Diet and Dental Health: Differential Diets of the Middle Horizon (CE 400-1000) in San Pedro de Atacama, Northern Chile

Research Thesis

Presented in partial fulfillment of the requirements for graduation *with research distinction* in Anthropological Sciences in the undergraduate colleges of The Ohio State University

By

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Abstract

This research utilizes dental health data from three archaeological sites from the Middle Horizon (AD 400-1000) period in the Atacama oases of northern Chile: Coyo 3, Quitor 6, Solcor 3 elite, and Solcor 3 non-elite. The Middle Horizon is characterized in the Andes by the establishment of the Tiwanaku State, which exerted political and economic influence in much of the South-Central Andes, which is explored here using the two Solcor 3 sites. In this thesis, I analyze the aspects of oral health of the population using the prevalence of dental caries, abscesses, tooth loss, and occlusal wear. I calculated the frequency of each type of dental pathology for males, females, and the total population for different parts of the dental arcade, to test if there are significant differences in oral health, and therefore in dietary practices, between the sites. The dental arcade was divided into six sections: anterior, posterior, superior, inferior, right, and left. Then, using statistical tests of Chi-Square and Analysis of Variance, I tested for significant differences between each section and between sexes. I found that there was a significant difference in total presence of dental pathological conditions throughout the entire dental arcade between males and females at all sites, showing a possible difference in diet between the sexes. In addition, all sites had significant differences between the posterior and anterior sections of the dental arcade and two sites, Coyo 3 and Quitor 6, had significant differences between the superior and inferior sections of the dental arcade when all dental conditions were considered. The Solcor 3 Pre-Tiwanaku and Solcor 3 Tiwanaku individuals had similar rates of abscesses and antemortem tooth loss, but significantly different rates of caries, possibly suggesting a change in diet after the establishment of the Tiwanaku state.

Introduction

The oases of San Pedro de Atacama are sites of long-established human presence beginning around 10,000 years BP with hunter-gatherer groups that migrated seasonally into the area (Torres-Rouff & Hubbe, 2013). Permanent settlement began approximately by 3000 years BP (Pestle et al. 2016). This presence resulted in an extensive record of human occupation in the area. Researchers often utilize dentition in prehistoric populations because it preserves well in archaeological sites and the San Pedro de Atacama oases are no exception. Dentition provides a wealth of information that researchers use to determine diet (Larsen, 2015; Hillson, 1996), stress levels while dentition is forming, oral health, and age at death. Although many other markers of dental health exist, caries, abscesses, antemortem tooth loss, and wear are the most common markers to study oral health in the past (Larsen, 2015; Hubbe et al 2012). As such, they are used in this thesis to study diet and dental health in the Middle Horizon San Pedro de Atacama oases to answer questions about differences in diet and social inequality.

Despite their usefulness in discerning life history, there are some issues with using dentition. For example, some differences in susceptibility to caries has been suggested between males and females. Lukacs & Largaespada (2006) show that when caries are reported by sex, females tend to show higher rates. They suggest that this is due to earlier eruption of teeth in girls, easier access to food supplies and snacking, and hormonal changes during pregnancy (Lukacs & Largaespada, 2006). In addition, caries rates are usually only based on carious lesions on teeth present in a skeletal sample, but Lukacs (1995) suggests that a portion of teeth lost antemortem would have been lost due to caries. He also notes that it is impossible to tell if a missing tooth was lost antemortem or postmortem because teeth lost shortly before death would show none of the alveolar resorption and remodeling (Lukacs, 1995).

Prehistory of San Pedro de Atacama

The prehistory of the San Pedro de Atacama Oases is divided into four main periods: Formative Period, Middle Horizon, Late Intermediate Period, and the Inca Period. The Formative Period (1200 BCE - CE 400) in this area was characterized by the formation of permanent and semi-permanent settlements and the introduction of agriculture to this area. The Late Formative Period (300 BCE - CE 400) represents the first stable occupation of the oases during which the people of this area became more sedentary and relied more on trade with other regions. The intensification of these features and the appearance of Tiwanaku objects on the archaeological record would become indicative of the following period, the Middle Horizon (Torres-Rouff & Hubbe, 2013).

The Middle Horizon (CE 400 - 1000) is characterized by the intensification of the features that appeared in the Late Formative Period as well as increased population and general prosperity (Torres-Rouff & Hubbe, 2013; Torres-Rouff et al. 2013). Individuals from this period show, in general, greater stature which may point to better nutrition (Neves and Costa, 1998). Grave goods also increased in quality and quantity and material culture overall developed rapidly during this period (Hubbe et al. 2012). This period also includes the cultural influence of the Tiwanaku polity and the peak of a complex system of interregional exchange (Torres-Rouff & Hubbe, 2013). This system of trade linked the Atacama Oases to the south-central Andes and utilized a vast network of llama caravans tied to the Tiwanaku state. The Atacama Oases were significantly influenced by the Tiwanaku state, though the nature of their influence is still debated. Recent research has shown that the interaction was likely not military. Because of this interaction, Tiwanaku iconography is seen on grave goods and other material culture from this period (Hubbe et al. 2012).

The Late Intermediate Period (CE 1000 - 1450) is defined by the collapse of the Tiwanaku polity and the rise of local leadership. The Tiwanaku likely collapsed due to internal strife as well as increasing aridity in the area. This effectively halted their expansive trade networks and thus ended their influence in the San Pedro de Atacama Oases (Hubbe et al. 2012). This phase also included increased violence and social conflict, as well as the construction of more fortified sites and a decreasing number and quality of grave goods (Torres-Rouff & Hubbe, 2013; Torres-Rouff et al. 2017)

The final period in the prehistory of the San Pedro de Atacama Oases is the Inca Period. This relatively brief period spans from CE 1450 until the Spanish conquest in CE 1560. During this period, the oases were incorporated by the Inca Empire as shown by Inca iconography, material culture, and roads that appeared during this time (Torres-Rouff & Hubbe, 2013).

Throughout all of these periods including the Middle Horizon, the individuals living in the Atacama oases were divided into geo-political units called *ayllus*. The *ayllu* are traditional Andean kin-based political structures that represented geographical separations as well as divisions between populations (Torres-Rouff et al. 2013). Material culture shows that these political units probably had varying ties to foreign groups within the interregional system. The sites used here -- Coyo 3, Quitor 6, and Solcor 3 -- all represent different *ayllus* and probably interacted with the Tiwanaku state at different times and levels (Torres-Rouff et al. 2013; Torres-Rouff et al. 2017).

Previous Studies

The Middle Horizon is one of the best studied by bioarchaeologists. Previous studies on the Middle Horizon in this area have utilized isotopes, cranial traits, and dental pathologies to study social inequality, health, and diet (Hubbe et al. 2012; Torres-Rouff et al. 2017; Pestle et al.

2015, 2016; Knudson & Torres-Rouff 2014; Knudson et al. 2015). Originally, this area was partially excavated by amateur archaeologist Father Gustavo Le Paige in the 1950s and 60s. The remains from these excavations do not include postcranial remains and are curated at the Museo Arqueológico R.P. Le Paige. Other cemeteries in San Pedro de Atacama, including the three used in this study, were excavated in the 1980s by the Instituto de Investigaciones Arqueológicas y Museo, where the complete skeletons are curated today (Torres-Rouff, 2011).

Using these remains, researchers have studied social inequality and violence in these populations, challenging the idea that the Middle Horizon was a time of "peace and tranquility" and mapping the increased violence after the fall of the Tiwanaku polity in the Late Intermediate Period. Torres-Rouff (2011), for example, found that cranial trauma occurred in almost 15% of a sample from four Middle Horizon cemeteries. If other types of trauma were included it may reveal more cases of violence, but part of the sample only included craniums. In addition, there were significant differences in rates of violence when comparing elite and non-elite populations. This showed that the prosperity of the time was not equally dispersed and social inequality and violence was still a major part of life during the Middle Horizon (Torres-Rouff, 2011). Social inequality also leads to questions about population structure and the presence of foreign individuals in the oases.

Population structure in San Pedro de Atacama has also been studied using multiple different methods including nonmetric cranial traits (Torres-Rouff et al. 2013) and isotopes (Torres-Rouff et al. 2015). In Torres-Rouff et al. (2013), they studied biodistance using nonmetric cranial traits to determine the degree of interaction between foreign groups and the Atacameños. They found that there were greater phenotypic differences between individuals in the Middle Horizon context than those from the subsequent Late Intermediate Period; however,

they argue that this is due to more than the interaction between the Atacameños and the Tiwanaku polity, but could also be due to the oases' role as a stopping point in the complex interregional systems of the time (Torres-Rouff et al. 2013). Torres-Rouff et al. (2015) uses strontium, carbon, and nitrogen isotopes to study a different *ayllu* called Larache. These tests showed that the individuals buried in Larache made up a diverse, potentially elite, population that had been integrated into Atacameño culture (Torres-Rouff et al. 2015).

Isotopes have also been used to study diet in the San Pedro de Atacama oases. Pestle et al. (2016) models the diet of a sample of individuals from several cemeteries from the Quitor *ayllu* especially during the transition from the Middle Horizon to the Late Intermediate Period. It aims to provide further and more specific evidence for dietary differences between sexes and a shift in diet between periods, as was shown using dental pathologies by Hubbe et al. (2012). Pestle et al. (2016) hypothesized that the Middle Horizon diet was more diverse as the population became more reliant on carbohydrates, that female diets consisted of less meat and more carbohydrates when compared to the males during the Middle Horizon, and that female diet stayed more consistent than male diet between the Middle Horizon and subsequent Late Intermediate Period. Ultimately, the study found that there was a change in diet between the Middle Horizon and the Late Intermediate Period but had a greater reliance on terrestrial meat than predicted. It also found that the diets of males and females were more similar during the Late Intermediate Period than the Middle Horizon. Finally, they found that females did not have homogenous diets over time as predicted, and that males did have a change in meat and C_4 consumption as predicted (Pestle et al. 2016).

Hubbe et al. (2012) used dental health to test if the general affluence during the Middle Horizon affected the diet of individuals from this time period equally or if differences in diet

between social groups and sexes existed. Similar to Torres-Rouff (2011), this study found that the affluence of the time did not affect all groups equally and that males and elite groups benefited more than females and non-elite groups.

The current study continues to explore the ideas presented in Hubbe et al. (2012) by looking at rates of caries, abscesses, and antemortem tooth loss as well as the degree of wear within the populations of Coyo 3, Solcor 3, and Quitor 6. In addition, this study goes more in depth to compare rates of dental disease based on the size, jaw, and type of tooth at each site. Based on the results of Hubbe et al. (2012) in the Atacama oases and more general dental health studies done on differences in dental health between the sexes (see Lukacs & Largaespada, 2006; Larsen, 2015; Hillson, 1996), this study predicts there to be significant differences in dental health between the males and females interred at these sites as well as between the elite and non-elite populations at the Solcor 3 site. In addition, we predict that the type of tooth will have some effect on the rates of dental disease for that area of the jaw.

Materials

I examined previously compiled dental data from 147 individuals (83 females and 64 males) interred in three cemeteries from the Middle Horizon and the Late Intermediate Period in the San Pedro de Atacama Oases: Coyo 3, Solcor 3, and Quitor 6. These three sites were all excavated in the 1980s and 1990s by the Instituto de Investigaciones Arqueológicas y Museo, where the remains are curated today. All of the remains used in this paper have been dated to either the Middle Horizon (Solcor 3 and Coyo 3) or the Late Intermediate Period (Quitor 6) using pottery sequences and radiocarbon dating (Hubbe et al. 2012). All individuals used in this study are adults whose sex could be definitively determined.

Solcor 3 is the earliest of the three cemeteries used here, appearing at the beginning of the Middle Horizon and continuing to the beginning of the Late Intermediate Period (around CE 1000). Solcor 3 appears to have contained an area of elite burials associated to grave goods tied to the Tiwanaku Polity and thus will be divided into two sections: elite and non-elite. Elite versus non-elite burials were determined for this study using exclusively grave inclusions (Hubbe et al., 2012). Individuals that were buried with Tiwanaku material culture and high-status pottery were considered to be elite, while individuals buried without Tiwanaku or other foreign grave inclusions and with rudimentary pottery were considered to be non-elite (Hubbe et al. 2012). The data for this site includes a total of 37 elite individuals and 32 non-elite individuals. Within the elite population there were 22 females and 15 males, while within the non-elite population there were 17 females and 15 males.

Coyo 3 was occupied later than Solcor 3. It was occupied from the end of the Middle Horizon into the Late Intermediate Period. This site has fewer and more rudimentary grave inclusions, though it is clear that they were still influenced by the Tiwanaku polity (Hubbe et al. 2012). The data for Coyo 3 includes 45 total individuals with 23 males and 22 females. Finally, the Quitor 6 cemetery is dated to the early Late Intermediate Period. This cemetery exhibited considerable wealth during the Middle Horizon, but few to no grave inclusions during the Late Intermediate Period. The data for this analysis includes 33 individuals from Quitor 6 with 22 being female and the remaining 11 being male.

Methods

In this analysis, we used four markers of dental health: caries, abscesses, antemortem tooth loss, and wear. This data was previously compiled by Hubbe et al. (2012). The dental arcade was divided according to size, jaw, and type of tooth to see if any correlation between

rates of the four markers of dental health and section of the dental arcade could be determined. The sections are described as anterior and posterior, superior and inferior, and right and left. The anterior section of the dental arcade for this study included both the upper and lower canines and incisors, while the posterior teeth include both the upper and lower molars and premolars. This effectively divides the dentition by both size and use. The remaining divisions were along the normal planes used to divide the dental arcade (superior/inferior and right/left).

Dental caries are areas of tooth decay caused by acid secreted by bacteria found in plaque (Hillson, 1996; Lukacs & Largaespada, 2006). Rates of dental caries typically increase in comparison to hunter-gatherer populations with the adoption and intensification of agriculture due to increased carbohydrate intake, making them useful in determining diet (Lukacs & Largaespada, 2006; Hubbe et al. 2012). In this study, caries were assessed in each individual and quantified as either present (1), absent (0), or missing (9) for each tooth. Then, the frequencies of caries were calculated using the number of teeth present with caries divided by the total number of teeth present (excluding missing teeth). This was done for each of the different sections of the dental arcade as well as for both males and females. The results of this were represented in a bar graph. Finally, chi-square tests were done for each site assuming $\alpha=0.05$. The first test was between the total rates for both males and females to see if there were significant differences between the sexes. Subsequent chi-square tests were done between the different sections of the mouth: anterior versus posterior, inferior versus superior, and right versus left.

A dental abscess is defined as an infection in the pulp chamber of the tooth, but in archaeological populations they are often seen as a fistula or hole around the root of the tooth usually on the buccal side (Hillson 1996). There are a number of causes for abscesses, the most common being dental caries and periodontal disease. When the tooth root becomes infected, the

area surrounding the root becomes inflamed and filled with pus causing the resorption of the alveolar bone surrounding the tooth (Hillson, 1996). The abscesses were quantified the same way as the caries for each site: present (1), absent (0), or missing (9). Again, the frequency of abscesses was calculated by dividing the number of alveoli with abscesses by the total number of alveoli present (excluding missing teeth). A bar graph showing the frequencies in each section of the dental arcade for males, females, and total was then created. Chi-square tests were performed for the total population, males, and females for each section of the mouth assuming an $\alpha=0.05$. A final chi-square test ($\alpha=0.05$) compared the rates of abscesses between males and females.

Antemortem tooth loss (AMTL) is defined as the loss of a tooth during an individual's life. AMTL can be caused by multiple factors, but it is most often due to exposure of the tooth's pulp chamber. It is often apparent in archaeological populations as the resorption and remodeling of the alveolar bone. AMTL can be caused by a number of conditions including injury, caries, periodontal disease, attrition, and purposeful removal (Lukacs, 1995; Hubbe et al. 2012). The missing teeth were scored by the following features: tooth is present (1), tooth was lost in life (2), tooth was lost post mortem (3), congenital absence of the tooth (5), tooth is retained in the alveolar bone (6), tooth has lost its crown (7), and the tooth is missing (9). I calculated the frequency of AMTL by dividing the number of teeth lost in life (2) by the sum of all the categories (1 through 7, excluding 9) for each sex and section of the dental arcade. A bar graph comparing these frequencies was then created. Chi-square test were performed with $\alpha=0.05$ to compare the prevalence of AMTL between the sexes and between sections of the dental arcade.

Occlusal wear was the final dental marker studied. Wear is caused by an abrasive surface, usually other teeth or food, acting on the surface of the tooth. The degree of wear is determined by many factors including type of food being consumed, amount of food processing, and the

degree to which teeth were being used as tools. Wear is accumulated over time so age greatly affects its severity. In addition, different teeth are affected differently due to varying eruption times and the differential function of teeth (Hubbe et al. 2012). Wear in this studied was scored on a scale from 1 to 8 with one being little to no wear and 8 being the most severe degree of wear (crown completely eroded; Molnar, 1971). This scale was grouped into Low (1-2), Medium (3-5), and Severe (6-8) degrees of wear for each section of the mouth. In addition, the mean and standard deviation was calculated for the total population of each site and for each sex so that severity of wear could be compared between the sites and sexes.

The final step of this study was to compile all the data from each site so that the sites could be compared to one another. To do this, I began by listing the total number of caries, abscesses, and AMTL for each site over the total number of teeth present for the entire site. Then, I did the same thing with each section of the dental arcade: anterior, posterior, inferior, superior, right, and left. Using this information, the percent of presence in the total population of each site and in each section of the dental arcade was calculated. Then, chi-square tests with $\alpha=0.05$ were done between the sexes and each section of the dental arcade for caries, abscesses, and AMTL combined. Finally, chi-square tests were run for the populations of all three sites combined and separated by sex and each section of the dental arcade. This provides us with the ability to compare sites as well as an overall prevalence in the area.

Results

Table 1 shows the prevalence of abscesses, caries, and AMTL for each site as well as for all sites combined. The rates of overall caries prevalence vary from about 0.32 to 0.52. Rates of abscesses vary between sites from about 0.18 to 0.23. Finally, rates of AMTL between sites range from 0.37 to 0.52. The non-elite population of Solcor 3 shows the highest rates of

abscesses followed by Quitor 6, the elite population of Solcor 3, and finally Coyo 3. Quitor 6 has the highest rates of caries prevalence followed by the non-elite population of Solcor 3, then the

	Site									
	Coyo 3		Quitor 6		Solcor 3 Non-Elite		Solcor 3 Elite		All Sites	
	Presence/ Total	Frequency	Presence/ Total	Frequency	Presence/ Total	Frequency	Presence/ Total	Frequency	Presence / Total	Frequency
Abscesses										
Presence	121/684	0.18	136/605	0.22	100/433	0.23	148/734	0.2	357/2456	0.15
Superior	75/321	0.23	85/317	0.26	52/197	0.26	96/397	0.24	308/1232	0.25
Inferior	46/363	0.13	51/288	0.17	48/236	0.2	52/337	0.15	197/1224	0.16
Anterior	53/345	0.15	27/264	0.1	41/219	0.19	54/324	0.17	175/1152	0.15
Posterior	68/339	0.2	109/341	0.32	59/214	0.28	94/410	0.23	330/1304	0.25
Left	67/343	0.2	66/299	0.22	56/236	0.24	84/372	0.23	273/1250	0.22
Right	54/341	0.16	70/306	0.23	44/197	0.22	64/362	0.18	232/1206	0.19
Caries										
Presence	199/619	0.32	275/525	0.52	152/334	0.46	181/539	0.34	807/2017	0.4
Superior	116/297	0.39	161/267	0.6	75/156	0.48	87/273	0.32	439/993	0.44
Inferior	83/322	0.26	114/258	0.44	77/177	0.44	94/264	0.36	368/1021	0.36
Anterior	64/297	0.22	81/232	0.35	51/148	0.34	49/211	0.23	245/888	0.28
Posterior	135/322	0.42	194/293	0.66	101/185	0.55	132/326	0.4	562/1126	0.5
Left	99/310	0.32	135/260	0.52	77/173	0.45	96/268	0.36	407/1011	0.4
Right	100/309	0.32	140/265	0.53	75/160	0.47	85/269	0.32	400/1003	0.4
AMTL										
Presence	597/1271	0.47	334/897	0.37	436/831	0.52	204/413	0.49	1571/3412	0.46
Superior	274/605	0.45	168/454	0.37	199/383	0.52	100/201	0.5	741/1643	0.45
Inferior	323/666	0.49	166/443	0.37	237/448	0.53	104/212	0.49	830/1769	0.47
Anterior	145/477	0.3	85/330	0.26	110/310	0.35	52/151	0.34	392/1268	0.31
Posterior	452/794	0.57	249/567	0.44	326/521	0.63	152/262	0.58	1179/2144	0.55
Left	301/644	0.47	170/449	0.38	217/423	0.51	101/202	0.5	789/1718	0.46
Right	296/627	0.47	164/448	0.37	219/408	0.54	103/211	0.49	782/1694	0.46

Table 1: Total prevalence of each type of dental disease for each plane of the dental arcade. The table shows the number present over the total number of teeth and the frequency for each site.

elite population of Solcor 3, and finally Coyo 3. The non-elite population of Solcor 3 had the highest rates of AMTL, followed by the elite population, then Coyo 3, and finally Quitor 6. Table 2 shows the median wear for each site as well as the standard deviations. The highest levels of wear were found at Coyo 3, but wear for all sites fell within a moderate range.

	Median Wear for All Sites			
	Coyo 3	**Quitor 6**	**Solcor 3 Non-Elite**	**Solcor 3 Elite**
Total				
Median	4.0	4.0	3.0	3.0
Standard Deviation	1.86	1.35	1.82	1.14
Males				
Median	4.0	3.0	4.0	3.0
Standard Deviation	1.9	1.36	1.74	1.04
Females				
Median	4.0	3.0	3.0	3.0
Standard Deviation	1.71	1.21	1.96	1.26

Table 2: Median and Standard Deviation for wear for all sites quantified on a scale based on severity [1-8] (Molnar, 1971).

Solcor 3

For the Solcor 3 non-elite site, frequencies of caries ranged from 0.32 to 0.63 (Figure 1). Frequencies of abscesses ranged from 0.14 to 0.37 (Figure 2). Finally, frequencies of AMTL spanned from 0.26 to 0.74 (Figure 3). For caries, when tested using chi-square tests, all tests (total population, males, and females) found significantly higher rates of caries in the posterior teeth compared to the anterior teeth. When chi-square tests were run for the number of abscesses,

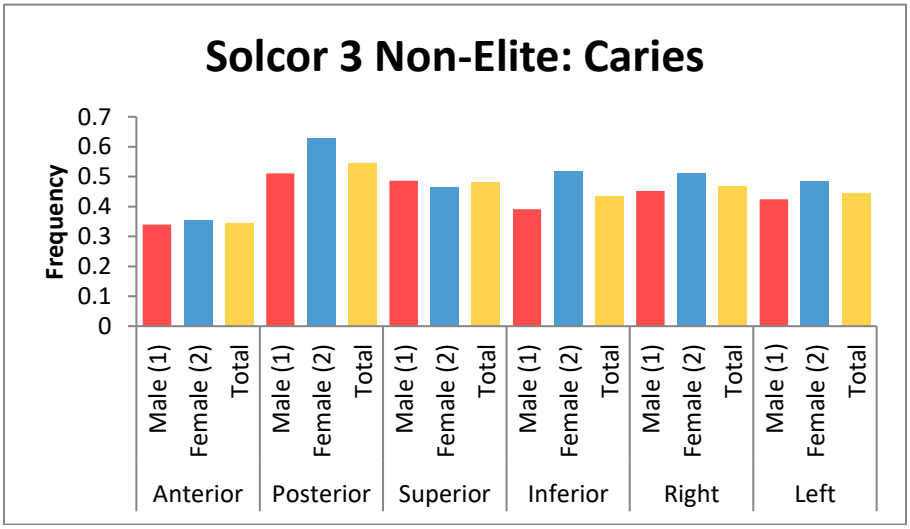

Figure 1: Frequencies of caries in the non-elite population of Solcor 3.

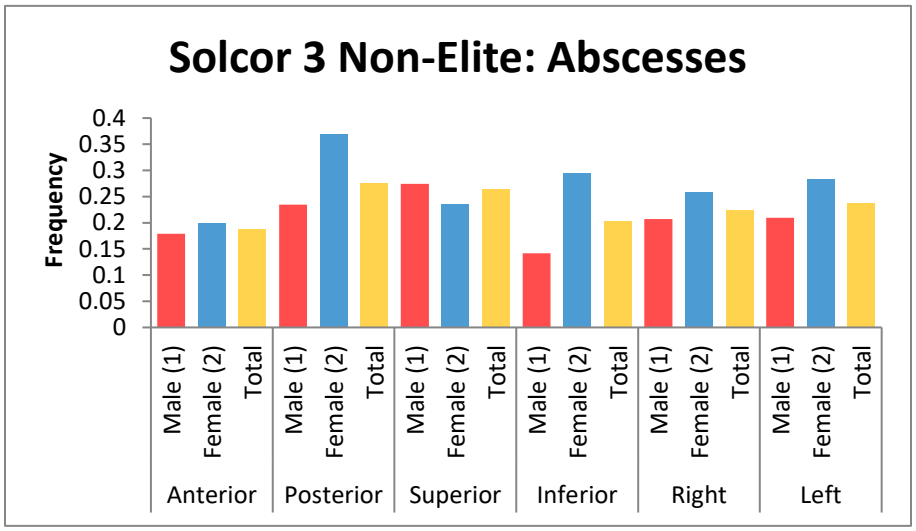

Figure 2: Frequencies of abscesses in the non-elite population of Solcor 3.

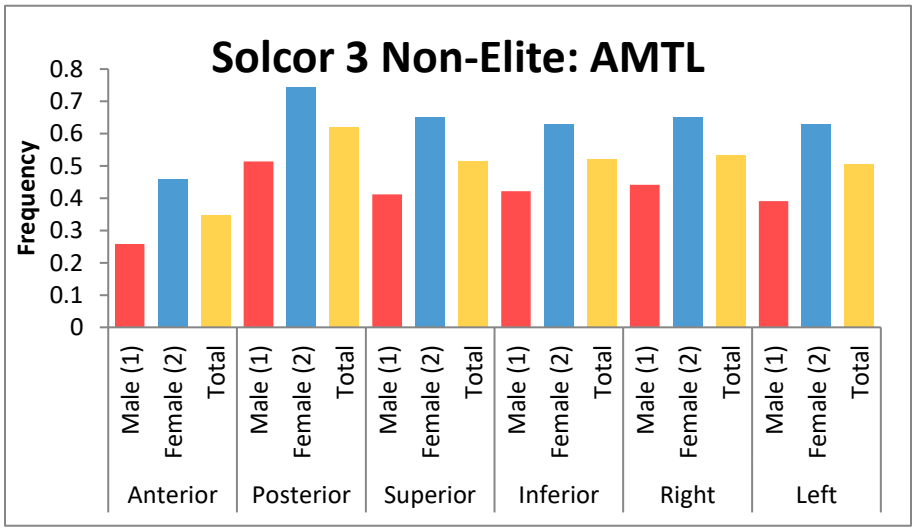

Figure 3: Frequencies of AMTL in the non-elite population of Solcor 3.

there were significantly higher rates in the superior teeth than inferior teeth in males. There were also significantly higher rates for abscesses in posterior teeth than anterior teeth for the total population and females. The chi-square tests run for AMTL showed significantly higher rates of AMTL in females than males. Posterior teeth also had significantly higher rates of AMTL than anterior teeth for the total population, males, and females (Table 3). Wear for this site was separated into 4 categories: none, low, moderate, and severe. Most of the teeth of this population

P-values for Solcor 3 Non- Elite			
	Caries	**Abscesses**	**AMTL**
Males vs. Females	0.335	0.127	**<0.001**
Superior vs. Inferior Male	0.147	**0.005**	0.896
Superior vs. Inferior Female	0.607	0.439	0.722
Superior vs. Inferior Total	0.403	0.136	0.812
Anterior vs. Posterior Male	**0.009**	0.248	**<0.001**
Anterior vs. Posterior Female	**0.004**	**0.021**	**<0.001**
Anterior vs. Posterior Total	**<0.001**	**0.028**	**<0.001**
Right vs. Left Male	0.676	0.966	0.330
Right vs. Left Female	0.778	0.724	0.719
Right vs. Left Total	0.664	0.731	0.492

Table 3: P-values for chi-square tests run for Solcor 3 Non-Elite. Bolded values represent significance.

	Degree of Wear in Solcor 3 Non-Elite			
	None (0)	**Low (1-2)**	**Moderate (3-5)**	**Severe (6-8)**
Number of Males	1	45	110	41
Number of Females	0	20	45	27
Total	1	65	155	68

Table 4: Number of teeth for each category of wear for the non-elite sample of Solcor 3.

fell within the Moderate category (Table 4). The median for wear in non-elite Solcor 3 was 3.0 with a standard deviation of 1.82. The median wear for the male portion of the non-elite population was also 3.0 with a standard deviation of 1.74. Finally, the median wear for the female portion of the non-elite population was 3.0 as well with a standard deviation of 1.96 (Table 2).

For the Solcor 3 elite population, frequencies of caries ranged from 0.09 to 0.53 (Figure 4), abscesses from 0.07 to 0.36 (Figure 5), and AMTL from 0.22 to 0.61 (Figure 6). Chi-square tests were done for caries, abscesses, and AMTL. The chi-square tests for caries showed significantly higher rates in caries for females than males. In addition, posterior teeth had significantly higher rates of caries when compared to anterior teeth for the total population and males. The chi-square tests for abscesses also showed significantly higher rates in females when

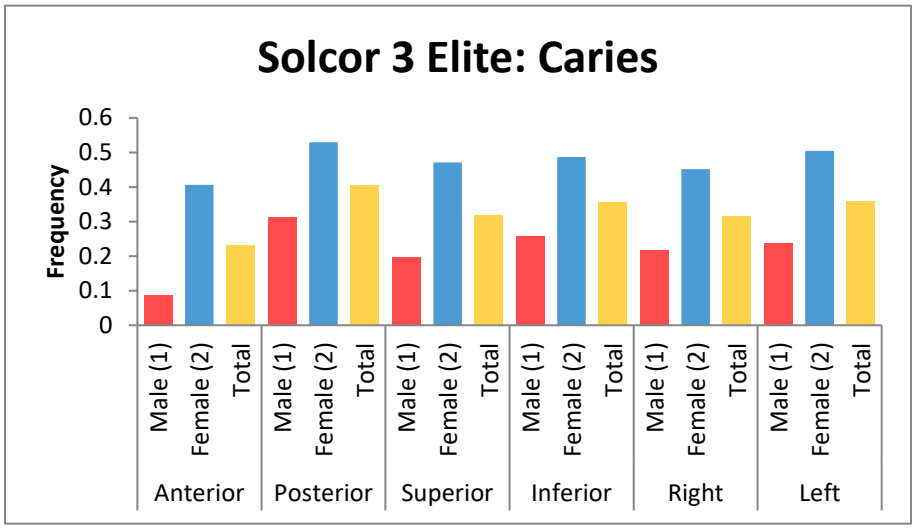

Figure 4: Frequencies of caries in the elite population of Solcor 3.

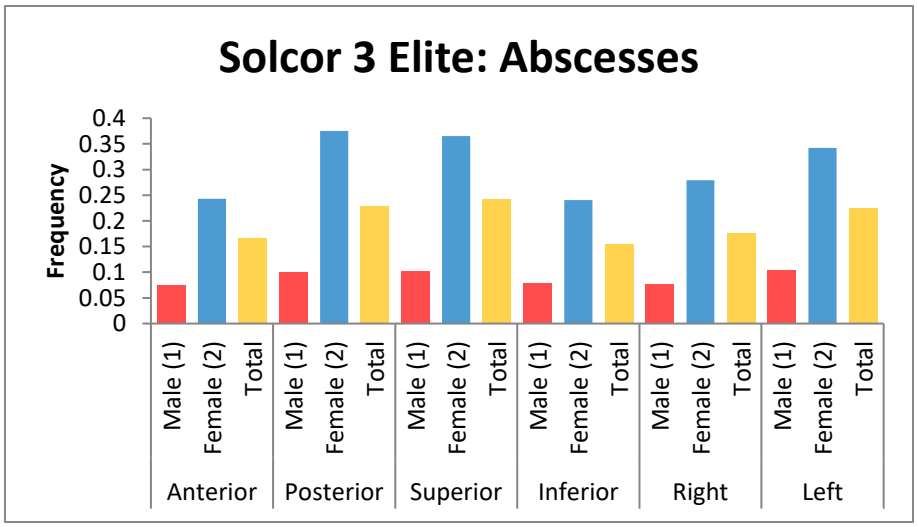

Figure 5: Frequencies of abscesses in the elite population of Solcor 3.

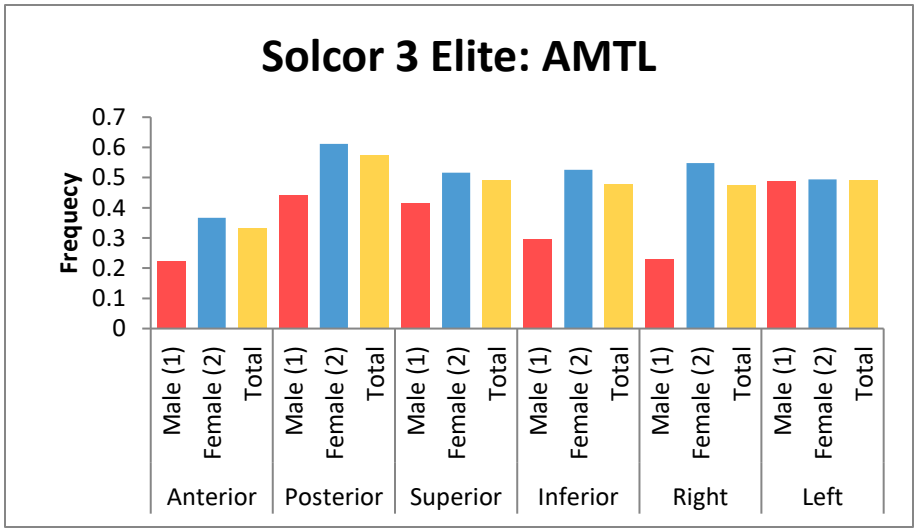

Figure 6: Frequencies of AMTL in the elite population of Solcor 3.

compared to males. Superior teeth had significantly higher rates for abscesses when compared to

inferior teeth for the total population and females. Similarly, posterior teeth had significantly more cases of abscesses than anterior teeth for the total population and females. The chi-square tests done for the AMTL in the elite population of Solcor 3 also showed significantly higher rates

P-values for Solcor 3 Elite			
	Caries	**Abscesses**	**AMTL**
Males vs. Females	**<0.001**	**<0.001**	**0.022**
Superior vs. Inferior Male	0.206	0.425	0.419
Superior vs. Inferior Female	0.810	**0.010**	0.901
Superior vs. Inferior Total	0.359	**0.003**	0.887
Anterior vs. Posterior Male	**<0.001**	0.393	0.068
Anterior vs. Posterior Female	0.064	**0.006**	**<0.001**
Anterior vs. Posterior Total	**<0.001**	**0.035**	**<0.001**
Right vs. Left Male	0.675	0.352	**0.008**
Right vs. Left Female	0.419	0.193	**<0.001**
Right vs. Left Total	0.300	0.098	0.809

Table 5: P-values for chi-square tests run for Solcor 3 Elite. Bolded values represent significance.

	Degree of Wear in Solcor 3 Elite		
	Low (1-2)	**Moderate (3-5)**	**Severe (6-8)**
Male	91	171	10
Female	72	119	11
Total	163	290	21

Table 6: Number of teeth for each category of wear for the elite sample of Solcor 3.

for females than males. Significantly higher rates of AMTL were also found in the posterior teeth when compared to the anterior teeth for the total population and females. Finally, significantly higher rates of AMTL were found in the right teeth than the left teeth for females and in the left teeth than the right teeth for males (Table 5). Wear for this site was separated into 3 categories: low, moderate, and severe wear. Most of the teeth of this population fell within the Moderate category (Table 6). The median wear for the total population was 3.0 with a standard deviation of 1.14. The median wear for males and females were both 3.0 with standard deviations of 1.04 for males and 1.26 for females (Table 2).

Quitor 6

For Quitor 6, frequencies of caries ranged from 0.28 to 0.68 (Figure 7). Frequencies of abscesses ranged from 0.07 to 0.33 (Figure 8). Finally, frequencies of AMTL spanned from 0.19 to 0.46 (Figure 9). The chi-square tests for caries resulted in significantly higher rates in the superior teeth than inferior teeth as well as in the posterior than anterior teeth of the total

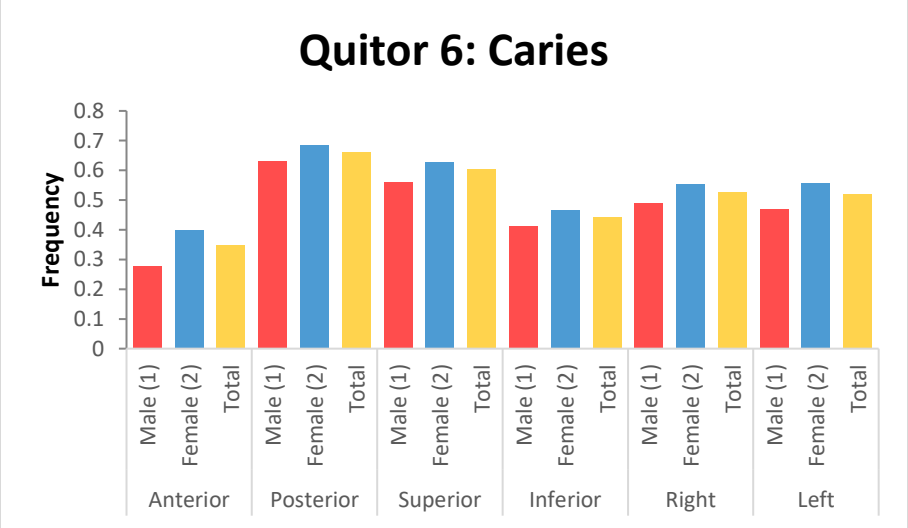

Figure 7: Frequencies of caries in Quitor 6.

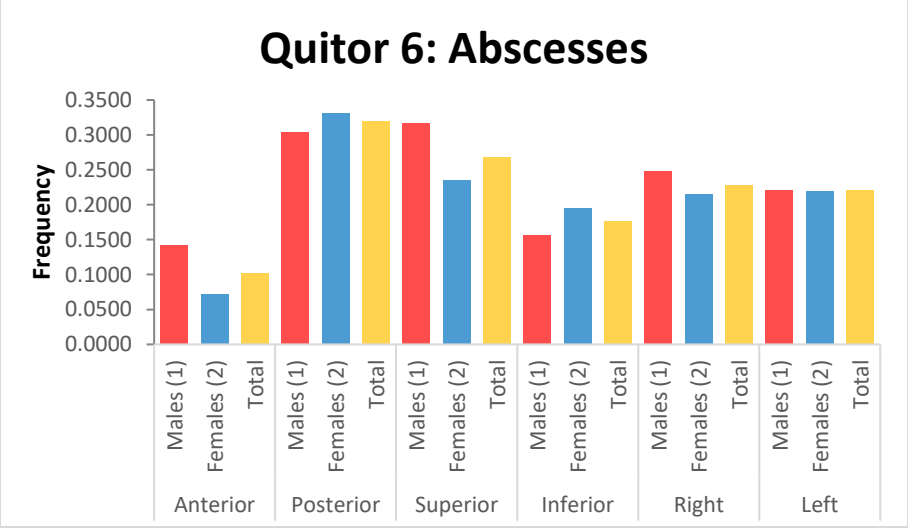

Figure 8: Frequencies of abscesses in Quitor 6.

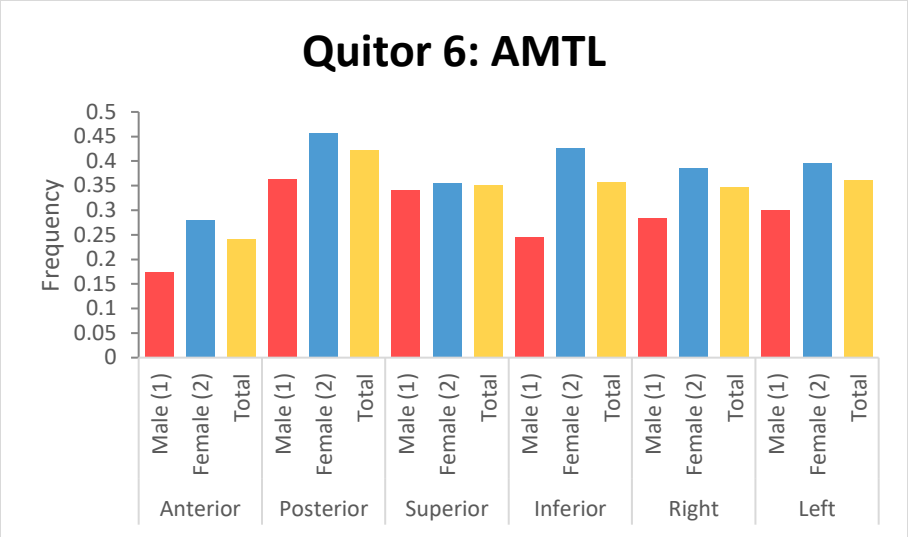

Figure 9: Frequencies of AMTL in Quitor 6.

population, males and females. For abscesses, the chi-square tests found significantly higher rates in the superior than inferior teeth for the total population and males. Posterior teeth also had significantly higher rates than anterior teeth for the total population, males, and females. The chi-square tests for AMTL at Quitor 6 found there to be significantly higher rates in females than males. The superior teeth had significantly higher frequencies of AMTL than inferior teeth for males. Posterior teeth also had significantly higher rates of AMTL when compared to anterior

P-values for Quitor 6			
	Caries	**Abscesses**	**AMTL**
Males vs. Females	0.085	0.615	**0.001**
Superior vs. Inferior Male	**0.028**	**0.002**	**0.040**
Superior vs. Inferior Female	**0.004**	0.361	0.086
Superior vs. Inferior Total	**<0.001**	**0.007**	0.884
Anterior vs. Posterior Male	**<0.001**	**0.002**	**<0.001**
Anterior vs. Posterior Female	**<0.001**	**<0.001**	**<0.001**
Anterior vs. Posterior Total	**<0.001**	**<0.001**	**<0.001**
Right vs. Left Male	0.733	0.611	0.750
Right vs. Left Female	0.979	0.900	0.796
Right vs. Left Total	0.835	0.813	0.697

Table 7: P-values for chi-square tests run for Quitor 6. Bolded values represent significance.

teeth for the total population, males, and females (Table 7). Wear for this site was separated into 3 categories: low, moderate, and severe wear. Most of the teeth of this population fell within the Moderate category (Table 8). The median wear for the total population of Quitor 6 was 3.0 with

a standard deviation of 1.35. For males, the median wear was slightly higher at 4.0 with a standard deviation of 1.36. The median wear for females was 3.0 with a standard deviation of 1.21 (Table 2).

	Degree of Wear in Quitor 6		
	Low (1-2)	**Moderate (3-5)**	**Severe (6-8)**
Male	25	145	18
Female	89	155	16
Total	114	300	34

Table 8: Number of teeth for each category of wear for Quitor 6.

Coyo 3

For Coyo 3, frequencies of caries ranged from 0.14 to 0.52 (Figure 10), abscesses from 0.12 to 0.27 (Figure 11), and AMTL from 0.19 to 0.61 (Figure 12). The chi-square tests for caries showed significant higher rates in females than males. In addition, superior teeth had significantly higher rates of caries when compared to inferior teeth for the total population, males, and females. Posterior teeth also had significantly higher rates than anterior teeth for the total population, males, and females. When chi-square tests were run for the number of abscesses

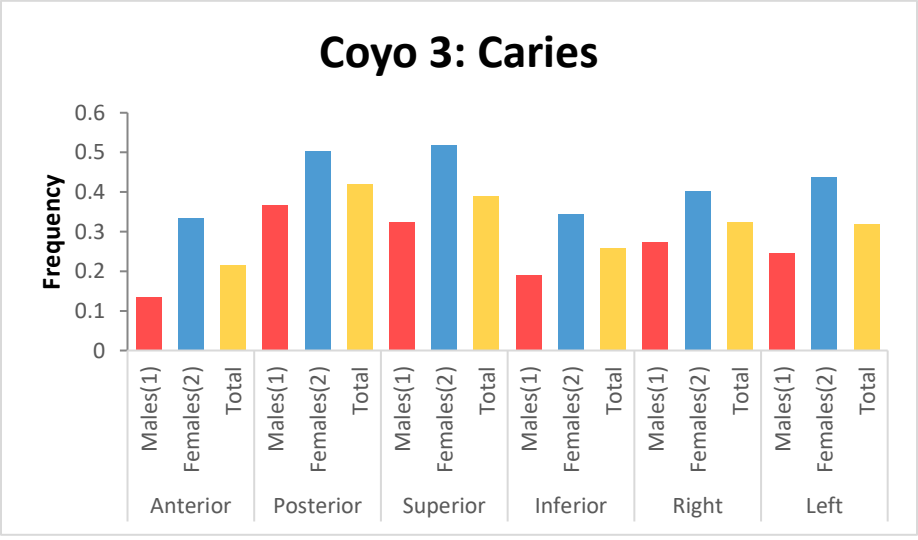

Figure 10: Frequencies of caries in Coyo 3.

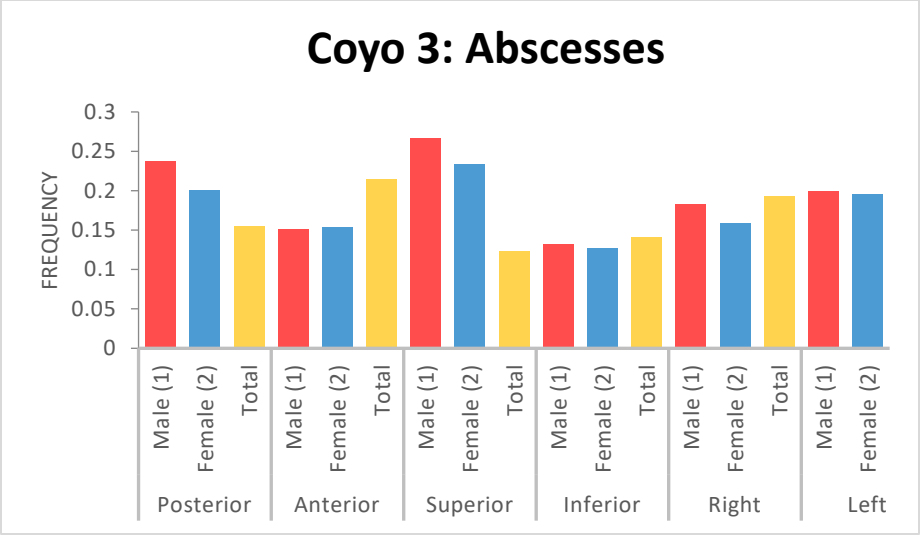

Figure 11: Frequencies of abscesses in Coyo 3.

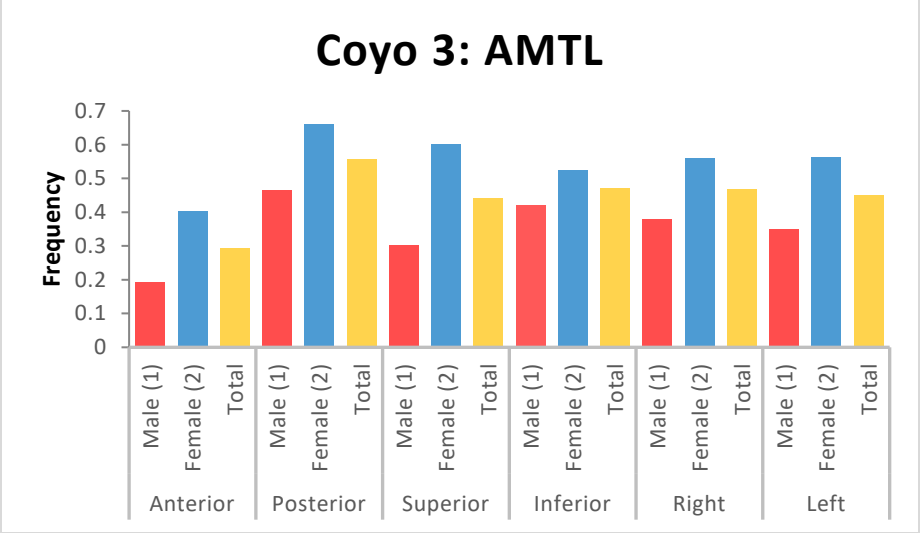

Figure 12: Frequencies of AMTL in Coyo 3.

in the Coyo 3 population, significantly higher rates were found for the superior teeth than inferior teeth of the total population, males, and females. The chi-square tests for AMTL in Coyo 3 showed significantly higher rates for females when compared to males. Inferior teeth had significantly higher rates of AMTL than superior teeth for the male sample. There were also significantly higher rates of AMTL for posterior teeth when compared to anterior teeth for the total population, males, and females of Coyo 3 (Table 9). Wear for this site was separated into 3 categories: low, moderate, and severe wear. Most of the teeth of this population fell within the

Moderate category (Table 10). The wear for the total population of Coyo 3 had a median of 4.0 with a standard deviation of 1.86. For the female portion of the population, the median for wear was also 4.0 with a standard deviation of 1.71. Finally, the median wear for males at Coyo 3 was 4.0 as well with a standard deviation of 1.9 (Table 2).

P-values for Coyo 3			
	Caries	**Abscesses**	**AMTL**
Males vs. Females	**<0.001**	0.439	**<0.001**
Superior vs. Inferior Male	**0.003**	**0.011**	**0.002**
Superior vs. Inferior Female	**0.006**	**0.005**	0.139
Superior vs. Inferior Total	**<0.001**	**<0.001**	0.252
Anterior vs. Posterior Male	**<0.001**	0.499	**<0.001**
Anterior vs. Posterior Female	**0.007**	0.075	**<0.001**
Anterior vs. Posterior Total	**<0.001**	0.107	**<0.001**
Right vs. Left Male	0.554	0.156	0.398
Right vs. Left Female	0.578	0.725	0.981
Right vs. Left Total	0.909	0.205	0.465

Table 9: P-values for chi-square tests run for Solcor 3 Elite. Bolded values represent significance.

	Degree of Wear in Coyo 3		
	Low (1-2)	**Moderate (3-5)**	**Severe (6-8)**
Male	65	157	105
Female	51	101	44
Total	116	258	149

Table 10: Number of teeth for each category of wear for Quitor 6.

Total Rates of Dental Pathologies

I found that there were significantly higher rates of all dental pathological conditions throughout the entire dental arcade in females when compared to males at all sites. In addition, all sites had significantly higher rates of overall dental disease in the posterior dentition than anterior dentition and two sites, Coyo 3 and Quitor 6, had significantly higher rates of overall dental disease in the maxillary dentition than the mandibular dentition. When the data from all individuals used here was considered, it showed significant higher rates of dental disease for

females than males, superior than inferior teeth, and posterior than anterior teeth overall (Table 11).

	Site P-values for All Dental Pathological Conditions Combined				
X^2	Coyo 3	Quitor 6	Solcor 3 Non-Elite	Solcor 3 Elite	All Sites
Males vs. Females	**<0.001**	**0.003**	**<0.001**	**<0.001**	**<0.001**
Sup. vs. Inf.	**0.015**	**0.002**	0.365	0.442	**<0.001**
Ant. vs. Post.	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Right vs. Left	0.684	0.961	0.393	0.128	0.524

Table 11: P-values for chi-square tests of all dental disease between males and females, anterior and posterior teeth, superior and inferior teeth, and right and left teeth. Bolded values are significant.

Discussion

The San Pedro de Atacama oases have been subject to study for decades, but many questions on the diet and population structure of this area remain unanswered. Because of this, diet and population structure have been studied using multiple different methods including nonmetric cranial features (Torres-Rouff et al. 2013), cranial trauma (Torres-Rouff, 2011), stable isotopes (Pestle et al. 2016; Torres-Rouff et al. 2015), and dental pathology (Hubbe et al. 2012). This study aims to provide a more in-depth study of the dental pathologies from Coyo 3, Solcor 3, and Quitor 6 by studying the rates of disease between the sexes, elite and non-elite individuals, and rates of dental pathology between jaw and type of tooth. The results presented above allow us to make inferences about the diet and social structure of these three sites.

Elite vs. Non-Elite

Between the elite and non-elite burials at Solcor 3, we found that the rates of all types of dental disease studied here were higher for the non-elite individuals than that of the elite individuals. This remained consistent no matter which sections of the jaws were compared. Decreases in rates of caries in particular are generally associated with lower carbohydrate intake, often because more protein sources are being utilized (Hillson, 1996; Larsen, 2015; Hubbe et al.

2012). In the case of the elite and non-elite populations of Solcor 3, the lower rate of caries in the elite population suggests that they had a different, higher protein, lower carbohydrate diet. Caries and other forms of dental disease, however, are not exclusively determined by diet. This means that while the higher rates of caries and dental disease in the non-elite population suggest a difference in diet, it must be taken into account that some of the differences may be due to other factors.

Wear for the total population and males of the elite and non-elite samples of Solcor 3 remained approximately the same with medians of 3.0 for both. Median wear for females between these two populations is slightly higher for the non-elite individuals (median wear is 4.0) than that of the elite (median wear is 3.0); however, these fall within the range of moderate severity of wear (Molnar, 1971). The standard deviation of these groups, however, show greater spread in wear among the non-elite individuals than the elite individuals for males, females, and the total populations. This could be due to multiple factors. One possibility is that more variation in wear could show more variation in the diet of the non-elite individuals when compared to the elite individuals (Larsen, 2015). The variation in wear could also be due to age. Age is an important factor in wear levels, but, other than all individuals being adults, age is not looked at here (Larsen, 2015; Hillson, 1996). Thus, greater variation in age for the non-elite sample than the elite sample could be the cause of greater variation in occlusal wear.

Males vs Females

When rates of caries, abscesses, and AMTL were compared individually at each site between males and females, there was some variability in the results. The elite population of Solcor 3 had significantly higher rates of all types of dental disease studied here for females than males, supporting the idea of differing rates between the sexes (see Lukacs & Largaespada,

2006; Hillson, 1996; Larsen, 2015). The non-elite population of Solcor 3 and the population of Quitor 6, on the other hand, only showed significantly higher rates in females when comparing rates of AMTL. However, this may be explained by the loss of teeth with carious lesions and abscesses and may show different results if the loss of these teeth was corrected for (Lukacs, 1995). Coyo 3 showed significantly higher rates in females when comparing caries rates and AMTL, but not for rates of abscesses. Despite this variability between types of dental disease, when all types were considered, all sites showed significantly higher rates in females than in males. In addition, when all individuals from all sites were considered for all types of dental disease studied here, females again had significantly higher rates. This supports our hypothesis that rates of caries and other dental disease are higher in females as well as the findings of previous studies done in this region (see Hubbe et al. 2012) and overall trends in dental pathology (see Lukacs & Largaespada, 2006; Larsen, 2015). This could be due to differences in diet between males and females. In this case, it suggests that females had higher carbohydrate diets while males were consuming more protein. However, it has been suggested that other factors such as hormonal changes during pregnancy, earlier tooth eruption times in girls, and easier access to food supplies and snacking could also cause higher rates of dental disease in females in general (Lukacs & Largaespada, 2006).

On the other hand, there were no significant differences in wear between the sexes. In all sites, wear for both sexes fell within moderate severity. Only at Quitor 6 and in the non-elite population of Solcor 3, was there any difference between the median wear. In the population with non-elite females from Solcor 3 having a median wear level of 4.0 while males had a median level of 3.0, and at Quitor 6 males had slightly higher median wear of 4.0, while females had a median of 3.0. The spread of the wear sample also does not appear to be connected with

sex as the standard deviation of wear is higher in males in Coyo 3 and Quitor 6 while higher in females for both the elite and non-elite population of Solcor 3. This shows that males and females were not participating in differential activities that would create different levels of severity for wear as has been seen in other archaeological populations (Larsen, 2015; Hillson, 1996).

Location in the Mouth

When the dentition was compared based on location, size, and shape of the tooth, there was, again, some variability, but some interesting trends could be seen. When the anterior and posterior teeth were compared, it mostly showed significantly higher rates of caries, abscesses, and AMTL for males, females, and the total population in posterior teeth, with the exception of abscesses for Coyo 3, abscesses for males in the non-elite sample of Solcor 3, and caries for females, abscesses for males, and AMTL for males in the elite sample of Solcor 3. However, when the total presence of dental disease between the anterior and posterior teeth was compared for each site, all sites showed significantly higher rates in the posterior teeth. This is also true for the total presence of dental pathologies in all individuals from all sites. The rates of dental pathologies are higher for posterior teeth than anterior teeth in all cases. This is unsurprising since posterior teeth generally have higher rates of caries than anterior teeth (Larsen, 2015; Hillson, 1996). Thus, the tests for anterior and posterior teeth fit our prediction that there would be significant differences due to type of tooth. Posterior teeth may have higher rates of dental disease in general because these teeth have a greater surface area and more complex morphology than anterior teeth. This creates more crevices for food and bacteria to accumulate.

Interestingly, many of the tests between superior and inferior teeth also showed significant differences between rates of caries, abscesses, and AMTL. This is most prevalent in

Coyo 3 and Quitor 6. For Coyo 3, superior teeth had significantly higher rates of caries and abscesses as compared to inferior teeth. This trend was observed in the total sample, males, and females. For Quitor 6, superior teeth had significantly higher rates of caries in the total sample, males and females. This trend was also seen for abscesses in Quitor 6, but only for the total sample and males. For Coyo 3, superior teeth also have higher rates of AMTL than inferior teeth in males. This trend was not observed in females, or the total sample. For Quitor 6, however, the inferior teeth have higher rates of AMTL than superior teeth in males. For Solcor 3, the non-elite population had significantly higher rates of abscesses in superior teeth than inferior teeth in males. The elite population of Solcor 3 also had higher rates of abscesses in superior teeth than inferior teeth for the total sample and females.

The frequency of caries, abscesses, and AMTL were all higher for the superior teeth than the inferior teeth except that of AMTL for Coyo 3 males. When all dental pathology was taken into consideration, only two sites, Coyo 3 and Quitor 6, had significantly higher rates in the maxillary dentition than the mandibular dentition. However, the test done using all individuals in this study also showed significantly higher rates in superior teeth when compared to inferior teeth. This trend of superior teeth having higher rates of dental pathology has been demonstrated in modern populations (Demirci et al. 2010), though there is also some evidence in archaeological populations as well (Mant & Roberts, 2015). While the cause of this trend is unclear, one possible explanation may relate to the movement of the tongue in the mouth. The tongue interacts with the lingual and buccal surfaces of the inferior dentition more easily and frequently than with the maxillary dentition. However, this hypothesis requires further exploration.

The right and left dentition were only significantly different for AMTL in the male and female populations (but not the total population) of the elite Solcor 3. Females exhibited higher rates of AMTL in the right dentition, while males exhibited higher rates of AMTL in the left dentition. Differences between right and left dentition were not significant for any site when all dental diseases were considered, nor were differences observed when all individuals were considered. The cause of this result is unclear. As this trend is not seen in any other population, it is likely not linked to behavior.

Conclusion

In conclusion, these results show significant differences in diet and social status between individuals living in the San Pedro de Atacama oases during the Middle Horizon and that, although this was a time of relative peace and prosperity, these benefits did not affect all individuals equally. This is similar to findings in previous studies as well (Hubbe et al. 2012; Pestle et al. 2016; Torres-Rouff et al. 2011; Torres-Rouff et al. 2013). Differences in the rates of caries, abscesses, and AMTL between males and females show that males likely benefited from higher protein and thus, less cariogenic, diets when compared to females. In addition, individuals interred with grave goods associated with the Tiwanaku polity, thus considered higher status individuals, also had significantly lower rates of dental disease than those individuals not associated with Tiwanaku material culture. Again, this points to a higher protein and less cariogenic diet for elite individuals in San Pedro de Atacama. Finally, we found higher rates of all types of dental disease in the posterior teeth on all sites, likely pointing to differential rates in dental disease based on size, shape, and use of teeth. Future research should include a more in-depth analysis of wear patterns as they could contribute significantly more to these questions.

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