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Dental health in Iron Age Cambodia: temporal variations with rice agriculture.

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ABSTRACT

The dental health of two Cambodian Iron Age (500 BC to 500AD) communities is interpreted through an analysis of advanced wear, caries, periapical lesions, and antemortem tooth loss (AMTL). The two communities, Phum Snay and Phum Sophy, just 40 kilometres apart, are temporally situated at a time of significant socio-political change prior to the establishment of Angkorian state rule. Dental pathology frequencies are compared between the two communities and with other prehistoric sites throughout Southeast Asia to determine whether dental health was affected by socio-political changes and the intensification of rice agriculture that also occurred at this time. The people of Snay and Sophy, despite their proximity, were found to exhibit significant differences in dental health. When subdivided by age and sex, Sophy older age class teeth had significantly more advanced wear, and older females had more periapical lesions, while the Phum Snay older age dentitions had significantly more AMTL. Caries rates were similar between the samples. When compared in the broader context of the Iron Age in prehistoric Southeast Asia, both Phum Snay and Phum Sophy suggest a trend of declining dental health during the period prior to the rise of the Angkorian state.

1. Introduction

The adoption and intensification of rice agriculture is a key subsistence change that dominates Southeast Asian history. This transition appears to have had a limited affect on dental health (Domett and Tayles, 2006; Oxenham et al., 2006). This contrasts with many other parts of the world, where caries in pre-agricultural communities were rare and increased markedly as carbohydrate based crops, such as maize, barley, and wheat, were consumed (Hillson, 2008; Lukacs, 1992; Larsen, 1995). Previous studies have highlighted the lower cariogenicity of rice as an explanation for the absence of a similar decline in dental health in Southeast Asian prehistory (Tayles et al., 2000; Domett and Tayles, 2006). In addition, Oxenham et al. (2006) hypothesize that a decline in oral health may not be apparent in prehistoric Southeast Asia until the Iron Age, a period marked by increased population aggregation and numbers of settlements alongside an intensification of rice agriculture (O'Reilly, 2000; 2008). A successful rice based economy is evident during northeast Thailand's Iron Age (Boyd and McGrath, 2001), but while rice cultivation was certainly utilised earlier than this, the scale for the Bronze and Neolithic periods is a point of debate (O'Reilly, 2008). There is evidence from some sites in central Thailand that millet was more common during the second millennium BC before rice became more dominant during the first millennium BC (Castillo, 2011; Weber et al., 2010). During the Iron Age significant changes in socio-political climate were evident, including increasing hierarchical structures (O'Reilly 2000). New evidence from Ban Non Wat has identified a potential elite during the early Bronze Age (Higham, 2011) but there is no evidence that this continued into later Bronze Age phases at Ban Non Wat or at contemporary sites; only further excavation can bring clarity to these issues.

To explore the implications of the hypothesis proposed by Oxenham et al. (2006), we report on two new Iron Age samples, Phum Snay and Phum Sophy, in northwest Cambodia (Fig. 1). The relationship between diet and dental pathology is explored and the influence of rice-based subsistence amid socio-cultural changes is considered. These communities existed during a period of significant cultural transformation in Southeast Asia, just prior to the rise of the Angkorian civilisation (AD 802-1432), a powerful state level organisation centred on Angkor in Cambodia. In the millennia immediately prior to this socio-political change, there was an increase in trade and conflict (Stark, 2004; Domett et al., 2011) and changes in subsistence practices. Such changes may have affected diet as communities engaged in state control of resources such as rice and agricultural land.

This study will significantly extend current data for long-term trends in dental health in prehistoric Southeast Asia into the late Iron Age. Specifically, we aim to explore 1) local trends in dental health and their potential causes in northwestern Cambodia; and 2) temporal trends in dental health in relationship to the development and intensification of rice agriculture, alongside environmental and social-cultural changes. While the nature of available comparative data precludes testing for statistical significance, we offer this as an initial exploration of the hypothesis that dental health declined in the Iron Age in Southeast Asia.

1.1 Biocultural Context

Recent archaeological excavations have markedly advanced knowledge of Cambodian prehistory (Stark, 2004; O'Reilly et al., 2006; Reinecke et al., 2009). As a consequence, human skeletal collections have increased, as has bioarchaeological knowledge of earlier peoples who occupied present-day Cambodia (eg. Domett and O'Reilly, 2009). Phum Snay and Phum Sophy, just 40 kilometres apart (Fig.1), were both occupied during the Iron Age which occurred from c. 500 BC to AD 500 (Domett & O'Reilly, 2009). Based on these recent research results from Cambodia and elsewhere in Southeast Asia, it is clear that significant socio-political changes occurred during the Iron Age (O'Reilly et al. 2006, Higham 2002b), including evidence for social tension reflected in the presence of weapons and a high percentage of cranial traumatic lesions at Phum Snay (Domett et al., 2011).

Iron Age Phum Snay, which was occupied from approximately 350 BC to AD 200 (O'Reilly et al., 2006), was a hierarchical society with a gender-based division of labor (Domett and O'Reilly 2009). Male burials had grave goods associated with agriculture, hunting, and warfare, such as projectile points, swords, and sickles. Female burials typically contained spindle whorls and some iron tools. Similarities in artefact assemblages and mortuary rituals link them culturally and temporally to other Iron Age sites in northeast Thailand. The presence of rice and sickles in some burial features indicates that rice cultivation was an important part of the subsistence regime (O'Reilly et al., 2006). The diet for the people of Phum Snay appears to have contained an adequate amount and variety of protein, with a range of animal bones found at the site, such as those of wild deer, turtles, and tortoises, along with domesticated species of dog, pig, cattle, chicken and duck. The large number of wild species and freshwater fish suggests that hunting and fishing were important (O'Reilly et al., 2006).

Preliminary information from Phum Sophy, which was occupied from approximately AD 100- 600 (Beavan, pers. comm. cited in Domett et al., in press), indicates that the suite of artefacts is similar to that of Phum Snay. Phum Sophy burials contained substantial wealth, such as semi-precious stones and large caches of ceramics and iron tools. A difference in burial wealth between the interments within Phum Sophy argues for the existence of a hierarchical society. Like Phum Snay, evidence suggests that a wide variety of ecosystems (forests, grasslands, rivers and inundated rice fields), were exploited, and that diet was broad-based. Faunal remains include pig, cattle, water buffalo, and chicken, all of which were probably domesticated (Voeun, 2010). Phum Sophy's location on a rich flood plain also made it an ideal location for collecting freshwater snails, shellfish and fish.

2. Material and Methods

2.1 The samples

The permanent dentition of human remains from Phum Snay and Phum Sophy were observed for this study. As 'Phum' refers to the Khmer word for 'village', the sites will hereafter be referred to as 'Snay' and 'Sophy'. The series from each site consisted of both an archaeologically excavated sample (Snay N=23; Sophy N=21) and an unprovenanced collection (Snay MNI=134; Sophy MNI=37). Both unprovenanced collections contained prehistoric skeletal material, the result of looting by local villagers. These collections consisted of isolated bones with no association by individual, including mandibles with maxillae. There was considerable fragmentation and post-mortem tooth loss due to both looting and curation procedures; loose teeth disassociated from supporting mandibular or maxillary alveoli were not included. Supplementary Table 1 indicates the teeth and tooth positions available for analysis.

2.2. Age at death estimation and sex determination

Buikstra and Ubelaker (1994) standards, modified for Southeast Asia due to later eruption times for certain teeth (Domett, 2001, Kamalanathan et al., 1960), were used to estimate age-at-death. If skeletons were complete, late-fusing epiphyses and pubic symphysis morphology were given priority. Age-at-death for individuals represented by isolated mandibles and maxillae was estimated, when possible, using molar attrition; thus comparisons between different age groups within or between samples is not possible when analysing advanced wear. Assignment to age categories (young adult, middle-aged adult or older adult) were made using molar wear grades (see below) for individuals whose ages were estimated by other parameters (such as pubic symphysis). The age of many individuals could not be estimated due to sample insufficiency. Permanent dentitions from subadults were included only when age could be estimated by dental development or diaphyseal length (Scheuer and Black 2000).

As most dental pathologies are strongly age progressive, pathology frequencies were separated into age classes (cf. Temple and Larsen, 2007), overcoming biases created by differing age structures for Snay and Sophy (see below). For this analysis, age groups were combined to form two age classes: ‘young’ (subadult and young adult permanent teeth), and ‘old’ (middle aged and older adults). ‘Total’ prevalence figures (sum of young, old, and unknown age permanent teeth) are also presented to facilitate comparisons with other Southeast Asian skeletal samples. These must, however, be treated conservatively due to demographic differences across samples.

Sex estimates were based on morphological features of the pelvis and/or cranium (Buikstra and Ubelaker 1994). For many of the unprovenanced remains this was not possible, either due to incomplete material or insufficient metric dimorphism in individuals sexed by other methods. The remains were therefore grouped into male, female, and unknown sex. All subadults in the sample were considered to be of unknown sex.

The demographic structure of the samples (Supplementary Table 1) showed significant age differences: Sophy had more people of advanced age, contrasting to the younger profiles at Snay. Given these differences, interpretations of our results will focus on comparing frequencies *within* age classes (between sexes and between sites) and not between different age classes. Sophy and Snay had very similar proportions of males and females overall (Teeth: Chi^2 p=0.9759; Tooth positions: Chi^2 p-value = 0.5981) though there was slightly more female teeth from Snay in the younger age sample (FET p-value = 0.0110) and more male teeth from Snay in the older age class (FET p-value <0.0001).

2.3. Dental Pathology Assessment

To assess overall dental health for each community, four parameters were recorded. These are advanced wear, caries, periapical lesions, and antemortem tooth loss.

The Smith (1984) system for assessing dental wear (grades 1-8) was used to evaluate anterior teeth and premolars, with grades of 6-8 considered ‘advanced wear’. Each quadrant of each molar was scored from grade 0 to 10 following Scott (1979); the average of the four grades was then calculated. Molars with average grades 7-10 were considered to have ‘advanced wear’. These grades were chosen as they represent wear with large areas of dentine and exposure of the pulp cavity. The definition of advanced wear can vary between studies making direct comparisons difficult, but most Southeast Asian studies equate advanced wear to exposure of the pulp cavity, despite the use of different grading systems such as those of Molnar (1971) and Brothwell (1981).

Caries were identified by the demineralization of enamel or root surfaces (Hillson 2008). Each tooth was scored for the presence or absence of caries; teeth with two or more caries were counted only once. Posterior teeth (postcanine) are more prone to caries than the anterior (Hillson, 2008). The Sophy and Snay samples had no significant differences in the presence of anterior and posterior teeth (Snay: 27.7% and 72.3%; Sophy: 27.3% and 72.7%, respectively; Chi^2 p-value = 0.7851), thus caries rates are not biased by the preservation of more posterior teeth in either sample.

Periapical lesions (also known as 'abscesses') and other alveolar defects were observed either apically as a discrete lytic lesion near the tooth root (representing the drainage channel of the abscess) (Buikstra and Ubelaker, 1994) or as an extreme localised depression (antemortem vertical bone loss) in the alveolar bone exposing much of the tooth root (Hillson, 2008). As it was difficult to ascertain whether or not this combination of defects was recorded for other Southeast Asian samples, regional comparisons may be biased by methodological differences. The results are presented as the proportion of periapical lesions to the number of tooth positions with intact alveolar bone.

Antemortem tooth loss (AMTL) is the absence of a tooth associated with at least some evidence of healing of the surrounding alveolar bone (Lukacs 1989). AMTL can be intentional, accidental or the result of pathology. Intentional AMTL has already been extensively investigated in Snay and Sophy (Domett et al., in press). Only the prevalence of pathological AMTL is reported here.

Sample sizes for the four classes of pathology varied slightly from the overall sample sizes shown in Supplementary Table 1, depending on preservation and the pathology being observed. Chi^2 (for larger sample sizes) and Fishers Exact Test (FET) p-values (for smaller sample sizes) were calculated to establish significant differences between samples. The p-value for significance was set at <0.05.

3. Results

3.1. Snay

There was significantly more advanced dental wear in older adult males compared with older females at Snay (Table 1). Advanced wear was significantly more common in the anterior teeth in females and close to significant in older males (Supplementary Table 2). Females were more commonly affected by caries than males in both age classes, but this was statistically significant only in the older class (Table 2). Periapical lesions were not present in young or older females; males presented a low percentage in both age classes (Table 3). Pathological AMTL percentage was low, and similar, in males and females for both age groups (Table 4).

3.2. Sophy

Older males showed slightly higher, but not statistically significant, rates of advanced wear compared with older females (Table 1). Advanced wear was not significantly different in either the anterior or posterior teeth in males and females in either age class, though the total sample, including those of unknown sex, in the older age class showed more wear in the anterior teeth (Supplementary Table 3). Caries rates were significantly more common in females for the young age class compared with males; older males and females had very similar caries rates (Table 2). Periapical lesion frequency was low in young males and females but significantly higher in older females compared with older males (Table 3). Pathological AMTL percentages were all very low; older females showed the highest percentage but no statistical differences were calculated (Table 4).

3.3. Comparison of dental pathology between Snay and Sophy

3.3.1. Advanced wear

Advanced wear in the older age class was significantly more common in the Sophy than in the Snay sample, despite similar low levels in the young age class at both sites (Table 1). Sophy and Snay males had similar percentages in each age class and were higher than females in the older age class. Sophy older females had nearly twice the percentage of teeth with advanced wear compared to older Snay females, although the difference was not statistically significant.

3.3.2. Caries

Caries rates were not significantly different between the Snay and Sophy dentitions for any age class or within either sex (Table 2). Non-statistically, older Sophy males had nearly twice the caries frequency compared to Snay males. Female rates were generally similar in both age groups for both sites but were highest in Snay older females.

3.3.3. Periapical Lesions

Periapical lesion frequencies were very low across the samples. They were most common in Sophy older females, significantly higher than Snay older females who showed no periapical infection (Table 3). Males had very similar rates for both age classes across the sites.

3.3.4. Antemortem Tooth Loss

Pathological AMTL (excluding ablated AMTL) was low in both samples, but the dentitions of older individuals from Snay had significantly more than older Sophy teeth (Table 4). Females in the older class at Sophy had the highest level of pathological AMTL, but this was not statistically significant.

4. Discussion

4.1. Snay

At Snay, older females had more caries while males had significantly higher frequencies of advanced wear; both sexes had low rates of periapical lesions and AMTL. Sex differences in dental profiles can be indicative of different diets stemming from a sexual division of labour. A combination of low caries and high advanced wear rates (seen in Snay older males) is typical of hunter-gatherer subsistence strategies, while high caries and low advanced wear rates (seen in Snay older females) are frequently associated with agricultural diets (Lukacs, 1989). However, varying caries rates could be due to non-dietary, physiological factors. Higher caries frequencies in females compared with males is very common in archaeological samples from around the world (eg. Temple and Larsen, 2007; Lukacs, 2011b), suggesting a non-dietary cause (Lukacs, 2011a). Physiological differences between the sexes, such as the rate of salivary consistency and flow, hormones, and pregnancy can differentially impact the dental health of females, resulting in more caries (eg. Lukacs, 2011a; Lukacs and Largaespada, 2006). The higher caries rate in Snay females could be due to the consumption of more cariogenic and softer foods such as taro, yams, rice and millet, and sugars from bananas and palm sugar (Tayles et al., 2000; Weber et al., 2010). Depending on the type of processing, rice is not particularly cariogenic, especially in its unpolished state, the type consumed during prehistory (Tayles et al., 2000; Domett and Tayles, 2007). Millet consumption is also not always correlated with high caries rates, as seen in the Shaanxi province in Northeastern China (Pechenkina et al., 2002). More sugary foods, rather than more starchy carbohydrates, may be the culprit, alongside non-dietary factors.

Grave good distributions (O'Reilly et al., 2006) and previous studies in the region (Higham, 2002a; Shoocongdej, 2002), suggest that males at Snay hunted and fished, and may, on these occasions, have been reliant on a different, perhaps coarser diet than females. The significantly higher wear rates in Snay males compared with females may also be due to the use of their teeth for utilitarian purposes, as has been shown to be the case in prehistoric Vietnam (Oxenham et al., 2006). Evidence for using teeth as tools is often seen in the anterior teeth, though not exclusively (Blakely and Beck, 1984). Advanced wear was more common in anterior teeth than in posterior teeth in both males and females at Snay; therefore, if there was a non-dietary use of teeth it was occurring in both males and females.

4.2. Sophy

Statistically significant sex differences in the Sophy dentition were not as apparent as in the Snay samples suggesting there may have been less sex differentiation in diet in the Sophy community. While many percentages were notably different between males and females, only the caries rates in the younger female age class were statistically higher than the males. Interestingly, the sex differences in caries did not continue into the older age class, though this may be a reflection of the small sample size (Table 2). Alternatively, carious teeth may have been lost at a young age in females, however, the AMTL frequencies (Table 4) are low in all groups and as such cannot account for this difference. Female dentitions did show a significant increase in periapical lesions with age, which may reflect the high percentage of caries at a young age. Caries can lead to pulp exposure leaving an individual more prone to periapical lesions (Lukacs, 1989). The significant increase in caries from young to older males is enigmatic; it may reflect a change to a more cariogenic diet as males age. Though the sample size is small, perhaps resource acquisition strategies varied between age classes. Older males may have spent more time on agricultural tasks while young males engaged in hunting, away from the village, thus exposing them to different diets.

4.3. Snay and Sophy: dental health in Cambodia

Dental health profiles differed significantly between Snay and Sophy, despite the two communities being in close proximity and with access to similar resources. In the older age class, Sophy dentitions had higher rates of advanced wear and older females had higher rates of periapical lesions than Snay. Older individuals from Snay had a higher frequency of AMTL. Caries rates were not significantly different. The demographic profiles of the samples were not identical, with significantly more older male teeth (but not tooth positions) and younger female teeth (but not tooth positions) in Snay compared with Sophy, but this does not explain all the differences; we would expect to see more older males at Snay with advanced wear, for example, but this is not the case. The key may be the difference in the way the two communities interacted with and utilised their local environments. The higher frequency of advanced wear in the older age class at Sophy may be explained by dietary differences, such as a higher consumption of gritty shellfish. However, the higher proportion of anterior versus posterior teeth with advanced wear in both samples suggests this may be more than a dietary difference. Further investigations into antemortem chipping, interproximal wear facets and general wear patterns may be useful for determining potential changes in use of teeth and distinguishing dietary from non-dietary causes of wear.

A further point of difference between Snay and Sophy was the significantly higher levels of violence recorded at Snay (23.4% with cranial trauma compared with only 2.8% at Sophy) (Domett et al., 2011; Domett, pers.comm.). During the development and later establishment of the strongly hierarchical Angkorian state (*c*. A.D. 800), local control over resources, including water and agricultural land, and commodities for exchange including salt and fish, is likely (Domett et al., 2011; O'Reilly et al., 2006) and may have lead to intercommunity violence. Subsistence practices at Snay may have been affected by the greater social tension in this community and as a result, procurement territories may have been restricted. However, archaeological evidence does indicate a large number and range of wild and domesticated species were available at Snay (O'Reilly et al., 2006). The sample from Sophy is from the later in the Iron Age (AD 100-600) compared with Snay (350 BC to AD 200) and perhaps socio-political changes were now in place with increased control and less violence. Additionally, Sophy is approximately 40kms west of Snay, further from the eventual centre of the Angkorian polity, and may have been less exposed to its influences. However both Sophy and Snay were on the ancient road to Angkor, between the expansion of Angkorian influence in northeast Thailand and the city of Angkor in northwest Cambodia.

4.4. Southeast Asian dental health trends

In many Southeast Asian studies population health has generally been stable with the intensification of rice agriculture (eg. Pietrusewsky and Douglas, 2001; Domett and Tayles, 2006). Rice is high in nutritional value and when even small amounts of meat, fish and vegetables are added, a rice diet is nutritionally balanced (Juliano, 1993). Placing the Cambodian data within a broader Southeast Asian context is complicated by methodological, sampling, and demographic issues that prevent statistical analyses. The following discussion is therefore limited to general trends, not statistically significant differences. In addition, some studies have not subdivided data by age, thus comparisons are based on total frequencies. The sites discussed include Neolithic (Con Co Ngua, Khok Phanom Di, early Non Nok Tha, early Ban Chiang, Man Bac), Bronze Age (late Non Nok Tha, Nong Nor, Ban Lum Khao, late Ban Chiang) and Iron Age sites (Ban Na Di, sites in the Ma and Ca Rivers, Noen U-Loke, Angkor Borei) (see Figure 1 and 2 for details). There is environmental variation across the samples with some coastal and many inland sites situated on river floodplains. This variation will be discussed where relevant below.

4.4.1. Temporal variation

The frequency of advanced wear does not show any consistent pattern through time. There are a mix of low and moderate frequencies in the Neolithic and Bronze Age, though most Bronze Age samples show higher frequencies. During the Iron Age there are higher levels at Noen U-Loke and lower levels in the later Iron Age Cambodian samples (Fig.2). The correlation between tooth wear and diet is long established (Lukacs, 1989), however other causes such as food preparation methods and the use of teeth as tools can contribute to wear patterns. Prehistoric communities that depend heavily upon marine resources often show comparatively high wear rates, such as those in the Arabian Gulf (Littleton and Frohlich, 1993). Southeast Asian dentitions do not consistently follow this pattern (Domett, 2001) proving that geographic location cannot always predict dental pathology profiles. For example, coastal Khok Phanom Di, with evidence for a diet of shellfish and other marine resources, had a low frequency of advanced wear while the only other sample reasonably close to the coast with advanced wear, Nong Nor, had the highest frequency (Fig. 2) (Domett, 2001). Inland Non Nok Tha males with a moderate wear frequency, particularly high on anterior teeth, may have used their teeth as tools (Douglas 2006). Wear also increases in general at Non Nok Tha from the early to late groups and Douglas (2006) suggests dietary grit or fiber may also have increased. Anecdotally (no data provided), Reinecke et al. (2009) provide a similar dietary explanation for the advanced wear in the Iron Age Prohear community in southern Cambodia. Tooth wear at this site was so considerable that even young children were markedly affected.

<Figure 2>

Caries rates were variable during the Neolithic, low to moderate throughout the Bronze and early Iron Ages followed by higher levels in the late Iron Age (Fig. 3). High caries frequencies among the northwest Cambodian Iron Age communities runs counter to previously observed trends for declining or stabilising rates during this period (Domett and Tayles 2006). Given that the other Iron Age samples do not show such high caries frequencies, this may underscore variation due to local factors or sampling error. There is evidence for a drier climate in the Iron Age in the Upper Mun River Valley (UMRV) in northeast Thailand along with increased deforestation for rice cultivation and associated water management (Boyd 2008); these factors would have affected foods consumed at Noen U-Loke. Whether this climate change was also experienced in northwest Cambodia is unknown, but this may be a point of difference between the two areas during the Iron Age.

The Snay and Sophy communities were also much closer to the eventual centre of the Angkorian civilization and may have been more affected by the increasing levels of external control prior to establishment of state rule compared to northeast Thailand and southern

Cambodia. This may have meant that certain foods were increasingly under external control and thus limited in their availability. There may also have been variation in food preparation methods; refined rice (milled and polished) has a higher cariogenicity than unrefined brown rice (Juliano, 1993). A range of non-dietary factors can also influence caries development that are difficult to discern from prehistoric skeletons including frequency of eating, oral pH levels, and dental hygiene (Tayles et al 2009).

<Figure 3>

The frequency of periapical lesions was relatively low during the Neolithic, with the exception of the Khok Phanom Di sample. Levels were also generally low in the Bronze Age (Fig. 4). Iron Age samples show more mixed results but tended to be moderate to high. The communities with the highest frequencies, Khok Phanom Di, Noen U-loke, Snay and Sophy, all showed intentional ablation of anterior teeth (Tayles, 1996; Nelsen et al., 2001; Domett et al, in press). Dental modifications may have increased the risk for infections and inflammation of surrounding dental tissues, though these sites also have either high caries or advanced wear as well.

<Figure 4>

Across Southeast Asia, AMTL frequencies are mixed but mostly moderate to high during the Neolithic and Bronze Age and generally low in the Iron Age (Fig. 5). Given that some of the Iron Age samples show the highest levels of periapical lesions, for example Sophy and Noen U-Loke, this result may reflect an improvement in their ability to contain (or fight) infection without the loss of teeth. Domett and Tayles (2006: 222) suggest that “through time, the health of the prehistoric people may be expected to have improved as their ability to exploit their environment developed”. This low AMTL may be one sign that Sophy individuals were healthier than their predecessors.

<Figure 5>

4.4.2. Sex differences

Sex differences in dental health profiles can suggest gender differences within communities. The development and severity of dental pathology can also be influenced by nondietary factors such as age, varying hormone levels, genetic predisposition, as well as the general health of the individual.

Sex differences in advanced wear rates are inconsistent through time. Douglas (2006: 216) found a reduction in advanced wear rates in females from early (Neolithic) to late (Bronze Age) Non Nok Tha people, attributing this to “a shift toward softer, more processed agricultural foodstuffs” in females. Ikehara-Quebral (2010) also attributes the sex differences in Angkor Borei dental remains to diet differences. Bronze Age males consistently had higher advanced wear rates compared with females, while the reverse was true in the early Iron Age (Fig.2).

In 12 of the 16 (75%) Southeast Asian sites studied, caries rates are higher in females than males (Fig. 3). This is seen in many studies around the world (eg. Temple and Larsen, 2007; Lukacs, 2011b). Physiological differences between the sexes, such as the rate of salivary consistency and flow, hormones, and pregnancy can differentially impact the dental health of females, resulting in more caries (eg. Lukacs, 2011a; Lukacs and Largaespada, 2006). Based on animal research, caries rates increase with estrogen fluctuations, with high fluctuations occurring during pregnancy (Lukacs and Largaespada, 2006; Watson et al., 2010). In Snay dentitions there was an increase in caries rates with age among females (Table 3). This increase in caries and

AMTL prevalence’s in older age could result from the physiological factors associated with pregnancy as young adults. Thus, communities with evidence of high fertility may also have high caries rates in females (Lukacs, 2008). Sites with high fertility, based on calculations such as the Juvenile - Adult ratio and Mean Child Mortality, include Neolithic Khok Phanom Di, new evidence from Neolithic Vietnamese sites Man Bac and An Son, Bronze Age Ban Lum Khao and Iron Age Angkor Borei (Domett and Oxenham, 2010; Ikehara-Quebral, 2010; Willis and Oxenham, 2011). Of these, only the Neolithic sites have been shown also to have high caries rates (Willis and Oxenham, 2011); the other sites have more moderate caries rates suggesting that fertility may be only one of many factors affecting caries rates.

Males tended towards higher frequencies or periapical lesions in the Bronze Age, while females tended to have higher levels in the Iron Age. This relates to the pattern of advanced wear; Bronze Age males had higher advanced wear rates that may have resulted in their higher periapical lesions, while the opposite was true in the early Iron Age with females showing higher wear and higher periapical lesions. This suggests that the route of periapical infection is strongly linked with pulp exposure through advanced wear.

Sex differences in pathological AMTL across time are not particularly strong. Both the Neolithic and Iron Age samples frequently show more AMTL in females. This may be linked to a parallel trend in caries: when females develop caries they are more likely to lose their teeth prematurely.

5. Conclusion

This study focused upon estimating local trends in dental health for Iron Age northwest Cambodia and their potential causes. We also placed these local dental pathology frequencies within the wider Southeast Asian context by exploring temporal trends in relationship to the development and intensification of rice agriculture. In the latter case, we considered the hypothesis that dental health declined during the Iron Age, as proposed by Oxenham et al (2006).

5.1 Dental health in Iron Age northwest Cambodia

The Snay and Sophy dental pathology data indicate that broadly contemporaneous populations in similar physical environments exhibit differences in dental health. Overall, it is not possible to say that one community had better dental health than the other, with Sophy dentitions showing higher rates of advanced wear and periapical cavities, and Snay showing a higher frequency of AMTL. Caries rates were not significantly different. Assuming similarities in genetic background, a plausible assumption based on the proximity of the sites, there may have been subtle differences in diet, such as more fish consumption by people at Sophy and/or more hunting undertaken by people from Snay; this will be investigated further through isotopic paleodietary analyses and more detailed faunal analyses.

Both samples were dated to within the Iron Age, however, the Snay sample is predominantly early to mid Iron Age while Sophy is mid to late Iron Age and closer in time to the establishment of the Angkorian state formation, though also physically further from the eventual centre of Angkor than Snay. Due to the evidence for violence at Snay, limited food resources might have been available during this politically unsettled time. Violence between groups could limit trade within the region, and opportunities to hunt and fish since resources were being used to defend villages. Sophy's later occupation dates and lack of interpersonal violence might showcase greater state control over resources within this community and warrants further investigation. Thus, factors such as these, associated with potential changes in food preparation methods could have differentially affected overall dental health.

5.2 Dental health in prehistoric Southeast Asia: temporal trends

Together, the results from the Snay and Sophy dental remains extend the Southeast Asian trends of dental pathology from the Neolithic into the late Iron Age. The temporal trends, though the data are not sufficiently robust or comparable for statistical testing in their current form, suggest changing influences on dental health. Change in diet is one explanation, along with variation in genetic predisposition between groups and other nondietary physiological factors.

Overall, the results show higher dental pathology frequencies in the Iron Age for caries and periapical lesions, especially when compared with Bronze Age samples. This argues for a decline in dental health in the Iron Age and thus generally supports Oxenham et al.'s (2006) hypothesis. However, this does not necessarily equate with a decline in *overall* dental health since fewer people were losing their teeth to pathology as reflected in the lower frequencies of AMTL during the Iron Age. Rice consumption increased at the community and regional levels from its inception in Neolithic times to its abundance during the Iron Age, but it is only one factor in the complex set of influences on dental health. This regional study showcases how the dental health of prehistoric communities responds to shifting political structures and the subsequent impact on the way in which the community engages with the environment. This study of dental health provides a model for understanding how prehistoric communities utilised resources and reacted to socio-political transformations.

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