Full Title: Oral Health and Non-Molar Dental Attrition in the Siwa-period individuals from the Bronze Age Mogou cemetery, Northwest China

Suggested Running Title (up to seventy characters including spaces): Oral Health in Siwa-period individuals from Bronze Age China

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Authors: Shannon Monroe* (1), Jenna M Dittmar (2), Elizabeth Berger (3), Angela Dautartas (4), Ruilin Mao (5), Hui Wang (6), Ivy Hui-Yuan Yeh (7)

Authors' Institutional Affiliations:

(1) New York University, Institute for the Study of the Ancient World, New York, NY, US
(2) University of Aberdeen, Department of Archaeology Aberdeen, Aberdeen, UK
(3) University of California, Riverside, Department of Anthropology, Riverside, CA, US
(4) Troy University, Department of Anthropology, Sociology, and Criminology, Troy, AL, US
(5) Gansu Provincial Institute for Cultural Relics and Archaeology, Lanzhou, Gansu, CN
(6) Institute of Archaeological Science, Fudan University, Shanghai, CN
(7) Nanyang Technological University, School of Humanities, Singapore, SG

*Corresponding author email: shannon.monroe@nyu.edu
*Corresponding author phone number: +1 (307) 287-2712
*Corresponding author permanent mailing address: 302 Canterbury Blvd, Steubenville, OH 43952 (US).

Abstract (up to 300 words):

Dental data can reveal evidence for a past population's oral health, nutrition, and certain cultural activities. This study aims to explore oral health and dental attrition during the late Bronze Age in order to explore health outcomes in different subgroups as well as aspects of foodways and changes in subsistence strategies during the second millennium BCE in northwest China. To do this, the skeletal remains of adult individuals associated with the Siwa material culture (1400–1100 BC) from the Mogou site (n=28) were macroscopically assessed and compared to previously published data derived from a subsample of individuals associated with Qijia period material culture complex (1750–1400 BC) from the same site. The results show that the Siwa-period population experienced a high frequency of carious lesions and antemortem tooth loss associated with advanced attrition (of both molars and non-molar teeth), which did not vary significantly by sex. Females had a higher prevalence of carious lesions and antemortem tooth loss than did males, while males had a higher prevalence of dental calculus. These male/female health outcomes are also attested during the earlier Qijia period at the Mogou site. The Siwa period differs from the Qijia in that females experienced slightly worse attrition than their predecessors. Overall, oral health does not diverge significantly between the Qijia and Siwa

period, suggesting that the factors that contributed to oral health including dietary practices may have persisted diachronically for individuals buried at this site.

Special Issue:

This is not a submission for a special issue.

Data Availability Statement:

The data that supports the findings of this study are available in the supplementary material of this article, and from the corresponding author upon reasonable request.

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Supporting Information:

Supporting Figures (Figures 1 and 2 included in body of text):

Figure S1: Sex-pooled sample of all individuals shown as a violin-and-boxplot with average attrition scores on the Y-axis and tooth identification number on the X-axis

Figure S2: Sex-pooled sample of Young Adults shown as a violin-and-boxplot with average attrition scores on the Y-axis and tooth identification number on the X-axis

Figure S3: Sex-pooled sample of Young Middle Adults shown as a violin-and-boxplot with average attrition scores on the Y-axis and tooth identification number on the X-axis

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Figure S5: Sex-pooled sample of Old Adults shown as a violin-and-boxplot with average attrition scores on the Y-axis and tooth identification number on the X-axis

Figure S6: Regression showing the relationship between AMTL and non-molar attrition

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Figure S9: Regression showing the relationship between overall calculus score and non-molar attrition

Supporting Tables (Tables 1 through 8 included in body of text):

Table S1: LDA confusion matrix for cohort classification based on attrition

Supporting Data:
Data S1: This Excel file contains data for each Siwa individual, with all data for their dentition.

Main Text (Supporting Information in separate files, along with individual files for all tables and figures):

1. Introduction

Teeth are often the best-preserved skeletal remains in archaeological context, due to their high mineral content. They are also the only elements of the human skeleton which are exposed for the majority of one's life. They are highly visible to others, used on a daily basis, and—therefore—liable to suffer the slings and arrows of one's biocultural context. For populations with poor oral health, it is often the molars which are most affected by the pathological conditions here evaluated, including attrition, usually leading to antemortem molar loss. Studying non-molar teeth, therefore, provides an inroad to evaluating oral health for these populations by comparing preserved teeth across sex and age subgroups. In addition, due to their more anterior location in the dentition, non-molar teeth are more likely affected by parafunctional use due to accessibility, and they are also more visible than the molars (and therefore, better candidates for intentional ablation or other aesthetic manipulation). Rather than eliminating populations from consideration due to molar loss, researchers can instead approach them from the perspective of the non-molar dentition.

In the case of Early China (before the end of the Han Dynasty at 220 CE), studies of oral health have approached skeletal material from multiple perspectives, often for the purpose of dietary reconstruction. Though dietary reconstruction is best accomplished with a combination of methods, including stable isotope analysis of human bone collagen and apatite, oral health can reveal broad patterns. A study of dental disease and attrition at three Yangshao (middle Neolithic) sites in northern China found heavy anterior wear for both males and females, with much more severe wear among males, and a higher incidence of carious lesions for females (Meng et al. 2011). Liu et al. (2010) compared dentitions from three Bronze Age sites in modern Xinjiang to those from sites in central China to assess differences in diet and lifestyle between these different regions. They argued that in the west, individuals consumed harder diets consisting of unprocessed foods, while Central Plains populations ate more carbohydrate-rich (and cariogenic) foods. This led them to conclude that agriculture was the preferred method for food production in the Central Plains (Liu et al. 2010). Another study of ancient Chinese oral health evaluates caries prevalence among males buried in the Qinshihuang Mausoleum (3rd cen. BCE) (Meng et al. 2014). The Qijia culture, which immediately predated the Siwa, has also been studied through oral health by Zhao et al. (Zhao et al. 2012; 2014).

However, no studies of oral health have been published for the Bronze Age Siwa culture of northwestern China. Very little is known about the Siwa compared with other Bronze Age cultures of the region. One archaeological site which sheds light on this culture is the Mogou (磨沟) cemetery (located in modern-day Lintan County, Gansu Province, China), which was used from 1750-1100 BCE (radiocarbon dating by Liu et al. 2014 and Cheung et al. 2017), or middle to late Bronze Age, and includes graves containing material of the Qijia Culture (1750-1400

BCE) and later the Siwa Culture (寺洼) (1400-1100 BCE) (Figure 1). These material culture complexes are found across the northwest at sites where people apparently practiced diverse subsistence strategies, the details of which are still being reconstructed.

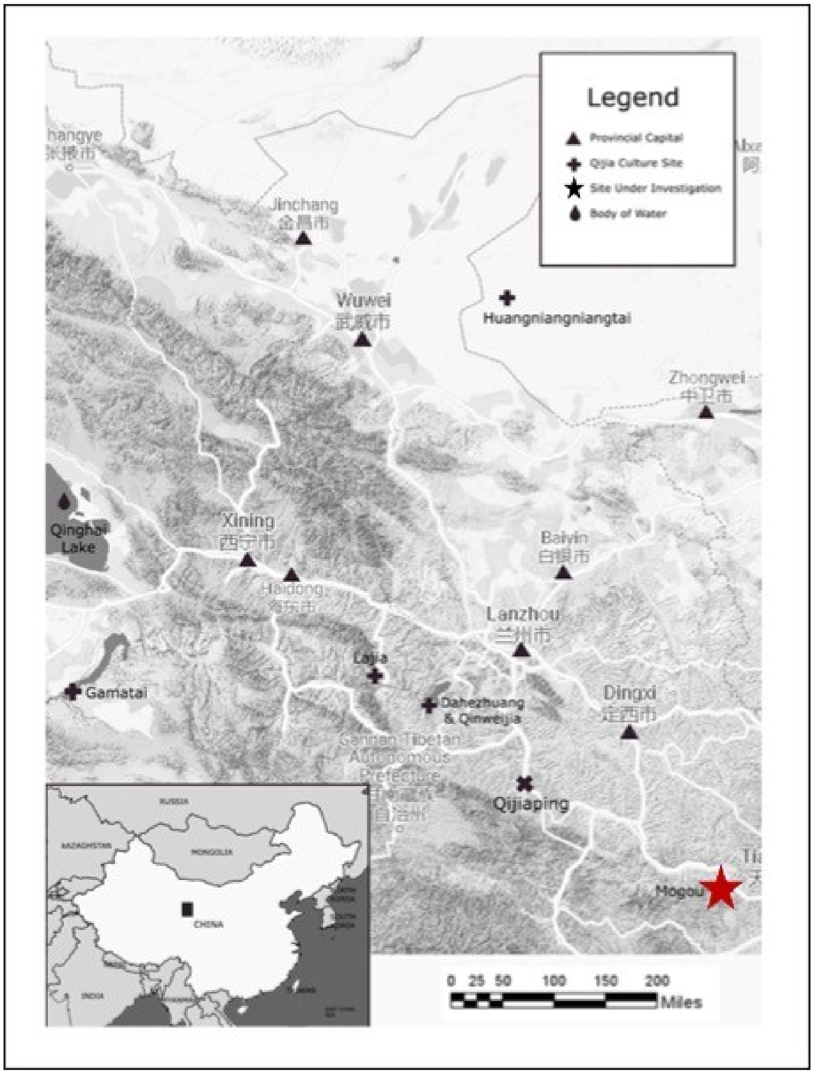

Figure 1: Location of Mogou site (indicated by red star). Map by Chuan Zhu.

Preliminary results of bioarchaeological research at Mogou indicates that the people buried there consumed nutritionally poor diets and experienced chronic physiological (and possibly psychosocial) stress (Dittmar et al. 2021). Dietary reconstruction research is ongoing for individuals buried at the Mogou site, alongside paleopathology research on the remains. Though Qijia sites and others with close temporal and spatial relations to Siwa sites have been examined for human health including oral health (Zhao et al. 2014) and dental attrition (Zhao et al. 2012), and some Siwa remains have been examined for relatedness to other populations (Wang 2006), research on oral health and paleopathology of human remains from Siwa sites is still largely lacking.

This period is critical for understanding the complexity of economic activities in the second millennium BCE in northwestern China (Jaffe and Hein 2021). There are well-documented shifts in human food procurement strategies and diet from the late Neolithic and throughout the Bronze Age. This includes evidence from Mogou itself, and from other sites in southeastern Gansu and the Tao River Valley. Domesticated pigs and dogs are found in the region as early as the sixth millennium BCE (Brunson et al. 2020), along with domesticated millet species (*Panicum miliaceum* and *Seteria italica*) (Liu and Reid 2020). There is also evidence for human consumption of primarily C4 plants prior to around 2000 BCE (Cheung et al. 2019). Certain West Asian domesticates, including caprine species and cattle, were incorporated into the local food system in the second millennium BCE, along with wheat and barley, through a complex process of transmission and trait selection (Brunson et al. 2020, Dodson et al. 2013, Dong et al. 2017, Flad et al. 2010, Ritchey et al. 2022, Vaiglova et al. 2021). Stable isotope evidence shows a change to human consumption of C3 plants, along with a rise in carious lesions (Cheung et al. 2019). Domesticated animals also seem to have been partly provisioned with crops and partly grazed on wild plants at this time, signaling a greater reliance on not only domesticated animal species, but varied pastoral food production, during the Bronze Age (Vaiglova et al. 2021).

There was evidently a great deal of variation between individual sites and sub-regions; geographic variation, food production specialization, or climate changes could account for some of these differences (Dong et al. 2013, 2022, Jaffe and Flad 2018, Li 2019, Lu and Yuan 2018). There is even some evidence for sex differences in staple crop consumption in some parts of North China (Liu and Redi 2020). However, additional fine-grained analysis is needed. For instance, in a regional analysis, the sites of southern Gansu, including Mogou, are variously considered part of the Continental Interior, grouped with the Tibetan Plateau (Liu and Reid 2020), the more narrowly defined Gansu-Qinghai region (Brunson et al. 2020, Cheung et al. 2019), the southeastern Hexi Corridor (Vaiglova et al. 2021), or the Loess Plateau sphere, under the influence of the East Asian summer monsoon (Ritchey et al. 2022). Oral health is one indicator of ancient diet, and therefore careful analysis of oral health at specific sites and in specific time periods can contribute to our growing understanding of this complex picture of dietary change, especially inter-site and inter-regional variation in what food was consumed, by whom, how it was prepared and how these behaviors interacted with other aspects of health and lifeway.

This study of Siwa oral health seeks to answer questions surrounding the severity of oral pathologies and dental attrition to create a foundation for studying daily life in the past by revealing aspects of Siwa foodways and health outcomes for subgroups of this population. The research questions for this analysis are as follows:

1) Do certain teeth in the non-molar dentition show more advanced attrition than others? (This question focuses on non-molar teeth because they were better preserved across sex and age cohorts, allowing meaningful comparison.)

2) Does this attrition pattern vary by age cohort or by sex?

 a) does average non-molar attrition vary by sex for this sample?

3) What is the relationship between non-molar attrition and the presence of oral pathologies such as ante-mortem tooth loss (AMTL), apical periodontitis, caries, and calculus in a population from Bronze Age China?

To do this, the skeletal remains of all adult individuals associated with the Siwa material culture (1400–1100 BC) from the Mogou site were macroscopically assessed and compared to published data derived from a subsample of individuals associated with Qijia period material culture complex (1750–1400 BC) (see Zhao et al 2012; Zhao et al 2014).

2. Materials and Methods

2.1 Materials

The cemetery site of Mogou (磨沟) in Lintan County, Gansu Province was discovered prior to the construction of a reservoir and was completely excavated between 2008 and 2012 by the Gansu Provincial Institute of Cultural Relics and Archaeology and the School of Cultural Heritage of Northwest University. The site is located on a terrace above the south-west bank of the Tao River, covers more than 30ha and yielded a total of 1688 graves. Radiocarbon dates of five samples of human bone collagen from Mogou indicate that the site was in use between 1750–1100 BC (Liu et al. 2014); radiocarbon dates from other studies at the site also fall within this range (Ma et al., 2016; Chen et al., 2012). Based on artefact typology, the grave goods suggest it was used to inter individuals associated with the Qijia material culture complex from around 1750–1400 BC, and later with the Siwa material culture from around 1400–1100 BC (Mao et al., 2009; Xie et al., 2009).

The excavators originally estimated that over 4000 individuals were interred in the 1688 graves. Due to the number of commingled infant remains encountered during the first five seasons of the Mogou Bioarchaeology Project (during which 757 exhumed individuals were analyzed), it is likely that the total number of individuals actually exceeds 5000. The vast majority of these come from graves associated with Qijia material culture; only 55 graves contained Siwa material culture, including 23 graves excavated in 2009 from the western part of the cemetery with clear superposition or intrusion on the Qijia graves and relative lack of spatial organization, and 32 graves excavated in 2012 from about 200 meters west of the Qijia cemetery (Gansu, 2014; Yin, 2014).As of the 2019 field season, 93 individuals from 40 graves have been analyzed. Of these, individuals over the age of 15 with dentitions that were at least 50% complete (n=28) were recorded to assess oral health by Dittmar and Monroe (Table 1).

Table 1: Demographic data for individuals included in study

Age group	Abbreviation	Age Range	Biological sex					Total number of individuals
			Male	P. Male	Female	P. Female	Sex unobservable	
Adolescent	ADO	15-17		1				1
Young Adult	YA	18-25	2	-	-	-	-	2
Middle Adult*	MA	26-45	10	-	4	-	1	15

Old Adult	OA	>46	4	-	5	-	-	9
Unknown	UNK		-	-	-	-	1	1
		Total	16	1	9		2	**28**

*The category "middle adult" was further divided into the sub-categories of "young middle adult" (26-35 years) and "old middle adult" (36-45 years).

The Siwa Culture was a Late Bronze Age material culture complex found in eastern Gansu and the upper Yellow River drainage (Xie, 2002). Based on stratigraphic studies and radiocarbon dates, Siwa material culture postdates Qijia material, though there is likely some temporal overlap in the two traditions, including at Mogou: Chen et al. (2012) and Ma et al. (2016) dated human bone and charcoal from three Qijia graves at Mogou and found a combined range of 1450-1260 BCE, within the purported dates for Siwa use of the site. Some scholars of ancient texts argue that the Siwa tradition constitutes the remains of groups found on the borders of the Chinese states and recorded in the Chinese records as the "Qiang" and "Rong" (Wu, 2015; Yi, 2020), and that there is evidence for their influencing the material culture of the State of Qin (Tian, 1986; Zhu, 2016), though there is reason to question the equation of historically recorded groups with archaeological cultures (Jaffe and Hein, 2021).

Though it is usually described as a cohesive material culture horizon, it is not clear that Siwa material represents one "culture" in terms of economic activity. Many studies refer to a transition from agriculture before and during the Qijia period to agropastoralism, especially incorporating caprine pastoralism,by the time of the Siwa material cultural and the contemporaneous Xindian culture (Brunson et al. 2020, Cheung et al. 2019). However, Siwa sites appear to vary greatly in terms of the evidence for economic activity. Further, evidence for this period comes disproportionately from funerary contexts, which presents problems of interpretation (Jaffe and Hein, 2021). What data do exist—plant and animal remains, and stable isotope analysis—suggest that people at Siwa sites relied on agricultural subsistence indistinguishable from that of Qijia sites. Though there is some evidence for shifts in material culture and spatial distribution of sites during the Siwa period, there is insufficient evidence to conclude that these were associated with subsistence change or, as is also sometimes posited, abrupt climate change. Cheung and colleagues (2019) and Liu and colleagues (2014), in multi-site studies of stable carbon and nitrogen isotopes from human bone collagen from Northwestern Chinese sites, have found overlapping values for Mogou and other contemporaneous sites with the Siwa-culture site of Zhanqi, suggesting no major dietary shifts between 2000 and 1000 BCE. Interestingly, Tache and colleagues (2021), using residue analysis, have also demonstrated the presence of both ruminant dairy fats and millet in vessels from the Zhanqi site. More research is clearly needed to reconstruct the variety of diet and economic activities at Siwa sites in detail.

Siwa sites also vary in terms of evidence for degree of inequality, e.g. from grave goods or violent trauma on skeletons. In fact, Mogou is one of the sites with more evidence for inequality during the Siwa period (Womack, 2021). At Mogou, the forms of the burials containing Siwa material differ slightly from the Qijia graves: they include more shaft graves than side chamber graves (Qijia graves are the opposite), the side chamber graves are simpler in structure than those of the Qijia period, and about half contain wooden coffins (Yin, 2014). However, the similarities are also striking: in both periods, many are multiple burials, an unusual feature for a Siwa site.

Of the 55 Siwa graves, 16 were single burials, 35 were multiple burials containing between two and seven individuals, and four contained fragmentary or disturbed remains with unclear number of individuals. More than half of the joint burials contained both nonadult and adult individuals. Furthermore, this is the first known instance of side chamber graves at a Siwa site. This suggests a certain degree of cultural transmission or influence between the Qijia period users of the burial ground at Mogou and the Siwa period users (Chen, 2003; Yin, 2014). Furthermore, based on a mean measure of divergence analysis of cranial nonmetric traits among the human burials at Mogou, the people buried in the graves containing Qijia and Siwa material culture are not biologically distinct, making an in-migration of new people at the Qijia/Siwa transition unlikely (Zhao et al., 2017).

Previous work on the oral health of Qijia-period individuals at Mogou (Zhao et al., 2014) has found results consistent with a diet derived from farming and gathering, which is also supported by relative lack of animal remains at the site, though again the funerary context presents interpretive difficulties for dietary reconstruction. The study also found sex differences (more caries and periodontal disease in females, more dental calculus and abscesses in males), more lesions in anterior teeth, and an association between heavy attrition and periodontal disease and abscesses in individual teeth. Another study that focused on tooth wear in 218 Qijia-period individuals from Mogou (Zhao et al., 2012) found greater wear on the teeth of males than females, on mandibular than maxillary dentition (perhaps due to earlier eruption of mandibular teeth), and on anterior than posterior dentition, though there was left-right symmetry in wear patterns. This study also identified several unusual wear patterns on the dentition of a small number of individuals: lingual surface attrition of maxillary anterior teeth, severe first molar attrition, localized lingual wear of the second molar, localized lingual wear of the mandibular incisors and canines, and localized wear on the distal maxillary canine. Overall, tooth wear was more severe than in other archaeological agricultural groups in China. This heavy wear, as well as the unique wear patterns observed on some individuals, might be explained by the persistence of gathered foods as part of the diet. Starch grain analysis from human dental calculus taken from two Qijia-period individuals at Mogou (Li et al., 2010) found that 70% of starch grains came from wheat, barley, buckwheat, and millet species. Other species identified by that study include legumes, as well as acorns and Gingko biloba, all of which suggests a diverse dryland agricultural diet that included both East and West Asian crops, supplemented by wild plant food sources.

Direct dietary reconstruction from Mogou itself consists of stable isotope analysis of human bone collagen. For specimens from the entire span of Mogou's use, Liu et al. 2014 found a mean carbon stable isotope value in human bone collagen of –13.9 ± 1.6‰, indicating consumption of C_4 plants but with more C_3 plants (or animals fed on them) than in previous periods. This study's nitrogen stable isotope results are 10.2 ± 1.2‰, which are interpreted within a regional context as indicating relative aridity of the environment, rather than degree of animal consumption. This same study found stable isotope results at Zhanqi, a Siwa culture site near Mogou, that were very similar to the Qijia period results from Mogou ($\delta^{13}C$ mean –16.0 ± 1.6‰, $\delta^{15}N$ mean 9.2 ± 2.1‰). Analyzing remains from the Qijia phase of the site's use, Ma et al. (2016) found a mean $\delta^{13}C$ value of -14.7 ± 1.8‰, part of a pattern of a pronounced shift from consumption of C_4 to C_3 or mixed C_3/C_4 plants or animals who consumed those plants after 3600 BCE in Northwest China. Botanical evidence from other sites suggest this was due to an increase in consumption of wheat, barley, and/or oats. $\delta^{15}N$ results show no evidence for change in consumption of animal protein at Mogou compared to earlier sites, but these results are preliminary. These results all support a finding that newly introduced West Asian C_3 crops, whatever their route of introduction, were adopted into the diet of this area very rapidly after their arrival, and that the dietary changes of the Siwa period were already underway during the Qijia, at least at Mogou, with a high degree of continuity between the periods.

2.2 Methods

2.2.1 Osteological Methods

Biological sex was estimated for individuals over 15 years of age by examining the morphological characteristics of the pelvis and skull (Buikstra and Ubelaker, 1994; Klales et al., 2012; Phenice, 1969). Individuals that did not have sexually diagnostic regions of the skeleton preserved were classed as 'unknown'. Adult age-at-death was estimated by pubic symphyseal morphology (Brooks and Suchey, 1990), auricular surface morphology (Buckberry and Chamberlain, 2002; Lovejoy et al., 1985), medial clavicle (Langley-Shirley and Jantz, 2010), and sternal rib ends (İşcan et al., 1984; 1985). Age-at-death estimates for nonadult skeletal remains were obtained by assessing dental development (AlQahtani et al., 2014; Moorrees et al., 1963; Smith, 1991). Age cohorts were defined in the following manner: late adolescent (15-17) (this age range is defined as 'mid-adolescence' by Barrett 1996; see Lewis 2022), young adult (18-25), middle adult (26-45), old adult (46+). The 'middle adult' category was further subdivided into the sub-categories: "young middle adult" (YMA) for individuals between the ages of 26-35 years and "old middle adult" (OMA) for individuals between the ages 36-45 years in alignment with the age categories listed by Powers (2012) for greater discrimination in the age-based statistical analysis.

2.2.2 Oral pathology

Each individual was assessed for the following: dental caries, apical lesions, antemortem tooth loss (AMTL), calculus deposition and dental attrition. The Universal Tooth Numbering system (also called the American System) was used in all recording forms.

The presence and location of carious lesions was recorded using the system described in Hillson (2001), which distinguishes occlusal, contact point, and root surface caries, as well as gross caries (advanced to cavitate the crown, or more advanced such that the caries origin in root or crown is uncertain). Furthermore, it was recorded when a tooth appeared to be lost ante-mortem (with signs of remodeling) or post-mortem with no remodeling. Non-eruption, partial eruption, and atypical eruption were likewise recorded. Discoloration of the enamel was considered insufficient evidence for the presence of carious lesions.

Apical lesions (also known as periradicular or periapical pathosis) were recorded based on Ogden (2007). These lesions, formed from dental pulp exposure followed by microorganism colonization, may be classed as granuloma, cyst, or abscess, based on and severity of the soft-tissue infection. However, due to the impact of cortical thickness and root shape on the size of the lesion, this study classed apical lesions simply as 'present' or 'absent' without a distinction by size or quality.

Calculus forms through the mineralization of accumulated dental plaque on the supra- or subgingival surface, which has not been cleaned mechanically (such as by brushing or the use of toothpicks). Calculus deposits were recorded based on size on a 0 to 3 scale as described by

Brothwell (1981). The exact location of such deposits (gingival, subgingival) was also recorded. While 0 indicated the total absence of calculus, a score of 1 indicated slight presence, 2 indicated less than 50% of the tooth surface affected, and 3 indicated that more than 50% of the tooth was affected by the deposition.

Attrition (the gradual wearing-down of teeth, from enamel to dentine and finally pulp) occurs for all people who chew their food, regardless of diet or cultural practice, due to the functional occlusion of the dentition. However, the severity of attrition will be influenced by several factors. As mentioned above, for example, the onset of carious lesions, calculus, and dental trauma can increase the speed or intensity of attrition. Attrition may be worsened due to sandy inclusions in the diet, such as by grinding grains with stone implements. Attrition also may be localized in areas of the dental arcade used for cultural practices (e.g. clasping or clenching artifacts between the teeth). Differences in attrition furthermore may indicate different diets or food preparation techniques, or different uses of the teeth for tool manipulation, between males and females or social classes in a population (or any projected/perceived identities). Among Neanderthals from Krapina, for example, attrition hypothesized to be caused by leather processing with the anterior teeth (based on microwear) is found equally in male and female dentitions; therefore, there is not necessarily any sexual division of the proposed category of "processing" labor. This use of the teeth also occurs among Early Modern Humans, as at Dolni Vestonice (Frayer and Fox, 1997). Finally, attrition may increase on teeth with carious lesions, as the zone of decay erodes more quickly than intact enamel, and attrition may culminate in the onset of apical periodontitis (due to dentine and pulp exposure) and/or antemortem tooth loss (Hammerl, 2013).

For this study, molar attrition was recorded on a scale of 1-10 for each quadrant as modeled in Scott, 1979; these scores were composited to give each molar an attrition score of 4-40. This method accounts for the uneven wear of the broad occlusal surface of molars, which might (for example) express dramatic reduction on the buccal quadrants and very little on the lingual quadrants. Non-molar teeth were given scores on an ordinal scale of 1-8, after Smith, 1984. The single number assignment for each anterior tooth's attrition score is appropriate because these teeth wear in a more uniform pattern across their narrow, incisive surface. Each individual in the sample was given an average attrition score for their molars, and a separate average attrition score for their non-molar dentition. In this way, the degree of anterior wear for one individual could be compared to another, even if they did not possess the same anterior teeth for direct comparison.

2.2.3 Statistical Methods

Age cohorts were created in order to assess attrition within like-groups, since older individuals generally have more advanced attrition than younger individuals (Hammerl, 2013). The individual in the "unknown" cohort has 19 observable teeth, but the skeleton (including maxilla, mandible, and pelvis) is highly fragmentary. For this reason, age, sex, and oral pathologies associated with the alveoli are unobservable.

Attrition scores for each tooth were tested for normality (for example, all individual scores of attrition for Tooth #4), as were the average attrition scores given to each individual (for example, all female average non-molar attrition scores). Since there were fewer than 30 observations for these categories, a Shapiro-Wilk test was chosen to assess normality. While the attrition scores for some individual teeth (22, the lower-left canine; 23, the lower-left second incisor; and 24, the lower-left first incisor) likely did not derive from a normal distribution (for each tooth, *p(same mean*) <0.05), necessitating nonparametric tests or transformation of the data, the averaged scores for each individual showed likely derivation from a normal distribution when compared across individuals, and parametric tests were therefore implemented for comparisons of individuals.

Tukey boxplots and violin-and-boxplots were used initially to assess visually the attrition scores for individual non-molar teeth within each age cohort (again, the preservation of non-molar teeth allowed comparison which was not possible with molars due to AMTL and large carious lesions). Then, a Mann-Whitney U test (nonparametric) and pairwise comparison with Bonferroni corrected p-values was used to identify teeth with statistically significantly different attrition scores from other teeth in the maxillae and in the mandibles.

One-way ANOVAs (analyses of variance, parametric) were used to compare average non-molar attrition scores for males and females within age cohorts and in a pooled sample of adults excluding the old adults, due to the smaller number of observations for that cohort due to excessive antemortem tooth loss. In order to investigate further the implications of attrition severity in this sample, the relationship between attrition and other indicators of oral health was assessed. As each of these given variables was recorded as continuous (number of teeth or alveoli affected by the oral health indicator and degree of attrition for the individual based on average attrition for the arcade), a Simple Linear Regression (Ordinary Least Squares) was chosen to model the shape of the relationship between independent variable (attrition) and dependent variable (apical lesions, AMTL, caries, or calculus). As the designation of variables indicates, it was assumed in the model that the degree of attrition for any given individual would affect (though not directly cause) the presence and even severity of oral pathologies; it was the shape of this relationship which was tested by the regression. Antemortem tooth loss was scored by number of teeth lost antemortem (0-32), caries and calculus were scored by number of teeth affected by the lesions (0-32), and apical lesions were scored by recording the number of alveoli infected with abscess, cyst, and/or granuloma.

Each condition was also assessed through descriptive statistics. While 28 individuals were evaluated, not all conditions could be observed for each due to preservation (hence the differing n values). In order to compare dental pathologies from the Qijia period to those of the Siwa period, a t-test was used for each data set, as well as a Chi-Square Test for Association comparing male and female dentitions for each age cohort. Significance level was set at 0.05.

3. Results

3.1 Caries, Apical Lesions, Calculus, and Antemortem Tooth Loss

A total of 458 permanent teeth and 847 alveoli were assessed to determine the prevalence and frequency of pathological conditions in the individuals under study. Prevalence rates for each condition for males and females can be found in Table 2. For each pathological condition evaluated, a Shapiro-Wilk test was used to assess the probability that the data derived from a normal distribution (see supplementary information), which guided the choice of parametric versus nonparametric statistical tests.

Table 2: True prevalence (%) of pathological conditions in adult male and female individuals

Sex	Caries	Calculus	AMTL	Apical lesions
Males (n=17)	88% (15/17)	100% (17/17)	65% (11/17)	65% (11/17)
Females (n=9)	100% (8/8)++	50% (4/8)	100% (9/9)	89% (8/9)
Total (n=26)	92% (23/25)++	84% (21/25)	77% (20/26)	73% (19/26)

+ Late adolescent individual and individual of unknown sex excluded from analyses prior to Section 3.1.
++ Edentulous individual excluded from this analysis

In the young adult cohort (18-25 years), there were too few observations to compare males and females for each condition. However, in the middle adult cohorts (26-45 years, including the ageing categories of both young middle adult and old middle adult), males showed a higher prevalence of caries than did females. The difference in caries prevalence between sexes in this cohort was not, however, statistically significant. Females had a prevalence of antemortem tooth loss which was higher than males of the same age, which was statistically significant. Apical lesions did not significantly differ between the sexes for middle adults. However, the prevalence of calculus did differ significantly, with a higher prevalence for males.

Among the old adults (46+), females had a notably higher caries rate than males with statistical significance (Table 3). Antemortem tooth loss likewise differed significantly, skewed towards females. For calculus, however, males had significantly more teeth affected when compared to females. There was no difference in the deposition score (based on Brothwell, 1981) between males and females (Table 4).

Table 3: Frequency of permanent teeth affected by dental caries, and the total number of alveoli for permanent teeth indicating ante-mortem tooth loss, by sex and age group for Siwa burials

	Carious teeth									**Antemortem tooth loss**								
	Males			Females						Males			Females				
Age group	n=	% of teeth affected	No./Total	n=	%of teeth affected	No./ Total	χ2 (df = 1)	p value	Obs. alveoli	% of teeth affected	No./Total	Obs. alveoli	% of teeth affected	No./ Total	χ2 (df = 1)	p value
15-25+	3	20.8	15/72	0	-	-	-	-	92	1.1	1/92	-	-	-	-	-
26-45	10	23.0	41/178	4	16.7	12/72	1.24	.26	295	20.7	61/295	120	30.8	37/120	4.88	.027*
46+	4	10.7	5/61	5	39.3	11/28	12.60	.0004*	120	35.8	43/120	160	70.6	113/160	33.64	<.0001*
Total	17	17.5	54/309	9	23.0	23/100	1.51	.22	509	19.3	98/509	280	53.6	150/280	98.7	<.0001*

+ Late adolescent and young adult categories combined

Table 4: Frequency of calculus observed in male and female individuals

	Calculus									
	Males				Females					
Age group	Obs. Teeth	% of Teeth	No./Total	Average Calculus	Obs. Teeth	% of Teeth	No./Total	Average Calculus	χ2 (df = 1)	p value

		Affected		Score per affected tooth (0-3)		Affected		Score per affected tooth (0-3)		
15-25+	51	64.7	33/51	1.00	-	-	-	-	-	-
26-45	174	63.4	111/174	1.18	72	40.3	29/72	1.00	11..5	0.0001*
46+	61	73.8	45/61	1.00	24	62.5	15/24	1.06	1.05	0.30
Total	286	66.1	189/286	1.06	96	45.8	44/99	1.03	14.41	0.0001*

+ Late adolescent and young adult categories combined

For all three of these cohorts, females had a significantly higher rate of antemortem tooth loss than did males (Table 3). For all cohorts, there was not a statistically significant difference in the prevalence of apical lesions between males and females (Table 5).

Table 5: Frequency of apical lesions observed in male and female individuals

	Apical lesions							
	Males			Females				
Age group	Obs. alveoli	% of Alveoli Affected	No./Total	Obs. alveoli	% of Alveoli Affected	No./Total	χ2 (df = 1)	p value
15-25+	92	1.1	1/92	-	-	-	-	-
26-45	295	9.8	29/295	120	10.0	12/120	.002	.96
46+	120	4.2	5/120	160	6.3	10/160	.59	.44
Total	507	6.9	35/507	280	8.0	22/280	1.39	.24

+ Late adolescent and young adult categories combined

3.2 Non-molar Attrition Analysis

Due to the high prevalence of large carious lesions, abscesses, and antemortem tooth loss of the molars in this sample (preventing meaningful, within-age-cohort comparisons of molar attrition) only non-molar teeth were assessed further. Initial visual assessment using Tukey boxplots and violin-and-boxplots to interpret attrition of individual non-molar teeth for each age cohort revealed, in general, higher attrition scores for incisors than for other teeth in the arcade (Figures S1 through S5 in the supporting information).

Results of the Mann Whitney U test and pairwise comparison for attrition rates of specific teeth are as follows: In the age and sex-pooled sample, attrition scores for teeth #4 (upper-right P4), 8 (upper-right first incisor), and 12 (upper-left P3) were significantly different from other teeth. While 4/URP4 and 12/ULP3 had lower attrition scores than other non-molar teeth, 8/URI1 had the highest attrition scores. While there were no significant differences in attrition scores for mandibular teeth, they were on average more heavily worn than the maxillary. After excluding the late adolescent and old adults, no teeth differed significantly in wear from one another, regardless of cohort.

Within each age cohort with enough male and female observations for comparison, and within the adult-pooled sample (excluding old adults and the late adolescent), average non-molar attrition did not vary by sex, with a *p(same mean)* of 0.36 for middle adults (0.28 for young middle adults and 0.28 for old middle adults), 0.26 for old adults, and 0.22 for adults excluding ADO and OA (see Tables 6 and 7).

Table 6: Average non-molar wear for each age cohort for males and female individuals

			Average Non-Molar Attrition		
Pathology	**Etiologies**	**Age**	**Male**	**Female**	**Significant Statistical Difference?**
Attrition (oral wear)	Fibrous diet, sandy inclusions in diet, behavior (e.g. clasping with teeth)	Young Adult (15-25) +	2.38	-	NA (no females)
		Middle Adult (26-45) ++	4.60	5.60	No
		Old Adult (46+)	5.43	5.60	No
		Adults Pooled (excluding ADO and OA)	4.53	5.44	No
		All Cohorts Pooled	4.55	5.52	Yes

+ Late adolescent and young adult categories combined
++ Individuals (n=2) of unknown sex excluded (one Middle Adult, 2012_M3_R1, and one individual of unknown age and sex, 2012_M32_R2).

Table 7: Results of the one-way ANOVA to compare attrition between males and females in each age cohort

Age Classification	**p(same mean)**
Adolescent (ADO)	NA (only one individual in cohort)
Young Adult (YA)	NA (no females in cohort)
Middle Adult (MA)	0.36
Young Middle Adult (YMA)	0.28
Old Middle Adult (OMA)	NA (only one female in sample)
Old Adult (OA)	0.26
Pooled Adults (excluding ADO and OA)	0.22
All Samples Pooled	0.04

The Linear Discriminant Function Analysis classified the unknown individual as "late adolescent," with a 100% correct classification matrix (Table S1 and Figure 2). Jackknifed confusion matrices did not significantly change the correct classification percentage.

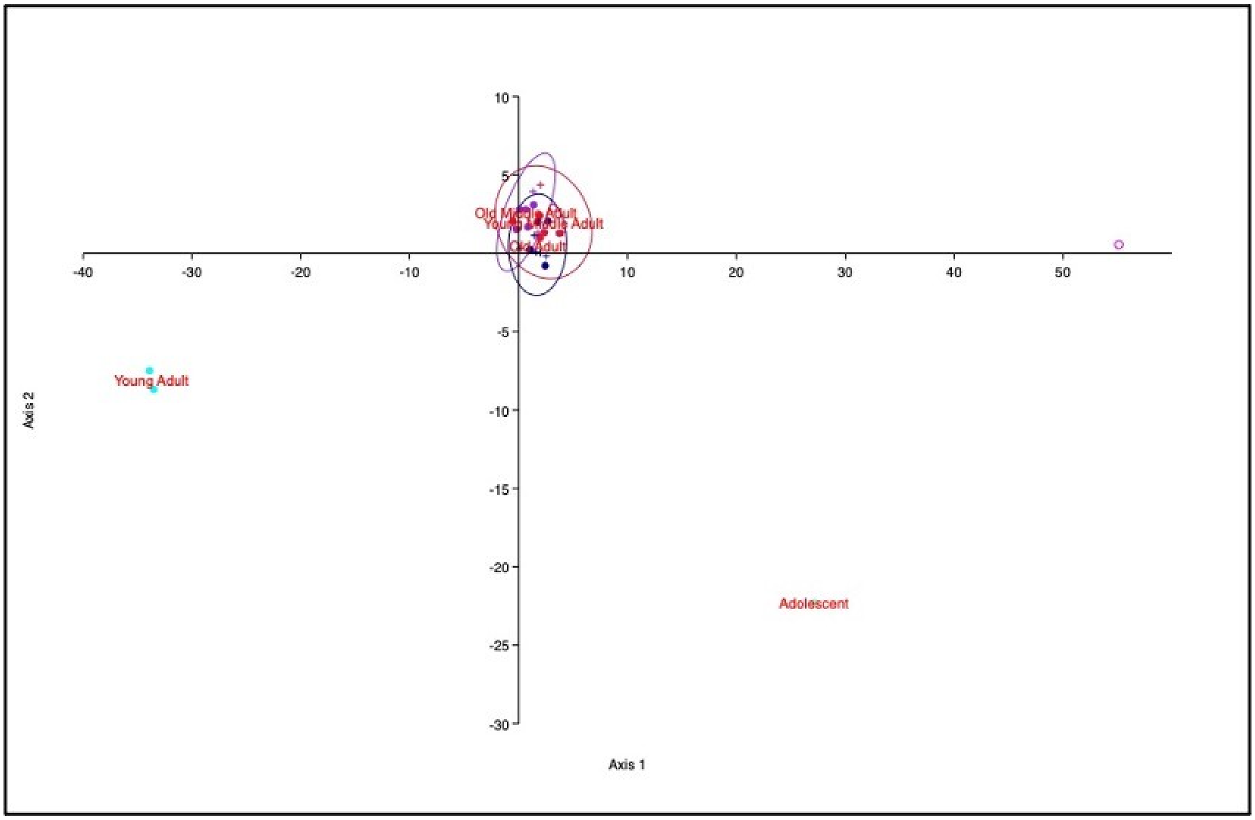

Figure 2: Here, LDA shows classification of individuals within groups (the unknown individual can be seen in the (+,+) quadrant, nearest to the "adolescent" category based on group centroids (see also Table S1 for classification).

Results of the regression to evaluate relationship between non-molar attrition and other indicators of oral health are presented in Figures S6, S7, S8, and S9 in the supporting information. This analysis revealed that individuals with greater average levels of non-molar attrition had more antemortem tooth loos and had a greater number of teeth affected by apical lesions. This also showed that individuals with greater rates of attrition did not show higher levels of caries and calculus.

3.3 Comparison of Siwa to Qijia

When comparing the data acquired from the Siwa-period individuals to previous work on the Qijia-period individuals from the Mogou site, similar trends were identified in oral health outcomes for males compared to females, with regard to carious lesions, and the number of teeth affected by calculus (Table 8). However, both these variables increased significantly diachronically. That is to say, males and females alike experienced a greater prevalence of carious lesions and calculus during the Siwa period. There was a statistically significant difference in the presence of apical lesions between the sexes in the Qijia-period individuals. Although a similar trend was observed in the Siwa-period, this was not a statistically significant difference. No significant differences were observed in dental attrition between males and females in the Qijia- or Siwa-period individuals (see Zhao et al. 2012, p. 435-436). Age-pooled average non-molar attrition scores are at least one degree of severity higher for Siwa females compared to Qijia females. Males and females for each age cohort during both Qijia and Siwa periods score above the median on the Smith scale for attrition (4 of 8). While studies on attrition during the Qijia period reference significant left-right asymmetry and several instances of idiosyncratic wear patterns, the Siwa-period population did not show such asymmetries nor such idiosyncratic patterns of attrition.

Table 8*:* Age-pooled *comparison of Siwa-period and Qijia-period oral health at the Mogou site. Data for the Qijia period was published by Zhao et al. 2012 and Zhao et al. 2014.*

	Percent of observable teeth or alveoli affected					
	Qijia Period		**Siwa-period**			
	Male	**Female**	**Male**	**Female**	**Significant Statistical Difference during Qijia Period**	**Comparison between Qijia- and Siwa Periods**
Carious lesions (cavities)	4.53%	8.77%	17.5%	23%	Yes (greater for females)	M/F relationship during Qijia period similar to Siwa (more caries among females), although percentage increases for both in Siwa period
Calculus (mineralized plaque)	6.69%	2.19%	66.1%	45.8%	Yes (greater for males)	M/F relationship during Qijia period similar to Siwa (more calculus among males), although percentage increases for both in Siwa period
Antemortem tooth loss	Not specified	Not specified	19.3%	53.6%	Unobservable	Not recorded in the Qijia studies (AMTL recorded for individual teeth with sex and age pooled)
Apical lesions (root canal infection)	1.00%	1.85%	5.7%	8%	Yes (greater for females)	M/F relationship during Qijia period similar to Siwa (more lesions among females)
Periodontitis (gum disease)	6.06%	3.46%	Not recorded	Not recorded	Yes (greater for males)	Not measured in the Siwa study (see discussion)
	Average attrition score for full dentition					
Attrition (oral wear)	3.79	3.56	Molars scored using a different method from non-molars	As at left	No+	Full dentition attrition was not measured in Siwa study, as different recording methods were used for molars and non-molars (see discussion)

	Average non-molar score attrition score					
	3.93	3.75	4.6	5.38	No	M/F relationship during Qijia period similar to Siwa, although score increases for both in Siwa period (by more than one point for females)

+ The abstract indicates sex difference in attrition (more in males), the data from the table on pages 435-436 shows no statistically significant difference between attrition scores for the sexes

4. Discussion

4.1 Discussion of Research Results

As discussed above, no single indicator of oral health or its degradation can be studied in isolation. Rather, each can serve to exacerbate or ameliorate another factor under consideration. Further confounding the analysis of these biological processes is behavior, moderated by culture, and embodied differently by subgroups delineated by age or sex. While this study focuses on the observation and analysis of non-molar dental attrition, therefore, it must consider the roles of pathological conditions for the Siwa-period sample under investigation.

First, in the age-pooled sample, incisors showed the highest rate of attrition after molars had been excluded. This may be because incisors are generally the first permanent teeth to erupt in the permanent dentition (Hammerl ,2013). Tooth #24 (lower left I1) most frequently showed the highest average attrition score for each cohort. However, the age and sex pooled sample, MWU comparisons showed that tooth #8 (upper right first incisor) differed significantly from other teeth, with higher attrition. It is possible that these individuals engaged in cultural practices which alter the pattern of oral wear between individual teeth, focused on these parts of the dental arcade. This anterior attrition likewise matches that seen during the Qijia period at Mogou (Zhao et al., 2012). However, the extent of difference is less extreme than the example cited above, so it is unclear whether the use of teeth as tools is the cause of these more-worn teeth. Importantly, males and females did not show different patterns of wear either in the age-pooled sample or within age cohorts.

Second, within each age cohort with enough male and female observations for comparison, and within the adult-pooled sample (excluding old adults and the late adolescent), average non-molar attrition did not vary by sex. This indicates that diet may not have differed for males and females of any age cohort in this sample, based on this indicator in isolation. The sample pooling all age cohorts was significant, indicating a difference based on sex; however, this is likely because the single adolescent individual is a probable male, and most of the old adults (who show more advanced attrition) are female. As discussed for the etiology of attrition and other indicators of poor oral health, there is a bias towards female acquisition of dental pathology due to hormonal factors (Lukacs, 2011). It is unlikely therefore that males and females differentially engaged in craft production (such as textile processing) or habits (such as pipe smoking) which modify attrition on the basis of sex; if one sex practiced intensive leather processing, for example, so too did the other. Similarly, it is unlikely that the “toughness” or “grit” of male and female diets differed. Their food was likely processed in the same manner and composed of the same substances (i.e., meat was not necessarily preferentially distributed to males.

The relationship between attrition and other indicators of oral health varies by pathology; in the case of both antemortem tooth loss and apical lesions, those with greater average levels of non-molar attrition showed higher incidences of both, which might be related to older age. Contrarily, those with greater rates of attrition did not show higher levels of caries and calculus. This is likely because teeth which are heavily worn are difficult to score for pathologies such as carious lesions (occurring as they do on the enamel of the tooth, at least initially), while apical lesions can still be readily apparent on the heavily worn and even (eventually) toothless mandible or maxilla. While it is possible to generate a corrected caries rate for a population (following, for example, the method developed by Lukacs (2011) or that of Duyar and Erdal (2003) such calibrations require a distinction between caries-induced pulp exposure and attrition-induced pulp exposure, with greatest accuracy for populations with high rates of caries-induced pulp exposure. As this Siwa-period population shows advanced attrition even of non-molar teeth (which are less often carious), it is more likely that posterior teeth show pulp exposure through attrition inducement, rather than carious lesion prevalence, rendering the corrections developed by Lukacs (2011) and Duyar and Erdal (2003) unnecessary for this context.

The relationship between attrition and oral pathology for this population reveals poor holistic oral health even for the young adult age cohort. Females (especially older females) show higher incidence of dental pathologies, which may be caused by physiological biases; however, attrition did not vary significantly by sex. While the incidence of caries and apical lesions among both males and females could indicate a diet of sugar-producing carbohydrates (often associated with agriculturalists), the advanced attrition has been previously associated by scholars with “hard foods” diets, such as those of foragers and pastoralists who prioritize meat and fibrous foods consumption. It is possible that higher rates of attrition for certain teeth in the dentition indicate use of the teeth as a “third hand,” which did not vary by sex, or the presence of hard inclusions in local foods (supported by the region’s sandy ecology).

While the Qijia and Siwa periods differed in non-molar attrition, the difference is not enough to indicate diachronic changes to subsistence practice, parafunctional use of the teeth, nor major shifts in the comparative diets of males and females. This supports earlier findings of cultural transmission from both archaeological data (for example, mortuary analysis by Yin 2014, Chen 2003, and Jaffe and Heine 2021) and biological data (for example, carbon isotope analysis by Cheung et al. (2019) and Liu and Reid (2020)). However, there is an upward trend in caries and calculus prevalence over time, with an increase in caries prevalence among males (12.97% greater than during the Qijia period) and females (14.23% greater), and an increase in calculus prevalence by 55.03% and 47.27%, respectively. While attrition rates do not indicate diachronic change, therefore, and the relationship between male and female oral health outcomes did not shift over time, the changes to caries rates (with sexes pooled) could indicate a population-level dietary shift which favored the consumption of cariogenic over fibrous foods.

There are several limitations to the comparison between these populations. Apical lesion prevalence was recorded using different methods for each study; so, while results for the prevalence between males and females can be compared, it is not possible to compare data directly. Similarly, different methods were used to score attrition for the full dentition. While the Siwa study used the Scott system (1979) to score molars, assigning a distinct score to each quadrant, the Qijia studies by Zhao et al. (2012 and 2014) used the Smith (1984) system for all teeth in the dentition. Again, this allows meaningful comparison of non-molar attrition and wear patterns generally (as in the case of idiosyncratic wear), but it does not allow direct comparison of the data through full dentition average attrition scores. In addition, it is likely that different methods of cleaning dental remains prior to macroscopic analysis led to different levels of observed calculus between the two studies. Finally, AMTL was not measured for the Qijia period, nor periodontitis for the Siwa period, preventing their direct comparison. For the Siwa sample, it is also important to note the small sample size (n=28). For both the Qjia and Siwa samples, inter- and intra-observor error was not calculated, although multiple researchers worked together to score these pathologies.

4.2 Conclusions and Significance

This study of Siwa-period oral health has shown poor oral health for all population sub-groups, biased slightly towards females (and older females in particular), but unbiased with regard to the severity of non-molar attrition. There were no sex-based or age-based differences in indicators of diet or parafunctional use of the teeth.

Archaeologically, this study supports the hypothesis of continuity in subsistence practice from the Qijia to the Siwa periods in northwestern China during the Bronze Age. It also suggests a possible increase in consumption of cariogenic food in the populations buried at Mogou, in contrast to the usual narrative of a shift towards pastoral food sources over the course of the Bronze Age in this region. The Siwa period population not only shows biological affinity to the Qijia period population (as attested by Zhao et al., 2017; Chen, 2003; Yin, 2014), but also shows some degree of shared economic practice as related to foodways. A distinction between the periods might be made with regard to idiosyncratic wear patterns. While the Qijia population included individuals with very distinct patterns (possibly related to parafunctional use of the teeth), the Siwa population did not. Continued comparison of this sample to others of northwestern China during the Bronze Age will certainly reveal more nuance in the debate surrounding continuity and change in the archaeological record.

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