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Keywords: Cambodia, bioanthropology, Pre Funan culture, Iron Age, cemetery

Abstract: The Early Iron Age site of Prohear in southeastern Cambodia was discovered and nearly completely looted in 2007. From 2008 to 2011, the German Archaeological Institute together with the Memot Centre for Archaeology carried out rescue excavation of 76 intact or only partly looted graves directly under the main road through the village. Of these, 42 burials still contained human remains. This study presents the final results of the bioanthropological analyses and their regional and chronological context. Given the fact that human bones were poorly preserved in the majority of the burials, most of our information – such as the age at death distribution, health and disease, nutrition or on migration and integration – has come from the teeth.

Introduction

The village of Prohear is located in the Prey Veng province of southeastern Cambodia, some 22 km northeast of Prey Veng town (Fig. 1). In May 2007, archaeology students observed the looting of prehistoric burials at Prohear and informed the Memot Centre for Archaeology in Phnom Penh. However, it took more than a half year before the first excavation by the German Archaeological Institute and the Memot Centre for Archaeology could begin. During that time, the major part of the burial ground was systematically looted. According to local reports, 32 Heger-I bronze drums, more than a thousand ornaments made from gold and silver, and many thousands of stone beads disappeared into the illegal antiquities trade.

The last remaining intact burials were situated directly underneath sections of the village road. During three rescue campaigns in the Spring of 2008, 2009 and 2011, an area of 168 square meters, over a length of 60 m of the village road, was excavated (Fig. 2) and 76 burials were recovered. Of these, 42 burials still contained human remains. Thus, from Prohear we have one of the largest series of skeletal remains excavated in southern Cambodia. Many burials were richly equipped with prestige grave goods: drums, bowls or bells made of bronze, jewelry in silver and gold, bracelets of iron and bronze, and beads made from glass, carnelian, agate or garnet. The faces of some individuals were covered with a bronze disc or bowl, while the skull of another had been laid inside a Heger-I bronze drum from present-day northern Vietnam (Reinecke *et al*. 2009, Reinecke / Vin Laychour 2010). In general, the burials at Prohear belonging to the Pre-Funan culture (before 100 A.D.) are more richly equipped with gold and silver objects than other documented cemeteries of the Early Iron Age period in Southeast Asia (400 B.C.–A.D. 200). Most burials are dated to the period from 150/100 B.C. to A.D. 50, which means that the site is approximately

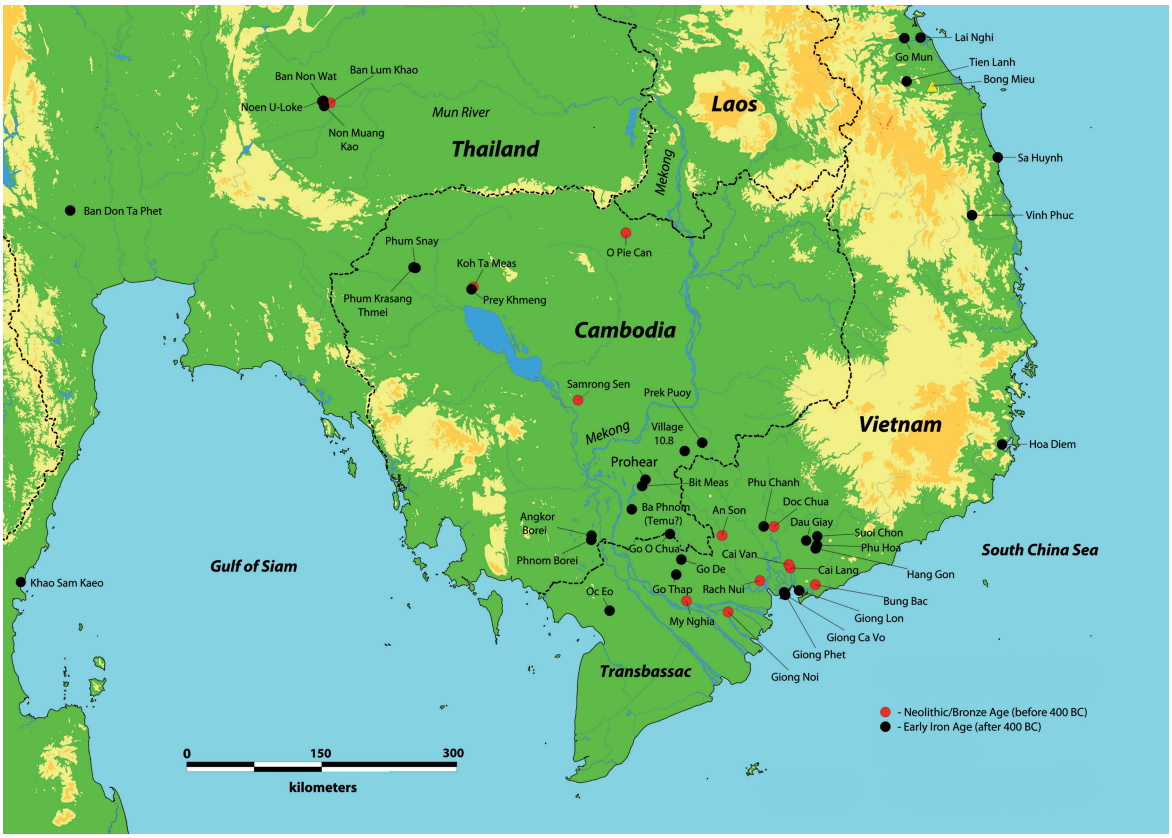

Fig. 1. Prohear and other Neolithic, Bronze and Iron Age sites in Cambodia, southern Thailand and southern Vietnam.

1000 years older than the Angkorian civilization (A.D. 800–1400).

Some preliminary reports concerning the archaeological (Reinecke *et al.* 2009; Reinecke / Vin Laychour 2010, 2011) and bioanthropological (Krais / Seng Sonetra 2010, 2011) results of the three excavation campaigns have already been published. The grave goods and human remains recovered from Prohear are currently stored at the Memot Centre for Archaeology in Phnom Penh, where they have been undergoing restoration and analysis. An exhibition featuring the most precious objects from Prohear opened at the National Museum of Cambodia in Phnom Penh at the end of 2010. A second exhibition was set up in March 2011 at the Provincial Museum in Prey Veng.

This study will focus on the results of the bioanthropological analyses. Due to a very poor preservation of the human bones, special emphasis is placed on the anthropological potential of archaeologically recovered human teeth. By applying different morphological, histological and archaeometrical methods we were able to achieve various results. Firstly, the preservation of the human remains from Prohear will be discussed followed by demographic parameters, non-metric-traits and indicators for health and disease as well as nutrition. Additionally, evidence for the culture-related modification of teeth, migration as well as integration is reviewed, followed by a short discussion about postmortem color-transformations of tooth enamel due to bio-chemical and geo-chemical soil processes.

The following bioanthropological results from Prohear will be placed in a regional and chronological context by comparison with appro-

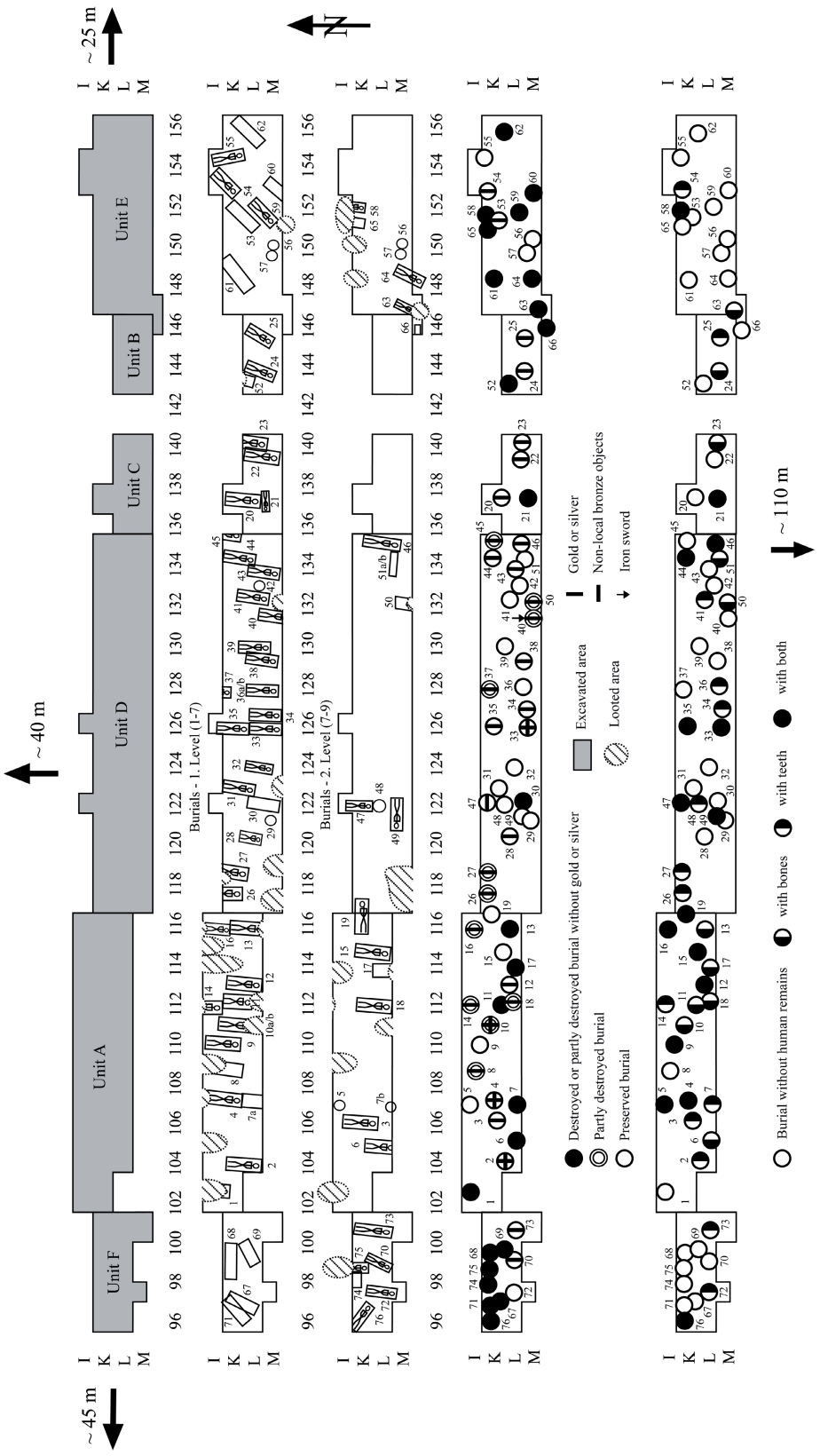

Fig. 2. Excavated units and burials at Prohear.

Fig. 3. Burial 15: Almost the whole torso was recovered. The individual has been buried in extended supine position, with the right hand on the upper torso and the left hand on the lower torso. The head was orientated to the southwest.

priate skeletal samples. A very brief comparative representation of Neolithic, Bronze and Iron Age samples from contemporary cemeteries in Cambodia and northeastern Thailand (Vat Komnou, Ban Lum Khao, Noen U-Loke, Ban Na Di, Ban Chiang, Non Nok Tha), including a summary of basic data from these sites, has been published in the context of the bioanthropological analysis of the skeletal remains from Phum Snay (Domett / O'Reilly 2009, 62). The bioanthropological results of this study are principally compared with two sites that are culturally, geographically and chronologically closely linked to Prohear: the Vat Komnou cemetery (Pietrusewsky / Ikehara-Quebral 2006) and Go O Chua (Francken *et al.* 2010). The relationship between these sites is very clear as demonstrated by similarities in the funeral rites of the inhumations, such as the head orientation, the arrangement of the offerings as well as the pottery types (Reinecke *et al.* 2009, 43–44, 140–146).

The Vat Komnou cemetery is located 85 km southwest of Prohear and is dated from 200 B.C. to A.D. 400. More than 50 inhumation burials were found in 1999 and 2000 (Stark 2001; Pietrusewsky / Ikehara-Quebral 2006). At the site of Go O Chua, which is situated 65 km to the south-southeast of Prohear in the Long An province of southern Vietnam, about 68 inhumations and seven jar burials were excavated from 1997 to 2008 and are mostly dated from 400–100 B.C. (Francken *et al.* 2010).

Traditionally, the bioanthropological results of skeletal samples from different sites are compared using quantitative data and frequencies.

The basis of this study however, is a relatively small sample (N = 42) that is poorly preserved. We estimate that at least a thousand other burials must have been destroyed by the looting (Reinecke *et al*. 2009, 60). Thus, the poorly-preserved remains of 42 individuals probably do not adequately reflect the past population of Prohear, and most of the following results cannot be statistically representative, a problem many bioanthropologists encounter during fieldwork. Hence, comparisons of quantitative frequencies from such small and poorly-preserved samples have to be handled with caution.

Preservation

A total of 76 burials, comprising 69 inhumations and seven jar burials, were uncovered during the three excavation campaigns. The burial character of some ceramic complexes in the upper layers without offerings or skeletal remains cannot be clarified with certainty. However, the shape and extension of these ceramic complexes indicate that they could have been destroyed graves. Besides, many excavated burials were so heavily looted that only a few sherds or vessels were found in situ (Fig. 2).

Four burials (7, 10, 36 and 51) appeared to consist of two partly destroyed features (7a/b, 10a/b, 36a/b, 51a/b), as could be seen in the dispersal of the offerings. However, in each burial context during excavation, the skeletal remains of only one individual were found, so that 7, 10, 36 and 51 are listed in our archaeological statistics as four individual burials. During the bioanthropological analysis of all the remains from feature 10a, the leg bones of two individuals were identified, but due to the heavy disturbance of this burial context, the offerings could not be accurately separated. Thus, in practice, we actually have indices for 77 burials.

Among the 42 burials containing human remains, only two inhumations (burials 15 and 19) were exceptionally well preserved (Fig. 3); both belonged to the deepest group of burials. The overall preservation of the other human remains varies from poor to very poor due to the highly acidic soil conditions or looting (Table 1). While 22 individuals are represented by only five percent or less of skeletal remains, on average, about ten percent of the bones are preserved. Predominantly, teeth and long bone fragments were recovered, while most of the small and fragile bones had already disintegrated. The surface of the vast majority of bones is eroded and their interior matrix is extremely softened. Thus, most of the bones are deformed and fragmented by the pressure of the covering soil. Despite various restoration and reconstruction attempts, it is impossible to utilize the full potential of modern bioanthropological methods due to the severe corrosion of the bones.

Essentially, our results have been obtained from the remaining human teeth, which were found in a better condition. Tooth enamel is the hardest tissue in the human body and thus teeth, especially the enamel, are the skeletal elements most likely to be preserved (Hillson 1996; Goodman / Rose 1990, 61). In thirteen burials however, no teeth were preserved, while eleven individuals are represented by only one to three teeth.

Orientation and deposition

The deposition of the dead invariably reflects a culture's beliefs and traditions. Commonly, changes in the burial rite, such as the orientation of the body or the nature of the grave goods, are interpreted as reflections of wider cultural influences or even population shifts.

The general preservation of the burials from Prohear does not allow us to reconstruct the orientation and deposition of each individual, but the inhumations with appropriate preservation showed the correct anatomical order of primary burials, with the individuals buried in an extended supine position. The orientation of the inhumations varied within the burial ground. The position of the skeletal remains within each burial indicates that only two individuals (burials 21 and 49) were buried with their

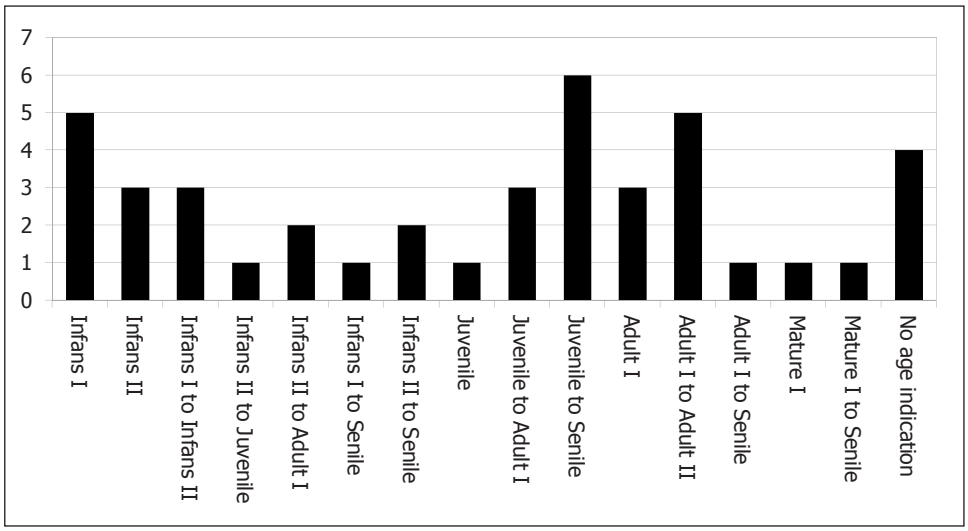

Fig. 4. Age at death distribution of the skeletal sample from Prohear.

heads oriented to the west and two individuals to the east (burial 19) or southeast (burial 76). The other 29 individuals with sufficient skeletal remains and offerings to determine orientation (burials 2–4, 9, 10a1, 10a2, 11–18, 25–27, 33–35, 41, 44, 46, 47, 54, 58, 63, 72, and 73) were buried with their skulls oriented to the south, or slightly to the southwest. The poor preservation of some individuals (burials 5, 6, 7, 23, 24, 36a, 50, 51b) did not allow any conclusions to be drawn, but by examination of the position of earrings, bracelets and other jewelry the orientation of the body could be reconstructed. Through our analysis of the funeral rites, the orientation of the head, the burial offerings and the depth of each burial, the 76 graves have been separated into two main mortuary periods. The individuals buried with their heads oriented to the east or west (burials 19, 21, 49, 51 and 76) belong to mortuary period I (500–150/100 B.C.), while those buried with their heads to the south or slightly to the southwest belong to period II and are more richly equipped (150/100 B.C.–A.D. 100; Reinecke *et al.* 2009, 39–41).

For most burials there were no or not enough remains to infer the position of the arms at the time of deposition. In four cases (burials 11, 15, 35 and 47) there is evidence that the arms were placed across the torso. All of these individuals were oriented to the south or southwest and belong to mortuary period II. For only one individual (burial 19) is there an indication that the arms had been placed along the sides of the body. This was also the only example of a burial oriented to the east and it belongs to period I.

Demography

Morphological age at death estimations

The study of age at death is a crucial parameter for bioanthropology, indicating living standards, economic variables and disease pressures (Brothwell / Higgs 1969). For the assessment of the age at death of the Prohear sample, standard macroscopic morphological methods (Ubelaker 1978; Szilvássy 1988; Scheuer / Black 2000; Nemeskeri *et al.* 1960; Ferembach *et al.* 1978; Herrmann *et al.* 1990; Brothwell 1981) have been used, as well as microscopic tooth cementum annulations (Wittwer-Backofen *et al.* 2004; Wittwer-Backofen / Buba 2002) in four cases with appropriate cementum preservation. The age at death classification system used for this study follows current German

Burial	Bones In % (5%-Steps)	Preserved Teeth
2	-	6
3	-	6
4	5	2
5	10	-
6	5	-
7	-	1
9	15	3
10a1	10	-
10a2	15	-
11	25	-
12	5	26 (dentition)
13	20	-
14	-	1
15	60	10 (dentition)
16	30	19 (dentition)
17	15	-
18	5	-
19	75	23 (dentition)
21	20	2
23	5	-
24	5	-
25	-	3
26	-	22 (dentition)
27	-	14 (dentition)
33	5	31 (dentition)
34	-	3
35	20	7
36 a	-	1
41	-	10
44	5	24 (dentition)
46	5	6
47	10	20 (dentition)
48	-	15 (dentition)
49	20	21 (dentition)
50	5	-
51	5	-
54	5	2
58	5	14
63	?	-
72	-	1
73	-	1
76	5	19 (dentition)
Total	415:42=9.88%	313:42= 7.45%

= burials with 5% preservation or less (22 individuals)

Table 1. Preservation of the Prohear skeletal sample (evaluation of bone preservation in 5% steps).

standards (Herrmann *et al.* 1990, 52; Grupe *et al.* 2005, 90).

Due to the very poor preservation of the human bones, an age at death determination was primarily reached through the analysis of tooth status and dental wear. Thirteen individuals (31 percent of the sample) were subadult (of less than 20 years old), while eleven individuals (26.2 percent of the sample) were adult at the time of death. For a further fourteen individuals (33.3 percent of the sample) the poor preservation only permits a rough classification into general groups, ranging between subadult and adult, while for four individuals we had no age indications at all. The small sample size, poor preservation and resultant lack of statistical representivity must always be considered when evaluating this demographic distribution. However, as it is normally expected that at least 30 percent of the sample will be subadults in a prehistoric context, the demographic distribution of Prohear seems to be quite normative. The high child mortality is much more representative for a prehistoric group than the ratio found at Go O Chua, which revealed only seven subadults (of less than 20 years) out of a total of 52 bioanthropologically evaluated inhumations (Reinecke *et al.* 2009, 48; Francken *et al.* 2010, 16). In comparison, the Iron Age cemetery of Noen U-Loke in northeastern Thailand counted 53 subadults (of less than fourteen years) out of 120 individuals (Tayles *et al.* 2007, 252), while at Angkor Borei, subadults (a few months to nineteen years) constituted over 40 percent of the burials (Pietrusewsky / Ikehara-Quebral 2006, 86). The detailed age at death distribution data of Prohear is presented in table 2 and figure 4. The following section will explain the methods and results of the age at death estimation for each individual.

Within the group of subadult individuals, burial 5 – a jar burial (Reinecke *et al.* 2009, 39, 43, 125) – contains the youngest individual within the sample. From the fragmented remains of the upper extremities and torso, an age at death of about six months has been estimated. The ten individuals from burials

Age	Total Individuals	Burial-No.
About 6 months	1	5
2–10 y	1	25
4–5 y	2	41, 48
5 y	1	58
5–7 y	1	27
5–10 y	1	54
About 6 y	1	49
About 9 y	3	16, 44, 47
12–19 y	1	7
13–19 y	1	2
Subadults total	13 (31 %)	
Infants I to Senile (O-x y)	1	72
Infants II to Adult I (7–29 y)	2	9, 34
Infants II to Senile (7–x y)	2	63, 73
Juvenile to Adult I (13–29 y)	3	14, 35, 36 a
Juvenile to Senile (13–x y)	6	10a1, 10a2, 13, 17, 18, 51b
Between subadult and adult total	14 (33.3 %)	
Adult I (20–29 y)	3	15, 26, 76
Adult I to Adult II (20–39 y)	5	3, 11, 12, 19, 46
Adult I to Senile (20–x y)	1	21
Mature I (40–49)	1	33
Mature I to Senile (40–x y)	1	4
Adults total	11 (26.2 %)	
No indication	4 9.5 %)	6, 23, 24, 50
All individuals total	42 (100 %)	

Table 2. Age at death categorization of the skeletal sample from Prohear.

16, 25, 27, 41, 44, 47, 48, 49, 54 and 58 (23.8 percent) have incomplete permanent dentition and could thus be allocated to the Infant I and Infant II categories (Ubelaker 1978). The individual from burial 2 could be considered a Juvenile by tooth status. Burials 7, 9, 34 and 36a only contained fragments of teeth or a single tooth. In these cases, the presence of particular teeth, or their fragments, in combination with a total absence of dental wear, signals the age at death. Thus, the individual from burial 7 could be allocated to the comprehensive age group of late Infant II to Juvenile, the individuals from burials 9 and 34 to Infant II to Adult I, and the individual from burial 36a to Juvenile to Adult I. The individual from burial 35 could also be classified to the same age group by tooth status.

Within the group of adults, for eight individuals (burials 3, 12, 15, 19, 26, 33, 46 and 76) with permanent dentition, the dental wear was assessed as an age indicator in the absence of other skeletal age signals. The evaluation of dental wear was accomplished by intra- and inter-individual comparison (Brothwell 1981). Several samples show extreme wear of the first molars and mild wear of the second molars, while the third molars show only very mild wear or no wear at all. In these cases the dental eruption sequence of the molars has to be considered, as well as the fact that the posterior teeth of the jaw naturally suffer less from exposure to chewing than the anterior teeth and so these teeth naturally show less wear (Fig. 5). These individuals were assigned to the age groups Adult I or Adult II.

For the age at death estimation of two individuals, not only the teeth but also additional features of the bones were used. The individual from burial 11 could be defined as Adult I to Adult II by the combination of the already ossified epiphyseal plate of the iliac crest and the lack of any kind of degenerative changes in two remaining lumbar vertebrae (Scheuer / Black 2000; Owings 1981). The individual from burial 4 could be categorized as Mature I to Senile by the advanced degree

of sutural closure, the morphological parameters of a mandible fragment and two teeth that show an extreme wear, to a degree that one tooth crown had almost completely worn away (Fig. 6).

For six individuals (burials 10a1, 10a2, 13, 17, 18, 51b), representing 14.3 percent of the whole sample, no skeletal remains were preserved that could provide detailed information about their age at death. Only the length of the long bones indicates that these individuals were not infants. They have thus been allocated to the large comprehensive group of Juvenile to Senile.

In three cases (burials 63, 72, 73) even larger comprehensive age categories (Infant I to Senile and Infant II to Senile) had to be considered, because we only know that they were not small infants – judging by the size of the bone fragments or the presence of fragments of particular permanent teeth.

Four more individuals (6, 32, 24 and 50) show no morphological age indication at all, as they are only represented by small pieces of eroded human bone on the surface of iron objects found within the burial context.

Fig. 5. Burial 12: The molars of the left lower jaw show strong wear of the first molar, milder wear of the second, and very mild wear of the third.

Fig. 6. Burial 4: Extreme wear of two molars.

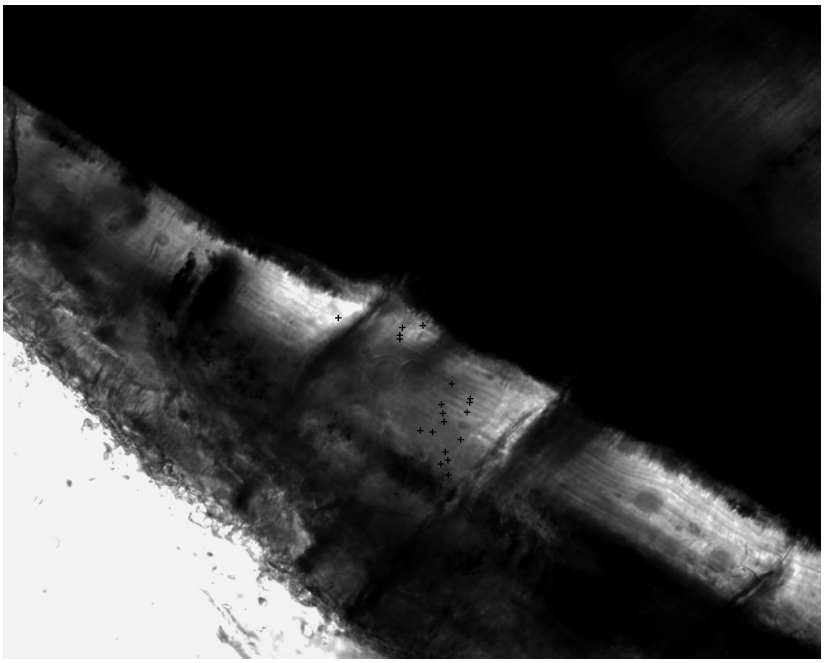

Fig. 7. TCA section from individual 19 with enlarged cutting thickness.

Tooth cementum annulation

To verify the morphological age at death estimation, the chronological age was assessed by tooth cementum annulation (TCA). For TCA, transverse microscopic images of the tooth roots are assembled. The acellular cementum of the root displays annual incremental lines that make the TCA technique a very reliable method for chronological age estimation with error ranges of about 2.5 +/- years for recent teeth (Wittwer-Backofen *et al.* 2004; Wittwer-Backofen / Buba 2002). However, various authors have reported poorer results when this method has been applied to archaeological samples and have suggested the need for further research (Roksandic *et al.* 2009; Wittwer-Backofen *et al.* 2008). Thus, the results of TCA analysis of soil exposed teeth have to be regarded with caution. Due to the poor preservation of most of the tooth roots from Prohear, the method could only be applied to four individuals (burials 14, 15, 19 and 33). Preparation methods for soil exposed teeth have been applied and best cutting results have been achieved with cuts slightly thicker than the standard cuts for recent teeth (Fig. 7). The detailed TCA results are shown in table 3.

Three of the four TCA results (for burials 14, 15 and 19) confirmed the morphological age estimation entirely, even though they all ranged in the lower part of the suggested morphological age span. In one case, burial 33, the morphological age estimation (30–39 years) could not be confirmed; while TCA suggests an age of 49.15 to 49.75 +/- the standard variable of 2.5 years, the morphological age estimation was at least ten years lower. The morphologically derived age at death estimation of individual 33 was based on the presence of a full permanent dentition and a relatively

Burial	Morphological Age Estimation	Tca Result
14	13 years to Adult I	16.81–18.61 +/- 2.5 y
15	Adult I	21.15–21.45 +/- 2.5 y
19	Adult I to Adult II	26.39–26.69 +/- 2.5 y
33	Adult II	49.15–49.75 +/- 2.5 y

Table 3. Comparison of morphological age at death estimation and TCA results of burials eligible for TCA.

low degree of dental wear. An alveolus in the right upper jaw of this individual showed signs of strong inflammation in combination with an intravitem tooth loss and a serious caries lesion of the adjacent tooth, which probably led to the irregular pattern of dental wear that appears much stronger on the left side. Individuals with pain in one part of the jaw tend to spare the affected section and thus chew their food mainly on the other side of the jaw or change their nutritional habits accordingly. This might be one explanation why, in this specific case, the dental wear indicated a lower age.

In summary, the age at death distribution at Prohear indicates that the whole age range from very young children to senior adults is represented, but the allocation shows a couple of irregularities. Such irregularities are not unexpected, as we do not assume that the sample is representative. The small sample size may serve as an explanation in itself, but other possible explanations should be considered as well. Firstly, out of thirteen subadult individuals, only one was clearly Juvenile (burial 2) and thus juveniles are under-represented. In this context, the group of six individuals (burials 10a1, 10a2, 13, 17, 18, 51b) that could only be roughly classified as Juvenile to Senile (14.3 percent), the group of three individuals (burials 63, 72 and 73) between Infants to Senile and the four individuals (burials 6, 32, 24 and 50) with no age indication at all must be considered. Additionally, four other individuals (burials 7, 14, 35, 36a) also fit into comprehensive age groups that might include the juvenile phase.

Secondly, children prior to four years old are in general under-represented and are totally absent from the inhumation burials. With an age of about six months, the infant in burial 5 – a jar burial – was the only individual preserved who died before reaching the fourth year of life. Frequently, the fragile bones of small children are not preserved in the soil because they decay much faster than the bones of adults. The fact that infant bones from burial 5 are preserved may be simply due to the sheltering jar the infant was buried in. In addition to jar burial 5, there is evidence for another 6 jar burials, but no bones were preserved in them. Besides burial 5, bracelets with a small diameter that would only fit the wrist of a child were also found in jar burials 48 and 57. Thus it is probable that very small children were deposited as jar burials. Besides this possibility, the custom of cremating very young children before deposition, or of burying them separately, could also explain this underrepresentation (Domett / O`Reilly 2009, 64; Lohrke 2004; Pinhasi / Bourbou 2008, 33–34). It is also possible that children younger than four years enjoyed the enhanced care of adults or were still breast-fed and thus better able to resist disease. Breast-feeding has a protective effect by supplying maternal antibodies and it buffers the impact of nutritional deficiencies (Hillson 1996).

Thirdly, there was apparently an increased risk of death for children between four to nine years old: eight of the thirteen subadult individuals died during this age period (burials 16, 27, 41, 44, 47, 48, 49 and 58). This result is not unusual for prehistoric samples and could be related to weaning. There is evidence that in many prehistoric – and also in some contemporary – communities, children enjoy extended breast-feeding. The following period of weaning however leads to a significantly higher risk of death, since this period implies a fundamental change to a solid food diet and can be very critical for children due to underfeeding or malnutrition (Brothwell / Brothwell 1969). As discussed below, we may have indications for a pronounced phase of breast-feeding at Prohear.

Sex determination

Due to the poor preservation of the bones, in only one case was a morphological estimation of sex possible (burial 11). Thus, many of the standard parameters like the age at death or health parameters cannot be considered in relation to the distribution of the sexes within the sample. The preserved parts

Fig. 8. Burial 19: Foramina molaria with mild caries in the foramen's cavity.

of the skulls from burials 4, 15, 16, 19 and 33 are too fragmented or highly deformed as a result of the softened bone matrix and the pressure of the soil and are subsequently not suitable for well-grounded sex determination. Only in burial 11 was a major part of the pelvic bone preserved, which shows significant markers for sex estimation. All of them (preauricular sulcus, auricular surface, arc composé and a greater sciatic notch) show a hyperfeminine morphology (Ferembach *et al.* 1978). At Prohear, some burials seem to have specific offerings for women or men. For example, men are often identified by phallic-shaped stone pestles placed between the legs (burials 2, 11 and 76) or by a short sword in burial 40. Spindle whorls – which have been found in clear connection with the burials and not in the re-filled soil – were found in some graves together with bracelets or finger rings with a diameter that would indicate the inhumation of women.

Non-metric traits

The term "non-metric traits" describes small anatomical variations in the human skeleton that appear to be cumulative within groups and their genetic pool. The hereditary traits of these anatomical features have not yet been completely investigated and further research needs to be done (Hauser / De Stefano 1989; Alt 1997). However, sets of traits are used to prove the possibility of genetic kinship.

Because of the poor preservation of the bones, the detection of only one dental non-metric trait was possible. The preserved teeth of seven individuals (burials 2, 7, 19, 27, 44, 49 and 58), representing 31.8 percent of the 22 individuals with one to eleven preserved molars, show one to four foramina molaria for each individual. The foramina molaria is a small pit in the buccal surface of the molar (Fig. 8)

Indicator Of Stress	A/O*	%
Cribra cranii	1/5	20
Dental attrition (dentin exposed)	111/209	53.11
Dental caries	9/259	3.47
Dental calculus	15/86	12.9
Intravitem tooth loss	6/68	8.82

*A/O = affected / observed

Table 4. Frequencies of occurrence for indicators of stress recorded in the Prohear skeletons. Frequencies are only given if observed individuals or skeletal elements are 5 or more.

(Alt 1997, 88–89). In total, 10.5 percent of all preserved molars (10/95) show this feature. We have to consider the fact that the strong wear of some molars could have eradicated some of the foramina molaria, so the actual frequency might be even slightly higher. However, the foramina molaria is in general a quite common non-metric trait. There is currently no data available for comparison of non-metric traits with other Southeast Asian Bronze or Iron Age sites.

Health

There are certain indicators that allow conclusions to be drawn on the quality of life, for example by examining the health status of an individual. Steckel *et al.* (2002) suggest that health has two main components: the length of life and the quality of life. For measuring the quality of life, parameters such as pathological changes in skeletal tissues and body height are commonly used. An estimation of stature based on long bone measurements, in comparison with data from contemporary sites, can suggest inferences regarding net nutrition and environmental factors (Steckel *et al.* 2002). Owing to the poor preservation of the long bones from most individuals at Prohear and the deformation of bones resulting from the pressure of the soil, it was not possible to take reliable osteometric measurements and due to the eroded surface of most of the bones various kinds of pathologies like infectious diseases, degenerative joint diseases or fractures, could not be investigated in most cases. Due to the better preservation of the enamel, most pathological changes observed were dental pathologies (Table 4). The analysis of this particular part of the human skeleton can deliver valuable information about the diet and the general health status of an individual and of a sample as a whole.

One individual from burial 13 shows a benign tumor on the left femur and a well healed compression fracture on the right third metatarsal, which commonly occurs as a result of objects falling onto the foot from above (Czarnetzki 1996). Another individual (burial 15) shows multiple bone lesions: porous structures on the surface of the parietal bones (cribra cranii), which are generally interpreted as indications of anaemia. In addition, the cortical bone of the femora had thickened and multiple large striae along the length of the femora as a sign of periosteal vascularization could be observed, both of which are indications of an unspecific but acute infectious disease (Larsen 1997; Goodman *et al.* 1984; Goodman / Martin 2002). These two symptoms could be linked, as anaemia can be caused by infectious diseases that affect the absorption of nutrients or ease the entry of pathogenic agents by weakening the immune system.

Dental health

The most prominent phenomenon among the dental pathologies is pronounced dental wear. Almost all individuals – except very young children – and 53.11 percent of all evaluated teeth (111/209) show exposed dentin. At Vat Komnou, the frequency is even higher (67.8 percent). Wearing of the occlusal surface of the teeth is due to mechanic attrition during the chewing process and is thus a normal and age-related process that can only be termed pathological beyond a certain degree. Additionally, dental wear contributes to the reconstruction of diet patterns as discussed below.

In burial 4 – the individual with the highest age at death estimation in the Prohear sample – two molars remained in a bronze drum that had enclosed the skull of the individual at deposition (Reinecke *et al.* 2009, 45–47, 77–78). The wear on one of these teeth is so acute that the root canal is opened. This was probably extremely painful for the individual and must have complicated the consumption of solid food.

One marker in assessing childhood health is linear enamel hypoplasia, the most commonly occurring type of enamel defect reflecting nonspecific physiological stresses like malnutrition or diseases during childhood. It occurs as

transverse lines of deficiency in enamel thickness resulting from physical stress during the secretory phase of amelogenesis (Goodman / Rose 1990; Goodman / Armelagos 1988; Goodman *et al.* 1984; Goodman / Martin 2002; Schultz 1988). Since enamel does not remodel, enamel hypoplasitic lesions are permanent and retrospective indicators of physiological perturbation. By assessing the position and the defect width it is possible to ascertain the duration of physical stress and the age at which it occurred (Goodman / Martin 2002). Within the skeletal sample from Prohear, ten individuals (burials 2, 7, 21, 25, 26, 27, 36a, 44, 47 and 48) show very mild surface irregularities on one or several teeth (13.58 percent of all evaluated teeth), most of which covered the whole enamel crown. These irregularities, that look like a very mild form of hypoplasia and are characteristically seen as thin, perikymata-like surface depressions, are not included in most bioanthropological elevations or are rated under the heading "no hypoplasia" (Schultz 1988, 494). Goodman and Rose suggest that these surface features may not be evidence of physical perturbation, because there is currently a lack of any direct association between these mild irregularities and abnormal histological prism morphology (Goodman / Rose 1990: 59). Interestingly, most of the Prohear individuals affected by this phenomenon (7/10) died as subadults. For linear enamel hypoplasia, there is strong evidence of correlation with decreased longevity in prehistoric populations (Goodman / Armelagos 1988). At this point, we do not know if this correlation might indeed suggest after all that these mild irregularities are also pathological and further research needs to be done. None of the Prohear individuals however suffered from the regular forms of linear enamel hypoplasia, thus indicating a relatively stress-free growth period, as opposed to individuals from the Vat Komnou site, where 8.3 percent of incisor and canine teeth were affected by this pronounced form of enamel deficiency (Pietrusewsky / Ikehara-Quebral 2006, 88).

Six individuals (burials 2, 3, 9, 19, 33 and 35) show dental caries on one or two teeth, comprising 3.47 percent of all evaluated teeth (9/259). Due to the low number of remaining teeth on some individuals, and focusing on a more qualitative approach, in a second phase of analysis only individuals represented by at least ten teeth were evaluated. These results are even lower; only 1.56 percent (3/192) of the evaluated teeth have caries lesions. The degree of almost all lesions is very mild, and only in one case (burial 33) is the caries lesion quite serious. At Vat Komnou, the occurance of carious lesions is also low (3 percent), while at Go O Chua, 10 out of 32 analyzed individuals have carious lesions (Pietrusewsky / Ikehara-Quebral 2006, 89; Francken *et al.* 2010, 20). Caries is seen as an infectious disease; the most common germs for spreading dental caries are streptococcus mutans and lactobacillus. However, the formation of dental caries is promoted by a lack of hygiene, and also requires carbohydrate substrates. The bacteria ferment the carbohydrates into sour metabolites, which cause the dissolution of tooth minerals (Katzenberg / Saunders 2000; Alt 2001).

After the consumption of protein-rich food, oral bacteria turn the proteins into alkalis. The resulting alkaline environment supports the formation of dental calculus, and the presence of dental calculus also indicates longstanding plaque accumulation (Katzenberg / Saunders 2000; Orschiedt 1996, 111). Four individuals (burials 9, 15, 19 and 33) show mild dental calculus. This comparatively low occurrence of dental calculus might be the result of a diet that contained few proteins, the practice of some kind of dental care, or simply the poor preservation of the human remains, which could have caused a lowering in the calculus levels by the loss of the calculus substance. In the Go O Chua sample, more than 90 percent of 32 analyzed individuals show dental calculus (Francken *et al.* 2010, 20), while in the sample from Vat Komnou, 22.5 percent of all observed teeth suffer from this problem (Pietrusewsky / Ikehara-Quebral 2006, 89).

Our observation of the following dental health indicators – periodontosis, parodontitis, intravitem tooth loss and dental abscesses – is based

on the preservation of jawbones or jawbone fragments from five individuals (burials 4, 15, 16, 19 and 33), representing 11.9 percent of all inhumations. The term periodontosis describes the horizontal degradation of the alveolar ridge that is conditional upon mechanical processes and mostly age-related (Orschiedt 1996, 113). Two individuals (burials 19 and 33) have mild forms of periodontosis affecting 16.67 percent of their teeth's alveoli. A set of inflammatory diseases of the periodontium is referred to as parodontitis. It results in increased vascularization, which causes the surface of the bone tissue to appear porous and laced with small pits (Orschiedt 1996, 113; Herrmann *et al.* 1990, 155). Only one individual (burial 33) shows parodontitis related to the intravitem tooth loss discussed below.

Intravitem tooth loss can either be age-related, due to physiological and mechanical conditions, or caused by diseases of the periodontal apparatus. After the loss of a tooth, the alveolus is closed by a neoplasm of bone tissue. By each phase of this process, it is possible to estimate the time of the tooth loss in relation to the time of death of the individual, as it takes at least four to six months before the alveolus is completely closed (Herrmann *et al.* 1990, 153). Three individuals (burials 4, 15 and 33) had intravitem tooth loss, representing 8.82 percent (6/68) of all the teeth that still remained in a jaw bone, while four of these intravitem tooth-losses belonged to one individual (burial 4) and were probably age-related. The alveoli of all the affected individuals had not closed entirely. One individual (burial 15) had a dental abscess that is probably related to an intravitem tooth loss.

Nutrition

As already mentioned above, the investigation of dental wear patterns can contribute to the reconstruction of diet patterns. In summary, a generally extreme wear was observed on the teeth at Prohear, the only exception being those of small infants. Very strong dental wear is commonly found within farming communities, while foraging groups commonly show lower rates of affliction (Schultz 1988, 494). Agricultural tools were not found among the offerings. Animal bones are poorly preserved, but remains of fish, pig and bovinae have been detected. Some grains of rice were discovered in the bronze drum of burial 4. One can assume that these finds accurately reflect the main elements of the diet, but it is not possible to estimate the comparative roles of fishing, farming or hunting in this community.

Additionally, the strong increase of dental wear after only a few years of life – as observed among most adult individuals by intra-individual comparison of the dental wear of molars – is a sign of the consumption of very hard food or of small fragments of stone, sand or dust that often remain within prepared food among prehistoric populations (Brothwell 1981; Jarosová / Dockalová 2008). Next to the wear of the occlusal surface of the tooth crowns, some adult individuals show interproximal tooth wear. This phenomenum "tends to be more extensive among nonindustrial groups living in harsh environments" demanding heavy masticatory activity with "vertical or near vertical movement of teeth" (Kaidonis *et al.* 1992, 105)

The patterns of occlusal dental wear of infants from Prohear may indicate that the phase of weaning correlated with the aforementioned age of increased risk of death from four to nine years. A comparison of each child's dental wear suggests that children who died between the age of four and five years show no dental wear (burials 41 and 48). However, children who died between five to nine years of age show a moderate to very strong wear gradient relative to their age at death (burials 16, 27, 44, 47 and 54). This could be an indication that the children younger than four years consumed very soft food or enjoyed a protracted period of breast-feeding.

Next to this absence of dental wear among infants under the age of six and the increasing wear among children up to age nine, the deciduous teeth of these older children from Prohear

show particularly extreme levels of wear. On the one hand, the enamel of deciduous teeth is softer than the enamel of permanent teeth; on the other hand, this indicates that these older children were not exempted from the consumption of hard food or food in which solid pieces remained.

The low levels of dental caries may indicate a diet low in carbohydrate substrates, due to the aforementioned processes of caries formation. Additionally, a nutrition low in sugar and starch is generally suggested by low frequencies of dental infection. There is evidence for rice agriculture in Southeast Asia from at least 2000 B.C. and it is suggested that rice was an important component of diet in the Bronze and Iron Age. Although a positive correlation with dental caries is suggested for the adoption of agriculture in general, for the adoption of rice this correlation does not appear significant, due to complex interactions between the process of caries formation and the nutritional composition of rice (Tayles *et al.* 2009). Thus the low levels of caries observed at Prohear is compatible with the consumption of rice as a staple crop, which is rich in carbohydrates.

The afore-mentioned porous structures on the surface of the parietal bones (cribra cranii) of the individual in burial 15 indicates anaemia and may thus be related to insufficient food intake – among various other possible reasons (Stuart-Macadam 1992; Walker *et al.* 2009). As we have only one case of cribra cranii among five individuals with preserved parietal, frontal and occipital bones, we cannot draw any conclusions about possible malnutrition among the whole group.

Culture-dependent modifications of teeth

Every change of body tissue is somehow embedded in the cultural context in which individuals are living and acting. The following modifications contain indications of culture-related activity patterns: activity-related dental attrition and tooth blackening, the deliberate staining of teeth. Firstly, we should mention that we found no evidence for a specific modification that has been reported from other sites in Southeast Asia: intravital tooth ablation, the deliberate removal of teeth (Tayles 1997; Domett / O´Reilly 2009, 70). There was also no evidence for tooth ablation at the site of Vat Komnou (Pietrusewsky and Ikehara-Quebral 2006), but one case has been noted at the site of Go O Chua (Francken *et al.* 2010, 20; Vương Thu Hồng 2008).

Activity-related attrition

Two individuals from Prohear show very irregular patterns of dental wear: One individual (burial 12) shows a peculiar bilateral pattern of increased wear on the occlusive surfaces of the upper anterior teeth (Fig. 9), while another individual (burial 33) shows small tears on the anterior part of the occlusive surfaces of some canine teeth and incisors.

Pronounced dental wear, as well as certain irregular patterns of dental wear like these, can point to a tool-like use of teeth or the use of teeth for manipulative purposes, for example work on sinews, leather or other materials, as has been reported for prehistoric communities and is still quite common among many contemporary populations (Brothwell 1981; Jarosová / Dockalová 2008, 90–91).

Tooth blackening

The buccal and labial surfaces of the teeth from four individuals display very light brown to dark reddish-brown stains (burials 12, 19, 33 and 35). While the concentration of staining is most intense on the labial aspect of the anterior teeth, its intensity is reduced or even completely absent on the posterior teeth. Also, probably due to the poor preservation, the staining does not have the same intensity on all the individuals affected. The teeth of the individual from burial 33 – who had the best-preserved dentition from the site – show very intense staining (Fig. 10 and 11).

The actual color of the staining might have changed through the long time of burial in an

Fig. 9. Burial 12: Peculiar bilateral wear pattern of the upper anterior teeth.

acidic soil. The reddish-brown color of the staining seems consistent with the coloration resulting from betel nut consumption but is darker. The habitual chewing of betel nut is a widespread custom in Southeast Asia as well as in other parts of the world and it is also circumstantiated in archaeological contexts (Zumbroich 2008; Nguyên 2006; Oxenham 2002). In the Duyong Cave in the Philippines, skeletons were found with evidence of betel staining dating back to about 2.700 B. C. (Fox 1970).

At the Vat Komnou cemetery this coloration, equally distributed on the labial, buccal and lingual tooth crown surfaces, and thus interpreted as evidence of habitual betel nut chewing, was found on the majority (75.1 percent) of adult teeth (Pietrusewsky / Ikehara-Quebral 2006, 89). The lack of staining on the lingual and occlusal surfaces of the teeth, and the decline in intensity to an absence of coloration towards the posterior teeth, as observed among the Prohear samples however, indicates a deliberate application of betel nut residues or other dyeing substances

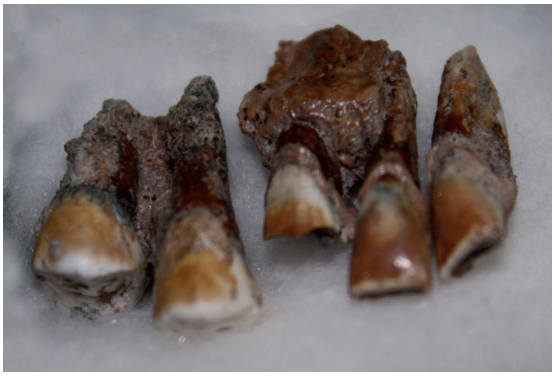

Fig. 10. Burial 19: Reddish-brown stain on the surface of the anterior teeth.

onto the outer surfaces of the teeth rather than a more incidental, all over staining resulting from betel nut chewing (Oxenham 2002). The staining patterns seem similar to the various traditions of tooth blackening, which used to be quite common in many cultures, especially in Southeast Asia, and has only recently lost its cultural importance (Zumbroich 2009). In contemporary Laos, for example, a soot or

Fig. 11. Burial 33: Intense stain on labial aspect, reduced stain on posterior teeth.

paste made from plants is typically applied to the teeth with the index finger. The intention is aesthetic and for dental preservation (Tayanin / Bratthall 2006; Suddhasthira *et al.* 2006). Application of the paste with the index finger leads to the same staining pattern as that found in the Prohear samples.

Ethnographic and cultural anthropological reports suggest that in many populations which still practice this deliberate tooth blackening, the process is an important age-related life cycle event (or 'rite of passage') and a sign of entering adulthood performed around puberty (Zumbroich 2009, 381). At Prohear, the limited data available are consistent with an age-related distribution. Three of the individuals with dental stains were adults (burials 12, 19 and 33), and while a detailed age at death estimation was not possible for the individual from burial 35, he or she must have belonged to one of the comprehensive age groups between subadult and adult.

Since there is already evidence for some kind of tooth blackening with betel or betel-like substances from the Bronze Age site of Nui Nap in present-day northern Vietnam (Oxenham *et al.* 2002), it is likely that the custom travelled further south and the same phenomenon is represented in the Prohear material. The same occurrence of deliberate staining patterns was also observed on the remaining teeth of many individuals from Go

O Chua. This indicates at least some kind of shared cultural practice, or even cultural bond, between these two communities. The burial customs and material offerings from Prohear have their strongest relations to the North, especially to present-day northern Vietnam. The large number of bronze drums from Prohear suggests an immigration of people from northern Vietnam to this area about 100 B.C. Thus, the tooth staining can be considered in relation to various archaeological finds as another indication of cultural links to northern Vietnam. However, further research needs to be done to accurately reconstruct the spatial distribution of this custom, as the picture given by the small number of archaeological reports currently available is perhaps inconsistent with the actual distribution in prehistory.

Fig. 12. Burial 49: Postmortem discoloration of the anterior teeth.

Migration, integration and similar cultural practices

Teeth from 26 individuals were sampled for Strontium vs. Oxygen isotope analysis (carried out by Mike Schweissing and Marina Vohberger, Ludwig-Maximilians-Universität Munich, Germany). The values of Strontium and Oxygen isotopes in bones and teeth indicate changes of habitat during the individual lifetime, since isotopes are incorporated into the skeletal material through bodily intake (Schweissing / Grupe 2003, Grupe *et al.* 2005, 131–133). At present, 21 analyses have revealed seven non-local individuals (burials 6, 7, 11, 15, 19, 33 and 48), which is not surprising given that non-local offerings already pointed towards the possibility of migration processes at Prohear (Reinecke *et al.* 2009). Interestingly, the tooth modifications discussed above are found within both groups of local (burials 12 and 35) and non-local inhabitants (burials 33 and 19). This could indicate that the immigrants either came from a population that performed similar body modifications, thus making it likely that their group or area of provenance was culturally related to Prohear, or that the immigrants were somehow very well integrated into the host population, as suggested by their participation in local rites. Additionally, no other significant differences, for example concerning health or length of life, between the group of local and non-local individuals could be found.

Colored teeth: postmortem transformations

The enamel of some human teeth (burials 7, 19, 27, 35, 44, 47, 48 and 49) as well as one fragment of animal tooth (from burial 11) display grayish to bluish areas of discoloration (Fig. 12). Their appearance is laminar or linear on different parts of the enamel and they do not match the morphological features of systematic crown growth. They are therefore probably due to postmortem bio-chemical and geo-chemical processes in the soil, for example the accumulation and diagenesis of substances like iron, zinc, manganese or strontium, additional to postmortem decay factors of structural and chemical alteration like those reported from other sites with similar phenomena. The discoloration predominately occurs on deciduous teeth, probably as a result of their lower density (Mansilla *et al.* 2003). The burials affected were scattered across the excavation site, so it is not merely a characteristic of the soil

in one particular area. Up to now, the exact causal substance is not known, and further research should be done.

Conclusions

The human remains from Prohear constitute a sample of 42 individuals. Their bones are mostly very poorly preserved. Thus, our results demonstrate how much individual information is stored in archaeological human teeth. We were able to find indications for the age at death distribution of the sample, health and disease, nutrition, culture-dependent tooth modifications as well as information about migration and integration.

The demographic age distribution indicates a high rate of child mortality that fits well with several other burial sites of the same time period. Available data concerning health and disease, mostly extracted from the dental evidence – such as the low frequencies of dental caries – suggest that the early historic inhabitants of Prohear were relatively healthy. Absence of any serious enamel hypoplasia avers to a quite stress-free childhood. Strong patterns of dental wear indicate heavy masticatory activity and irregular wear patterns suggest the tool-like use of teeth. The occurrence of cultural modification of teeth appears to link Prohear with other sites nearby or situated further north.

However, the results cannot be considered statistically representative due to the small sample size and many bioanthropological parameters that are normally assessed through the analysis of human bones – such as infectious diseases, trauma, stature, osteoarthritis and other degenerative changes – could not, or could only partially, be observed and comparisons with other sites need to be conducted with caution. A determination of the sex of an individual was only possible in one case, so that cultural parameters could not be considered in relation to gender. Standard osteometric measurements were not possible due to the poor preservation of the bones.

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