ARTICLE / *ARTICLE*

The Bronze Age necropolis of Koh Ta Meas: insights into the health of the earliest inhabitants of the Angkor region

La nécropole de l'âge du Bronze de Koh Ta Meas : un aperçu de l'état de santé des plus anciens habitants de la région d'Angkor

M.A. Frelat · C. Souday

Abstract The Koh Ta Meas site, near Angkor, Cambodia, has revealed a partially excavated Bronze Age necropolis (2870 BP +/- 60) comprising 27 burials. The aim of this study is to shed light on the earliest inhabitants known to date in the Angkor region and to gain further knowledge on Early Bronze Age populations in Southeast Asia. The burials of some individuals, probably wrapped in matting, the type of funeral artefacts or the presence of pig skulls suggest sophisticated mortuary rituals and evoke other Southeast Asian sites. Analyses of the skeletal remains show that the sample individuals are characterized by a short stature and gracile bones. As expected given the poor bone preservation, we found very little significant evidence of pathology, including infections and trauma. The dental health pattern at Koh Ta Meas is generally good and consistent with the consumption of rice, and may suggest a gendered division of activities. Comparisons between this small group and Iron Age series from the region indicate a possible decline in dental health with the intensification of rice agriculture. An interesting pattern of intentional tooth ablation identified at Koh Ta Meas confirms the cultural continuity in the Pre-Angkorian region, as suggested by the archaeological evidence. As in other Southeast Asian skeletal samples, the health profile of the earliest inhabitants of Angkor is generally good and consistent with the adoption of rice agriculture during the Bronze Age.

Keywords Bioarchaeology · Cambodia · Protohistory · Burial archaeology · Palaeopathology

M.A. Frelat (✉)
Dipartimento di Beni Culturali, Università di Bologna,
Via degli Ariani 1, 48100 Ravenna (RA), Italie ;
UMR CNRS 7268 ADèS, Aix-Marseille Université,
Faculté de Médecine Secteur Nord, 51, Bd Pierre Dramard,
13344 Marseille cedex 15, France
e-mail : melanieagnes.frelat@unibo.it

C. Souday
Équipe de Paléontologie Humaine, UMR 7194 du CNRS,
Département de Préhistoire du Muséum national d'Histoire
naturelle, Paris, France

Résumé La fouille du site de Koh Ta Meas (Angkor, Cambodge) a révélé une nécropole partielle de l'âge du Bronze (2870 BP +/- 60) comprenant 27 sépultures. Le but de cette étude est de dévoiler les plus anciens habitants connus à ce jour dans la région d'Angkor et d'accroître la connaissance des populations du Bronze ancien en Asie du Sud-Est. Les sépultures de certains individus, probablement enveloppés dans une natte, le type d'objets funéraires ou la présence de crânes de porc, suggèrent des rituels funéraires sophistiqués, évoquant d'autres sites en Asie du Sud-Est. L'analyse des ossements montre que l'échantillon se caractérise par une petite taille et des os graciles. Les os étant mal conservés, très peu de pathologies importantes – infections, trauma – ont été recensées. Le profil de santé dentaire, en général bon à Koh Ta Meas, est en accord avec la consommation de riz, et suggère une répartition sexuelle des activités. La comparaison de ce petit groupe avec des séries de l'Age du Fer de la région indique une dégradation possible de la santé dentaire avec l'intensification de la riziculture. L'identification d'ablations dentaires à Koh Ta Meas confirme la continuité culturelle suggérée par les artéfacts archéologiques du territoire préangkorien. Comme les autres populations d'Asie du Sud-Est, les premiers habitants d'Angkor ont bénéficié d'un état de santé relativement bon, cohérent avec l'adoption de la riziculture pendant la période du bronze.

Mots clés Bioarchéologie · Cambodge · Protohistoire · Archéologie funéraire · Paléopathologie

Introduction

The Koh Ta Meas site is located within the western *baray*[1] of the Angkor Thom temple, 1300 metres west of the Mebon, near Siem Reap in northwest Cambodia (Fig. 1).

It is a large and slightly elevated area that is flooded for most of the time under 1 or 2 metres of water. Thanks to two consecutive exceptionally dry seasons (2004, 2005), two brief salvage excavations were launched by C. Pottier under the "Archaeological Mission for Regional Planning of Angkor" (*Ecole Francaise d'Extrême Orient*, EFEO) with the collaboration of the APSARA authority (*Autorité pour la Protection du Site et l'Aménagement de la Région d'Angkor*) [1-3]. The site yielded not only a necropolis (test pit 2000, excavation 2004; excavation 2005), but also a habitation zone (test pit 3000, excavation 2004) [2-4]. Comparative analyses of the artefacts have enabled the archaeologists to date this necropolis to the Bronze Age. One AMS radiocarbon date on a charcoal has been completed so far and confirms this assumption, dating the sample at 2870 BP +/- 60 [5].

The archaeological evidence found at Koh Ta Meas is thus of the utmost importance as it represents the earliest settlement known to date in the Angkor region. In view of the growing number of projects in this region over the last decade (e.g. Greater Angkor Project [6]), this discovery demonstrates the existence of an early settlement at this site, pre-dating the Angkorian period (and the *baray* itself), but also any pre-Angkorian settlement [1-5].

Bronze Age populations are very well documented in Northern Thailand and Northern and Southern Vietnam (Fig. 2), with issues primarily spanning the dating of the adoption of bronze production, the nature of social organization and the modelling of populations history of Southeast Asia [7-13]. In Cambodia, numerous recent discoveries of Early Iron Age burials (dating from c. 500 BC to 500 AD) are addressing questions of the origins of the more complex polities of the pre-Angkorian and Angkorian periods by looking into variations in diet, dental health and cultural behaviour [14-20]. Evidence from the earliest known burials at Village 10.8 (400 to 100 BC) to the most recent burials at Phum Snay (100 BC to AD 500) shows that funeral practices did not substantially change during the Iron Age but were quite similar across the whole region (Phum Snay [13-16], Phum Sophy [18,19] and Prohear [11,20]). Two older prehistoric excavations (Samrong Sen and Mlu Prei), where some human remains were recovered, have been considered to be sites representing the Late Stone Age – early Bronze Age transition. Unfortunately those two sites are not reliably dated [1].

The Koh Ta Meas skeletons, although not well preserved, are therefore the oldest human remains attested to, not only in the Angkor region but in the whole country. The aim of this study is to shed light on the earliest inhabitants known to date in the Angkor region and to gain further knowledge on Early Bronze Age populations in Southeast Asia. After presenting the demographic and morphological characteristics of the sample from the Koh Ta Meas necropolis (n=24), several skeletal and dental indicators of physiological stress are investigated and compared with other skeletal series from a similar chronological period in Cambodia and in mainland Southeast Asia. Although the ceramic corpus of Koh Ta Meas seems fairly distinct from the ceramics excavated in nearby pre-Angkorian sites, the Koh Ta Meas artefacts have closer similarities with those found in the prehistoric sites of Samrong Sen and Mlu Preithan than with any other of the much better known sites of Northern Thailand [1]. This paper discusses new material on the health and lifestyles of one of the earliest human settlements in the Angkor region, bringing new insights into early Cambodian ancestry.

Archaeological context

Twenty-seven burials, or traces of burials, were identified in the field (Fig. 3). Among these, only 19 contained human remains: seven contained substantial skeletons and twelve yielded only very incomplete remains (Table 1). Three of the latter were within the boundaries of the excavations, yielding only parts of skeletons. Because the exact limits of the graves were rarely identifiable, the exact number of burials is uncertain [5]. Despite the poor state of preservation of the skeletal remains, typical of burial conditions in acidic and aqueous environments, many immature remains were recovered during the excavation but no special funeral treatment was recognized at that time. However, two additional burials were assumed during the laboratory phases to be those of young children (under 15 years of age) (Table 1). Finally, more than 478 isolated bones and teeth, mostly incomplete and fragmented, were collected on site or recognized during the final inventory. They were not included in this study.

Of the six main chronological phases identified by the archaeologists, three burial phases (Phases 2, 3 and 4, Fig. 3) were identified based on the stratigraphy, altimetry, configuration and orientation of the bodies [2,5]. After analysis of the skeleton positions, following archaeothanatological methods during the excavation [21,22], burial rites and the existence of possible funeral arrangements were discussed. Apart from the orientation of the skeletons, there are no significant differences between the burials. They

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[1]This huge water reservoir, 8 km long by 2 km wide, is assumed to have been built during the 11th century, in an area known to have been occupied since the pre-Angkorian period.
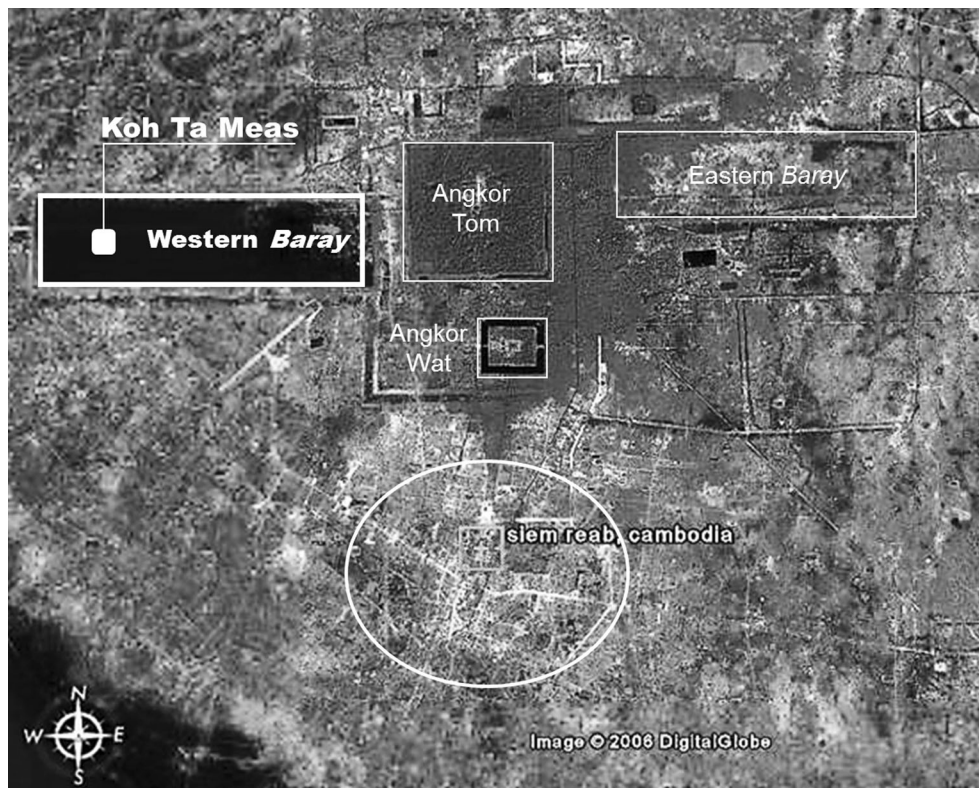
Fig. 1 Location of the Koh Ta Meas archaeological site (Note that the site is usually under water) / *Localisation du site archéologique de Koh Ta Meas (Notez que le site est habituellement submergé)*
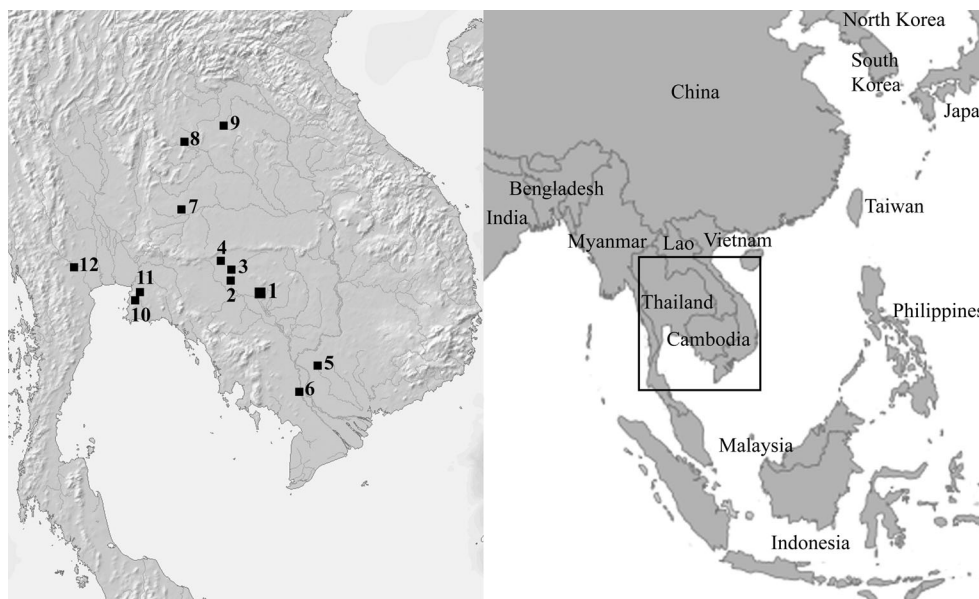

Fig. 2 Locations of the protohistoric sites mentioned in the text. 1, Koh Ta Meas, Prei Khmeng, and Angkor (Siem Reap); 2, Phum Snay, Krasang Thmei; 3, Phum Sophy; 4, Koh Krabas; 5, Prohear; 6, Angkor Borei; 7, Noen U Loke, Ban Non Wat, and Ban Lum Khao; 8, Non Nok Tha; 9, Ban Chiang; 10, Khok Phanom Di; 11, Nong Nor; 12, Ban Kao / *Localisation des sites protohistoriques mentionnés dans le texte. 1, Koh Ta Meas, Prei Khmeng, and Angkor (Siem Reap); 2, Phum Snay, Krasang Thmei ; 3, Phum Sophy ; 4, Koh Krabas ; 5, Prohear ; 6, Angkor Borei ; 7, Noen U Loke, Ban Non Wat, et Ban Lum Khao ; 8, Non Nok Tha ; 9, Ban Chiang ; 10, Khok Phanom Di ; 11, Nong Nor ; 12, Ban Kao*
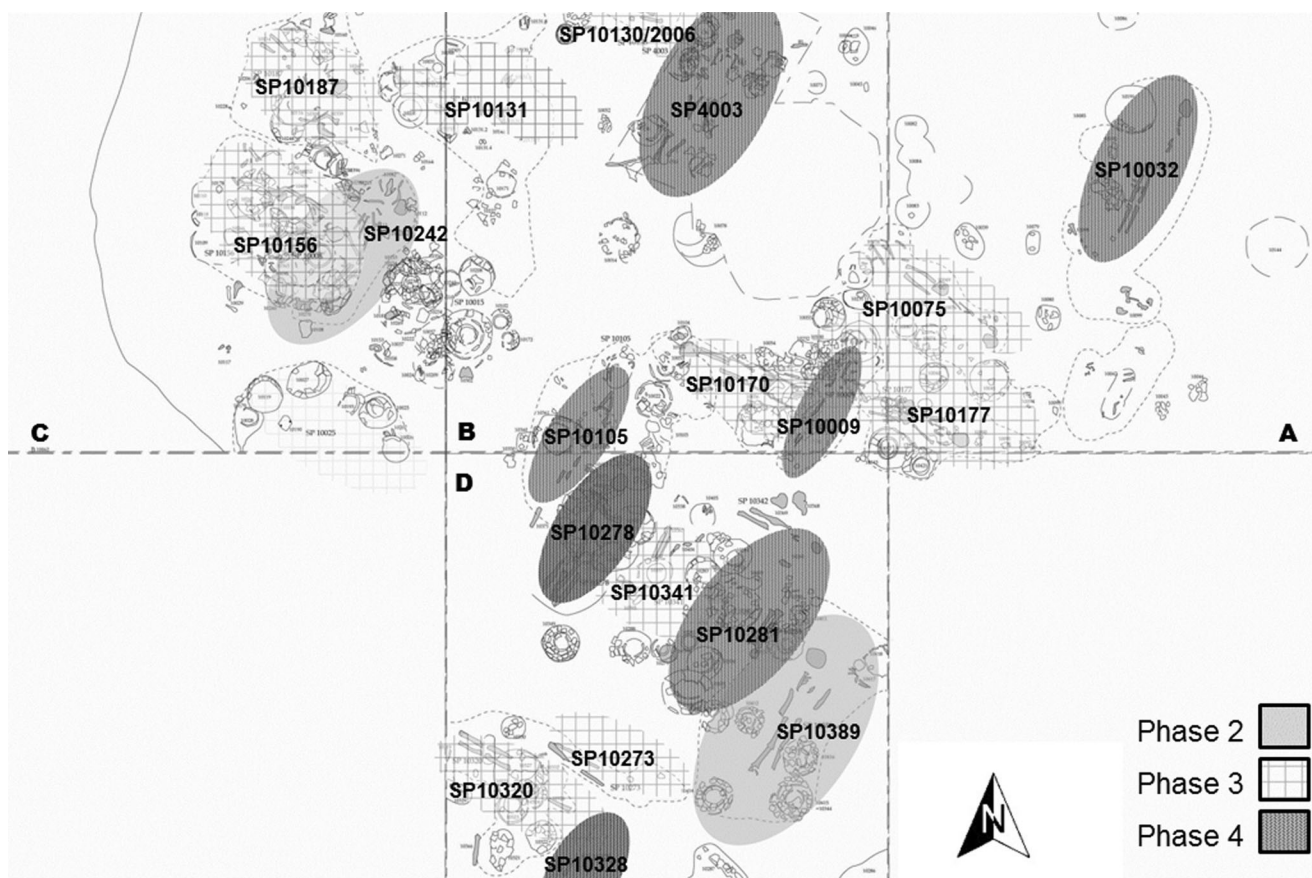
Fig. 3 Map of the 19 burials recognized during the field work. The site is divided into four archaeological zones (A, B, C, and D) and three burial phases were identified (Phase 2, Phase 3, and Phase 4) / *Plan des 19 tombes enregistrées en cours de fouille. Le site se compose de 4 zones archéologiques (A, B, C et D) et trois phases funéraires ont été identifiées (Phase 2, Phase 3 et Phase 4)*

consist of single burials where the bodies laid on the back with the arms alongside the body, with the head either towards the northeast (Phases 2 and 4, Fig. 3) or the southeast (Phase 3, Fig. 3). One exception was found where the legs are slightly flexed (burial SP10177 A/B, Phase 3, Fig. 4). This could reflect a specific status of this individual, as suggested by the various artefacts associated with the body. However, the arrangement of the vessels may also have constrained the position of the body.

In general, some zones of decomposition in empty space (flattening of the rib cage) were observed, and some zones of partial constraint were noted at the shoulders and the pelvises. This could suggest that the bodies were wrapped in matting for burial. Nevertheless, the secondary spaces must have been quickly filled in, because joints such as the hands and feet are still connected in some cases (burials SP10187 C, Phase 3, SP10389 D, Phase 2). According to the position of some of the skulls, and the presence of sand patches close to them, the heads may have rested on a perishable pillow. Most of the skeletons were in a primary position but a few others were displaced into a secondary position after decomposition, either during construction of the *baray* (burial

SP10032 A, Phase 4), or more probably by later burials (Phase 2: SP10242 C; Phase 3: SP10170 B; Phase 4: SP10105 B, SP10278 D). The remains of a perinatal infant were recovered during the laboratory excavation of the chest bloc of the individual from SP10187. Unfortunately, no evidence was left to hypothesize whether the bone positions of the foetus resulted from taphonomic movements during the decomposition of the body, suggesting that the woman was still pregnant at the time of death; or whether both individuals died from a complicated delivery with the baby being placed on its mother's chest just after birth. Finally, one burial (SP10281 D, Phase 4) yielded three different individuals: a relatively well preserved adult skeleton and two other individuals, one adult and one subadult, mainly represented by their cranium deposited on the rib cage of the first individual. This could represent the only case of multiple burials on the site but might also be the result of secondary displacements.

The artefacts associated with the burials mostly consist of complete pottery vessels (Fig. 4a, Fig. 5a), from two to twelve pots per grave, occasionally piled up on top of each other and placed around the skeleton, and more rarely placed

Table 1 Archaeological and biological data for each Koh Ta Meas burial / *Données archéologiques et biologiques par tombes.*

Individual	Burial	Zone	IF	EF	API	QBI	Age	Age group	Sex
Phase 2									
10242	single	C	21.6	5.2	11.3	50.0	>50 y.[1]	[>50]	F[7]
10389	single	D	7.7	39.1	63.0	40.0	25-29 y.[2]	[20-29]	M[7]
10391	not described	C	1.9	1.7	5.5	30.0	2.5-3 y.[3]	[1-4]	
Phase 3									
10015/10269a	not described	C	8.3	12.4	16.3	0.0	3.1-4.4 y.[4]	[1-4]	
10075	single, rearranged?	A	23.3	3.8	16.4	26.7	19.1-19,5 y.[4]	[15-19]	I
10130/2006	single, partially dug, rearranged	B	4.1	NA	NA	77.8	45-55 y.[1]	[>50]	M[7]
10131	single	B	4.8	0.0	3.9	20.0	~6 y.[3]	[5-9]	
10156	single	C	9.0	3.5	17.7	30.8		adult	I
10170	single	B	4.9	44.0	68.1	60.0	40-49 y.[2]	[30-49]	I
10177	single	A	14.1	51.4	74.9	30.0	30-39 y.[2]	[30-49]	M[7,8]
10187.a	single or double	C	29.5	22.1	53.0	18.8	30-39 y.[2]	[30-49]	F[7,8]
10187.b			6.8	4.0	24.5	0.0	32-34 w.[3]	[0]	
10273	single	D	3.9	0.0	1.7	0.0		adult	I
10320	single, partially dug	D	4.3	NA	NA	0.0		adult	I
10341	single	D	2.8	0.6	2.2	50.0	45-55 y.[1]	[>50]	M[7]
Phase 4									
4003	single	B	8.2	34.3	59.1	90.0	40-49 y.[2]	[30-49]	F[7,8]
10009	single	B	14.1	2.8	19.9	5.6	>50 y.[2]	[>50]	I
10032	single	A	4.1	1.1	12.1	0.0		adult	I
10105	single	B	4.4	0.0	2.8	28.6	20-24 y.[1]	[20-29]	F[7]
10278	single, rearranged?	D	4.9	7.9	28.0	37.5	16.4-16.9 y.[4]; 13-19 y.[3]	[15-19]	
10281.a	Multiple or rearranged?	D	19.3	34.3	47.5	18.8	27-49 y.[5]	[30-49]	I
10281.b			27.3	NA	NA	50.0	>50 y.[1]	[>50]	M[7]
10261			28.8	NA	NA	0.0	6.2-8.8 y.[4]	[5-9]	
10328	single, partially dug	D	5.9	NA	NA	0.0	16-20 y.[1]	[15-19]	

[1]dental wear [34]; [2]auricular surface [32]; [3]long bone length [29,30]; [4]dental development [26-28]; [5]pubic symphysis [33]; [6]long bone ossification [31]; [7]cranial morphology [37]; [8]pelvis morphology [35,36].

on the top of the legs. So far, the study of the ceramics has identified two different types of fabrics [5]. The remarkable thinness of most of the second type of fabric, which predominates in most of the graves, the large size of the vessels (40 cm or more in diameter) and the absence of any traces of use suggest they were specially made for mortuary rituals [5]. Other types of artefacts were associated with the bodies, such as bone or bronze bracelets (Fig. 4c, Fig. 5b) and bronze arrow heads or bone points (Fig. 4b). Grave offerings also included animal bones like pig skulls and mandibles (Fig. 5a), and more rarely bird bones. The burial fillings yielded a very significant quantity of fish bones, without any particular concentration in the vessels [23]. A piece of turtle shell, probably used as an ornament, was found on the chest of the adult individual from the SP10187 burial, together with the perinatal bones. A few bone beads or clay balls were also associated with some burials. It is premature to conclude as to a hierarchy, as these graves were much disturbed and partially cut through by the digging of the *baray*, but with its 12 bronze bracelets with a twisted cord pattern on the left forearm, the SP4003 burial (Fig. 5) is the richest of the graves excavated so far.

The skeletal data from Koh Ta Meas

A minimum of 24 individuals (Table 1) were recovered from the 21 graves containing human remains (19 identified in the field and 2 in the laboratory phases); isolated bones and teeth are not taken into account in this report. The state of preservation of each individual was assessed using two preservation indices: the anatomical preservation index (API), and
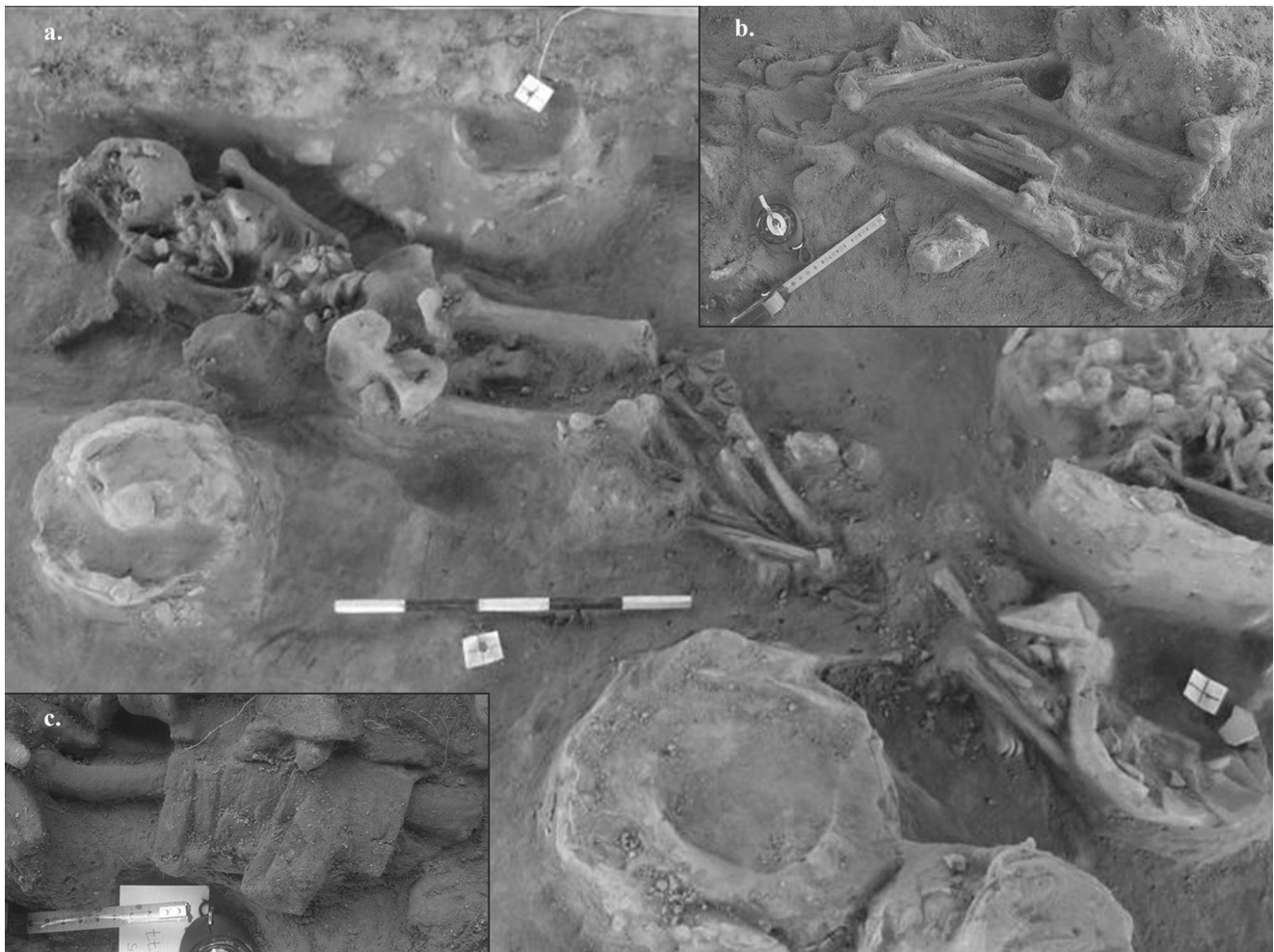
Fig. 4 Burial SP10177: (a) adult male with 11 bone points between the lower legs (b) and bone bracelets on both forearms (c) (Note the flexed position of the lower limb, probably due to the abundance of grave goods) / *Sépulture SP10177 : (a) homme adulte avec 11 pointes en os entre les jambes (b) et des bracelets en os sur les avant-bras (c) (Notez la position fléchie des membres inférieurs probablement due à la présence d'un riche mobilier funéraire)*

the qualitative bone index (QBI) [24]. The degree of fragmentation was evaluated by calculating the extension of fragmentation (EF), i.e. the proportion of complete skeleton elements relatively to the total number of pieces per individual, as well as the intensity of fragmentation (IF), i.e. the ratio of the total number of identified skeleton pieces (NISP) to the minimum number of anatomical elements (MNAE) [25]. The skeletons are generally very incomplete and in a poor state of preservation (Table 1). Nearly 75% of the burials yielded only very incomplete individuals (API < 50%), either due to poor bone preservation or to later disturbance by more recent burial phases or digging of the *baray*. Only five individuals were well preserved, with an API of more than 50%. All the specimens are highly fragmented, with a mean of 14.1% for EF and 11 for IF. Very few long bones were recovered intact, complete anatomical elements being almost exclusively - when present in the grave - teeth,

hand and foot bones, and more rarely vertebrae, patellae, first ribs or mandibles. As a very likely result of the site being under water for more than a millennium, only 25% of the individuals have qualitatively well-preserved bones (QBI > 50%). Thus, the very high bone fragmentation and the considerable alteration of the cortical bone may further bias palaeopathological prevalence [24].

Biological identification

The study of the osteological data has produced some demographical information on the Koh Ta Meas sample, despite the poor state of preservation of the bones. Estimation of the age at death of subadults was based on the method developed and described by Smith for dental development [26]. When possible, a comparison was made with Raungpaka
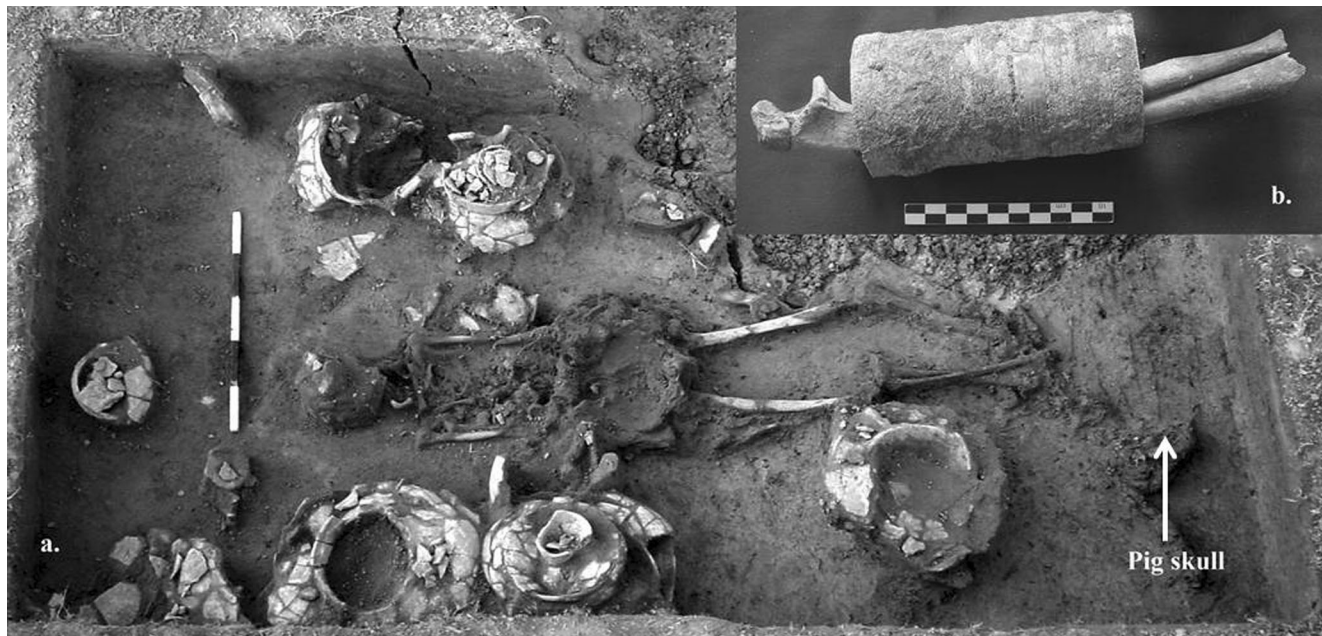
Fig. 5 Burial SP4003: (a) adult female with bronze bracelets on the left forearm (b) (Note the numerous funerary pottery vessels and the pig skull at the feet) / *Sépulture SP4003 : (a) femme adulte avec des bracelets en bronze sur l'avant-bras gauche (b) (Notez l'abondance de la céramique funéraire et la présence d'un crâne de porc au niveau des pieds)*

[27] and Ubelaker [28]. When teeth were missing, the age of subadult skeletal remains was estimated from their bone development (ossification and fusion of epiphyses, intermetaphyseal maximum length of long bones) as described by Fazekas and Kosa [29] for perinatal remains and Maresh [30] and Scheuer and Black [31] for older stages. Subadults were assigned to the classical immature age groups (perinatal, infants less than 5 years, then 5-year age groups). Adult age at death was preferably estimated by observing the auricular surface and the pubic symphysis [32,33], and when the pelvic girdle was not available, by recording tooth wear [34]. Because adult age estimation is less accurate than for subadults, only three general groups were considered (young, middle-aged and old adults).

Eight subadults (33.3%) were identified, including the fairly well preserved 32 to 34 week-old foetus whose bones were found with the female individual from burial SP10187 (Phase 3). Two infants (1-4 years) and two older children (5-9 years) were identified during laboratory work (Table 1). No remains could be assigned to the preadolescent class (10-14 years), but three adolescents were identified during the excavation (15-19 years). The best preserved immature remains were found in the western and southern part of the excavation, but when isolated bones are considered, no particular spatial distribution can be plotted. Similarly, immature remains were found in all the burial phases of the site.

Sixteen adults represent the other two thirds of the individuals (Table 1). Two of the adults (12.5%) were assigned

to the youngest age group. Nearly two third of the adults were middle-aged (31.3%) or old (31.3%). Because of the high level of dental wear in this sample, the older class could be over-represented.

Pelvic morphology was used in preference to cranial morphology to estimate the sex of the adults [35-37]. The sex of only some of the adults was determined, resulting in 4 women and 5 men. There does not seem to be any sex- or age-specific distribution of the adult skeletal remains, either in space or time (equally distributed all over the excavation field, and throughout all phases). Although the necropolis was only partially excavated, the sex ratio (1:0.8) is quite close, indicating no obvious bias.

Indicators of health

Stature and growth disturbances

Stature was estimated from the lengths of long bones, whenever possible, using regression equations developed on Thai and Chinese cadavers using the bone available with the least standard error and following Domett and O'Reilly's recommendations [15,38,39]. We measured at least one of the long bones of six of the 16 adult individuals; the average stature estimates are given in Table 2. Two undetermined adults have rather extreme values and are consequently considered as male for 10281a (tallest individual, 168.4 cm) and female for 10170 (smallest individual, 151.3 cm). With an average

stature of 164.3 cm in males and 152.8 cm in females, Koh Ta Meas stature estimates fall within the lower the range of the variation observed in the comparative samples (152.4 – 176.9 for males, 146 – 173.7 for females) (Table 3).

Linear enamel hypoplasia (LEH) was observed in 2 of the 4 female individuals (14.1% of female teeth), in 2 of the 6 male individuals (10.6% of male teeth) and in 2 of the 3 subadults with permanent teeth (6.7% of subadult permanent teeth). Compared to other Southeast Asian samples (Table 3), the percentage of female teeth (n= 91) with LEH observed in the Koh Ta Meas sample falls within the upper range of variation (4.2% - 15.1%) while the percentage of male teeth (n= 79) with LEH is in the middle range (5.3% - 15.7%). However, the difference between male and female frequencies of LEH from Koh Ta Meas is not statistically significant. The moderate level of enamel hypoplasia, close to that described at the Early Bronze Age Thai site of Ban Lum Khao [40], indicates that the Koh Ta Meas individuals were under moderate stress during their growth.

In the limited Koh Ta Meas sample of males and females with both long bones and dentition, we found no apparent correlation between stature and LEH. The tallest male, the middle-aged adult 10281a, shows evidence of LEH while the shortest male, the middle-aged adult 10177, shows none. The third male (10389), with evidence of LEH, is a rather short young adult. The shortest and tallest females - 10170 and 10187a respectively - both show evidence of LEH. These observations may indicate that some individuals whose growth was disturbed during childhood were able to compensate with a period of catch-up growth that could have

Table 2 Stature estimates (cm) for each adult long bone preserved at Koh Ta Meas and average individual estimates (cm) / *Estimation de la stature (cm) de chaque os long adulte conservé à Koh Ta Meas et estimation moyenne individuelle (cm).*

Specimen	Sex	Femur	Tibia	Humerus	Radius	Ulna	Mean
10177	M	161.1	161.8	160.8	158.8	162.2	160.9
10389	M	162.6		161.6		166.3	163.5
10281a	I		166.6			170.2	168.4
10170	I				151.3		151.3
4003	F			154.9	151.0	153.7	153.2
10187a	F				154.0		154.0

Table 3 Comparison of Koh Ta Meas stature (cm) and Linear Enamel Hypoplasia (LEH) with other prehistoric southeast Asian populations (adapted from [15]) / *Comparaison de la stature (cm) et de la prévalence des Hypoplasies Linéaires de l'Email dentaire à Koh Ta Meas avec d'autre populations Sud-est-asiatiques (adapté d'après [15]).*

	N	Mean	Range	S.D.	LEH (permanent teeth)
Females					
Koh Ta Meas	*4*	*152.8*	*151.3–154*	*1.4*	*14.1*
Non Nok Tha	32	153.4	146–162	4.0	4.2
Ban Chiang	24	154.4	149.2–161.0	3.0	6.5
Noe U-Loke	4	154.6	151.5–161.6	4.7	15.1
Ban Lum Khao	25	154.7	147.9–162.2	3.8	12.4
Ban Na Di	13	155.9	150.0–164.4	4.0	12.6
Vat Komnou	6	156.6	151.1–159.8	3.2	4.9
Phum Snay	6	161.1	153.7–173.7	8.0	0
Males					
Koh Ta Meas	*5*	*164.3*	*160.9–168.4*	*3.8*	*10.6*
Ban Lum Khao	18	164.7	152.4–174.9	6.2	11.2
Non Nok Tha	32	165.4	158–173	3.5	5.3
Ban Chiang	29	165.7	160.3–173.7	3.6	7.6
Vat Komnou	6	167.0	160.5–174.2	5.9	12.9
Phum Snay	4	167.7	160.6–176.9	7.9	7.0
Ban Na Di	17	168.0	159.5–176.0	4.9	15.7
Noen U-Loke	9	169.3	165.3–173.3	3.1	6.6

occurred with adequate post-disturbance nutrition [41]. For the others, growth disruption may have been severe enough to result in a reduction of the final stature, or the necessary period of catch-up growth did not occur due to an insufficient diet [41]. This difference may result from unequal access between individuals to resources or to care when sick. However there seems to be no correlation between LEH and grave offerings, which would have indicated that better care was associated with a higher social rank.

One late adolescent from burial SP10075, and probably - but less clearly - one other individual (10242), may have suffered from chronic anaemia, as several skull fragments show unusual thickness and expansion of the diploe (Fig. 6). However, neither signs of porotic hyperostosis on the outer table of the cranial vault fragments or on the very fragmentary orbits, nor any evidence of postcranial skeletal changes could be identified, due to the very poor state of preservation of the skeletons (Table 1). The adolescent also has LEH on the maxillary anterior teeth, confirming that he or she suffered from some growth retardation. The young adult age estimation would make Paget's disease unlikely

but, given the geographical context, the thickness of the diploe may be consistent with thalassaemia [42]. More analyses are needed to determine more accurately whether the population of Koh Ta Meas might have been exposed to malaria.

Skeletal health

There was very little significant pathology among the 24 individuals from Koh Ta Meas. Given that most of the epiphyses of the long bones were not preserved, and that the cortical surface was significantly eroded in general, it is not surprising that only two individuals show evidence of degenerative joint disease. The middle-aged woman buried with the bracelets (burial SP4003) has very slight lipping on the femoral heads and the old adult male (2006) found in a secondary position has moderate lipping on the right proximal ulna.

Of the seven individuals whose vertebral column was sufficiently well preserved, five show evidence of various degrees of Schmorl's nodes on their lumbar and lower thoracic vertebrae [43]. All of these are middle-aged adults,
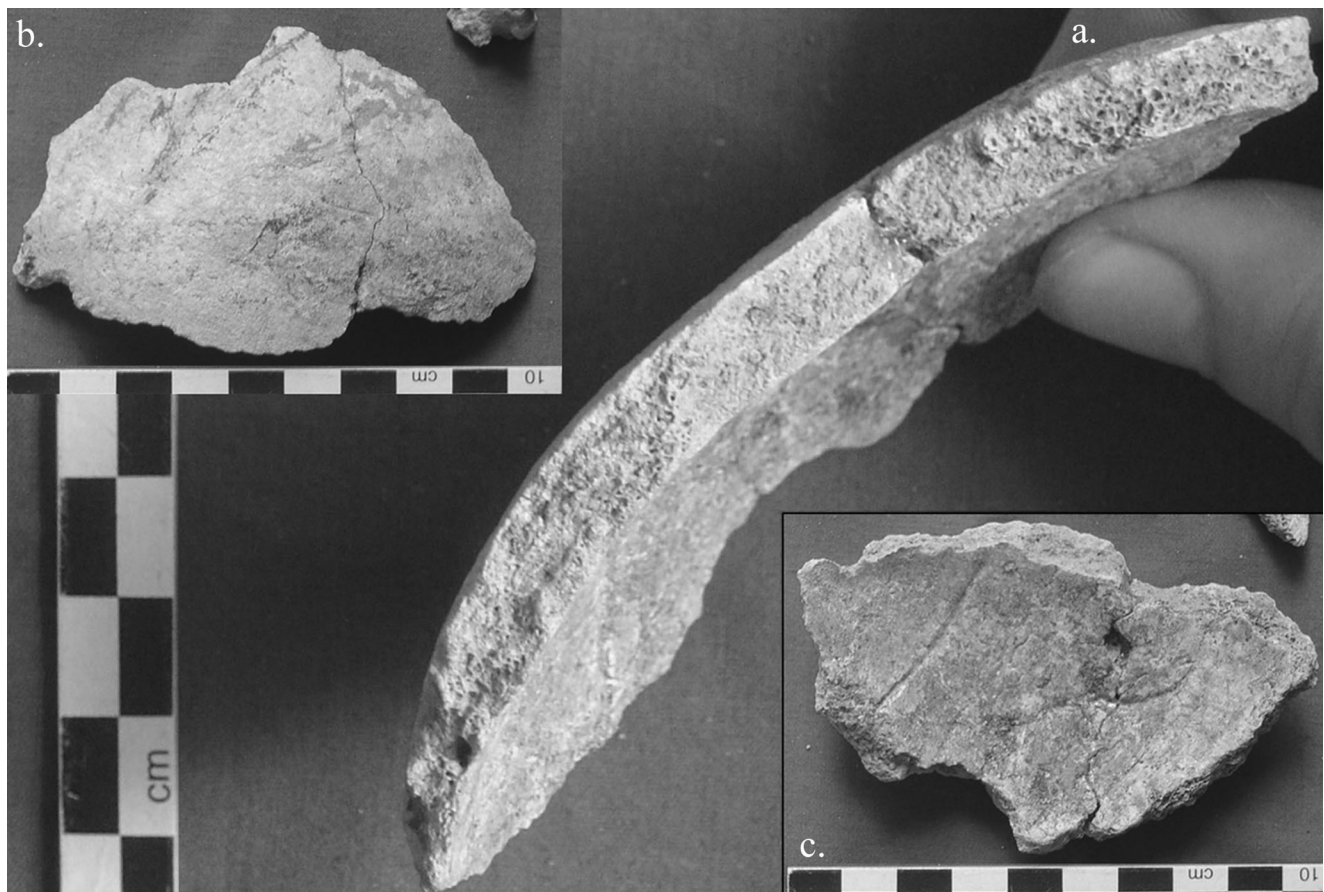

Fig. 6 a: Broken section of the 10075a frontal bone demonstrating hyperplasia of the diploe; b: 10075a frontal bone, external view; c: internal view / *a : Section du fragment de l'os frontal 10075a, présentant des signes d'épaississement du diploé ; b : vue externe du fragment d'os frontal 10075a ; c : vue interne*

while the unaffected individuals are the young male from burial SP10389 and the adolescent from burial SP10278. There seems to be no sex differences in the distribution of Schmorl's nodes as both males and females are equally affected. Although most of the vertebral remains are too fragmented to allow any positive observation, some of the lower thoracic and lumbar vertebrae show slight vertebral body expansion but no sign of osteophytic expression. In general, no particularly severe cases were observed, indicating that significant effects on the mobility of Koh Ta Meas individuals were very unlikely.

Only three individuals exhibit evidence of *antemortem* trauma, mainly localized on the phalanges (hand and foot) and on the forearm. The proximal phalanx of what is probably the forefinger of the woman from burial SP4003 appears to have an oblique consolidated fracture. The fifth proximal phalanx of the left foot of a middle aged man (10281a) shows post-traumatic osteoarthritis with *varus* deformation. Phalanges are common sites of traumatic injuries and if the fracture line enters the joint then osteoarthritis is a likely complication. Dislocations of phalanges are mainly due to forced hyperextension while pedal phalanges, particularly of the great toe, often suffer crushing injuries from direct trauma. The old woman from burial SP10242 exhibits a consolidated fracture of the distal shaft of her right ulna, with little displacement. The associated radius is too fragmented for any kind of trauma to be observable. The lower arm is often a site of fractures due to falls, but may also sustain nightstick fractures, a type of trauma often due to interpersonal violence [44]. Although solitary fractures of the ulnar shaft with little or no displacement are often due to a blow to the forearm [44,45], some clinicians have described fractures of the ulna in the absence of a direct blow. These fractures are apparently stress fractures associated with tasks involving strong and repeated pronation and supination of the forearm [46]. At least one clinical source states that isolated fractures of the ulnar shaft may be caused by a fall with the hand and arm outstretched [47]. Moreover the high IF calculated

for this individual and its old age estimation (>50 years) may suggest evidence of osteoporosis that could have been responsible for this forearm fracture. The absence of cranial trauma and the scarcity of weapons at Koh Ta Meas suggest that in the Early Bronze Age, the inhabitants of the Angkor region were not yet engaged in warfare like the later Iron Age population from Phum Snay [48,49].

Due to the extreme weathering of the cortical bones in the sample (Table 1), only one individual has visible signs of infection, and probably, but less clearly, one other. The young adult from burial SP10032, despite the poor condition of the cortical bone, shows evidence of marked periostitis on both lower legs. The middle-aged woman from burial SP10170 might also have experienced periostitis on her right tibia and fibula.

Oral health status

A total of 277 fairly complete, erupted permanent teeth (including 202 teeth that were recovered *in situ* or refitted) and 286 tooth positions were observed among five females, six males and six individuals of unknown sex (including three adolescents) (Table 4). The state of preservation of the permanent dentition among the individuals under study is very mixed, some having both mandibular and maxillary arches and the full dentition (e.g. 10075a, 10389 or 10187a) and others only one to four teeth (e.g. 10105, 10130/2006, 10032). Isolated teeth that could not be associated with mandibular or maxillary alveoli were not considered in this study. Occurrences and frequencies of advanced dental wear, caries and *antemortem* tooth loss (AMTL), both pathological and intentional, were recorded. Smith's grades 6 to 8 [50] for anterior teeth and premolars, and Scott's grades 7 to 10 [51] for molars were considered as advanced wear. Each tooth was scored for the presence or absence of caries; teeth with two or more caries were counted only once. Neither abscesses nor alveolar defects were observed in the sample but *antemortem* vertical bone loss was quite common in

Table 4 Age and sex distribution of the osteo-dental remains studied / *Distribution par âge et par sexe de l'échantillon ostéodentaire étudié.*

	Females			Males			Unknown Sex		
	Ind.[1]	Teeth[2]	Tooth pos.[3]	Ind.[1]	Teeth[2]	Tooth pos.[3]	Ind.[1]	Teeth[2]	Tooth pos.[3]
Adolescents							3	75	52
Young[4]	1	3	10	1	29	32			
Old[5]	4	88	98	5	53	75	1	9	9
Unknown Age							2	20	10
Total	5	91	108	6	82	107	6	104	71

[1]Number of individuals with permanent preserved dental material included in the study; [2]Number of permanent erupted teeth; [3]Number of tooth positions in permanent dentition; [4]Individual age <30 years, including three adolescents; [5]Individual age >30 years.

both sexes. Nevertheless AMTL was scored at each tooth position. The results are presented as the proportion of AMTL to the number of tooth positions preserved. Sample sizes for the four parameters recorded were slightly different, depending on the state of preservation and the pathology being observed. Chi^2 tests were calculated to establish significant differences between males and females for comparable age-at-death ranges (significance *p*-value <0.05).

Older males and females show similarly high rates of advanced wear, and taken altogether, older individuals are significantly more affected than the young (Table 5). Generally at Koh Ta Meas, molar teeth are the most worn, especially the first molar, and when both arches (upper and lower) are present, the mandibular arch has the most marked wear. Considering the teeth of all individuals, the caries rate at Koh Ta Meas is quite low, at 5.4% of the 277 teeth observed (Table 6). These lesions are predominantly on the occlusal surface, more rarely on interproximal surfaces. Female caries rates are higher than in males in the older class, but the difference is only significant when all age categories are considered together. Pathological AMTL is not observed in the younger class, and is similarly moderate both in males and females of the older group (Table 7).

The Koh Ta Meas females generally have more caries than males, as recorded worldwide [52], while both sexes have a high rate of advanced wear and a moderate rate of AMTL. Variations in dental health profiles within a community are generally attributed to behavioural differences, and sex differences in caries prevalence suggest a gendered division of labour [52]. The combination of high advanced wear and low caries rates observed in Koh Ta Meas males is typical of hunter-gatherer subsistence strategies. But the high rates of advanced wear and caries seen in Koh Ta Meas females is not really consistent with agricultural diets (high caries rate and low advanced wear). High advanced wear rates are consistent with rice consumption, since it is likely that the rice was eaten unpolished [53]. The coarseness of the rice, whose presence is documented by several artefacts on the site, would explain the advanced wear rates observed in both sexes [53], but it would also indirectly affect caries development in both males and females. The higher prevalence of caries observed in Koh Ta Meas females may suggest that factors other than food consumption were involved. Females may have had access to more sugary foods such as taro, yams, millet, bananas and palm sugar [53] but higher caries frequencies in females compared with males also suggest non-dietary causes, such as physiological differences

Table 5 Proportion of advanced wear in Koh Ta Meas permanent teeth / *Proportions de l'usure avancée observée sur les dents permanentes de Koh ta Meas.*

	Females		Males		Sex diff. p-values	Unknown sex		Total	
	A/N	%	A/N	%		A/N	%	A/N	%
Young	0/3	0%	2/29	6.9%	0.4337	0/75	0%	2/107	1.9%
Old	20/88	22.7%	11/53	20.8%	0.9490	0/9	0%	31/150	20.7%
Age diff. p-values	0.8213		0.1847					<0.001*	
Unknown age						1/20	5.0%	1/20	5.0%
Total	20/91	22.0%	13/82	15.9%	0.4066	1/104	1.0%	34/277	12.3%

A: affected; N: number of observed teeth; *Statistically significant *p*-value <0.05.

Table 6 Proportion of caries in Koh Ta Meas permanent teeth / *Proportions des caries observées sur les dents permanentes de Koh ta Meas.*

	Females		Males		Sex diff. p-values	Unknown sex		Total	
	A/N	%	A/N	%		A/N	%	A/N	%
Young	0/3	0%	0/29	0%		3/75	4.0%	3/107	2.8%
Old	11/88	12.5%	1/53	1.9%	0.0606	0/9	0%	12/150	8.0%
Age diff. p-values	0.8046		0.7581					0.1384	
Unknown age						0/20	0%	0/20	0%
Total	11/91	12.1%	1/82	1.3%	0.0121*	3/104	2.9%	15/277	5.4%

A: affected; N: number of observed teeth; *Statistically significant *p*-value <0.05.

Table 7 Proportion of pathological *antemortem* tooth loss (AMTL) in Koh Ta Meas permanent dentition / *Proportions des pertes dentaires pathologiques observées à Koh ta Meas.*

	Females		Males		Sex diff. *p*-values	Unknown sex		Total	
	A/N	%	A/N	%		A/N	%	A/N	%
Young	0/10	0%	0/32	0%		0/52	0%	0/94	0%
Old	8/98	8.2%	7/75	9.3%	0.9987	0/9	0%	15/182	8.2%
Age diff. *p*-values	0.7602		0.1736					0.0098*	
Unknown age						3/10	30.0%	3/10	30.0%
Total	8/108	7.4%	7/107	6.5%	0.9851	3/71	4.2%	18/286	6.3%

A: affected; N: number of observed tooth positions; *Statistically significant p-value <0.05.

(saliva, hormones and pregnancy) [54]. Pathological AMTL frequencies are not significantly different between the sexes at Koh Ta Meas, but they increase significantly with age when both sexes are taken together. This may represent a normal aging process bearing little relationship to pathological processes [52].

Despite the recent publication of a very detailed description of the dental health of two Cambodian Iron Age sites [18], it is difficult to place Koh Ta Meas within a broader Southeast Asian context. Differences in methodological approaches, sampling and demographic profiles prevent any statistical analyses. It is nevertheless worth comparing the general trends that can be derived from observed differences. Compared to other Southeast Asian sites, percentages of advanced wear are high at Koh Ta Meas, while percentages of caries and pathological AMTL are moderate, as in most Bronze Age samples (Nong Nor, Ban Lum Khao, Ban Chiang Late) [18]. However, other Bronze Age males have consistently higher frequencies compared with females. Although the frequency of advanced wear does not seem to show any consistent trend over time, advanced wear at Koh Ta Meas is higher than in the later Cambodian Iron Age sample (Angkor Borei, Phum Snay, Phum Sophy) [18,55]. Sex differences in advanced wear have also been found to be inconsistent over time, and are generally attributed to dietary differences [18,55-57]. Compared to other Southeast Asian sites, caries rates in Koh Ta Meas females (12.5% of observed teeth, 3/4 individuals) are among the highest, while caries rates in Koh Ta Meas males (1.3% of observed teeth, 1/6 individuals) are in the lower range of variability [18]. Pathological AMTL in older Koh Ta Meas females (8.2%, 3/4) and males (9.3%, 3/6) is in the middle of the range observed in both Southeast Asian comparative samples. Taken as a whole, the Koh Ta Meas sample shows low caries prevalence (5.4%) and a moderate percentage of AMTL (6.3%). Compared to Phum Snay and Phum Sophy, the two northwestern Cambodian Iron Age sites, caries prevalence at Koh Ta Meas is significantly lower while AMTL

prevalence is significantly higher [18]. This observation could suggest that as rice agriculture intensified in the region, dental health declined, as seen in other parts of the world [52]. However, previous studies have reported that in south-east Asia, the pre-metal to metal period does not systematically follow this pattern because rice is not as cariogenic as other type of grains used by agricultural populations elsewhere [53,56,58,59]. It is also possible that the diet at Koh Ta Meas was quite varied, although rice may have been the primary source of food. According to the fish bones study, environment when the Koh Ta Meas site was inhabited was very similar to that of today, with floodplains regularly inundated during the rainy season [23]. These would have offered extensive fishing grounds, as evidenced by the large quantities of fish bones recovered and belonging to the relatively few species that are fished in rice paddies today. This would confirm that this group of people mainly supported themselves through rice cultivation. The people of Koh Ta Meas were also very likely fishing in the Tonlé Sap Lake or trading or bartering with people living in the surrounding area, as indicated by species that prefer the flowing waters of large rivers or lakes. Revealing new elements to describe the Koh Ta Meas diet will require incorporation of the isolated teeth in the study and the use of stable isotope analysis.

An interesting *antemortem* tooth loss pattern was identified at Koh Ta Meas. Lateral incisors and maxillary canines of three individuals (10170, 10187a and 4003) out of eight (37.5%) in whom the anterior part of the maxilla was preserved, were lost *antemortem* (Table 8). The absence of anterior teeth can be explained by several factors, including congenital absence, impaction or intentional ablation [60]. In the case of congenital absence of teeth, the maxillary lateral incisors are the most frequently missing anterior teeth worldwide, but the spaces normally occupied by the missing teeth are filled in the resulting dentition [61]. No pathology was associated with the Koh Ta Meas cases, the pattern of missing teeth is symmetrical in the two individuals whose

maxilla was preserved on both sides (10187a and 4003), and adequate space remains for the missing teeth (Fig. 7). These observations tend to support intentional ablation [19,60,61]. All three individuals were estimated as middle aged women. The five other individuals in whom the anterior part of the maxilla is preserved were identified as two adolescents, one young adult, one young man and one old man. Evidence of intentional ablation has been reported in several other northern Cambodian sites spanning a later time period: Prei Khmeng (Pottier, pers. comm.), Phum Snay and Phum Sophy, Krasang Thmey and Koh Krabas, and has also been documented in a wide range of Asian and Pacific populations [15,19,60,62-64]. The particular pattern of ablated lateral incisors and canines found at Koh Ta Meas has been recorded elsewhere: it represents 3 to 5% of the patterns registered at Khok Phanom Di, a Thai Neolithic site [60], and is the second most common pattern (10.6%) observed at the two northern Cambodian Iron Age sites, Phum Snay and Phum Sophy [19]. As the three individuals with ablation are older females, this intentional ablation could be related to some sort of rite of passage such as initiation, marriage or birth, or may be an indication of status such as mourning or engagement [60]. It is indeed tempting to conclude that only female individuals are concerned by intentional ablation, and that the ablation is age-related at Koh Ta Meas, but the small number of individuals cannot be seen as statistically significant. Only another exceptional drought would allow more extensive excavations of the site to obtain a larger sample.

Conclusion

The rich, dense and long-used necropolis at Koh Ta Meas is the only prehistoric site excavated in Angkor on such a scale so far, and the only example of such a settlement in the region at the beginning of the first millennium BC. However, only 100 square metres were excavated, a very limited area compared to the 40 000 square metres of the entire site [3]. In

particular, no investigations were made on the potential habitat suggested by one test pit in 2004, on the west side of the platform. Further archaeological studies are required and expected to be carried out if another drought permits it.

The burial of individuals wrapped in mats, the type of funeral artefacts and the presence of pig skulls suggests sophisticated mortuary rituals, which evoke other sites excavated in the Angkor area [2,3,17]. Apart from the rich female burial SP4003 with bronze bangles, no particular age- or
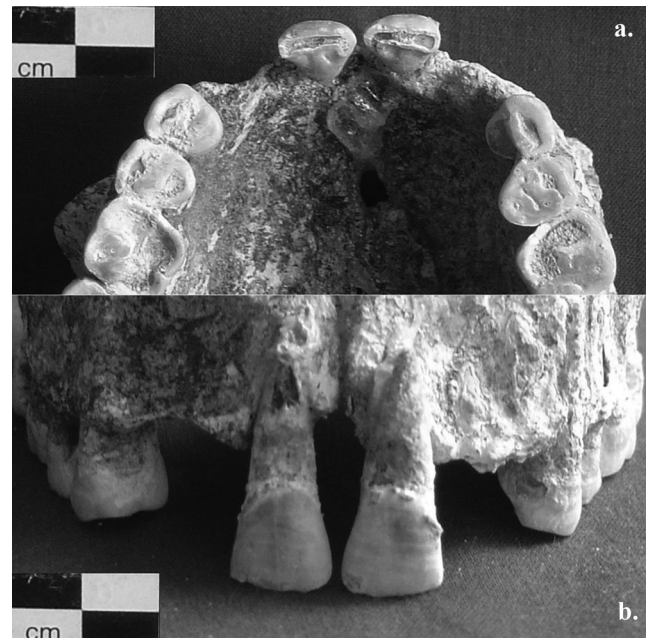

Fig. 7 Maxilla of the middle-aged female from burial SP10187 with intentional ablation of the lateral incisors and canines: a: inferior view; b: anterior view (note the presence of LEH on the central incisors) / *Maxillaire de la femme adulte, sépulture SP10187, comportant l'ablation intentionnelle des incisives latérales et des canines : a :vue inférieure ; b : vue antérieure (notez également la présence d'hypoplasies linéaire de l'émail sur les incisives centrales)*

Table 8 Proportion of intentional *antemortem* tooth loss (AMTL) in Koh Ta Meas permanent dentition / *Proportions des ablations dentaires intentionnelles observées à Koh ta Meas.*

	Females		Males		Sex diff. p-values	Unknown sex		Total	
	A/N	%	A/N	%		A/N	%	A/N	%
Young	0/10	0%\	0/32	0%		0/52	0%	0/94	0%
Old	10/98	10.2%	0/75	0%	0.0117*	0/9	0%	10/182	5.5%
Age diff. *p*-values	0.6257							0.0483*	
Unknown age						0/10	0%	0/10	0%
Total	10/108	9.3%	0/107	0%	0.0037*	0/71	0%	10/286	3.5%
A: affected; N: number of observed tooth positions; *Statistically significant *p*-value <0.05.									

sex-related differences in burial treatment were identified at Koh Ta Meas, suggesting a society based on relative equality [7]. It also suggests remarkable continuity in the funeral tradition observed hundreds of years later in the Iron Age necropolises of Prei Khmeng, Phum Snay, Phum Sophy, Prohear and Angkor Boreï, up to the introduction of Indic rituals [2,3,11,14,17].

Analyses of the remains, despite their poor state of preservation, shed light on the earliest inhabitants in the Angkor region. Although the sample size is very small, these remains could represent the living population to some extent, as the demographic profile at Koh Ta Meas is close to what is expected from prehistoric sites, with a third of subadult remains and a near-equal sex ratio (1:0.8). The sample is characterized by short stature and gracile bones, and there was very little significant skeletal pathology, including infections and trauma. This very low occurrence was expected because of the extremely poor state of bone preservation in the series (means of 14.1% for EF and 11% for IF), but it could also be related to the fact that only a few individuals lived to an older age, as generally observed in other early skeletal series. However, although the relatively low frequencies of dental enamel hypoplasia in the Koh Ta Meas remains suggest that these early inhabitants did not experience much physiological stress during childhood, evidence of anaemia was recorded. More analyses are needed to determine if the cause could be attributed to malaria. The presence of Schmorl's nodes indicates that the group probably experienced severe mechanical demands on their lower backs, which could be consistent with activities most likely related to rice agriculture. The few examples of healed limb bone fractures in this small sample suggest that this early group was also subject to injury, deliberate or otherwise.

Overall, the pattern of dental health at Koh Ta Meas is generally good. The relatively low percentage of caries indicates a low proportion of cariogenic food in the diet, and the high prevalence of advanced wear and pathological AMTL are consistent with abrasive food. This pattern is consistent with the consumption of rice, which would have been an important component of the diet during the Bronze Age [53]. The higher prevalence of caries observed in females suggests differences in diet stemming from gendered divisions in food gathering tasks, but other factors such as physiological differences may have been involved. An interesting *antemortem* tooth loss pattern was identified: there is evidence of intentional ablation of upper lateral incisors and canines in three middle-aged to old female individuals. The identification of this cultural behaviour at Koh Ta Meas may suggest a Bronze Age origin of the rituals later observed during the Iron Age in the region, and in particular at Phum Snay and Phum Sophy, and completes the current lack of recorded Bronze Age dental modification [19].

The evidence presented in this study confirms that the early prehistoric inhabitants of Angkor buried at Koh Ta Meas, with a few exceptions, were relatively healthy. The earliest inhabitants of Angkor seemed well adapted and display a general pattern of health similar to other southeast Asian skeletal samples from the Bronze Age (Non Nok Tha Late, Ban Lum Khao, Nong Nor, Ban Chiang Late) [19,40,57]. Comparison of this small group with Iron Age series from the region indicate a possible decline in dental health with the intensification of rice agriculture, but also confirms the cultural continuity in the Pre-Angkorian region suggested by the archaeological evidence [5,19].

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