

Cariogenic foods are classified as those with large amounts of refined carbohydrates and sugars, as well as fruits, honey, and some nuts and seeds (Towle et al. 2021). Knowledge of cariogenic foods can be used to estimate the diet and subsistence strategy of archeological specimens (Luna and Aranda 2014). For example, hunter-gatherers, who eat fewercarbohydrates than agriculturalists, have a lower association with caries than agriculturalists (Buzon and Grauer 2002; Luna and Aranda 2014).

For the present study, Towle et al.'s (2021) descriptions of caries are used. Towle et al. (2021) identify caries' locations on the tooth as being distal, buccal, occlusal, lingual, mesial, root, or a combination of these areas. Additionally, Towle et al. (2021) rank the severity of caries on a numerical scale from 1-4 (Table 3.6).

Table 3.6. System for scoring caries severity from Towle et al. (2021: 1).

Score	**Description**
1	Enamel destruction only
2	Dentin involvement, pulp chamber not exposed
3	Dentin destruction, pulp chamber exposed
4	Gross destruction with crown mostly affected

In addition to the locations listed above, interproximal-medial, or the space between the mesial side of the tooth in question and its neighboring tooth, and interproximal-distal, or the distal space of a tooth followed by the tooth behind it, sections of the teeth are considered. Furthermore, a similar scoring system is used. Other information about caries collected for this study included the amount of caries per tooth, the amount of caries per individual, and the frequency of caries in both the anterior and posterior teeth.

Ante-Mortem Tooth Loss (AMTL)

Ante-mortem tooth loss describes the condition in whicha tooth was lost during life, and there had been some degree of bone remodeling in the socket.It is affected by multiple factors (Bagis 2018; Hillson 1996; Lukacs 2007; Mower 1999). Researchers (Bagis 2018; Lukacs 2007; Mower 1999) state that food consistency and preparation are the primary factors in AMTL. Food consistency includes abrasive foods and softer foods. Abrasive foods can lead to attrition, pulp exposure, dental abscessing, and finally tooth loss (Bagis 2018). Soft foods that are cariogenic may lead to caries, which can lead to AMTL (Bagis 2018). Secondary causes of AMTL are nutritional deficiency diseases, cultural or ritual ablation, trauma, aging, periodontal disease, and intentional extraction (Bagis 2018; Fujita et al. 2013; Luna and Aranda 2014). However, these potential causes cannot be inferred as the reason for specific instances of AMTL (Chazel et al. 2005).

Scoring of Morphological Traits

Dental morphology, as defined by Scott (2008: 265), is the "distinct features or traits of the crowns and roots that are present or absent and, when present, exhibit variable degrees of expression." Morphological studies were initially based on linear measurements and qualitative descriptions, but currently quantitative descriptions and comparative morphology have become more common (Rizk et al. 2013). Many morphological traits can be measured on a continuous scale (McClelland 2003), meaning that they can be fully described by measurements (Jackes, Silva and Irish 2001). Such analysis can be aided by the Arizona State University Dental Anthropology System (ASUDAS) (Scott 2008) to help record the morphology of teeth.

The ASUDAS is a system to analyze dental morphology, and the computer system rASUDAS is used to calculate the probability of an individual's ethnicity or geographic origins based on those traits involving tooth crown and roots (Scott 2018). It involves the use of plaster dental casts/plaques to standardize observations of dental morphology through a numbered grading system (Artaria 2007). There are two versions of the ASUDAS. The alpha version involves 17 dental traits classified as either being present in the tooth or present to a point (Scott et al. 2018). The beta version involves 21 dental traits, which can be removed from the list or combined with other listed traits (Scott et al. 2018). These traits are used to estimate the ancestry of samples, which are applied to a reference sample of geographic areas (Scott et al. 2018).

These reference samples are the American Arctic and Northeast Siberia; American Indian; East Asia; Southeast Asia and Polynesia; Australo-Melanesia and Micronesia; Sub-Saharan Africa; and Western Eurasia (Scott et al. 2018). Other reference samples come from Christy G. Turner II's lab, who developed ASUDAS (Scott et al. 2018). rASUDAS allows the user to enter data regarding tooth morphology to estimate an individual's probable biogeographic ancestry (Scott et al. 2018).

The advantages to using the rASUDAS processor include having a genetic basis of dental morphology, which assists in understanding geographic ancestry (Scott et al. 2018). Estimating ancestry/geographic origins by this method involves collecting morphological tooth traits and analyzing which of those traits match with groups in areas of the world (Scott et al. 2018). Scott et al. (2018) discuss various tooth traits that are associated with geographic areas, such as shoveled incisors associated with areas in Asia, or Carabelli's cusp with Caucasian populations. These traits are analyzed through ASUDAS plaques and pictures. Estimating geographic ancestry can be done using the rASUDAS processor by entering data about morphological traits found in dental samples. The traits recorded will be matched to potential ancestry clusters (Scott et al. 2018). Furthermore, since teeth preserve well, they contain data that may have been lost in less-well-preserved parts of the body (Scott et al. 2018). Because the environment does not affect teeth as much as other parts of the body, they have more information on inherited and ethnicityrelated traits (Scott et al. 2018). Some of these traits are only found in teeth, increasing their importance when researching ethnicity (Scott et al. 2018).

When studying morphological traits, wear can lead to misinterpretations (Burnett, Irish and Fong 2013). The example given by Burnett, Irish and Fong (2013) is that a lower molar with a deflecting wrinkle may appear to have a Y-5 pattern. If such a misinterpretation occurs throughout a sample, it could appear that the pattern is more common in a population than it was (Burnett, Irish and Fong 2013). There have been multiple solutions proposed for the impacts wear can have on morphological traits, including the exclusion of teeth showing excessive wear when studying morphology, which is not a standardized method (Burnett, Irish and Fong 2013). This leads to the problem of how much wear makes a tooth ineligible (Burnett, Irish and Fong 2013).

In this study, 19 morphological traits were analyzed and scored according to the extent of the trait, if present, with information collected mainly on the upper and lower molars and incisors, and one trait for premolars. The numerical scales for these traits come from Buikstra and Ubelaker (1994), Edgar (2017), and Scott and Irish (2017). These traits can be seen in Table 3.7. The incisor traits of interest here include characteristics of spacing (including the midline diastema and winging), as well as characteristics that involve the structure of the tooth (including tuberculum dentale, interruption groove, and various types of shoveling of both the upper and lower incisors). The traits pertaining to molars involve accessory cusps (including the hypocone, Carabelli's cusp, protostylid, the fourth cusp of the lower second molars, and cusps 5, 6, and 7), as well as other traits related to the surface of the tooth (enamel extensions, groove pattern, deflecting wrinkle). The morphology of the third molar as pegged, reduced, or missing is also addressed in this study. The morphological trait of interest from the premolars also involves accessory cusps, solely on the lingual side of the tooth's crown.

Most of these morphological traits can be entered into the rASUDAS processor, which calculates the probability of an individual's biogeographic ancestry based on his or her dental morphology. Some traits (midline diastema, double shoveling, lower incisor shoveling) were excluded from the rASUDAS processor as they are not applicable to that system. The degree of probability estimated by rASUDAS depends on the extent of morphological traits. For example, low frequencies of all crown traits indicate a high probability of Western Eurasian ancestry, while high frequencies suggest a low probability of Western Eurasian ancestry (Scott et al. 2018). Ancestry estimation using rASUDAS is done using a Bayesian algorithm in R to estimate ancestry based on dental morphology of samples (Scott et al. 2018).

Table 3.7. Morphological traits collected for this study by type of tooth. Scoring systems found in Buikstra and Ubelaker (1994); Edgar (2017); and Scott and Irish (2017).

Type of tooth	**Morphological trait**	**Score range**
Molars	Hypocone (UM)	0-7

	Carabelli's cusp (UM)	0-8
	Cusp 5 (UM1)	0-6
	Enamel extensions (UM)	0-4
	Groove pattern (LM2)	Y/+/X/0 (not observable)
	4 cusps (LM2)	0-6
	Cusp 6 (LM1)	0-6
	Cusp 7 (LM1)	0-5

	Protostylid (LM1)	0-8
	Deflecting wrinkle (LM1)	0-4
	Pegged-reduced-missing (UM3)	Present/absent/not observable
Incisors	Midline diastema (UI1)	Present/absent/not observable
	Tuberculum dentale (UI1)	0-4
	Winging (UI1)	0-5
	Upper incisor shoveling (UI)	0-8
	Double shoveling (UI)	0-7

	Lower incisor shoveling (LI)	0-4
	Interruption groove (UI2)	0-2
Premolars	Multiple lingual cusps (LP3, LP4)	0-4

Every observable tooth (i.e., not missing, extensively damaged, severely worn, or obscured by the casting material) was scored for its respective traits. That information was recorded in the database and later entered into the rASUDAS biogeographic ancestry clusters processor, which produced information based on tooth morphology about the probable geographic origins of the samples. The data was then analyzed and interpreted to find the percentage of biogeographic ancestry clusters in the sample based on the biogeographic estimations of each individual.

Analyses

The approach to the analyses conducted in this study considers both individuals and individual teeth. It is important to establish whether the unit of analysis is the individual or the individual tooth (Gagnon and Wiesen 2013). When focusing on individuals from the sample, the sample size is smaller than when the focus is on each individual tooth from all the individuals because each individual is only one datum. This approach allows for the presence or absence of dental pathology and morphology to be studied per person.

Analyzing multiple teeth per individual increases the sample size. To avoid incorrect results from analyzing a large number of teeth, parts of the tooth, such as class (incisors, canines, premolars, molars) and area (mesial, distal, buccal, lingual, occlusal, etc.) can be studied for data related to wear, caries, tooth loss, and chipping. Studying both individuals and each tooth or tooth class allows for further exploration of dental pathology and morphology in the sample. To avoid overgeneralizations of the data and to distinguish between individuals with multiple affected teeth versus an individual with a single affected tooth, an inventory was kept recording the pathological and morphological traits of each tooth per individual.

Analysis of Caries and AMTL

According to Hillson (2001), carious lesions are best categorized according to the area where the caries occurred on the tooth. This is instead of using a single index, which is potentially problematic when analyzing caries in regard to tooth class, sex, and age (Hillson 2001). For this study, scores for caries and AMTL were analyzed in the context of both the individual and the individual tooth.

All tooth classes (incisors, canines, premolars, and molars) were observed for caries in all locations of each tooth. In addition to the location of caries on individual teeth, the frequency of their appearance per individual was recorded. The dental caries rate (DCR) was calculated to find the caries index for each individual. The DCR is found by dividing the total number of teeth observed to have caries by the total number of observable teeth, then multiplying it by 100 (Erdal and Duyar 1999; Hillson 1996; Hillson 2008). The equation is expressed as:

DCR = (Total number of carious teeth) / (Total number of observable teeth) X 100

An indicator of AMTL, as opposed to post-mortem loss, is resorption of the alveolar bone and/or porosity around the tooth socket (Eshed, Gopher and Hershkovitz 2006). In this study, presence or absence of a tooth in an alveolar socket is recorded as well as the total number of teeth lost prior to death per individual. Additionally, full or partial resorption, as well as porosity in the surrounding alveolar bone was used as evidence for AMTL versus post-mortem tooth loss (PMTL) (Fujita et al. 2013; Hillson 2001). The AMTL rate (AMTL-R) was calculated as the number of teeth lost prior to death divided by the number of empty sockets, which was then multiplied by 100. This equation comes from Cucina and Tiesler (2003). The AMTL-R equation is expressed as:

AMTL-R = (Number of teeth lost ante-mortem) / (Number of empty sockets) X 100

Intraclass Correlation Coefficient

Statistical testing was carried out using both the IBM Statistical Package for the Social Sciences (SPSS) version 28.0.1 (2021) program and by hand with a calculator. Statistical tests conducted using SPSS included descriptive statistics and frequencies. The descriptive statistics found with this program included the sample size (N), the maximum (mode) and minimum values, the mean of the values in each variable, and the standard deviation for each variable. Mean and standard deviation were excluded from this study. Tables were made using SPSS and Excel (2022) to compare the maximum and minimum score of pathological and morphological variables, and to analyze biogeographic ancestry clusters as they relate to pathological traits.

SPSS was also used to find the intraclass correlation coefficient for groups of variables. These variables were grouped together based on pathology (attrition, caries, AMTL) and morphological traits (tooth class, accessory cusps, traits scored by presence or absence, biogeographic ancestry, traits found on maxilla or mandible). These traits indicated the intraclass correlation coefficient for groups of variables from the databases of Health Data, Observer Error Health Data, Morph Data, and Observer Error Morph Data. Health Data includes scores for pathological traits of each individual in the sample, while Observer Error Health Data is the rescoring of 10% of Health Data. Morph Data consists of the scores assigned to the dental morphological traits of each individual in the sample, while Observer Error Morph Data is the rescoring of 10% of Morph Data. Health Data and Morph Data were re-scored to test for intraobserver error.

The intraclass correlation coefficients were compared between Health Data and Observer Error Health Data, and Morph Data and Observer Error Morph Data. It was found that groups were either statistically significant or not by using the equation:

$$Z_{Observed} = (Z_1 - Z_2) / \sqrt{}(1/N_1\text{-}3) + (1/N_2\text{-}3)$$

Where Z_1 and Z_2 are the z-scores for the respective intraclass correlation coefficients, and N_1 and N_2 are their sample sizes. A variable is statistically significant if it is less than or equal to the pvalue of 0.05, indicating a low intra-observer error.

The measure of central tendency employed in this study is mode, which is accompanied by least frequent scores of pathology and morphology variables. Mean and standard deviation were not available due to the expression of the data in the program used.

Chapter Summary

The methods for this study focus on the scoring of dental attrition and identification and recording of caries and AMTL. This was done through numerical scales that focus on a specific area or type of pathology (destruction of enamel/exposure of dentin on the molars, loss of crown on anterior teeth, extent of caries) as well as severity of a pathology (attrition, caries, AMTL). Morphology was also observed and scored numerically to analyze the extent and/or presence or absence of morphological dental traits found mostly on molars and incisors, but also on premolars. These traits were statistically analyzed using SPSS tests, including linear regression, the Mann-Whitney U test, Welch and Brown Forsythe procedures, the Kruskal Wallis ANOVA procedure, and MANOVA to better understand dental pathology and morphology within the sample.

Chapter 4: Results

This chapter presents the result of statistical analyses of the data for frequencies of dental attrition, caries, AMTL, and morphological traits. Intra-observer error was also analyzed, followed by descriptive and inferential statistics. The frequencies, mode, and least frequent scores for the pathology and morphology variables are then assessed in order to understand if and how the variables in health and morphological data may correlate and what that may indicate about the dental anthropology of the collection.

Intra-Observer Error

Seven individuals, or 10% of the sample, were randomly selected to find intra-observer error using the $Z_{Observed}$ equation discussed in Chapter 3. This included rescoring of all pathological and morphological traits in the Health Data and Morph Data databases to determine the observer's rate of error. The critical value, which indicates if the scoring differences are statistically significant or not, for all statistical tests in this study is ±1.96, which were run at a 95% confidence interval with a p-value of 0.05.

All pathology-related variables and most morphology variables were found to be statistically significant with p-values less than 0.05. Traits found to be statistically significant are considered to have a low intra-observer error, while traits that are not statistically significant have a high intra-observer error. Those that were found to have a high intra-observer error include morphological traits for incisors, all mandibular morphological traits, and morphological traits ranked as present or absent only. All other morphological traits and pathologies recorded for this sample had a low intra-observer error. The results of the Health Data intra-observer error tests can be seen in Table 4.1, and the results for Morph Data can be seen in Table 4.2.

Table 4.1. Intra-observer error for dental pathologies within the sample. Found by comparing variables from the Health Data and Observer Error Health Data databases.

Pathology	Relation to p-value	Statistically significant?	Intra-observer error
(Entire databases)	-1.545 < 0.05	Yes	Low
Caries	-0.96 < 0.05	Yes	Low
Wear	-0.96 < 0.05	Yes	Low
AMTL and chipping	-1.91 < 0.05	Yes	Low
AMTL and number of observable teeth	0.0035 < 0.05	Yes	Low
AMTL and caries	-2.30 < 0.05	Yes	Low

Table 4.2. Intra-observer error for dental morphological traits within the sample. Found by comparing variables from the Morph Data and Observer Error Morph Data databases.

Morphological trait	Relation to p-value (0.05)	Statistically significant?	Intra-observer error

(Entire databases)	-0.83 < 0.05	Yes	Low
Incisors	0.77 > 0.05	No	High
Molars	-3.40 < 0.05	Yes	Low
Accessory cusps	-1.91 < 0.05	Yes	Low
Present/absent	0.31 > 0.05	No	High
rASUDAS variables	-1.50 < 0.05	Yes	Low
Cusps 5, 6, 7	-0.99 < 0.05	Yes	Low

Pathological Traits

Table 4.3 displays the score ranges and the most and least frequent scores for pathological traits observed in the entire collection. Results from this table will be discussed in the corresponding sections below.

Table 4.3. Minimum and maximum scores for pathological traits.

Variable	Range of scores	Most frequent score	Most frequent score %	Least frequent score	Least frequent score %
Anterior attrition	1-8	7	21.65%	3	4.77%

Posterior attrition	1-10	3	33.81%	7	0.50%
Overall wear score (molars)	0-40	12	11.54%	23, 30, 36, 38, 39, 40	0.24% (each)
MolWear	1-9	1	54.45%	6	0.68%
Number of caries	N/A	5	11.39%	14	1.02%
Number of observable teeth	0-32	29	9.62%	32	1.58%
Number of teeth lost premortem	N/A	0	46.28%	5, 9	1.63% (each)
Chipping	Present/Absent	No	92.46%	Yes	7.54%
Total chipping	N/A	1	24.39%	9	1.63%

Dental Wear

Dental attrition was be analyzed by separating anterior and posterior wear. An example of wear from this collection can be seen in Figure 4.1.

Figure 4.1. An example of extreme wear of an adult female from the archeological site at Agaña, Guam. Note the loss of crown shape on the anterior teeth and severe wear facets on the molars.

The results indicate that attrition is most prevalent in this sample on incisors, canines, and premolars as compared to molars. Specifically, anterior attrition most frequently scored higher (7 out of 8) and least frequently scored lower (3 out of 8). Posterior attrition variables tended to score lower more frequently (posterior attrition at 3 out of 10; overall wear score at 12 out of 40; MolWear at 1 out of 9) and higher less frequently (posterior attrition at 7 out of 10; overall wear score tied at 23, 30, 36, 38, 39, 40 out of a possible of 40; MolWear at 6 out of 9). In the numerical scoring for anterior attrition, most anterior teeth had a score of 7 out of 8 in severity of attrition, that score occurring in 21.65% of the teeth sampled, with all other scores for anterior wear occurring less frequently.

The most common score for anterior attrition by archeological site was a score of 7 out of 8. The highest frequency of anterior attrition was 7 (21.65%) and the lowest was 3 (4.77%). Across all sites, anterior attrition in males occurred most frequently at the score of 7 (25.11%) and in females occurred most frequently at the score of 2 (17.45%). The most common score for posterior attrition by archeological site was a score of 3 (33.81%) out of 10 and the least frequent score was 7 (0.5%). Across all sites, posterior attrition in males occurred most frequently with scores of both 12 and 15 (10.97% each) and in females at a score of 20 (15.50%) (Table 4.4). This indicates that within the entire collection, males demonstrated higher anterior wear, while females demonstrated higher posterior wear. Overall, males in the sample exhibited more wear than females.

R-coefficients show that there is generally a medium-to-low correlation between the dental attrition variables that were tested, with the exception of posterior attrition and MolWear scores, which have a strong relationship (R coefficient of 0.990). This indicates that most of the independent variables, including anterior attrition, posterior attrition, overall wear score, and MolWear scores, had a small influence on the dependent variables (posterior attrition, overall wear score, and MolWear scores) except for posterior attrition's effect on MolWear, which is strong (R square of 0.981).

The MANOVA procedure indicates that archeological sites have a statistically significant difference in anterior attrition, posterior attrition, and MolWear, but that overall wear score does not. The MANOVA procedure for the impact sex has on dental wear variables indicates that only anterior attrition is affected by sex, while posterior attrition, overall wear score, and MolWear are not. The Wilks' lambda statistical significance for dental attrition by both sites and sex is <

0.001. The statistical significance of both anterior attrition and overall wear scores for the posterior dentition in the sample, as found by the Fisher-Freeman-Halton exact test and tested against sex, were statistically significant at 0.000, indicating a significant difference in dental attrition between males and females in the sample.

Table 4.4. Mean anterior dental score for individuals in the sample.

Site	Individual	Average anterior dental wear score
89-780	58	2.35
	44B	6.85
	61	2.80
	60	3.70
	62	5.70
	59	5.00
	57	1.55
	47	0.00

	31B	2.50
	35	6.00

	29B	0.00
	29A	1.20
	37	4.45
	28C	1.10
	19	1.35
	38	2.25
	44A	2.10
	23D	2.45
	23A	1.90
	42	5.05
90-882	1	4.65

	5	1.70
	6	4.45
	9	7.00
	8	4.25
	15	2.15
	11	2.65
	10	3.35
	2	3.25
AZ140	t68	3.80
	t73	5.40
	t67	4.15
	t76	4.30
	t72	2.75

	t78	4.80
	t88	0.92
	t74	3.75
	t80	4.10
91-1040	4A	1.45
	1A	2.55
92-1256	16	1.85
	18	5.00

	5	1.20
90-797	177	2.80
	321A	4.75
	245	4.15
	136C	6.80

90-796	5	1.17
	2	0.42
89-687	122	6.70
89-744N	39A	1.15
	41	1.65
89-757	9B	4.05
	9A	5.25
	4	0.70
	13A	1.75
	5	3.80
	7	4.20
	12	1.83
	6A	1.35
	1	5.75

89-744	5	2.50
89-661	1	1.10
89-737	4	0.42

AMTL

Within the entire collection, 53.72% of individuals exhibited AMTL. An example of AMTL can be seen in Figure 4.2 indicated by the red arrow. The data on AMTL indicates that many individuals in the sample (46.28%) did not experience AMTL, however there were instances of multiple teeth being lost in other individuals, the minority of teeth lost ante-mortem being tied at five and nine teeth prematurely lost.

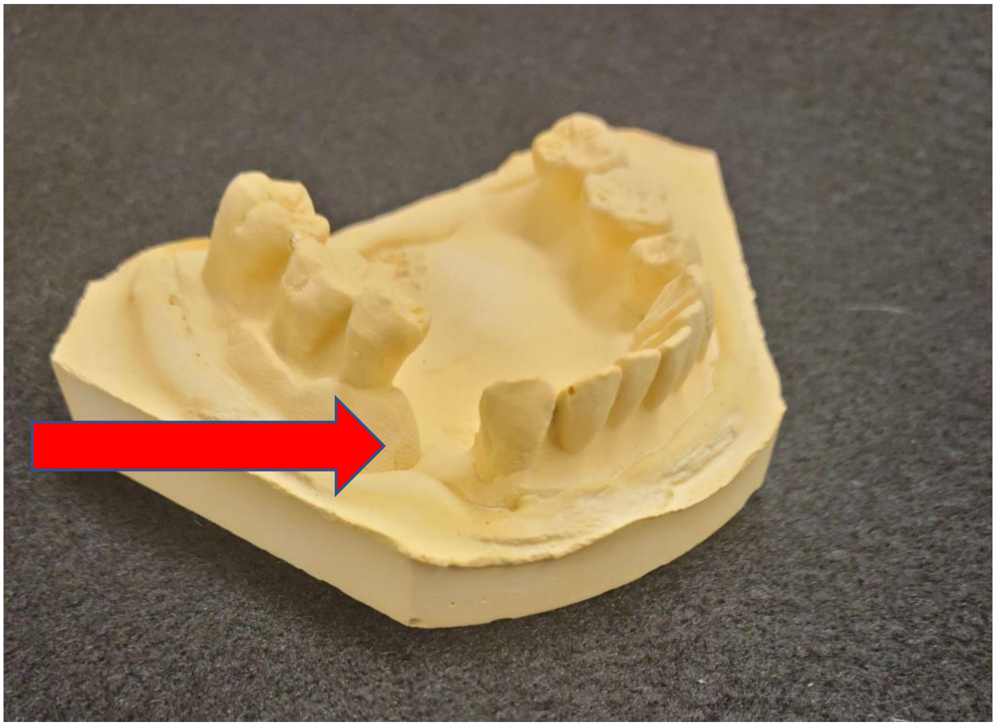

Figure 4.2. AMTL in a teenage female from the sample. Note the loss of the right third premolar and the alveolar resorption of the socket, indicating ante-mortem, as opposed to post-mortem, loss of that tooth.

The most frequent score for AMTL in the sample is 0 (46.28%) and the least frequent scores are 5 and 9 (both at 1.63%). The most frequent AMTL score for males in the collection is 1 (37.05%) and the most frequent AMTL score for females in the collection is 0 (66.87%). The frequency of AMTL in anterior (Figure 4.3) and posterior (Figure 4.4) dentitions are equal. The Fisher-Freeman-Halton exact test indicated statistical significance of AMTL by sex in the sample at 0.000, suggesting a significant difference in AMTL between males and females in the sample.

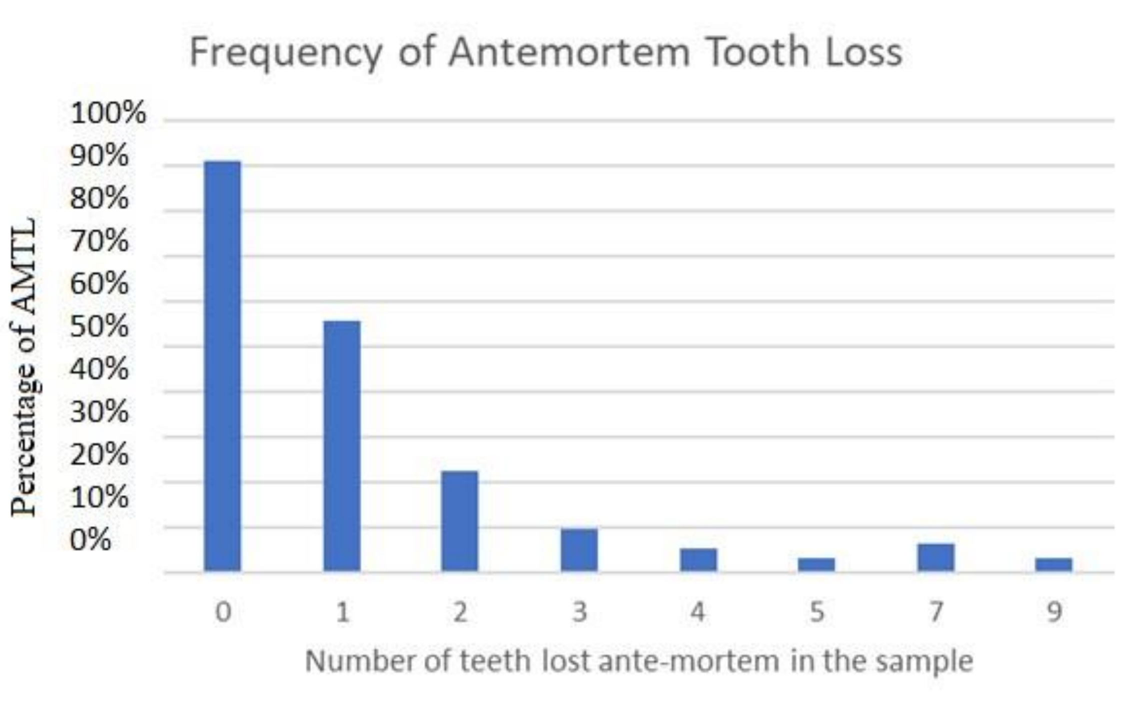

Figure 4.3. The frequency of teeth lost ante-mortem in the sample.

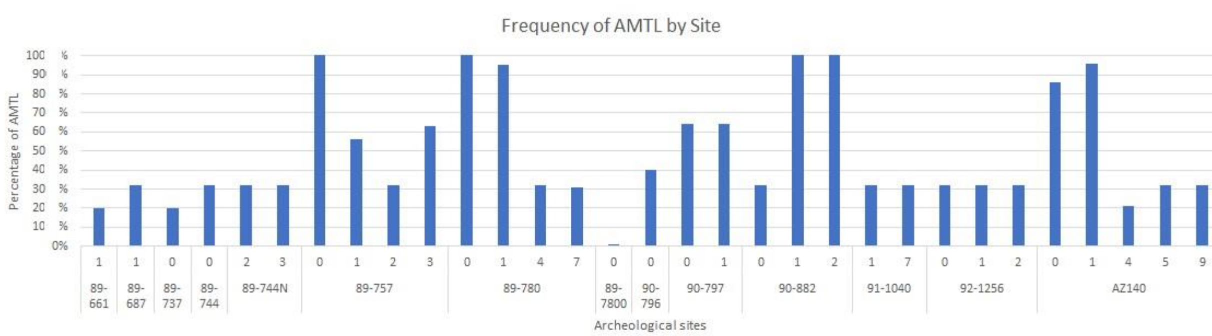

Figure 4.4. The frequency of AMTL in the sample by archeological site.

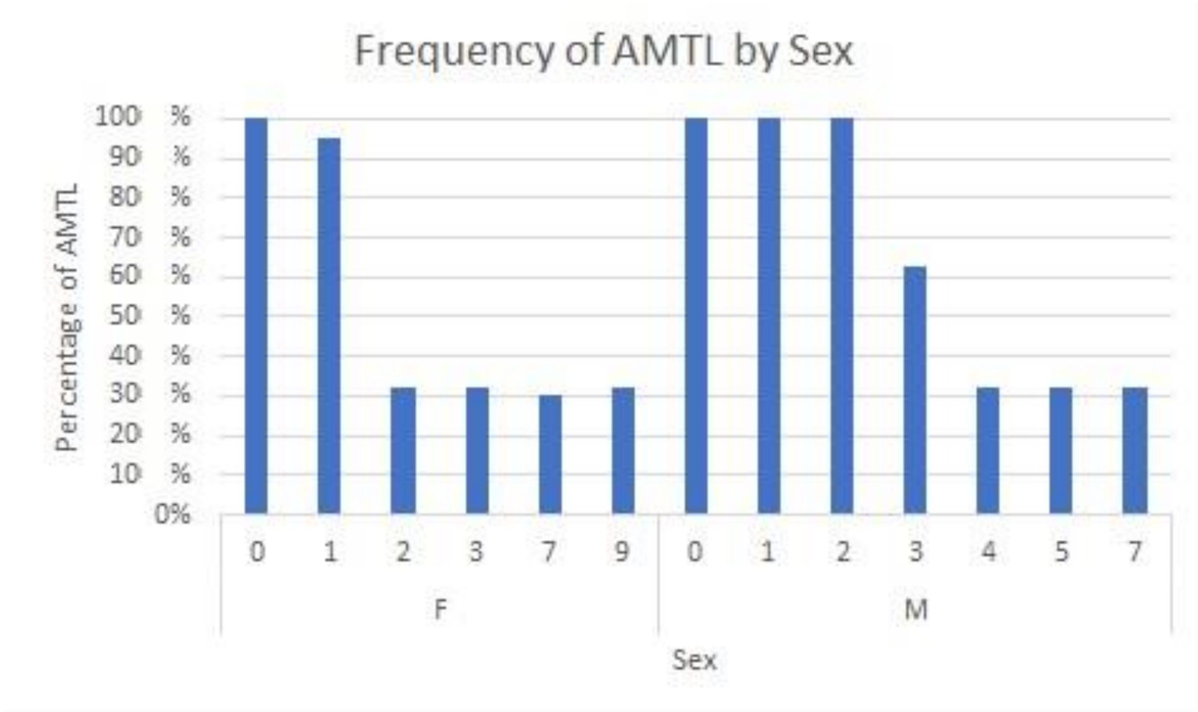

Figure 4.5. The frequency of AMTL in the sample by sex for females (F) and males (M).

Caries

98.44% (63/64) of individuals in the sample had at least one caries. At least one caries was observed in 35.13% of the teeth observed in the collection. An example of caries from the collection is shown in Figure 4.6. The majority of teeth (11.39%) exhibited five caries while the minority of teeth (1.02%) were found to have a higher amount of 14 caries. Chipping is low in the data gathered here, with 92.46% of teeth not being chipped and most of the chipping in the sample (24.39%) occurring only once while the lowest amount of chipping (nine chips) occurred in 1.63% of teeth.

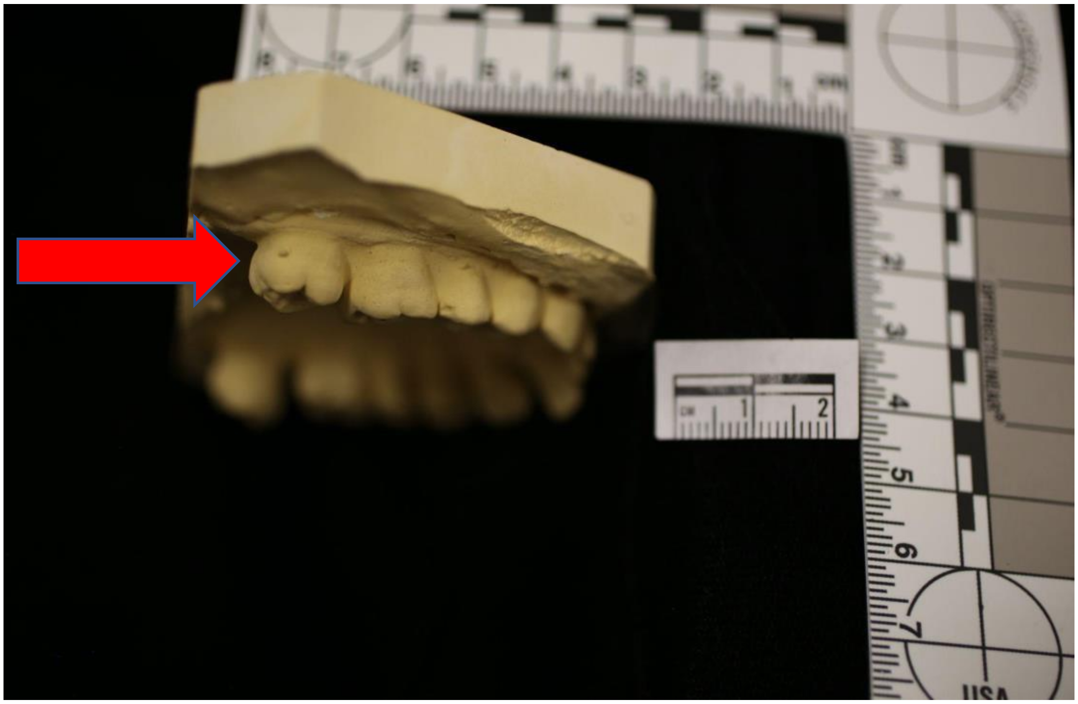

Figure 4.6. Caries on the buccal side of the second maxillary molar of an adult female from Agaña, Guam.

Within the collection, 34.94% (174/498) of the posterior dentition had at least one caries, and 22.14% (271/1,224) of the anterior dentition had at least one caries. In analyzing the range of caries in the sample by sites, the archeological site with the highest amount of caries (81.71%) was site 89-780, and the archeological site with the least amount of caries (0.86%) was site 89737. Within the sample, 83.88% of males, 56.48% of females, 18.68% of individuals of unknown sex had carious teeth.

There is a low correlation between the number of caries and attrition, as seen by the R coefficient from a linear regression test (0.474 for caries and anterior attrition and 0.615 for caries and posterior attrition). Additionally, the R square indicates the number of caries has little influence on anterior or posterior attrition, but a high influence on the number of observable teeth (0.985).

The number of caries was tested using the Wilks' lambda for MANOVA test by archeological sites and sex. There is statistical significance at < 0.001 of caries by site and amount of caries by sex. The Fisher-Freeman-Halton exact test of caries in the sample tested by sex indicated statistical significance of 0.000.

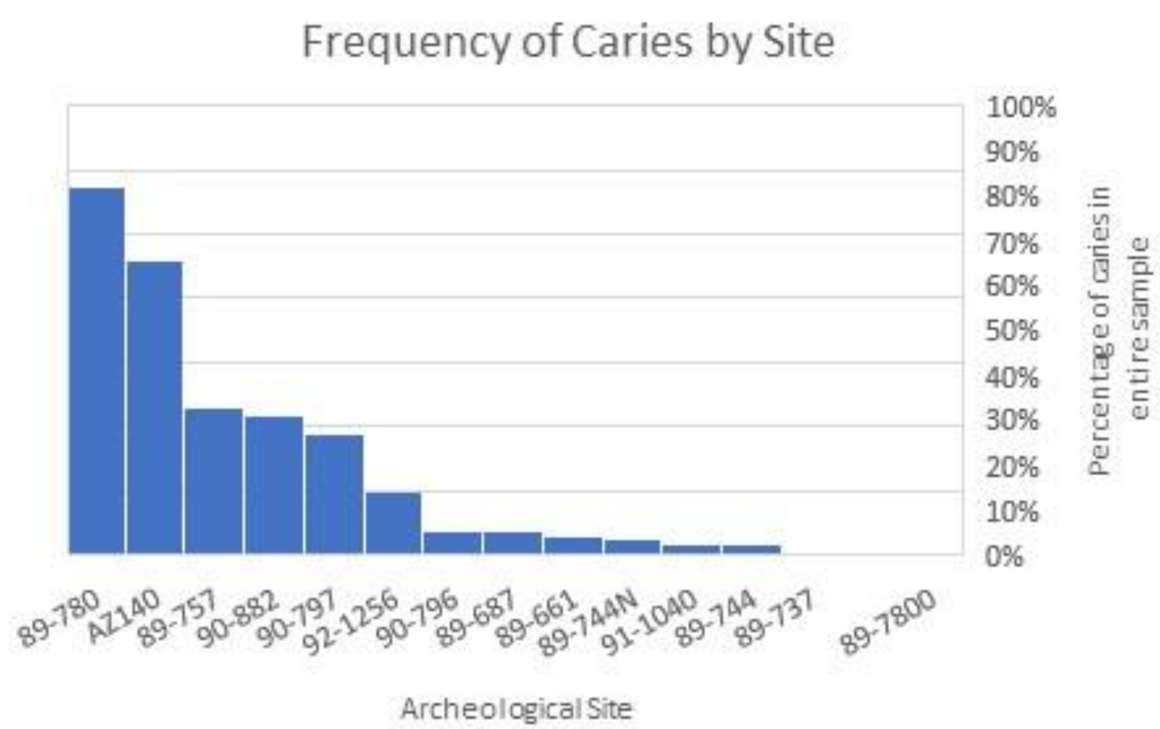

Figure 4.7. The frequencies of caries in the sample by archeological site.

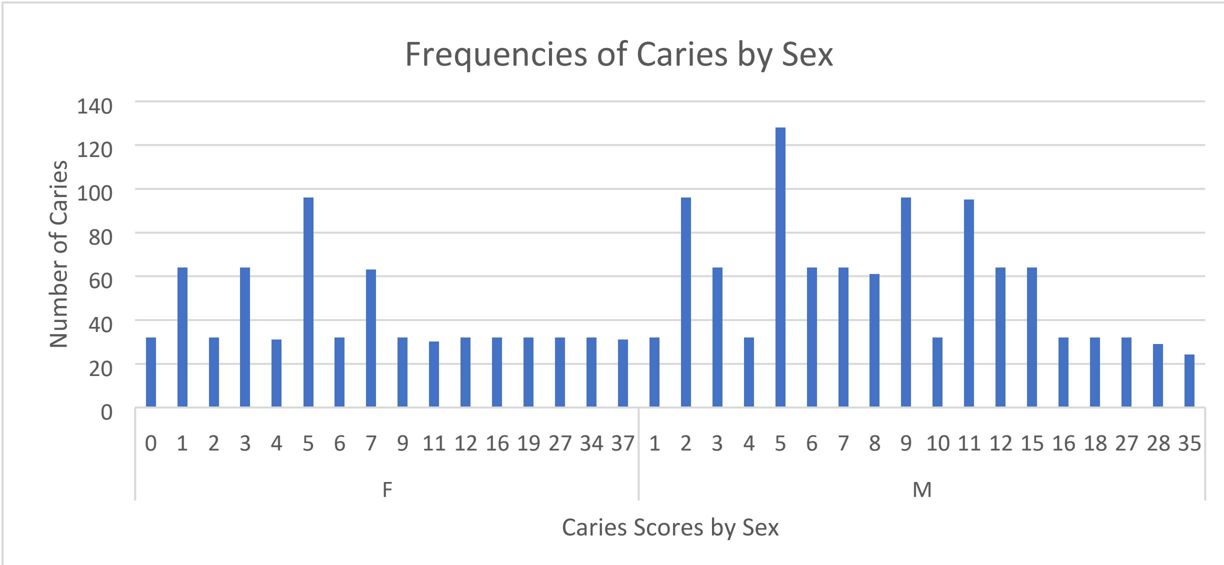

Figure 4.8. The frequencies of caries based on sex in the sample for females (F) and males (M).

Dental Caries Rate and AMTL Rate

Table 4.5 represents the dental caries rate for this sample. The DCR is generally low (below 50), with occasional instances of higher rates in certain individuals. These individuals are dispersed throughout the sample and do not belong to specific archeological sites.

Table 4.5. Dental caries rate for this sample.

Site	Individual	Caries number	Number of observable teeth	DCR
89-780	58	5	22	22.727
	44B	27	29	93.103

	61	12	26	46.154
	60	5	26	19.231
	62	4	20	20
	59	18	31	58.065
	57	3	15	20
	47	7	15	46.667
	31B	11	21	52.381
	35	37	28	132.141
	29B	1	5	20
	29A	9	8	112.5
	37	9	23	39.130
	28C	5	19	26.316
	19	5	10	50

	38	1	13	7.692
	44A	5	10	50
	23D	3	16	18.75
	23A	2	9	22.222
	42	11	32	34.375
90-882	1	8	24	33.333
	5	12	15	80
	6	7	29	24.138
	9	5	29	17.241
	8	7	29	24.138
	15	2	10	20
	11	7	20	35
	10	11	22	50

	2	9	21	42.857
AZ140	t68	11	30	36.667
	t73	27	30	90
	t67	10	28	35.714
	t76	16	16	100
	t72	35	20	175
	t78	34	23	147.826
	t88	9	16	56.25
	t74	8	25	32
	t80	5	25	20
91-1040	4A	2	8	25
	1A	4	13	30.769
92-1256	16	9	14	64.286

	18	15	31	48.387
	5	7	12	58.333
90-797	177	15	13	115.385
	321A	9	28	32.143
	245	19	27	70.370
	136C	16	27	59.259
90-796	5	10	10	100
	2	10	10	100
89-687	122	12	27	44.444
89-744N	39A	6	10	60
	41	2	9	22.222
89-757	9B	6	22	27.273
	9A	28	29	96.552
	4	0	5	0

	13A	3	11	27.273
	5	9	27	33.333
	7	1	23	4.348
	12	32	23	139.130
	6A	3	11	27.273
	1	1	29	3.448
89-744	5	6	15	40
89-661	1	14	19	73.684
89-737	4	3	8	37.5

Table 4.6 represents the AMTL rate for this sample. The AMTL-R for this sample is typically between 0 and 100. Some individuals reach between 100 and 200 AMTL-R; however, these are not associated with archeological sites.

Table 4.6. AMTL rate for this sample.

Site	Individual	Number of teeth lost ante-mortem	Number of empty sockets	AMTL-R

89-780	58	0	0	0
	44B	0	1	0
	61	0	0	0
	60	0	0	0
	62	1	1	100
	59	1	1	100
	57	0	0	0
	47	0	0	0
	31B	7	5	140
	35	0	0	0
	29B	0	0	0
	29A	1	2	50
	37	0	0	0

	28C	0	0	0
	19	0	0	0
	38	0	0	0
	44A	4	4	100
	23D	0	0	0
	23A	0	0	0
	42	0	0	0
90-882	1	2	2	100
	5	1	1	100
	6	2	2	100
	9	2	1	200
	8	1	1	100
	15	0	0	0

	11	1	1	100
	10	2	2	100
	2	1	2	50
AZ140	t68	1	2	50
	t73	0	0	0
	t67	1	4	25
	t76	1	14	7.143
	t72	0	2	0
	t78	9	9	100
	t88	4	4	100
	t74	0	1	0
	t80	5	6	83.333
91-1040	4A	7	3	233.333

	1A	1	1	100
92-1256	16	0	0	0
	18	1	1	100
	5	2	2	100
90-797	177	1	1	100
	321A	1	1	100
	245	0	0	0
	136C	0	0	0
90-796	5	0	0	0
	2	0	0	0
89-687	122	1	1	100
89-744N	39A	2	2	100
	41	3	2	150
89-757	9B	2	3	66.667

	9A	0	0	0
	4	0	0	0
	13A	0	0	0
	5	3	1	300
	7	0	0	0
	12	1	1	100
	6A	3	4	75
	1	1	1	100
89-744	5	0	0	0
89-661	1	1	1	100
89-737	4	0	2	0

Morphological Traits

The frequency results of morphological observations are shown in Table 4.7. Overall, these show a tendency toward low frequencies for all morphological traits (midline diastema, tuberculum dentale, winging, upper incisor shoveling, double shoveling, lower incisor shoveling, interruption groove, hypocone, Carabelli's cusp, cusp 5, enamel extensions, multiple lingual cusps, groove pattern, 4-cusped LM2, cusp 6, cusp 7, protostylid, deflecting wrinkle, and pegged-reduced-missing UM3), as can be seen by the maximum scores. Most of the maximum scores in the morphology databases are 0 (60.00%), with all other maximum scores being less than or equal to a score of 3. The incisor traits scored as present or absent had modes at lower scores. These are midline diastema at 54.54% individuals scoring absent, and interruption grooves found absent in 63.89% individuals. The other incisor traits that were scored using numerical scales occurred all at lower rates, with tuberculum dentale scoring most frequently at 1 (70.00%); winging at 3 (42.11%); upper incisor shoveling at 3 (25.00%); double shoveling at 0 (72.22%); and lower incisor shoveling at 0 (51.06%). The least frequent scores for those traits tended to be in the mid-to-upper scorings for each trait's respective ranking. This includes tuberculum dentale's least score of 4 (13.33%); upper incisor shoveling's score of 4 (8.33%); double shoveling's scores of 3 and 4 (2.78% each); and lower incisor shoveling's score of 3 (3.92%). The exception to this is the score of 1 (5.26%) for winging.

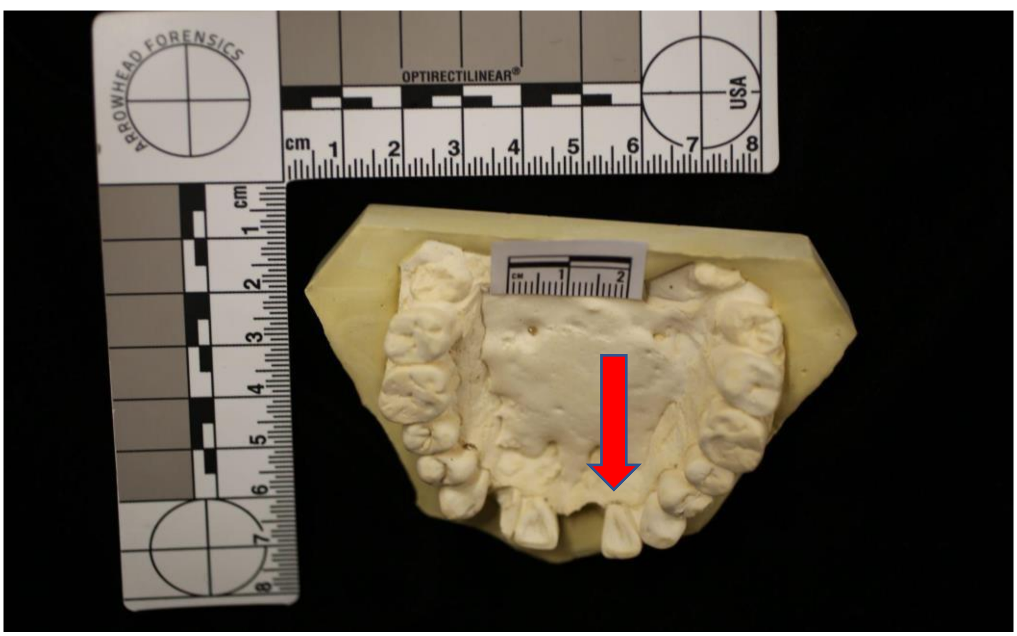

Figure 4.9. Upper incisor shoveling in a teenage male from Maitas Chiribaya, Guam.

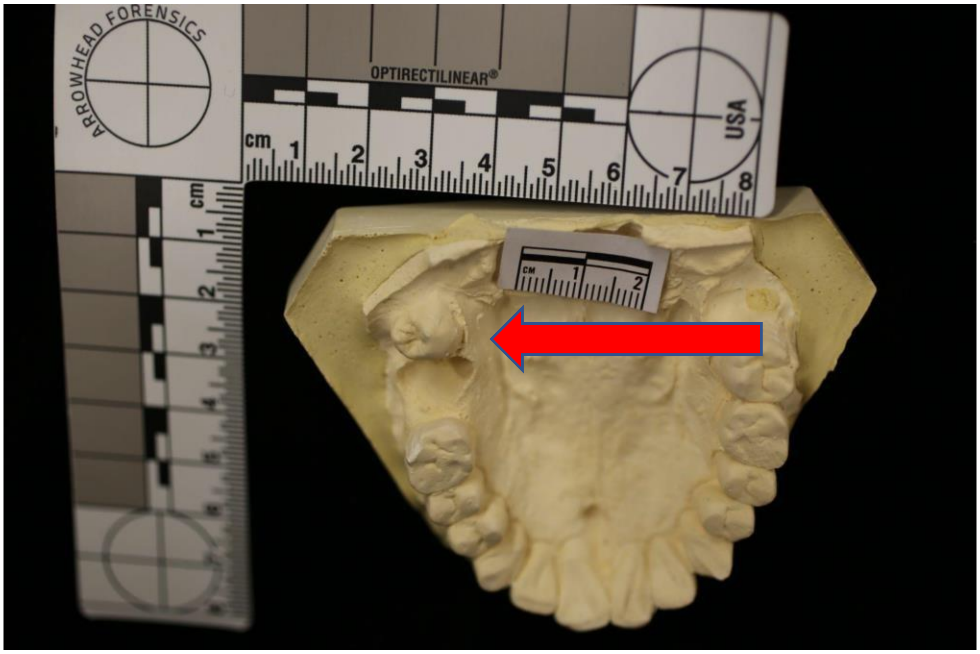

Figure 4.10. An example of a maxillary pegged UM3 from an adult male from Maitas Chiribaya, Guam.

The most frequent score for multiple lingual cusps on premolars is 1, indicating one lingual cusp is the most likely to be found in this sample. This score occurred 66.39% of the time in the premolars observed. The least frequent score for this trait was 3, occurring 1.68% of the time. This least frequent score was the highest score possible for the trait; the most frequent score was the lowest score besides absence of the trait.

Table 4.7. Minimum and maximum scores in morphological traits.

Variable	Range of scores	Most frequent score	Most frequent score %	Least frequent score	Least frequent score %

Midline diastema	Present/Absent	No	54.54%	Yes	45.46%
Tuberculum dentale	1-4	1	70.00%	4	13.33%
Winging	1-4/Absent	3	42.11%	1	5.26%
Upper incisor shoveling	0-7	3	25.00%	4	8.33%
Double shoveling	0-6	0	72.22%	3, 4	2.78% (each)
Lower incisor shoveling	0-3	0	51.06%	3	3.92%
Interruption groove	Present/Absent	No	63.89%	Yes	36.11%
Hypocone	0-6	3	46.76%	6	2.16%
Carabelli's cusp	0-7	0	69.66%	7	0.69%
Cusp 5	0-5	0	84.13%	1, 2	4.76% (each)
Enamel extensions	0-3	0	87.21%	3	1.16%
Multiple lingual cusps	0-3	1	66.39%	3	1.68%
Groove pattern	Y / + / X	+	85.00%	Y	3.33%

4-cusped LM2	0-5	0	43.27%	1	2.88%
Cusp 6	0-5	0	86.67%	5	0.95%
Cusp 7	0-4	0	80.95%	3, 4	2.86% (each)
Protostylid	0-7	1	39.32%	6	0.85%
Deflecting wrinkle	0-3	0	39.47%	3	3.95%
Peggedreducedmissing UM3	Present/Absent	Yes	71.64%	No	28.36%
Biogeographic cluster	*See list of biogeographic clusters, Table 8	East Asia	40.32%	Australo-Melanesia & Micronesia	1.61%

Pegged-reduced-missing UM3 was the only molar trait that was scored as present or absent. It was present a majority (71.64%) of the time. The other molar traits were scored using a numerical scale, with the most frequent scores being low on each trait's respective scale. The most frequent scores include the hypocone, scoring at 3 (46.76%); Carabelli's cusp, scoring at 0 (69.66%); cusp 5, scoring at 0 (84.13%); enamel extensions, scoring at 0 (87.21%); 4-cusped LM2, scoring at 0 (43.27%); cusp 6, scoring at 0 (86.67%); cusp 7, scoring at 0 (80.95%); protostylid, scoring at 1 (39.32%); and deflecting wrinkle, scoring at 0 (39.47%). Additionally, molar traits had least frequent scores typically higher on the scale for each particular trait, with the exception of cusp 5 and 4-cusped LM2. The least frequent scores are hypocone at 6 (2.16%); Carabelli's cusp at 7 (0.69%); cusp 5 at 1 and 2 (4.76% each); enamel extensions at 3 (1.16%); 4-cusped LM2 at 1 (2.88%); cusp 6 at 5 (0.95%); cusp 7 at 3 and 4 (2.86% each); protostylid at 6 (0.85%); and deflecting wrinkle at 3 (3.95%). The most frequent score for the groove pattern trait is + at 85.00%, with the least frequent score being Y at 3.33%.

Anterior Morphology

The frequencies for the anterior morphological traits analyzed in this study can be found in Table 4.7. All ranked morphological traits tested by site tend towards lower scores, as well as the scores for both males and females, except for winging. Similarly, all traits were found equally in males and females and did not vary significantly by site. Winging, as an exception, showed higher frequencies of higher scores for both males and females (a score of 3 out of 4 for 42.12% of all observable scores) compared to the other anterior morphological traits.

Posterior Morphology

The frequencies for posterior morphological traits in the sample can be found in Table 4.7. When tested by archeological sites, all posterior morphological traits tended towards lower scores such as 0 and 1 more frequently, with the exception of site AZ140 for 4-cusped LM2 and site 89-780 for the protostylid, which had more frequent rankings with higher scores than the other sites and variables at 3 out of 5, and 4 and 5, respectively.

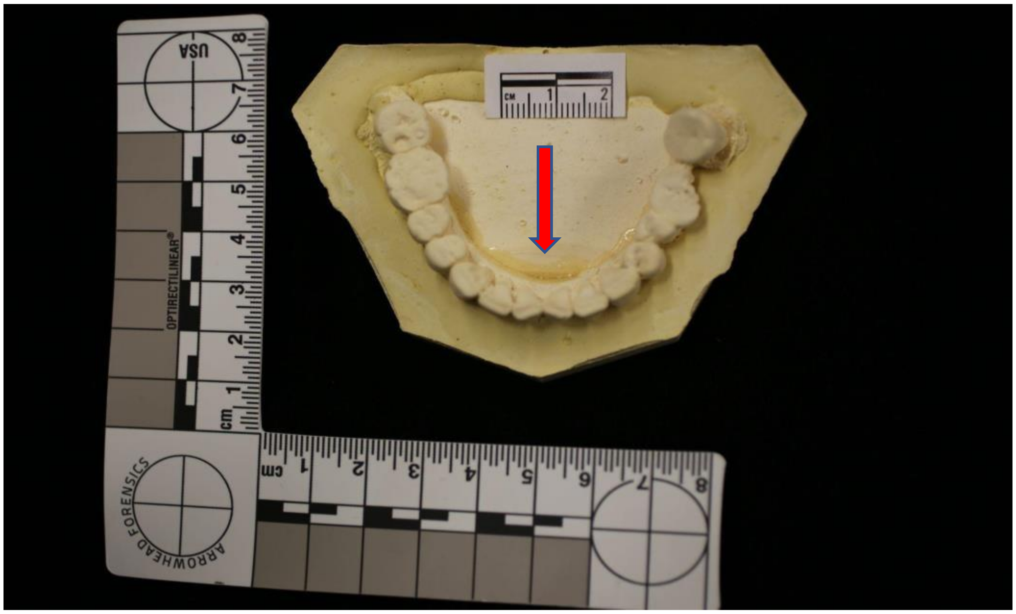

Figure 4.11. Winging of the mandibular central incisors of an adult female from Maitas Chiribaya, Guam. (Photo by author 2021.)

Biogeographic Ancestry Clusters

Data on morphological traits found in this sample was used to estimate biogeographic ancestry. The percentages of those ancestry clusters can be seen in Table 4.8.

Table 4.8. Estimates of biogeographic ancestry in the sample.

Biogeographic cluster	Presence in sample
American Arctic and Northeast Siberia	7.10%
Australo-Melanesia and Micronesia	2.58%
East Asia	27.74%
American Indian	21.94%

Southeast Asia and Polynesia	18.71%
Sub-Saharan Africa	12.90%
Western Eurasia	9.03%

East Asia (40.32%) is the most common biogeographic ancestry cluster in this sample, followed by American Indian and then Southeast Asia and Polynesia. The least common cluster found in this study is Australo-Melanesia and Micronesia (1.61%), which may be due to sampling issues in rASUDAS. There are also low frequencies of individuals from the American Arctic and from Western Eurasia, at less than 10%.

Chapter Summary

In this chapter, it was found that most of the variables that were statistically tested had a low intra-observer error and therefore had a high observer reliability. Analysis of the most and least frequent scores in the Health Data database showed a higher likelihood of high levels of attrition in the anterior dentition and low levels in the posterior dentition in the sample, as well as lower scores for pathologies such as caries and AMTL. In the Morph Data database, the most frequent scores tended to be lower, indicating less extensive morphological traits, while the least likely scores tended to be on the higher end of the respective scales. All pathologies and morphological traits used in this study were separated based on if they were for anterior or posterior teeth and Health Data and Morph Data traits were compared based on that division. Biogeographic ancestry within the sample was also analyzed, showing a high likelihood of individuals in the sample having biogeographic origins in East Asia and a low likelihood of ancestry from Australo-Melanesia and Micronesia.

Chapter 5: Conclusions

In this chapter, the information found in the Chapter 4 section will be applied and interpreted to address the research questions discussed in Chapter 1. These questions focus on patterns of dental wear, how they impact the observation of morphological traits and biogeographic history, and the patterns of caries and AMTL. Finally, this chapter will present the limitations and challenges of this project overall and propose future directions of the study.

What Are the Patterns of Dental Wear in this Sample?

Most of the attrition found in this sample is on the anterior teeth. The wear on the posterior teeth is present but is not typically severe within the dental casts used for this study. The most likely score out of all individuals studied regarding dental wear is one of a higher degree of anterior attrition, which indicates more frequent or more intense use of the incisors, canines, and premolars. It was found that only anterior dental attrition varied by sex in this sample, indicating possible differential access to dietary resources based on sex. Considering the wear patterns on the anterior dentition associated with betel nut chewing, it is possible that the individuals in this sample experienced dental attrition from that practice. However, the dental attrition on the anterior teeth in this sample may not be severe enough to justify this claim, and more research is needed.

In contrast, high scores for attrition of the molars occur less frequently than anterior teeth. Considering the three variables focusing on molar wear (posterior attrition, overall wear score, and MolWear) had modes with low scores, as well as the least occurring scores being higher in the ranking systems, the posterior dentition was most likely employed less by the individuals in this sample. This is in line with what is expected in betel nut chewers considering the finding that betel nut is often chewed using the posterior dentition, specifically being held in the retromolar space (IARC 2004).

As variables for posterior dental wear were generally found to be not statistically significant, it is not expected that the sample for this study reflects a larger population. However, anterior attrition has been found to be statistically significant for this sample, suggesting closeness with what would be expected in a larger population. This potentially indicates that individuals from this sample may have used their anterior dentition in a way resulting in similar wear patterns to larger groups, while using and subsequently wearing their posterior dentition differently. This may have been skewed by missing posterior teeth in the sample. For example, the maxillary and mandibular third molars were often missing on individuals. Additionally, the archeological sites from which the sample was collected as well as sex were both found to affect the dental attrition variables, indicating a correlation between the archeological sites and dental attrition, and sex and dental attrition. Currently, this may be due to differential use of betel nut chewing between the sexes, however more research is needed on archeological differences among male and female chewers and how the culture influenced the practice pre-contact.

What are the frequencies and patterns of caries and AMTL?

In this sample, AMTL and the related variables of number of observable teeth and chipping are generally representative of a larger population. Furthermore, these variables are representative of a larger population when compared with the variable for sites, indicating that these variables are not only applicable within the sample for this study, but possibly within the larger population of Guam. Additionally, AMTL and chipping do not vary by sex in this sample. This suggests that there may have been differential access to dietary resources based on sex at the archeological sites from which this sample originates that influenced AMTL and chipping but not the number of observable teeth within the sample. 91% of the individuals in this sample were found to lack AMTL, which conflicts with the findings of Leigh (1930), discussed above.

The frequencies of dental pathologies between males and females in this sample were generally similar. This is also reflected in the morphological traits of individuals in the sample, suggesting that pathological and morphological traits of the pre-contact Chamorro did not vary by sex.

The anterior dentition in this sample may be associated with the chewing of betel nut. Considering that the dental attrition in this sample was mostly concentrated in the anterior dentition, which is a pattern found in betel nut chewers, the individuals exhibiting AMTL along with severe anterior attrition may have chewed betel nut regularly. However, further study is needed to assess the extent of betel nut use as it relates to AMTL in this sample, since the patterns of dental wear resulting from betel nut chewing are not within the scope of this study. As discussed in Chapter 2, betel nut chewing is associated with AMTL. In modern Guam, individuals who have lost teeth to the point of becoming unable to chew betel nut find alternate ways to consume it. This indicates a modern correlation between AMTL and betel nut chewing, however, further research is needed to confirm the relationship between chewing betel nut and premature tooth loss.

Caries in this sample was found to be representative of a larger population in all statistical tests on between-subjects effects and tests run against the variable for archeological sites. The correlation between caries and sex in this sample requires further research, as the data for the relationship between the two in this study is conflicting. In modern Guam, caries is considered an endemic disease, especially among children. This conflicts with the number of caries found by

Lawrence at 7.94%, while in the analysis of this archeological sample by the author, 98.44% of individuals exhibited at least one caries. This difference may be due to differences in observers (i.e., the author and Lawrence). Such a change in the amount of caries between pre-contact and modern populations as described by Lawrence indicates that a possible change in diet, dental hygiene, or lifestyle occurred post-contact in Guam, while this study indicates a less dramatic difference in caries pre- and post-contact.

Does dental wear obscure morphology and affect biogeographic ancestry estimation?

Based on the dental morphological traits processed using rASUDAS, the most common biogeographic ancestry cluster in this sample is East Asia. The East Asian cluster is followed by the American Indian cluster, suggesting genetic ties between this sample from Guam/East Asian and groups found in the Americas. The American Arctic is not heavily associated with this sample, although the continents below it are. According to Pugach et al. (2020), the original inhabitants of Guam have a similar genetic makeup to those from Polynesia, indicating a similar homeland for both peoples.

Few of the dentitions for this study have morphology indicating association with areas east of Asia. This suggests that there was not much contact between the peoples migrating to Guam and those originating from Sub-Saharan Africa and Western Eurasia. However, it is of note that the probability of having ancestry with either of those two clusters is higher than those of the American Arctic and Northeast Siberia which indicates, based on this sample, individuals from Guam had more contact with populations in the east than in the north. It should be noted, as discussed in Lawrence (1996), that culture and language do not necessarily align with ancestry. Considering that, aspects of dental pathology and morphology also may not align with biogeographic ancestry due to differences in cultural uses of the teeth, such as the use of the anterior versus posterior teeth.

The low percentage of individuals associated with Australo-Melanesia and Micronesia is surprising. Considering the samples were taken from archeological sites in Guam, Micronesia, a larger number of specimens would be expected to have a high probability of ancestry from that cluster. This may be due to limited dental anthropological data from Micronesia used in ASUDAS. More research, possibly including a larger sample size, is needed to test the biogeographic ancestry of the areas this sample comes from.

The morphology for both the anterior and posterior dentitions in this sample were generally found to be not statistically significant, as well as the rASUDAS variables tested against the biogeography variable. This indicates that none of the variables from the sample are reflective of those that may be found in a larger population. However, statistical testing shows that the rASUDAS variables vary significantly by the archeological sites the samples originate from and the sex of the individuals in the sample. This suggests that the dental morphology and biogeographic ancestry for this sample is unique and not representative of other groups and that it could be useful to include these data in the rASUDAS databank, as those individuals found at the archeological sites may have unique dental morphological traits.

There are differences in dental pathologies between biogeographic ancestry clusters in this sample. As discussed above, these groups have some correlation as estimated via morphological dental traits. The biogeographical ancestry cluster consistent with morphology most frequent in those with Western Eurasian descent indicated higher amounts of caries than other areas of origin, as well as the highest number of observable teeth and a low number of teeth lost ante-mortem. This indicates that individuals with Western Eurasian traits in this sample are more prone to dental damage from caries, but not to the point of tooth loss, suggesting that premature tooth loss, specifically due to dental pathology, was not an issue for individuals from this sample that have dental morphological traits associated with the Western Eurasia biogeographic ancestry cluster.

There is a generally inverse relationship between the number of caries and the amount of AMTL in the biogeographic clusters sample. With the exception of traits consistent with the East Asia biogeographic cluster, the sample indicates high numbers of caries and low amounts of AMTL. This could also be due to high amounts of cariogenic factors in those areas accompanied by low numbers of AMTL, which would allow for the observation of carious teeth that were not lost premortem. If this is the case, individuals with dental morphology traits associated with the East Asian ancestry cluster may be more affected by dietary or hygiene factors that impact AMTL. The variables for AMTL, number of observable teeth, total chipping, and caries were all found to be reflective of dental diseases in a larger population such as the entire Chamorro population during a pre-contact period, while the variables for anterior and posterior morphology traits were found not to reflect the dental morphology of a larger population.

The dental morphology found in this sample tends not to be very pronounced. This is seen as most of the morphological traits are scored at lower numbers on a numerical scale. In looking at anterior teeth, both lower incisor shoveling and double shoveling typically have low scores, while interruption grooves and midline diastemas tend to be absent. Upper incisor shoveling and winging are recorded at higher scores more frequently, however, they do not reach the highest scores most of the time. It should be noted that this sample was selected for less extensive wear, which may influence the severity of dental attrition found in the sample.

The wear on incisors, canines, and premolars, as expressed in the anterior attrition variable, tends to be extensive. As seen above, the most common score for that variable is near the top of the scale, whereas lower scores appear less frequently. This suggests that individuals with less pronounced morphological traits on their incisors, canines, and premolars are more susceptible to attrition on those teeth. However, it is also possible that, due to dental attrition being more concentrated on the anterior dentition, the prevalence of the morphological traits that were scored for in this study may have been diminished due to that attrition.

Looking at posterior dental morphology, the modes for those traits are low on the numerical scales. As with anterior dentitions in this sample, most of the traits are scored at zero, and the mode of only one posterior trait, the protostylid, reaches above that at a score of one. On the opposite end of this analysis for both anterior and posterior morphological traits, the least frequent scores tend to be higher, indicating that most individuals exhibit less extensive traits most of the time. For example, the least frequent scores for the morphological traits for tuberculum dentale, lower incisor shoveling, hypocone, Carabelli's cusp, enamel extensions, multiple lingual cusps, cusp 6, cusp 7, and the deflecting wrinkle are all the highest score for those respective traits' numerical scales.

The wear found on the molars, as described by the variables for posterior attrition, overall wear score, and MolWear, tends to be on the lower end of their respective ranking systems. Considering the less extensive nature of the posterior morphology in this sample, this indicates that, less pronounced morphological traits on the molars is correlated with less attrition in that area of the dentition. This is seen by the typically low correlation between dental attrition traits discussed above.

In addition to there being low frequencies of morphology in this sample, it is evident that the attrition in anterior teeth tends to be more severe than that of the posterior dentition. The morphology of the posterior teeth does not appear to be obscured by dental attrition, as there is a generally low amount of wear recorded in the molars. The anterior attrition, although showing higher frequencies of wear than the posterior teeth, does not necessarily obscure tooth morphology. In addition to the above discussion, information on anterior dentition morphology is still available for scoring and application to rASUDAS. Overall, the wear patterns found in this sample do not obscure dental morphology.

Challenges and Limitations

One of the most significant limitations to this study is the sample itself. As mentioned above, Lawrence (1996) selected the dentitions used in this sample based on their good condition and lack of dental pathology. This skews the sample towards less dental attrition, caries, and AMTL, which are the focus of the present research. The sample for this study excludes individuals from the archeological sites in Guam that experienced more severe dental pathology, which limits the scope of knowledge on the topic.

Use of dental casts from plaster also limited the ability to observe more microstructural features such as hypoplasia. Lawrence (1996) also did not include any data about tooth discoloration from betel nut chewing, which would have been beneficial to this analysis as well as any information about boney oral pathologies. Another limitation to this study is the lack of additional archeological specimens to study. After Lawrence (1996) created the casts used in this research, all archeological individuals were reburied. Considering this, new data cannot be obtained from the population the sample is from. This places a limitation on how much information can be found from this group, as the casts used in this study are the only ones currently available.

Future Research

The potential for this study on pre-contact Guam reaches to modern Guam. Knowledge of dental pathology is imperative for understanding modern day activities affecting the dental health of the Chamorro. Understanding what foods and activities lead to aspects of oral health such as dental attrition, caries, and AMTL and their sociocultural significance to the Chamorro people may aid researchers in understanding why these pathologies occur and how to treat them. For example, further research into the cultural importance of betel nut chewing in Guam and the biological consequences of that activity can lead to a more holistic understanding of dental pathology among the Chamorro.

Finally, future work in anthropology more broadly should address how studies like this can use casted collections, photographs, and other metadata from repatriated collections and the importance of that as a method to support ethical practices using Indigenous remains. It could be worthwhile to assess trends and attitudes amongst biological anthropologists to this end within the larger discussions of Indigenous rights and ethical uses of remains.

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