We're all in this together: accessing the maternal-infant relationship in prehistoric Vietnam.

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Abstract

Family can be broadly defined as a community of care, cooperation and shared resources. As we move further into the past, however, our ability to observe these relationships becomes blurred. For most of human history, ethnographic and historical documents are lacking; identity and relationships are therefore inferred through the analyses of mortuary practices and evidence of production through artefacts and features. In this study, we examine the unique connection that exists between mother and infant, illustrating how this relationship gives potential insight into lived experiences in the past.

The human skeleton reflects an individual's biocultural life-course, recording information on diet, health, and stress. Using new methods for inferring physiological stress during the foetal, infant and childhood periods, this chapter investigates the early lives of two subadult individuals through the lens of the maternal-infant nexus from the Neolithic site of Man Bac in Vietnam. We apply a novel approach that incorporates stable isotopic evidence for weaning and diet, with a quantitative method of identifying and measuring linear enamel hypoplasia to assess physiological stress during development. These case studies are interpreted within a bioarchaeology of infant and child-care theoretical model approach that focuses on the maternal-infant nexus, and incorporates information on fertility, palaeopathological data, archaeological data on the natural and social environment, and social organisation.

The maternal-infant nexus

In recent years, the study of women and children has blossomed within historical, anthropological and archaeological research, giving voice to those individuals who were previously unseen, mislabelled, or defined only by their relationships to men (Lillehammer 2015;

Han *et al*. 2017; Gowland & Halcrow 2020). Although it is generally well acknowledged in bioarchaeology that children are sensitive measures of population health (e.g. Lewis 2006; Halcrow & Tayles 2008a), the maternal-infant nexus is relatively understudied. Understanding the relationship between mother and infant in the present and the past has far-reaching implications for interpretation of maternal and infant health, the developmental origins of health and disease, infant feeding practices, fertility and demography, social experience, and learning (Gowland & Halcrow 2020).

Pregnant women must meet the energetic demands of a rapidly growing foetus and may have increased susceptibility to malnutrition, infectious disease and/or the exacerbation of existing disease. The mother-infant pair is extremely sensitive to environmental stress and act as a barometer of overall population success (Halcrow *et al*. 2017; Halcrow 2020). Several studies have identified foetal burials in the archaeological record, including foetuses *in-utero*, post-partum foetuses and possible coffin-birth individuals (e.g. Halcrow *et al*. 2017; Le Roy & Murphy 2020; Lewis 2006: 34–36). There are several examples of mother-infant burials in the archaeological record from different time periods and parts of the world (Halcrow *et al*. 2017). Notable examples from prehistoric Southeast Asia are at Khok Phanom Di in Southeast Thailand, where there were two cases of newborn individuals placed on the shoulder of an adult female (Halcrow *et al*. 2008), and a mother and probable breech baby at An Son in Vietnam, both of which may have died due to birthing complications (Willis & Oxenham 2013a).

When considering the mother and the infant in bioarchaeology, it is presumed that if the developing baby experienced physiological stress, then so too did the mother. We rarely, however, consider the maternal experience further. This is particularly true in the context of recent stable isotope analyses that interpret increased nitrogen isotope values as evidence for *in-utero* stress (e.g. Beaumont *et al*. 2013; Beaumont & Montgomery 2015; Beaumont *et al*. 2015; King *et al*. 2018). But how can we improve our understanding of the social experiences of care and health relationships of mother and baby? It is a challenge within the archaeological context, as many of the post-term 'foetuses' who, for example, were still-born or died soon after birth as the result of maternal stress or birth trauma, are found without their mother (Halcrow *et al.* 2017).

Here, we present two case-studies to investigate the maternal-infant nexus to assess physiological stress through the novel integration of stable isotopic evidence for early-life diet

with a quantitative analysis of linear enamel hypoplasia. Maternal-infant care and health are assessed through data interpretation using the approach of Halcrow (2020) that considers maternal, infant and child stress in the context of fertility, and palaeopathological and archaeological data.

Bioarchaeological methods

Assessing diet and stress through incremental dentine stable isotopes
For several decades, isotopic techniques have been used to study weaning behaviour at a population level using bone collagen (Fogel *et al*. 1989; Katzenberg *et al*. 1993; Schurr 1998; Wright & Schwarcz 1999). However, the recent development of incremental dentine sampling of a single tooth allows weaning, childhood diet, and episodes of physiological stress to be observed at individual level (Eerkens *et al.* 2011; Beaumont *et al*. 2013). Weaning can be identified isotopically because it is a dietary change, and isotope ratios within tissues broadly reflect what was consumed during tissue development. As dentine does not turn over and forms incrementally, this allows us to diachronically sample to observe the childhood diet. Broadly speaking, nitrogen isotope (δ^{15}N) values vary with the trophic level of an individual, which can inform us of protein sources (Minagawa & Wada 1984). Carbon isotope (δ^{13}C) values vary based on the photosynthetic pathway of plants consumed (C_3 *vs*. C_4), as well as the proportion of marine resources in the diet (Craig 1953; DeNiro & Epstein 1981).

During pregnancy, isotopic values in the infant reflect the diet or health of the mother, potentially recording physiological changes in the maternal environment such as episodes of maternal morning sickness, or third trimester physiological stress (Fuller *et al*. 2005). After birth, infant isotopic values should hypothetically rise above maternal values, reflecting a trophic level shift during breastfeeding; the magnitude of this change is typically 2–3‰ (δ^{15}N) and 1‰ (δ^{13}C) (Fuller *et al*. 2006a). During the weaning process, isotopic values shift and these elevated values gradually lower to correspond with the mother's values (Fuller *et al.* 2006a), assuming that the infant is being weaned onto the same foods as the mother is eating.

Use of isotopic analyses to identify weaning is rendered problematic by several issues (Reynard & Tuross 2015; Tsutaya & Yoneda 2014). Firstly, the identification of a trophic level shift associated with weaning relies upon the comparison to adult female 'baseline' values,

despite our inability to identify those females within the archaeological record who were mothers. Secondly, isotopic changes associated with the weaning process may be either masked or exaggerated by changes associated with episodic stress. Finally, it is generally assumed that infants are weaned onto the same foods as their mothers. Childhood diets, however, may be distinct, with the potential for gendered access to food, and mothers may have had preferential access to food (or not) during pregnancy (Kusaka *et al*. 2010; Dong *et al*. 2017; Oxenham 2016; Miller *et al*. 2018, 2020). These factors can all complicate our understanding of isotopic changes in incremental dentine samples. Lastly, despite the high resolution of incremental dentine sampling, each increment represents the averaging of multiple months or years. Interpretations are therefore generalised and may miss important factors, such as changes in isotope values as a result of short-term stress.

Assessing stress through enamel defects

Linear enamel hypoplasia in permanent teeth
The study of childhood stress through linear enamel hypoplasia of permanent dentition is commonplace in bioarchaeology (e.g. Goodman *et al*. 1980, 1984; Chavez *et al*. 1991; Goodman & Rose 1991; Guatelli-Steinberg 2003; King *et al*. 2005; Hillson 2014). Systemic physiological stress, such as severe malnutrition or infection, is often cited as causing disturbances in enamel formation. Stress disrupts ameloblasts during their secretory phase, causing pits, grooves, and areas of missing enamel production. The most commonly studied are furrow-form defects along perikymata, referred to as linear enamel hypoplasia (LEH) (Goodman & Rose 1990; Fédération Dentaire Internationale 1992; Ten Cate 1994; Hillson 1996; Hillson & Bond 1997). The number of perikymata involved in the defect can be used to estimate the duration of disruption and subsequent recovery events (Hillson & Bond 1997; Hillson 2014). Unless teeth are heavily worn, these defects remain permanent features of the tooth crown. As LEH has multiple aetiologies and expressions, it is regarded as a non-specific indicator of stress, meaning that primary causation is unknown (Hillson & Bond 1997; FitzGerald & Saunders 2005; Hillson 2014). Permanent teeth can be analysed to examine the post-natal physiological responses to stress. The first three anterior permanent teeth, the central and lateral incisors and canines, capture nearly seven years of life experience. As these teeth begin to form at approximately 4.5 months of age (AlQahtani *et*

al. 2010), they can potentially provide evidence of non-specific physiological stress during breastfeeding, weaning, and beyond.

Linear enamel hypoplasia in deciduous teeth

Given their developmental timing, deciduous teeth can record stress from the pre- and post-natal environments, although they are rarely examined for this purpose. Most studies of defects in deciduous teeth involve either the observation of localised hypoplasia of the primary canine (e.g. Halcrow and Tayles 2008b; McDonell & Oxenham 2014), or of the neonatal line growth to examine if a perinate died before or after birth (Zanolli *et al*. 2011). The gap in the literature may be due to the anatomy of deciduous teeth, where the perikymata are difficult to observe due to number of factors, including the more bulbous shape of deciduous enamel in comparison to permanent enamel; an increase in prismless enamel; the geometry of striae of Retzius at the surface; and lack of clearly observable histological structures (FitzGerald & Saunders 2005; Mahoney 2012; Hillson 2014). However, as deciduous teeth form by the same mechanisms as permanent teeth, the logic applied to the study of LEH in permanent teeth should also apply to them (FitzGerald & Saunders 2005).

Pre-natal enamel in deciduous teeth can inform about the health of the mother and her physiological interactions with her baby. Although the chemical signatures and internal structures, including formation of striae of Retzius, in pre-natal enamel is rarely mentioned in the literature (FitzGerald & Saunders 2005; Fitzgerald & Hillson 2009; Birch & Dean 2014), it has been postulated that pre-natal circadian rhythms, derived from maternal rhythms, are insufficiently intense to trigger distinct histological formations (FitzGerald & Saunders 2005). Scrutiny of the histology and defects of pre-natal enamel allows us to better understand the maternal-infant nexus as directly as possible within bioarchaeology, untangling the symbiotic relationship between mother and baby. Deciduous teeth also react to events following birth that are inaccessible when studying permanent teeth alone, including both the gestational environment and its consequences, and the first few months of life.

Case Studies from Man Bac, Neolithic Northern Vietnam

Materials

The individuals presented here are from the Neolithic site of Man Bac (1906–1523 cal BC) in Yen Mo district, Ninh Binh Province, northern Vietnam (Oxenham *et al*. 2011; Buckley *et al*. 2019; Vlok *et al.* 2020). Surrounded by karst limestone mountains, the site is located approximately 25km from the coast although it would have been closer to the coast at the time of occupation due to higher sea levels (Oxenham 2006; Oxenham *et al*. 2011). Northern Vietnam currently experiences two seasons, one cold, and one hot, and year-round high humidity. The region also experiences typhoons that can disrupt agricultural production (Oxenham 2006; Matsumura & Oxenham 2011). While there was less ecological variation in northern Vietnam than the south, there is evidence at Man Bac of the exploitation of fish and deer (Sawada *et al*. 2011; Toizumi *et al*. 2011), as well as the earliest evidence of pig management in northern Vietnam (Jones *et al*. 2019). Additionally, the occupants of Man Bac may have grown rice, as long-grain rice phytoliths have been found in the occupation layers overlying graves (Willis & Oxenham 2013b). Radiocarbon dating of occupation layers contemporaneous with the burials discussed here places site usage between 2016 and 1524 cal BC, near the start of the Phung Nguyen period (Oxenham *et al.* 2011). This period is characterised by local food production via agricultural practices and hunting, including the exploitation of marine resources, along with ceramic production, and evidence for trade networks—all of which are believed to have been present at Man Bac (Matsumura & Oxenham 2010). Mortuary practices at Man Bac show little distinction in treatment between individuals by sex, and an individual with a disability was treated no different to others, although an age-based social hierarchy has been suggested (Oxenham *et al*. 2008b; Tilley & Oxenham 2011). Previous palaeopathological and demographic research shows that the Man Bac population experienced poor health, high fertility, high infant mortality, and the highest rate of natural population increase of sites within Mainland Southeast Asia during the Bronze through Iron Ages (Oxenham *et al.* 2008b; Domett & Oxenham 2011; Oxenham & Domett 2011; McFadden *et al.* 2018). This range of biosocial evidence is potentially valuable for addressing the impact of any occurrences of stress in early infant life. Two juveniles are examined here: (1) individual 07MBH1M3 was an adolescent who died between 12 and 18 years of age; (2) individual 05MBM36 was a young child who died around age 3 years $\pm$ 6 months (age assessment using dental eruption via visual and radiographic assessment, and epiphyseal fusion, see Domett & Oxenham 2011).

Methods

Stable isotope analysis

Only loose teeth with an antimere (the same tooth on the opposite side) present, no apparent pathologies, no post-mortem damage and no reconstructive glue, were analysed. Photographs were taken of all aspects of the teeth prior to sampling. Teeth were half-sectioned bucco-lingually into mesial and distal halves. One half was retained for future research. The other half was prepared for isotope analysis by removal of enamel and secondary and tertiary dentine using a diamond cutting disk and dental burr. Preparation of dentine followed Method 2 of Beaumont *et al*. (2013), which involves demineralisation, cutting into 1mm increments, before following a modified Longin (1971), during which collagen is gelatinised before lyophilisation.

Mass spectrometry of collagen was conducted at the Stable Isotope Biogeochemistry Laboratory (SIBL) at Durham University using a Costech Elemental Analyzer connected to a Thermo Delta V Advantage isotope ratio mass spectrometer. Carbon isotope ratios were corrected for ^{17}O contribution, and both carbon and nitrogen isotope results are reported in delta notation as $\delta^{13}C$ and $\delta^{15}N$. Isotopic accuracy was monitored through repeat measurements of standards (USGS40, USGS24, IAEA-600, IAEA-N-1, IAEA-N-2). Analytical error for carbon and nitrogen isotope analysis was calculated to be ±0.3‰ (2 SD) on replicate sample analysis. Collagen was considered to be of good quality if the C/N ratio fell between 2.9 and 3.6, carbon percentage by weight was between 35 and 50%, and nitrogen percentage by weight was between 11 and 16% (DeNiro 1985; Mook & Waterbolk 1985). The mid-point of the time period represented by each dentinal increment was calculated using the method of Beaumont and Montgomery (2015).

Quantification of LEH

High resolution silicone impressions of permanent and deciduous teeth were produced using Affinis (Coltene) Perfect Impressions Regular Body polyvinylsiloxane applied directly to the labial surface of all anterior maxillary and mandibular crowns. A resin replica of the teeth was produced using an epoxy resin (Epofix) with red liquid epoxy dye added for contrast during microscopy. The resin tooth replicas were analysed under a Sensofar "S Neox" 3D Optical Profiler Confocal Microscope. Measurements of enamel depth (z-axis) were taken every micron

at 20× magnification down the length of the tooth crown (y-axis) from the cementoenamel junction to the incisal edge, using the Sensoscan program. Data was processed according to Cares Henriquez and Oxenham (2017), creating micropolynomial estimations of teeth in order to quantify changes of enamel depth on the tooth surface; LEH are identified when residuals deviate negatively by at least 1 moving standard deviation.

Aging LEH on permanent teeth
The timing of defects must chronologically match at least two teeth to be considered representative of systemic stress (Hillson 2014). Defects on permanent teeth were aged following Cares Henriquez and Oxenham (2019), using regression-based formulae based on the histological work of Reid and Dean (2000, 2006), which takes into account the non-linear nature of enamel growth. By inputting the distance from the cemento-enamel junction, these equations estimate the age at which the defect began and ended.

Aging LEH on deciduous teeth
Although developmental timescales of permanent crowns have been a topic of extensive study over the past 30 years (e.g. Goodman & Rose 1990; Goodman & Song 1999; Reid & Dean 2000, 2006; AlQahtani *et al*. 2010; AlQahtani *et al*. 2014), deciduous teeth have not received the same scrutiny. We therefore used the ages assigned by Schour and Massler (1940) and AlQahtani *et al*. (2010) for different stages of deciduous tooth crown development (Table 1). Although the previous authors used different methodologies (histology and radiography respectively), which causes slight discrepancies in aging the same section of teeth (Hillson 2014), we apply these for our preliminary ageing system (Adams *et al.* 2019a). Assuming that a month encompasses four weeks and birth occurs at 40 weeks, we approximate growth as linear between the stages. This type of linear growth approximation is another point of potential error, as both deciduous and permanent teeth are assumed to grow non-linearly.

Table 1. Stages of deciduous crown growth and ages for anterior teeth. Ages in italics are our interpretations of the published values in weeks with birth as zero.

	Central maxillary incisors	Lateral maxillary incisors	Canines
Initiation	16 weeks gestation[*] *(–24 weeks)*	18 weeks gestation[*] *(–22 weeks)*	20 weeks gestation[*] *(–20 weeks)*
Crown 50% formed	30 weeks gestation[**] *(–10 weeks)*	34 weeks gestation[**] *(–6 weeks)*	4.5 months post-natal[**] *(+18 weeks)*
Crown 100% formed	1.5 months post-natal[*] *(+6 weeks after birth)*	2.5 months post-natal[*] *(+10 weeks)*	9 months post-natal[*] *(+36 weeks)*
% crown completed at birth	83.3% (5/6) formed[*]	66.7% (2/3) formed[*]	33.3% (1/3) formed[*]
Total time to form	30 weeks	32 weeks	56 weeks

[*]after AlQahtani *et al*. (2010)
[**]after Schour and Massler (1940)

Palaeopathology

A full skeletal assessment for pathology was undertaken for both individuals. Evidence for abnormal osteoblastic and osteoclastic activity was observed macroscopically, and specific diseases were differentially diagnosed using weighted diagnostic criteria (e.g. Brickley & Ives 2010; Snoddy e*t al*. 2018). The long bones of both individuals were radiographed for signs of disease, such as evidence for growth disruption or osteopenia. For these two individuals, lesion patterns do not suggest infectious disease, and differential diagnosis identified probable nutritional disease. Evidence for scurvy was diagnosed following Snoddy *et al*. (2018). Cribra orbitalia, the abnormal hyperplastic porosity of the orbital roofs attributed to anaemia in childhood, was recorded following standards by Stuart-Macadam (1985). As porosity of the orbital roofs can also occur due to capillary formation in regions of retro-orbital haematoma

development following microtrauma (Ortner & Ericksen 1997; Ortner *et al*. 1999, 2001; Klaus 2017), only cribra orbitalia porosity scored as *medium* or *severe* (Stuart-Macadam 1985) were included in analysis of childhood anaemia, as these grades denote marrow hyperplasia and not just cortically restricted porosity. Similarly, porotic hyperostosis (porosity of the ectocranium with associated diploic expansion of the cranial vault) was recorded as a marker of childhood anaemia (Ortner 2003). Evidence for anaemia, as identified through the presence of cribra orbitalia and porotic hyperostosis, is considered a marker of non-specific stress, as anaemia can result from genetic disorders, nutritional deficiency, and parasitic and pathogenic infections (Gowland & Western 2012). Standards for diagnosis of rickets following Brickley and Ives (2010) were also employed in the differential diagnosis.

Results

Case study 1: individual 07MBH1M3 (aged 12–18 years)

Incremental dental stable isotopes

Incremental isotopic results for 07MBH1M3 are given in Table 2 and Figure 1. A 2.4‰ decrease in δ^{15}N values during the first 2.2 years of life is suggestive of the weaning process. Weaning is usually also associated with a 1‰ decrease in δ^{13}C, as contributions from higher trophic level breastmilk decline during weaning until the infant adopts the same diet as their mother (Fuller *et al*. 2006b). However, in this individual, δ^{13}C during the proposed weaning period changes very little (less than 0.5‰) which may be due to this individual consuming a diet with slightly higher δ^{13}C values than their mother (Sandberg *et al*. 2014; King *et al*. 2018). The first isotopic increment's estimated mid-point age is 0.7 years, so it is also likely that some proportion of solid foods were already present in the diet at this time (Fuller *et al*. 2006a). Isotopic changes are also clear between 6 and 10 years of age in this individual. Between ~6.7 and 8.2 years of age, δ^{13}C values decrease by 1.1‰, before rising by 1.5‰ by 9.6 years old. These changes are also accompanied by shifts in δ^{15}N, which decrease by 0.7‰ between 5.9 and 7.4 years old, before increasing by 1.9‰ by 9.6 years old. This pattern may reflect dietary change in late childhood, although similar trends have been observed in other incremental studies and interpreted as relating to changes in normal growth rate and the reduction of nitrogen deficiency in late childhood (e.g. Henderson *et al*. 2014).

Table 2. Carbon and nitrogen stable isotope data and quality control parameters for increments for the mandibular permanent left first molar of individual 07MBH1M3.

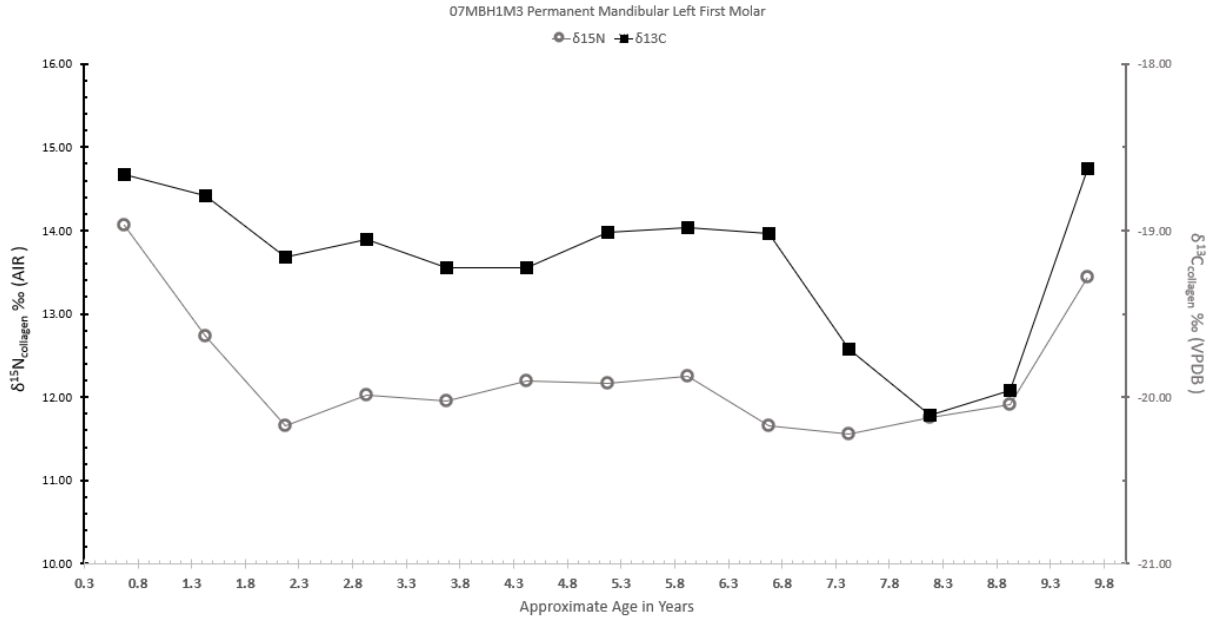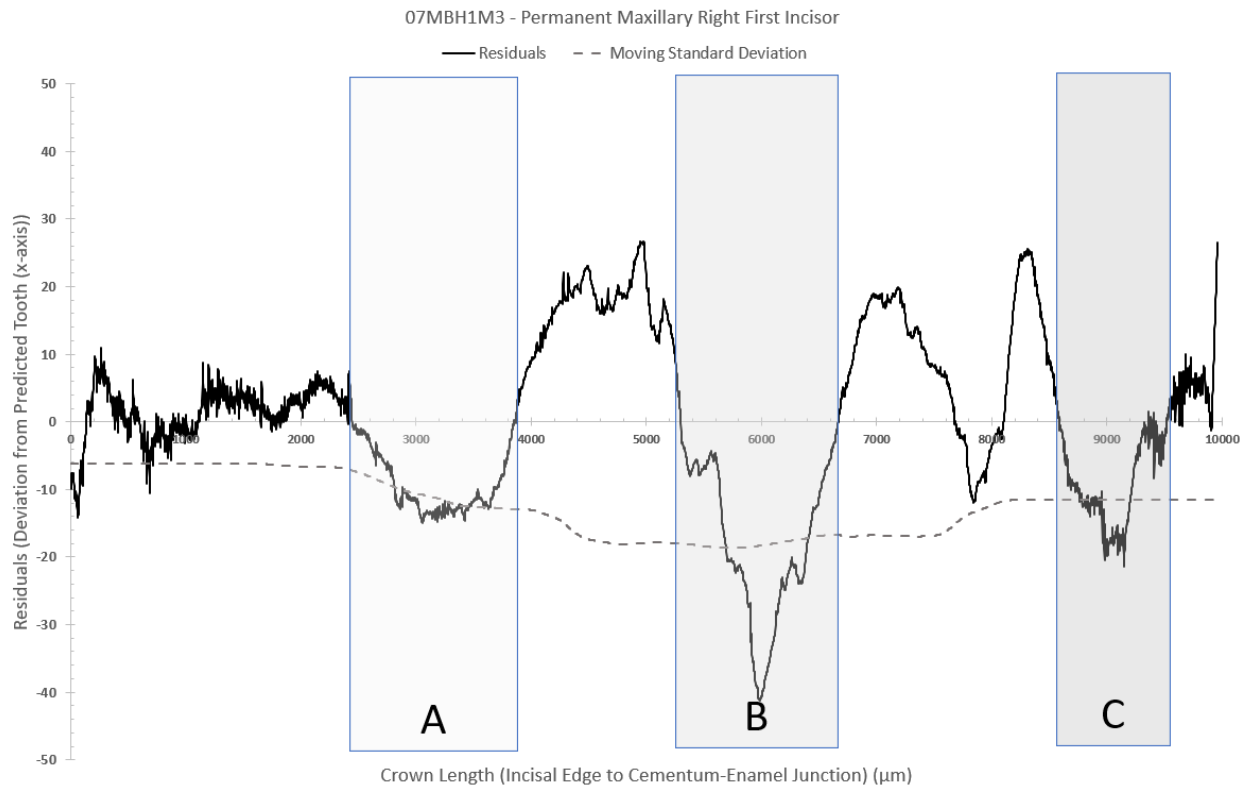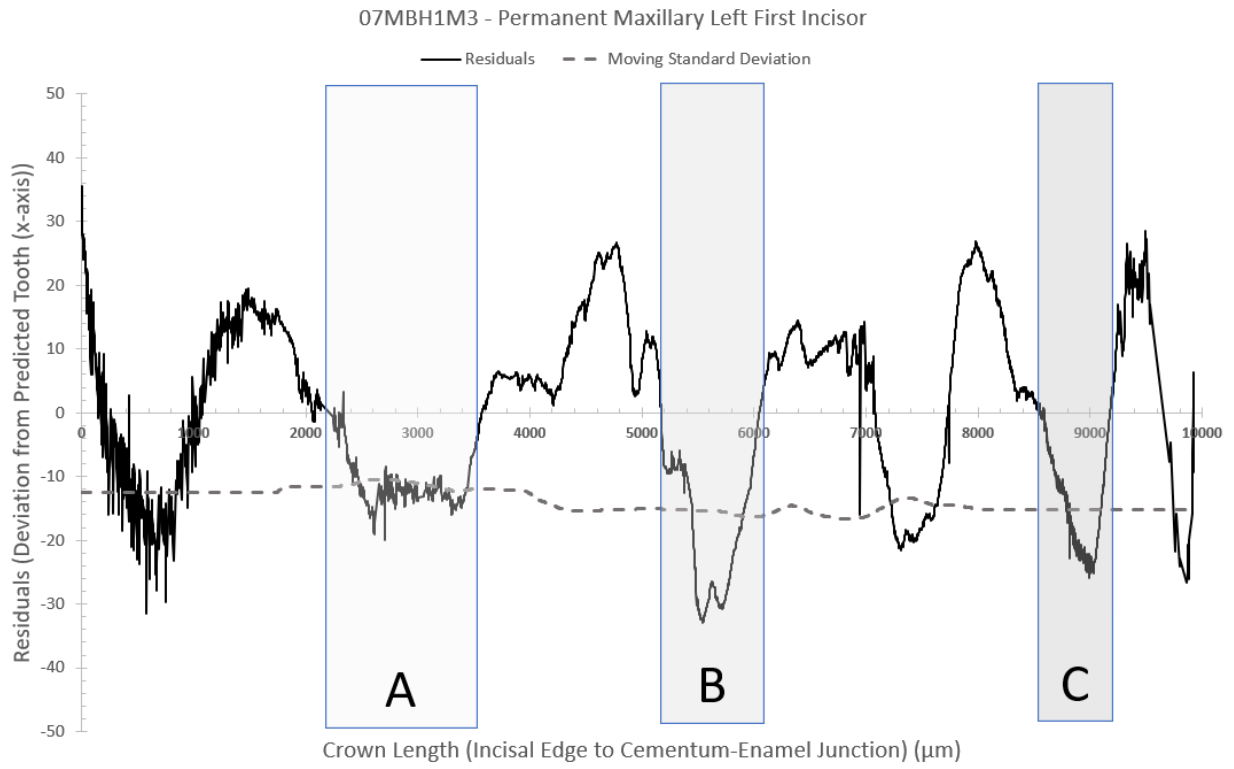| Increment	Mid-point age represented by increment (years)	δ^{15}N (‰ AIR)	δ^{13}C (‰ VPDB)	C:N	(%) N	(%) C
1	0.7	14.1	-18.7	3.3	15.0	42.1
2	1.4	12.7	-18.8	3.2	14.3	39.7
3	2.2	11.7	-19.2	3.2	12.9	36.0
4	2.9	12.0	-19.1	3.3	14.6	40.7
5	3.7	12.0	-19.2	3.3	14.5	40.6
6	4.4	12.2	-19.2	3.2	14.4	40.0
7	5.2	12.2	-19.0	3.3	14.2	40.0
8	5.9	12.3	-19.0	3.3	13.7	38.5
9	6.7	11.7	-19.0	3.3	13.5	38.1
10	7.4	11.6	-19.7	3.3	13.3	37.9
11	8.2	11.8	-20.1	3.4	11.9	35.0
12	8.9	11.9	-20.0	3.5	12.3	36.6
13	9.6	13.4	-18.6	3.3	14.9	41.5

Figure 1. Incremental isotopic profile for the permanent mandibular left first molar of individual 07MBH1M3.

The micropolynomial residual charts for 07MBH1M3 are provided in Figure 2 A–C. Three systemic defects are present across the three teeth, with stress and recovery occurring between the ages of ~1.6–2.0 years, ~2.5–3.1 years, and ~ 4.1–4.7 years. Note that the third defect, defect C, ~4.1–4.7, is not seen on the mandibular molar, as the crown had completed formation by this time.
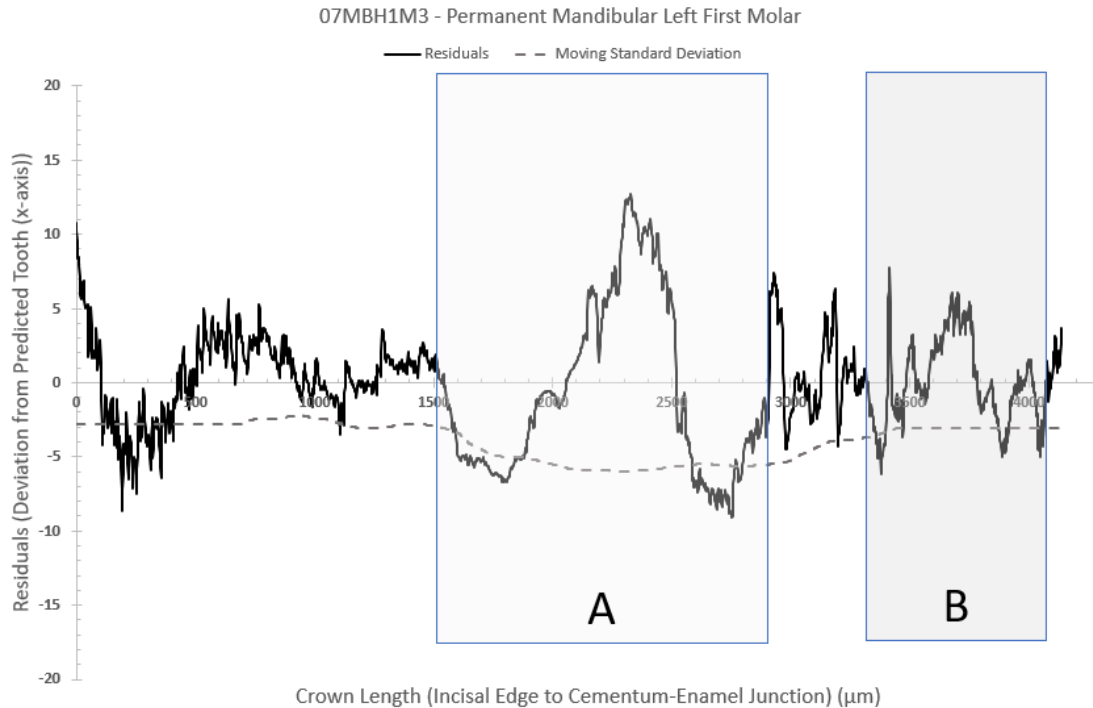
(2A)

07MBH1M3 - Permanent Maxillary Right First Incisor

—— Residuals   – – Moving Standard Deviation

Y-axis: Residuals (Deviation from Predicted Tooth (x-axis))

X-axis: Crown Length (Incisal Edge to Cementum-Enamel Junction) (μm)

(2B)

07MBH1M3 - Permanent Maxillary Left First Incisor

Crown Length (Incisal Edge to Cementum-Enamel Junction) (µm)

(2C)

Figure 2 A-C: Micropolynomial residuals for the permanent maxillary right first incisor (2A) of individual 07MBH1M3; the permanent maxillary left first incisor (2B); and permanent mandibular left first molar (2C), with matching systemic defects highlighted. Defect A = 1.6–2.0 years; Defect B = 2.5–3.1 years; Defect C = 4.1-4.7 years. Note that the method used to age the permanent first incisors (Cares Henriquez and Oxenham 2019) is functional only for anterior teeth. LEH on the mandibular molar had age estimated by the method of Reid and Dean (2000, 2006) (on which Cares Henriquez and Oxenham (2019) is based), and then matched with defect ages from the incisors. Ages presented are from Cares Henriquez and Oxenham (2019) only.

Linear enamel hypoplasias

Comparison of the timing of systemic LEH with the isotopic profile of 07MBH1M3 is presented in Figure 3, although we caution that there are potential problems with the comparison of Beaumont and Montgomery (2015) and Reid and Dean (2000,2006) rooted in differential aging theories (as per Adams *et al.* 2020). The first LEH, Defect A, occurred between ~1.6 and 2.0 years of age, between the isotopic increments aged 1.4 and 2.2 years of age. During this time, there is decrease in $\delta^{15}N$ values, associated with the $\delta^{15}N$ decrease within the weaning process, thus allowing us to place Defect A as occurring during the weaning process. The second LEH, Defect B, aged ~2.5–3.1 years of age, was associated with a slight increase in both $\delta^{15}N$ (0.3‰) and $\delta^{13}C$ (0.1‰), although these changes in isotopic values would not be categorised as stress in isotopic studies. Lastly, the third LEH, Defect C, occurs at ~4.1–4.7 years of age, associated with

an increment with an average age of 4.4 years. While there is no change of $\delta^{13}C$, $\delta^{15}N$ increased by 0.2‰. Although these LEH events do correspond with small changes to isotopic values, those changes are within analytical error and are thus unlikely to be associated with the stress-events that may have been responsible for LEH formation.
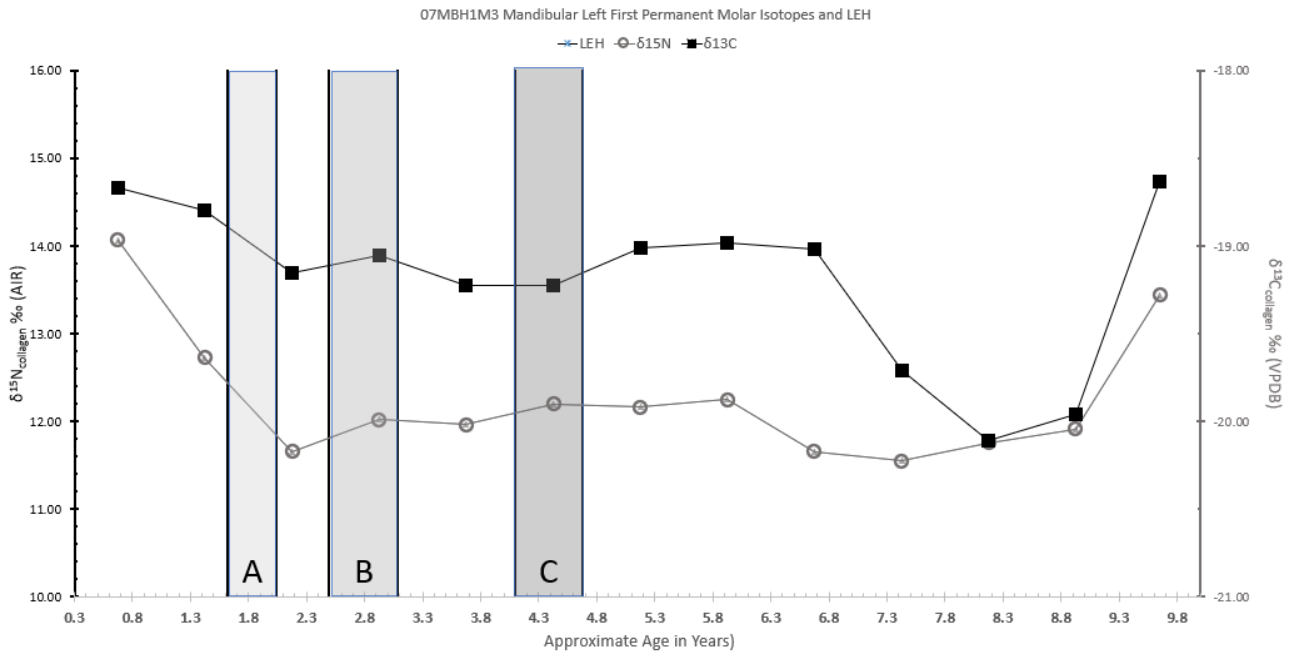

Figure 3. Incremental dentine isotopes and linear enamel hypoplasias by age for individual 07MBH1M3.

Palaeopathology

The 12–18-year-old individual 07MBH1M3 presented with bilateral severe, active cribra orbitalia, indicating anaemia around the time of death. Additionally, we noted lesions consistent with a diagnosis of probable scurvy (after Snoddy *et al*. 2018). These comprised bilateral and symmetrical discrete deposits of mixed active and remodelled subperiosteal new bone associated with abnormal cortical porosity on the external greater wing of the sphenoid bones, posterior maxillae and zygomatic bones, palatal surfaces of the maxillae, around the mylohyoid lines, and on the medial coronoid processes of the mandible. Symmetrical subperiosteal deposits of new bone on the proximal femora may be the result of a number of conditions but is also consistent with a diagnosis of scurvy. Evidence of mixed remodelling of the lesions suggest either that the

individual was recovering from a period of nutritional deficiency at time of death or was affected by repeated cycles of deficiency and recovery prior to death. Deep endochondral porosity exceeding 10mm from the metaphyseal plates of all the long bones—indicative of disruptions to osteoid production—is also consistent with Vitamin C deficiency during growth (Snoddy *et al*. 2017). No radiographic signs diagnostic for scurvy (e.g. pelkan spurs, Trummerfeld zones, and white lines of Fraenkel) were observed, although ground-glass osteopenia indicative of nutritional disease was present. Lesions consistent with a diagnosis of rickets were not present.

Case Study 2: individual 05MBM36 (aged ~3 years)

Incremental dentine stable isotopes

The incremental isotopic results for individual 05MBM36 are shown in Table 4 and Figure 4. Only three increments yielded good quality collagen. The $\delta^{15}N$ around birth is 15.2‰ but decreases by 2.4‰ in the first nine months of life. $\delta^{13}C$ values changed very little over the same period, decreasing by 0.4‰ in the first 5 months, before increasing by 0.6‰ by 9 months. The relatively high starting point and continual decrease of $\delta^{15}N$ suggest that this is not a typical weaning trajectory, see discussion below (Jay 2009; Craig-Atkins *et al*. 2018; King *et al*. 2018; Kendall *et al*. 2020). It is difficult to interpret this pattern without further isotopic data points, baseline data from the site, or other bioarchaeological and contextual information.

Table 3. Carbon and nitrogen stable isotope ratio data and quality control parameters for increments from the deciduous maxillary left canine of individual 05MBM36. Note that increment 4 has a C:N outside of the accepted range.

Increment	Mid-point age represented by increment (years)	$\delta^{15}N$ (‰ AIR)	$\delta 13C$ (‰ VPDB)	C:N	(%) N	(%) C
1	0	15.2	-18.7	3.4	14.1	41.1
2	0.4	13.7	-19.1	3.4	14.3	41.3
3	0.8	12.8	-18.5	3.4	13.3	39.4
4	1.2	11.3	-19.1	3.7	9.8	31.1

05MBM36 Deciduous Maxillary Left Canine
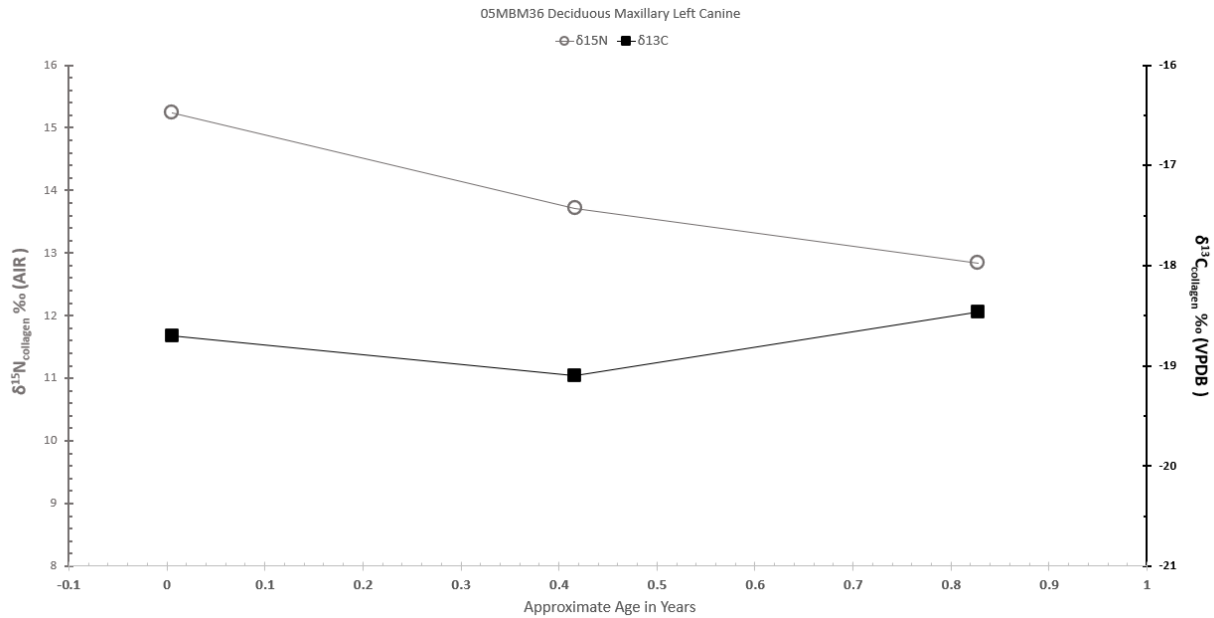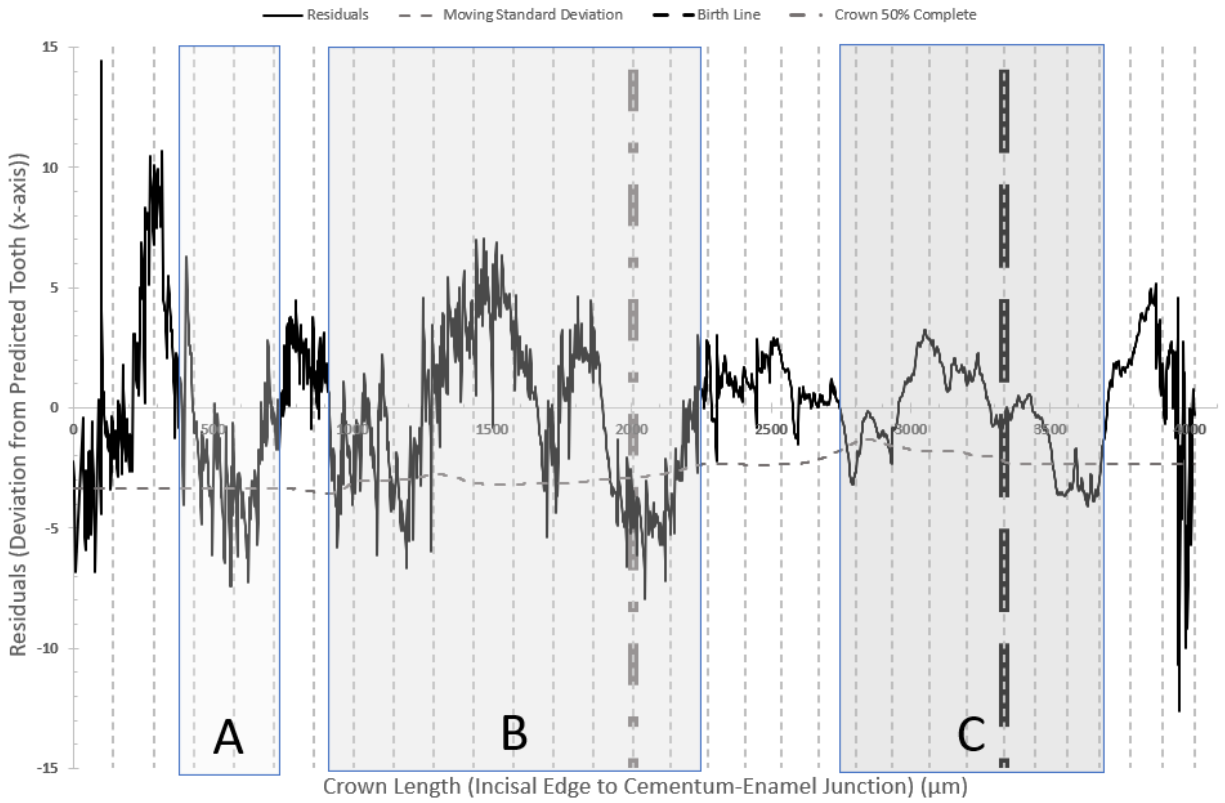
−○− δ15N −■− δ13C

Figure 4. Incremental isotopic profile of the deciduous maxillary left canine of individual 05MBM36.
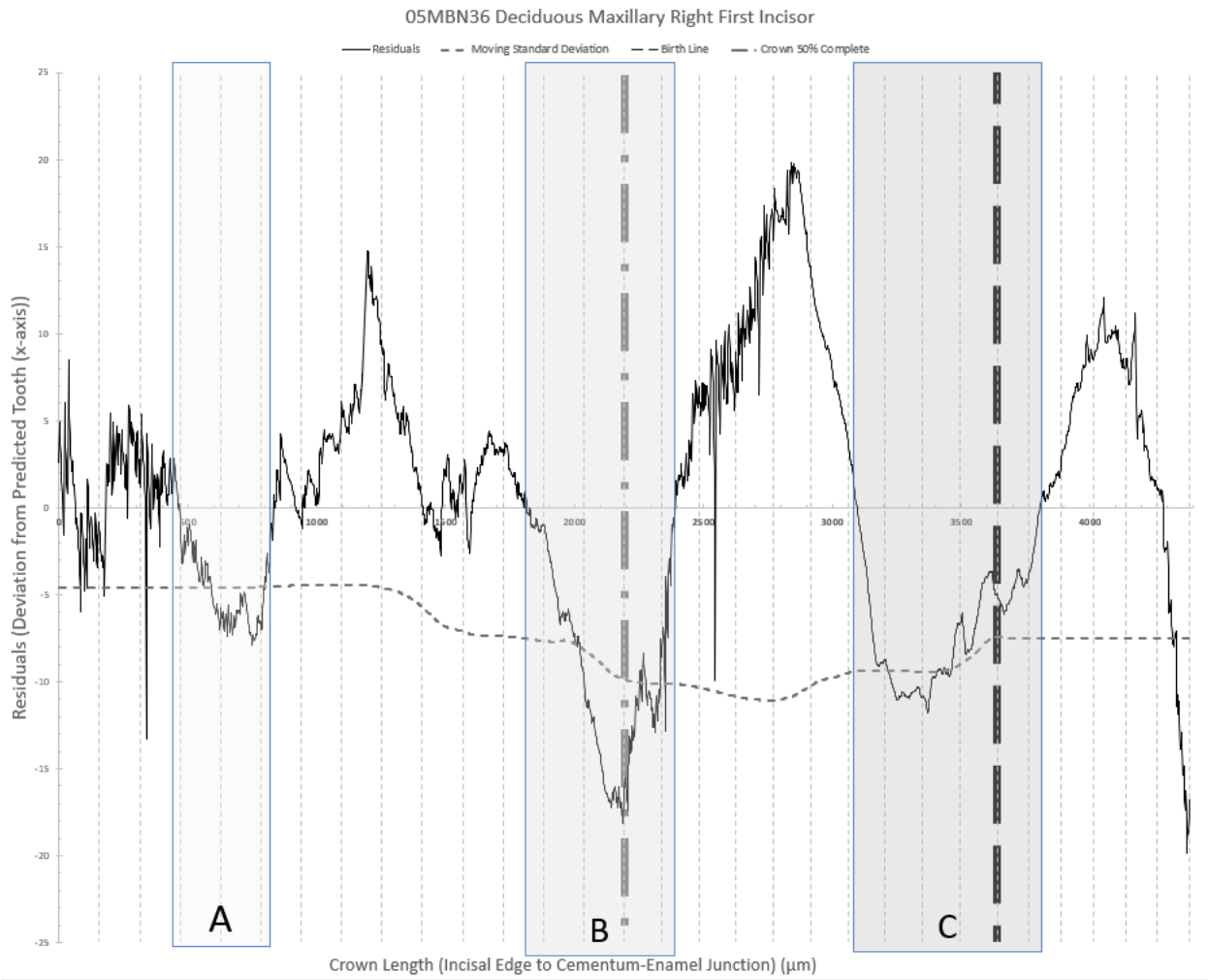
Linear enamel hypoplasia

The micropolynomial residual charts for individual 05MBM36 are provided in Figure 5 A–D. There are five systemic defects apparent across the four teeth, with stress and recovery occurring between the ages ~18 and 21.5 weeks gestation (Defect A), ~22 and 32 weeks gestation (Defect B), ~33 weeks gestation and 14 weeks post birth (Defect C), ~20–24 weeks after birth (Defect D), and ~24.5–74 weeks after birth (Defect E). Note that the Defect A (~18 and 21.5 weeks gestation) is only present on the maxillary incisors, and the Defects D and E orange and purple defects (~20–24 weeks after birth and ~24.5–74 weeks after birth) are only present on the maxillary canines. The presence of Defect A only on the maxillary incisors can be explained, as the maxillary canines had not yet initiated formation. Defects D and E appearing only on the canines is similarly explained by the crowns of the incisors having completed their growth.
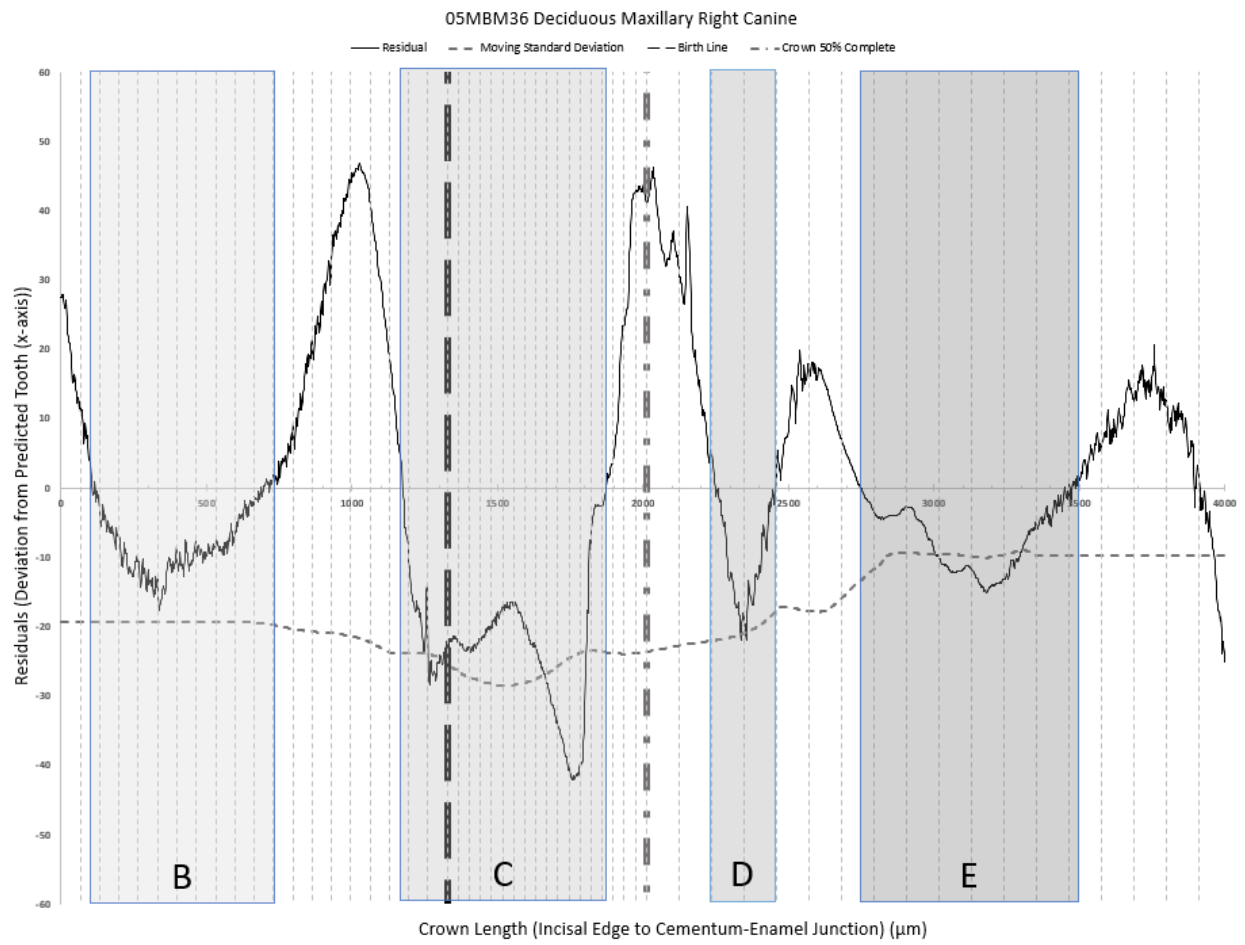
(5A)

05MBM36 - Deciduous Maxillary Left First Incisor

(5B)

05MBN36 Deciduous Maxillary Right First Incisor

(5C)

05MBM36 Deciduous Maxillary Right Canine

Residual — — Moving Standard Deviation —— Birth Line — · · Crown 50% Complete

(5D)

05MBM36 Deciduous Maxillary Left Canine

Residual — — Moving Standard Deviation — Birth Line — · — Crown 50% Complete

Residuals (Deviation from Predicted Tooth (x-axis))

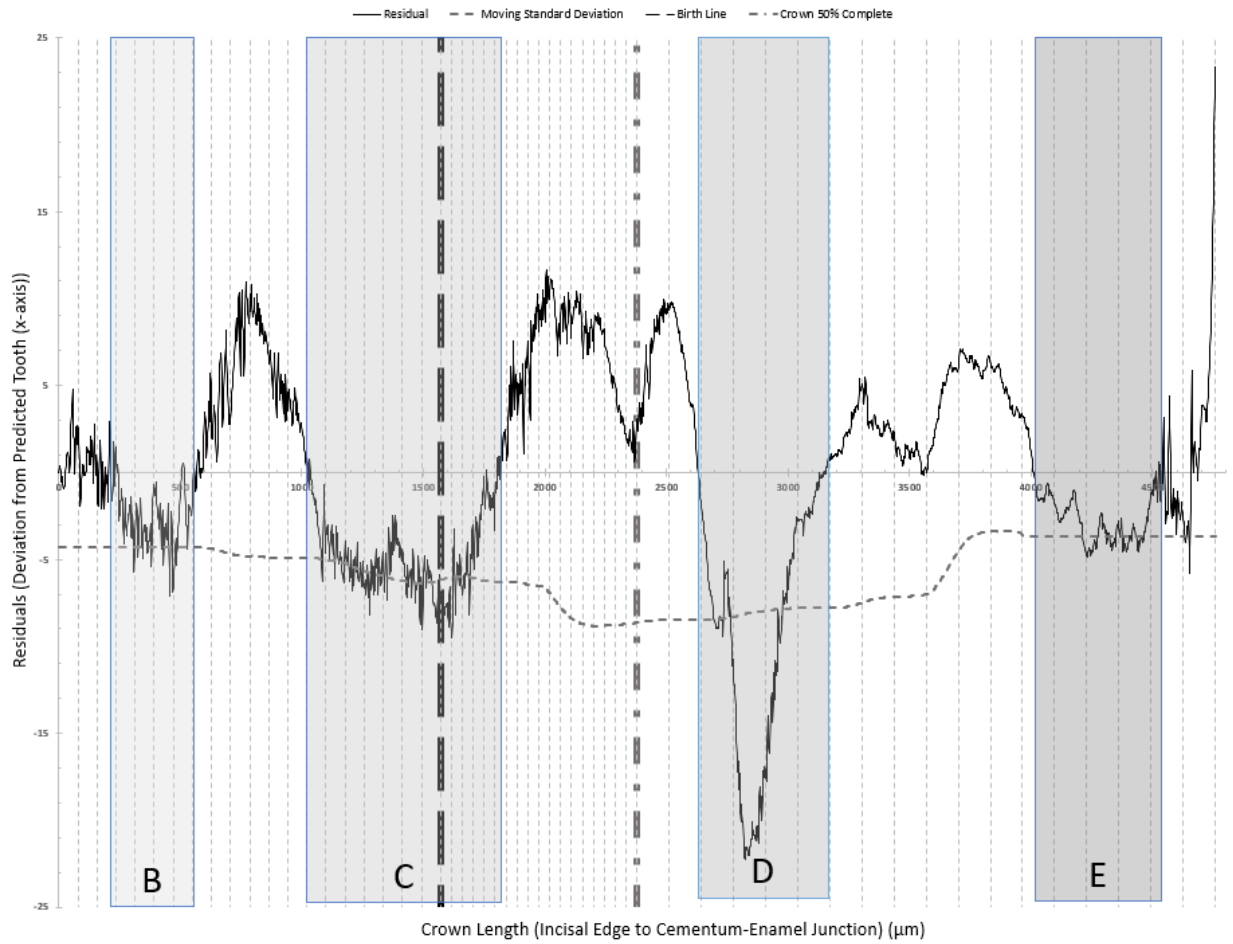Crown Length (Incisal Edge to Cementum-Enamel Junction) (µm)

Figure 5 A–D: Micropolynomial residuals for the deciduous maxillary left first incisor (5A) of individual 05MBM36; the deciduous maxillary right first incisor (5B); the deciduous maxillary right canine (5C); and the deciduous maxillary left canine (5D), with weekly aging lines included, and matching systemic defects highlighted. Defect A = ~18–21.5 weeks gestation; Defect B = ~22–32 weeks gestation; Defect C = ~33 weeks gestations to 14 weeks after birth; Defect D = ~20–24 weeks after birth; and Defect E = ~24.5–34 weeks after birth.

The comparison of the timing of systemic LEH with the isotopic profile of individual 05MBM36 (Figure 6) shows that the *in-utero* environment was a stressful one, with three of the five defects, Defects A, B, and C,occurring before birth at ~18 and 21.5 weeks gestation, ~22 and 32 weeks gestation, and ~33 weeks gestation, respectively. While we lack *in-utero* isotopic values, the first increment (while averaged to "0") represents the period just before and after birth. This increment has high $\delta^{15}N$ and $\delta^{13}C$ values, and overlaps temporally with Defect C, which continues until 14 weeks post-partum. The decrease in $\delta^{15}N$ values after birth may indicate that the postnatal environment was less stressful than the *in-utero* environment, as suggested by other isotopic studies (e.g. Fuller *et al*. 2005; Jay 2009; Beaumont *et al*. 2015; Craig-Atkins *et al*. 2018; King *et al*. 2018; Kendall *et al*. 2020). The fourth and fifth LEH, Defects D and E, occur in succession between approximately 5 and 8 months of postnatal age. These LEH occurred between two isotopic increments, with midpoints of 0.4 and 0.8 years of age. During this time, there was a 0.9‰ decrease in $\delta^{15}N$, while $\delta^{13}C$ increased by 0.6‰.
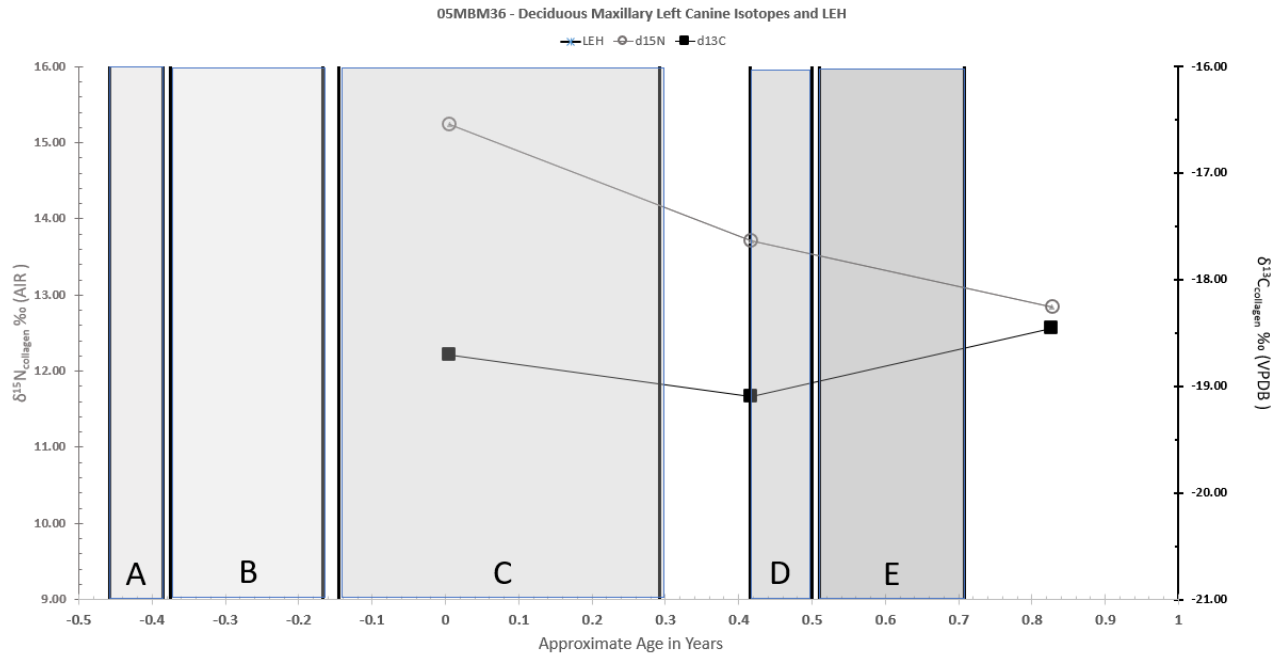
Figure 6. Incremental dentine isotopes and evidence for linear enamel hypoplasia by age for individual 05MBM36.

Palaeopathology

The ~3-year-old child, 05MB36, exhibited no evidence for anaemia. However, lesions consistent with a diagnosis of probable scurvy (after Snoddy *et al*. 2018) were observed. These comprised bilateral and symmetrical discrete deposits of active subperiosteal new bone and abnormal cortical porosity on the squama of the temporal bones, on the palatal surfaces of the maxillae, the anterior maxillae around the regions of the infraorbital foramina, on the superior orbital roofs, and on the anterior posterior zygomatic bones. Active, bilateral subperiosteal deposits of new bone on the tibiae are also consistent with a diagnosis of scurvy, and may represent subperiosteal haematoma formation in the lower limbs. The active nature of these subperiosteal lesions indicates that the individual was probably suffering from scurvy around the time of death (see Crandall & Haagen (2014: 3) for a discussion on the spectrum of vitamin deficient states and skeletal involvement). While the individual had no diagnostic radiographic signs of scurvy, thin cortices and ground-glass osteopenia consistent with nutritional disease was observed. No lesions consistent with a diagnosis of rickets were observed.

Discussion

To reconstruct the early life of these individuals through the experiences of diet, stress, and disease, we use a model that incorporates data within a bioarchaeology of infant and child-care theoretical model.

Early life histories from the LEH and isotopic evidence
For 12–18-year-old individual 07MBH1M3, weaning appears to have been completed around two years of age, following the introduction of solid foods potentially prior to 8 months of age, with slightly more positive $\delta^{13}C$ resources than the maternal diet. Although there is no isotopic evidence for childhood stress in this individual's tooth dentine, physiological stress during the weaning period and early childhood is expressed in the LEH timing. One defect is associated with a decrease in $\delta^{15}N$ linked to the gradual reduction of breastmilk in the diet. Two LEH defects occur after weaning is complete but are not associated with significant changes to isotopic values. This supports the view that not all occurrences of LEH are associated with the weaning period (Wood 1996) and highlights the importance of considering multiple aetiologies in their formation (Hillson 2014).

This individual's LEH and isotope data demonstrate the challenges in interpreting physiological stress from isotopic values. The $\delta^{15}N$ 'spikes' previously used to interpret stress have been associated with catabolism (Beaumont *et al.* 2015; King *et al.* 2018; Crowder *et al.* 2019) and are absent in this profile. The presence of LEH, however, suggests that potential stress events *did* occur during the weaning process. While $\delta^{15}N$ can inform us of macronutrient (protein) intake and metabolism, we are unable to see potential micro-nutrient deficiencies during this time which may be affecting immune functions. Stress during the weaning process is often attributed to risks, such as inadequate nutrition and/or the introduction of infectious elements through supplementary foods (Katzenberg *et al.* 1996; Lewis 2006), any of which may have contributed to high infant morbidity and mortality at Man Bac, in addition to other risks infants are exposed to at this age. Previous publications from the site (Oxenham *et al.* 2008b; Domett & Oxenham 2011; Oxenham & Willis 2017) suggest that a mortality spike at 1.5 years old (representing 10% of the mortuary sample) could be associated with the period of weaning, which would be early in comparison to other developing countries (Dettwyler 1995; Lewis & Roberts 1998; Sellen 2001). However, Domett & Oxenham (2011) also not that this spike may be an artefact of aging techniques clustering individuals, as weaning is usually a process, rather

than an abrupt cessation of breastfeeding (see Katzenberg *et al.* (1996) for a critique of interpretations of 'weaning stress').

Notably, the last LEH occurs at ~4.1–4.7 years of age and is only associated with a slight increase in δ^{15}N. Within their sub-adult mortality data, Domett and Oxenham (2011) showed an increase in mortality at 4 years of age, making total mortality of 1–4 year-olds (representing 27% of mortuary sample) higher than that of 0–1 year olds (representing 21% of mortuary sample). While this individual shows evidence of ongoing and prolonged cycles of nutrient deficiency and recovery before death (between 12 and 18 years of age), it is unclear how early life events may have played a part, if at all. However, the evidence of nutritional deficiencies for both individuals analysed here potentially signal a larger issue at Man Bac.

Three-year-old individual 05MBM36 has LEH evidence for stress *in-utero* and extending to approximately three months post-partum, with another episode between 5 and 8 months of age. This is accompanied by high δ^{15}N values at the start of their incremental isotopic profile, which continually decrease thereafter. Several isotopic studies have suggested that high *in-utero* values could be due to maternal stress (e.g. Fuller *et al.* 2005; Beaumont *et al.* 2015), while the formation of pre-natal LEH could be heavily influenced by maternal circadian rhythms and/or foetal health (Fuller & Saunders 2005; Birch & Dean 2014). A typical weaning pattern involves infant δ^{15}N values matching the mother's *in-utero* values, rising after birth and remaining high for some months during exclusive breastfeeding before they decrease during the weaning process (Jay 2009). However, that pattern is not observed here. If the mother was sufficiently stressed during pregnancy to affect the infant, this may explain the steep decline of δ^{15}N values after birth, when the maternal environment is no longer impacting the infant's δ^{15}N values (Beaumont *et al.* 2015; King *et al.* 2018; Kendall *et al.* 2020). However, this interpretation is not the sole explanation for stress during deciduous growth, as the presence of LEH for seven of the nine post-birth months for which we have data suggests further continuing factors affecting this individual physiologically.

Other processes can cause a decrease in δ^{15}N values immediately after birth, for example, maternal values (and therefore breastmilk values) may decrease due to a change of maternal diet to a lower trophic level after childbirth, or lowered stress levels post-parturition (Beaumont *et al.* 2015; King *et al.* 2018; Kendall *et al.* 2020). If maternal stress during pregnancy resulted in the death of the mother, another individual breastfeeding the infant may have markedly lower δ^{15}N

values and transfer these lower values via their breast milk. Kendall and co-authors (2020) suggested an individual they studied with unusual δ^{15}N and δ^{13}C patterning in ante- and postnatal dentine samples may have suffered from malnutrition in conjunction with breastfeeding from a mother consuming lower-trophic level foods (Kendall et al. 2020:117). While the individual Kendall et al. (2020) examined produced a longer dentine timeline from which to infer this pattern, the few early-life dentine samples of 05MBM36 from Man Bac follow the same trends, suggesting this may be one possible explanation for the isotopic data. Finally, others have argued that this pattern is most likely associated with a non-exclusive breastfeeding (e.g. Craig-Atkins *et al.* 2018). This final explanation is unlikely in our case, as there is no historical or published evidence for supplemental feeding with animal milk in Southeast Asia, and Man Bac lacks evidence for traditional domesticated milk producing animals (Jones *et al.* 2019; Oxenham *et al.* 2011). A complete absence of breastfeeding would almost certainly be fatal in the first few months of life (Knodel & Kintner 1977; Stewart *et al.* 2013), as the infant digestive system is underdeveloped for complementary feeding from birth, exposing the infant to significant digestive and potential malnutrition-related stress, as well as potential pathogens (Jay 2009; King *et al.* 2018). This type of isotopic profile, with its atypical values, and the paucity of datapoints, highlights the difficulties associated with interpretation due to isotopic equifinality (King *et al.* 2018). There are many variables from both mother and baby that could affect isotopic values. However, the merging of isotopic and LEH information allows for greater insight into this individual's early-life experience.

The third defect for individual 05MBM36 extends from ~10 weeks before birth to nearly three months post-partum. This could be interpreted as representing a continued stressful post-birth environment. The cervical wall of the LEH, however, always represents some period of recovery—an environment allowing normal enamel production. We are therefore uncertain as to what proportion of the later section of the LEH represents stress, and what proportion represents recovery (Hillson 2014; Guatelli-Steinberg 2015).

The two instances of LEH occurring between 5 and 8 months coincide with a decrease in δ^{15}N and an increase in δ^{13}C (<1‰). It is noted, however, that an infant's nutritional demands tend to increase at this age, accompanied by rapid growth in the first year post-partum, necessitating the introduction of complementary foods to breastfeeding in typical feeding strategies (McDade & Worthman 1998; Jay 2009). There is also a peak in mortality around this

age (representing 7% of the cemetery sample) at Man Bac, suggesting this period of life was particularly stressful at the site (Domett & Oxenham 2011). Stress at this time may be expected due to an increased risk of infectious elements introduced through supplementary foods in addition to other introductory pathways, or poor nutrition. *In-utero* conditions and early life stress may have continued to affect this individual's ability to adapt (Gowland 2015), potentially influencing the development of LEH at this time. However, due to external care and/or resiliency, this individual survived for another 2.5 years. This early life stress and potentially irregular infant feeding pattern may have left this individual more susceptible to other ailments. The pathological evidence for probable scurvy, for example, may have resulted from poor nutrition and/or lack of ability to absorb nutrients due to other infections such as intestinal parasites, which were probably highly prevalent in tropical and sub-tropical Vietnam (Buckley *et al.* 2014; Halcrow *et al*. 2014; Oxenham 2000; Oxenham & Willis 2017). Maternal transfer of vitamin C deficiency is also a possibility (Snoddy *et al*. 2018), although all of this individual's lesions were active, indicating that they were suffering from scurvy near time of death at three years of age. Factors relating to insufficient levels of vitamin C, such as malabsorption, genetics, or socioeconomically, culturally, or environmentally aggravated factors, would probably result in low dietary diversity and deficiencies in other micronutrients (Pimentel 2003; Popovich *et al*. 2009; Halcrow *et al*. 2014). Lack of vitamin C can also affect the immune system and absorption of iron, causing further stress and pathological conditions, such as anaemia (Langlois *et al*. 1997; Nguyen *et al*. 2006; Halcrow *et al*. 2014; Snoddy *et al*. 2018).

The evidence for potential *in-utero* stress from individual 05MBM36 suggests that both maternal and infant health were compromised. As previously noted, pregnant women face greater physiological demands and are more susceptible to nutritional deficiencies, infection, and the exacerbation of pre-existing disease. There are multiple lines of evidence that the Man Bac population experienced high levels of physiological stress (Oxenham & Domett 2011; Oxenham & Willis 2017). The rates of localised hypoplasia of the primary canine of subadults (41.7%, 10/24 subadults) may provide further evidence of maternal stress (McDonell & Oxenham 2014). Although a variety of causes have been proposed for the formation of localised hypoplasia of the primary canine, nutritional and dietary deficiencies—especially Vitamin A, D, and calcium—in the maternal diet during gestation may be implicated, affecting health outcomes for both mother and baby (Skinner & Hung 1989; Halcrow & Tayles 2008b; McDonnell & Oxenham 2014).

Contextualising the case studies

Both children in this study offer individual stories of the relationship between mother and infant, the feeding practices employed, and the stressors they may have experienced. Assessing these individuals within the wider bioarchaeological, palaeodemographical, and mortuary context allows us to understand how their stories may relate to care within their specific social, cultural and environmental setting.

Palaeodemographic analyses show a high ratio of <15 years individuals to adults at Man Bac, calculated as 1.48, the highest such dependency ratio recorded in Neolithic and Bronze Age Southeast Asia (Domett & Oxenham 2011). In many modern agricultural societies, children are cared for by other children (Zeller 1987). This may have been the case in the past, though some children may have been recurrently ill, as seen through the palaeopathological evidence in the two children presented, potentially affecting their ability to assist in childrearing. Our evidence for maternal and infant stress (in individual 05MBM36) adds to this picture, offering insights into the possible difficulties in caring for infants, the pressure on resources, and issues with maternal health. Oxenham and Willis (2017: 228) suggest that the sub-optimal level of childhood health at Man Bac "would have required an elevated level of care and nurturing beyond that normally provided to non-ill children of an equivalent age cohort in this community".

At Man Bac, there is evidence for extended community support through the long-term care of an individual with quadriplegia (Tilley & Oxenham 2011). It seems likely that such extended community systems would also have assisted in the rearing of children. In general, having community support or alloparenting networks decreases infant and maternal mortality significantly (Sear & Mace 2009). Although present-day evidence does not necessarily inform on past practises, within modern Southeast Asia, including Vietnam, community and extended families share roles in caregiving, socialisation and co-parenting of children. This is central to social organisation, with better access to health care and support systems for mothers affecting improved health outcomes for mother and baby (McHale *et al.* 2014; Mestechkina *et al.* 2014). Social organisation also may have also impacted the health of mothers and infants, and care afforded at Man Bac, specifically along the lines of age and gender. Pregnant and post-partum mothers in modern society often practice culturally mediated food taboos and avoidances, which by extension, adversely affect their offspring for a number of years. This may have been the case

in the past as well (Oxenham 2000; Oxenham & Willis 2017). Previous preliminary isotopic work at Man Bac suggested that males and females had slightly different diets, with females have more negative $\delta^{13}C$ values and lower $\delta^{15}N$ values (Oxenham & Domett 2011; Yoneda 2008), perhaps further placing mothers at risk. Additionally, macroscopic examinations of linear enamel hypoplasia formed during childhood found females were more likely to have more instances than males, indicating their early childhoods may have been more stressful (Oxenham & Domett 2011).

A correlation between an increasing quantity and quality of grave goods associated with increasing age-at-death at Man Bac suggests that age-based hierarchy may have been a central aspect of social organisation (Oxenham *et al*. 2008a). While the hierarchy is based on the presence of mortuary offerings, if this translated to access to resources, it may have affected health outcomes (Oxenham & Domett 2011; Vlok, forthcoming PhD). Core childbearing years have been quoted as 20-24 years of age within modern society (McFadden & Oxenham 2019), and though it is difficult to discern, this may have been younger prehistorically (Papadimitriou 2016; Pfeiffer et al. 2014). Not only would mothers be at greater risk due to risks of childbearing generally, young mothers may not have had social standing to acquire needed resources for healthy pregnancy and caring for young children.

For infants, their age may have disadvantaged them independently from their caregiver's standing. Approximately 40% of the mortuary sample of Man Bac is 2 years old or younger (Domett & Oxenham 2011). With weaning taking place between 1.5–2.2 years old (Adams *et al*. 2019b), perhaps it was only after this period that a change in the relationship between parent and child took place, and/or a new biosocial stage as an individual was achieved within both the family the community (Oxenham & Willis 2017; Miller *et al.* 2020). A potential difference in social age is suggested in differential mortuary investment with age, as children younger than 2 years frequently lack grave offerings (Oxenham *et al*. 2008a), although differential burial treatments may, of course, reflect the choices of the surviving caregivers (Oxenham *et al*. 2008b). In this relatively egalitarian community "it is clear that children of all ages were deemed worthy of mortuary ritual and thus arguably recognised as individuals, people, or at least members of the community" (Oxenham *et al*. 2008b: 203). Both individuals in our case study were interred with mortuary offerings that probably reflect the care which they were afforded in the mortuary record and the context of grief for these lost children. 05MBM36 was found with

shells, beads, and pottery fragments. The older 07MBH1M3, was buried with both shell and pot fragments (Huffer & Hiep 2011).

Conclusion

Here, we have presented a mixed-methods analysis of two individuals from the Neolithic site of Man Bac in northern Vietnam. In an attempt to better understand the maternal-infant nexus in this community, we analysed the dentition both chemically and through the use of cutting-edge LEH identification techniques. We show that while one of our individuals seems to have experienced a 'typical' weaning process, the other had a much more difficult time. We used LEH evidence to suggest that stress episodes were experienced by both individuals, with 05MBM36 probably experiencing significant *in utero* stress. This evidence emphasises the levels of stress and care experienced by both infants and their mothers at the Man Bac site. Their stories support broader-scale evidence of population stress and maternal demands associated with growing fertility in the Neolithic population. The evidence that many children were experiencing early-life stress also suggests that systems of community care may have been in place, aligning with evidence for care for the disabled in the same population. Overall, these case studies show that the examination of diet and stress during the pre- and perinatal period can help in untangling the maternal-infant nexus, and to better understand health ramifications for individuals and the community.

References

ADAMS, A. B., S.E. HALCROW, C.L. KING, M.J. MILLER, A. MILLARD, D. GRÖCKE, K.M. DOMETT, H. TRINH, T,M.H. NGUYGEN, T. MINH & M.F. OXENHAM. 2019B. Infant Feeding Practices in Neolithic Northern Viet Nam: Early Childhood Diet and Stress in the Transition to Agriculture. *33rd Annual Meeting of the Australasian Society for Human Biology Australian National University, Canberra, Australia.*

ADAMS, A. B., S.E. HALCROW, A.R. MILLARD, H. TRINH & M. OXENHAM. 2020. The Crossover Conundrum: Exploring the Relationship between Linear Enamel Hypoplasia and Incremental Dentine Isotopes in Prehistoric Vietnam. *85th Annual Meeting of the Society of American Archaeology, Austin, Texas, USA.*

ADAMS, A. B., S.E. HALCROW & M.F. OXENHAM. 2019A. The Deciduous Dilemma – New Perspectives from Neolithic Northern Vietnam for Studying Health and Stress in Infants. *American Journal of Physical Anthropology* 168 (S68):1.

ALQAHTANI, S.J., M.P. HECTOR & H.M. LIVERSIDGE. 2010. Brief communication: the London atlas of human tooth development and eruption. *American Journal of Physical Anthropology* 142: 481–90. https://doi.org/10.1002/ajpa.21258

– 2014. Accuracy of dental age estimation charts: Schour and Massler, Ubelaker and the London atlas. *American Journal of Physical Anthropology* 154: 70–78. https://doi.org/10.1002/ajpa.22473

BEAUMONT, J. & J. MONTGOMERY. 2015. Oral histories: a simple method of assigning chronological age to isotopic values from human dentine collagen. *Annals of Human Biology* 42: 407–14. https://doi.org/10.3109/03014460.2015.1045027

BEAUMONT, J., A. GLEDHILL, J. LEE-THORP & J. MONTGOMERY. 2013. Childhood diet: a closer examination of the evidence from dental tissues using stable isotope analysis of incremental human dentine. *Archaeometry* 55: 277–95. https://doi.org/10.1111/j.1475-4754.2012.00682.x

BEAUMONT, J., J. MONTGOMERY, J. BUCKBERRY & M. JAY. 2015. Infant mortality and isotopic complexity: new approaches to stress, maternal health, and weaning. *American Journal of Physical Anthropology* 157: 441–57. https://doi.org/10.1002/ajpa.22736

BIRCH, W. & M.C. DEAN. 2014. A method of calculating human deciduous crown formation times and of estimating the chronological ages of stressful events occurring during deciduous enamel formation. *Journal of Forensic and Legal Medicine* 22: 127–44. https://doi.org/10.1016/j.jflm.2013.12.002

BRICKLEY, M. & R. IVES. 2008. *The bioarchaeology of metabolic bone disease*. Amsterdam & Boston: Elsevier.

BUCKLEY, H.R., R. KINASTON, S.E. HALCROW, A. FOSTER, M. SPRIGGS & S. BEDFORD. 2014. Scurvy in a tropical paradise? Evaluating the possibility of infant and adult vitamin C deficiency in the Lapita skeletal sample of Teouma, Vanuatu, Pacific Islands. *International Journal of Paleopathology* 5: 72–85. https://doi.org/10.1016/j.ijpp.2014.03.001

BUCKLEY, H.R., M. VLOK, K. DOMETT, H.H. TRINH & M.F. OXENHAM. 2019. The antiquity of treponemal disease in the Asia-Pacific regions: implications for settlement history. *American Journal of Physical Anthropology* 168: 31.

CARES HENRIQUEZ, A. & M. OXENHAM. 2017. An alternative objective microscopic method for the identification of linear enamel hypoplasia (LEH) in the absence of visible perikymata. *Journal of Archaeological Science: Reports* 14: 76–84. https://doi.org/10.1016/j.jasrep.2017.05.040

– 2019. New distance-based exponential regression method and equations for estimating the chronology of linear enamel hypoplasia (LEH) defects on the anterior dentition. *American Journal of Physical Anthropology* 168 :510–20. https://doi.org/10.1002/ajpa.23764

CHAVEZ, A., A.H. GOODMAN & C. MARTINEZ. 1991. Nutritional supplementation and the development of linear enamel hypoplasias in children from Tezonteopan, Mexico. *The American Journal of Clinical Nutrition* 53: 773–81. https://doi.org/10.1093/ajcn/53.3.773

CRAIG, H. 1953. The geochemistry of the stable carbon isotopes. *Geochimica et Cosmochimica Acta* 3: 53–92. https://doi.org/10.1016/0016-7037(53)90001-5

CRAIG-ATKINS, E., J. TOWERS & J. BEAUMONT. 2018. "The role of infant life histories in the construction of identities in death: an incremental isotope study of dietary and physiological status among children afforded differential burial. *American Journal of Physical Anthropology* 167: 644–55. https://doi.org/10.1002/ajpa.23691

CRANDALL, J.J. & H.D. KLAUS. 2014. Advancements, challenges, and prospects in the paleopathology of scurvy: current perspectives on vitamin C deficiency in human skeletal remains. *International Journal of Paleopathology* 5: 1–8. https://doi.org/10.1016/j.ijpp.2014.04.005

CROWDER, K.D., J. MONTGOMERY, D.R. GRÖCKE & K.L. FILIPEK. 2019. Childhood "stress" and stable isotope life histories in Transylvania. *International Journal of Osteoarchaeology* 29: 644–53. https://doi.org/10.1002/oa.2760

DENIRO, M.J. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317: 806–809. https://doi.org/10.1038/317806a0

DENIRO, M.J. & S. EPSTEIN. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* 45: 341–51. https://doi.org/10.1016/0016-7037(81)90244-1

DETTWYLER, K.A. 1995. A time to wean: the hominid blueprint for the natural age of weaning in modern human populations, in P. Stuart-Macadam (ed.) *Breastfeeding: Biocultural Perspectives: 39-74.* New York: Routledge.

DOMETT, K. & M. OXENHAM. 2011. The demographic profile of the Man Bac cemetery sample, in M. Oxenham, H. Matsumura & N.K. Dung (ed.) *Man Bac: the excavation of a Neolithic site in northern Vietnam*: 9–20. Canberra: ANU Press. https://doi.org/10.26530/OAPEN_459363

DONG, Y., C. MORGAN, Y. CHINENOV, L. ZHOU, W. FAN, X. MA & K. PECHENKINA. 2017. Shifting diets and the rise of male-biased inequality on the Central Plains of China during Eastern Zhou. *Proceedings of the National Academy of Sciences of the USA* 114: 932–37. https://doi.org/10.1073/pnas.1611742114

EERKENS, J.W., A.G. BERGET & E.J. BARTELINK. 2011. Estimating weaning and early childhood diet from serial micro- samples of dentin collagen. *Journal of Archaeological Science* 38: 3101–11. https://doi.org/10.1016/j.jas.2011.07.010

Fédération Dentaire Internationale. 1992. A review of the developmental defects of enamel index (DDE Index). *International Dentistry Journal* 42: 411–26.

FITZGERALD, C. & S.R. SAUNDERS. 2005. Test of histological methods of determining chronology of accentuated striae in deciduous teeth. *American Journal of Physical Anthropology* 127: 277–90. https://doi.org/10.1002/ajpa.10442

FITZGERALD, C. & S. HILLSON. 2009. Deciduous tooth growth in an ancient Greek infant cemetery. *Frontiers of Oral Biology* 13: 178–83. https://doi.org/10.1159/000242414

FOGEL, M.L., N. TUROSS & D.W. OWSLEY. 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. Annual Report of the Director; Geophysical Laboratory 1988-1989 (pp.111-117). Washington, D.C.: Carnegie Institution of Washington.

FULLER, B.T., J.L. FULLER, N.E. SAGE, D.A. HARRIS, T.C. O'CONNELL & R.E.M. HEDGES. 2005. Nitrogen balance and δ15n: why you're not what you eat during pregnancy. *Rapid Communications in Mass Spectrometry* 18: 2889–96. https://doi.org/10.1002/rcm.1708

FULLER, B.T., J.L. FULLER, D.A. HARRIS & R.E.M. HEDGES. 2006. Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. *American Journal of Physical Anthropology* 129: 279–93. https://doi.org/10.1002/ajpa.20249

FULLER, B.T., T.I. MOLLESON, D.A. HARRIS, L.T. GILMOUR & R.E.M. HEDGES. 2006. Isotopic evidence for breastfeeding and possible adult dietary differences from Late/Sub-Roman Britain. *American Journal of Physical Anthropology* 129: 45–54. https://doi.org/10.1002/ajpa.20244

GOODMAN, A.H. & J.C. ROSE. 1990. Assessment of systemic physiological perturbations from dental enamel hypoplasias and associated histological structures. *American Journal of Physical Anthropology* 33: 59–110. https://doi.org/10.1002/ajpa.1330330506

– 1991. Dental enamel hypoplasias as indicators of nutritional status, in M.A. Kelley & C.S. Larsen (ed.) *Advances in dental anthropology*: 279–93. New York: Wiley-Liss.

GOODMAN, A.H. & R. SONG. 1999. Sources of variation in estimated ages at formation of linear enamel hypoplasias, in R. Hoppa & C. FitzGerald (ed.) *Human growth in the past, studies from bones and teeth*: 210–40. Cambridge: Cambridge University Press.

GOODMAN, A.H., G.J. ARMELAGOS & J.C. ROSE. 1980. Enamel hypoplasias as indicators of stress in three prehistoric populations from Illinois. *Human Biology* 52: 515–28.

– 1984. The chronological distribution of enamel hypoplasias from prehistoric Dickson Mounds

GOWLAND, R.L. 2015. Entangled lives: implications of the developmental origins of health and disease hypothesis for bioarchaeology and the life course. *American Journal of Physical Anthropology* 158: 530–40. https://doi.org/10.1002/ajpa.22820

GOWLAND, R.L. & A.G. WESTERN. 2012. Morbidity in the marshes: using spatial epidemiology to investigate skeletal evidence for malaria in Anglo-Saxon England (AD 410–1050). *American Journal of Physical Anthropology* 147: 301–11. https://doi.org/10.1002/ajpa.21648

GOWLAND, R.L. & S. HALCROW (ed.). 2020. *The mother-infant nexus in anthropology: small beginnings, significant outcomes*. Cham: Springer. https://doi.org/10.1007/978-3-030-27393-4

GUATELLI-STEINBERG, D. 2003. Macroscopic and microscopic analyses of linear enamel hypoplasia in Plio-Pleistocene South African Hominins with respect to aspects of enamel development and morphology. *American Journal of Physical Anthropology* 120: 309–22. https://doi.org/10.1002/ajpa.10148

– 2015. Dental stress indicators from micro- to macroscopic, in J.D. Irish & G.R. Scott (ed.) *A companion to dental anthropology*: 450–64). Malden: Wiley Blackwell.

HALCROW, S.E. 2020. Infants in the bioarchaeological past: who cares? in R. Gowland & S. Halcrow (ed.) *The mother-infant nexus in anthropology: small beginnings, significant outcomes*: 19–38. Cham: Springer International. https://doi.org/10.1007/978-3-030-27393-4_2

HALCROW, S.E. & N. TAYLES. 2008a. Bioarchaeological investigations of childhood and social age: problems and prospects. *Journal of Archaeological Method and Theory* 15: 190–215. https://doi.org/10.1007/s10816-008-9052-x

– 2008b. Stress near the start of life? Localised enamel hypoplasia of the primary canine in late prehistoric Mainland Southeast Asia. *Journal of Archaeological Science* 35: 2215–22. https://doi.org/10.1016/j.jas.2008.02.002

HALCROW, S.E., N. TAYLES & V. LIVINGSTONE. 2008. Infant death in late prehistoric Southeast Asia. *Asian Perspectives* 47: 371–404. https://doi.org/10.1353/asi.0.0007

HALCROW, S.E., N.J. HARRIS, N. BEAVAN & H.R. BUCKLEY. 2014. First bioarchaeological evidence of probable scurvy in Southeast Asia: multifactorial etiologies of vitamin C deficiency in a tropical environment. *International Journal of Paleopathology* 5: 63–71. https://doi.org/10.1016/j.ijpp.2014.01.004

HALCROW, S.E., N. TAYLES & G.E. ELLIOTT. 2017. The bioarchaeology of fetuses, in S. Han, T.K. Betsinger & A.B. Scott (ed.) *The anthropology of the fetus: biology, culture, and society*: 83–111). New York: Berghahn. https://doi.org/10.2307/j.ctvw04h7z.10

HAN, S., T.K. BETSINGER & A.B. SCOTT. 2017. *The anthropology of the fetus: biology, culture, and society*. New York: Berghahn. https://doi.org/10.2307/j.ctvw04h7z

HENDERSON, R.C., J. LEE-THORP & L. LOE. 2014. Early life histories of the London poor using δ13c and δ15n stable isotope incremental dentine sampling. *American Journal of Physical Anthropology* 154: 585–93. https://doi.org/10.1002/ajpa.22554

HILLSON, S. 1996. *Dental anthropology*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139170697

– 2014. *Tooth development in human evolution and bioarchaeology*. New York: Cambridge University Press. https://doi.org/10.1017/CBO9780511894916

HILLSON, S. & S. BOND. 1997. Relationship of enamel hypoplasia to the pattern of tooth crown growth: a discussion. *American Journal of Physical Anthropology* 104: 89–103. https://doi.org/10.1002/(SICI)1096-8644(199709)104:1<89::AID-AJPA6>3.0.CO;2-8

HUFFER, D. & T. HIEP. 2011. Appendix 1: Man Bac burial descriptions, in M. Oxenham, H. Matsumura & N.K. Dung (ed.) *Man Bac: the excavation of a Neolithic site in northern Vietnam*: 135–68. Canberra: ANU Press. https://doi.org/10.22459/TA33.05.2011.12

JAY, M. 2009. Breastfeeding and weaning behaviour in archaeological populations: evidence from the isotopic analysis of skeletal materials. *Childhood in the Past* 2: 163–78. https://doi.org/10.1179/cip.2009.2.1.163

JONES, R.K., P.J. PIPER, C.P. GROVES, T. NGUYễN ANH, M.H. NGUYễN THI, H. NGUYễN THị, T. HIEP HOANG & M. OXENHAM. 2019. Shifting subsistence patterns from the Terminal Pleistocene to Late Holocene: a regional Southeast Asian analysis. *Quaternary International* 529: 47–56. https://doi.org/10.1016/j.quaint.2019.01.006

KATZENBERG, M.A., S.R. SAUNDERS & W.R. FITZGERALD. 1993. Age differences in stable carbon and nitrogen isotope ratios in a population of prehistoric maize horticulturists. *American Journal of Physical Anthropology* 90: 267–81. https://doi.org/10.1002/ajpa.1330900302

KATZENBERG, M.A., D.A. HERRING & S.R. SAUNDERS. 1996. Weaning and infant mortality: evaluating the skeletal evidence. *American Journal of Physical Anthropology* 101: 177–99. https://doi.org/10.1002/(SICI)1096-8644(1996)23+<177::AID-AJPA7>3.0.CO;2-2

KENDALL, E.J., A.R. MILLARD, J. BEAUMONT, R.L. GOWLAND, M. GORTON & A. GLEDHILL. 2020. What doesn't kill you: early life health and nutrition in early Anglo-Saxon East Anglia, in R.L. Gowland & S.E. Halcrow (ed.) *The mother-infant nexus in anthropology: small beginnings, significant* outcomes: 103–23). Cham: Springer International. https://doi.org/10.1007/978-3-030-27393-4_6

KING, C.L., S.E. HALCROW, A.R. MILLARD, D.R. GRÖCKE, V.G. STANDEN, M. PORTILLA & B.T. ARRIAZA. 2018. Let's talk about stress, baby! Infant-feeding practices and stress in the ancient Atacama Desert, Northern Chile. *American Journal of Physical Anthropology* 166: 139–55. https://doi.org/10.1002/ajpa.23411

KING, T., L.T. HUMPHREY & S. HILLSON. 2005. Linear enamel hypoplasias as indicators of systemic physiological stress: evidence from two known age-at- death and sex populations from postmedieval London. *American Journal of Physical Anthropology* 128: 547–59. https://doi.org/10.1002/ajpa.20232

KLAUS, H.D. 2017. Paleopathological rigor and differential diagnosis: case studies involving terminology, description, and diagnostic frameworks for scurvy in skeletal remains. *International Journal of Paleopathology* 19: 96–110. https://doi.org/10.1016/j.ijpp.2015.10.002

KNODEL, J. & H. KINTNER. 1977. The impact of breastfeeding patterns on the biometric analysis of infant mortality. *Demography* 14: 391–409. https://doi.org/10.2307/2060586

KUSAKA, S., F. HYODO, T. YUMOTO & M. NAKATSUKASA. 2010. Carbon and nitrogen stable isotope analysis on the diet of Jomon populations from two coastal regions of Japan. *Journal of Archaeological Science* 37: 1968–77. https://doi.org/10.1016/j.jas.2010.03.002

LANGLOIS, M.R., J.R. DELANGHE, M.L. DE BUYZERE, D.R. BERNARD & J. OUYANG. 1997. Effect of haptoglobin on the metabolism of vitamin C. *The American Journal of Clinical Nutrition* 66: 606–10. https://doi.org/10.1093/ajcn/66.3.606

LE ROY, M. & E. MURPHY. 2020. Archaeothanatology as a tool for interpreting death during pregnancy: a proposed methodology using examples from medieval Ireland, in R.L. Gowland & S.E. Halcrow (ed.) *The mother-infant nexus in anthropology: small beginnings, significant outcomes:* 211–33. Cham: Springer International. https://doi.org/10.1007/978-3-030-27393-4_12

LEWIS, M.E. 2006. *The bioarchaeology of children: perspectives from biological and forensic anthropology*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511542473

LEWIS, M.E. & C. ROBERTS. 1998. Growing pains: the interpretation of stress indicators. *International Journal of Osteoarchaeology* 7: 581–86. https://doi.org/10.1002/(SICI)1099-1212(199711/12)7:6<581::AID-OA325>3.0.CO;2-C

LILLEHAMMER, G. 2015. 25 years with the 'child' and the archaeology of childhood. *Childhood in the Past* 8: 78–86. https://doi.org/10.1179/1758571615Z.00000000030

LONGIN, R. 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230: 241–242. https://doi.org/10.1038/230241a0.

MAHONEY, P. 2012. Incremental enamel development in modern human deciduous anterior teeth. *American Journal of Physical Anthropology* 147: 637–51. https://doi.org/10.1002/ajpa.22029

MATSUMURA, H. & M. OXENHAM. 2011. Introduction: Man Bac biological research objectives, in H. Matsumura, M. Oxenham & N.K. Dung (ed.) *Man Bac*: 1–8). Canberra: ANU Press. https://doi.org/10.22459/TA33.05.2011.01

MCDADE, T.W. & C.M. WORTHMAN. 1998. The weanling's dilemma reconsidered: a biocultural analysis of breastfeeding ecology. *Journal of Developmental & Behavioral Pediatrics* 19: 286–99. https://doi.org/10.1097/00004703-199808000-00008

MCDONELL, A. & M. OXENHAM. 2014. Localised primary canine hypoplasia: implications for maternal and infant health at Man Bac, Vietnam, 4000–3500 years Bp. *International Journal of Osteoarchaeology* 24: 531–39. https://doi.org/10.1002/oa.2239

MCHALE, J.P., K.T. DINH & N. RAO. 2014. Understanding coparenting and family systems among East and Southeast Asian-heritage families, in H. Selin (ed.) *Parenting across cultures:*

childrearing, motherhood and fatherhood in non-Western cultures: 163–73. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-7503-9_12

MCFADDEN, C., H. BUCKLEY, S.E. HALCROW & M. OXENHAM. 2018. Detection of temporospatially localized growth in ancient Southeast Asia using human skeletal remains. *Journal of Archaeological Science* 98: 93–101. https://doi.org/10.1016/j.jas.2018.08.010

MCFADDEN, C. & M. F. OXENHAM. 2019. The Paleodemographic measure of maternal mortality and a multifaceted approach to maternal health. *Current Anthropology* 60: 141-46. https://doi.org/10.1086/701476

MESTECHKINA, T., N.D. SON & J.Y. SHIN. 2014. Parenting in Vietnam, in H. Selin (ed.) *Parenting across cultures: childrearing, motherhood and fatherhood in non-Western cultures*: 47–57. Dordrecht: Springer. https://doi.org/10.1007/978-94-007-7503-9_5

MILLER, M.J., S. AGARWAL & C. LANGEBAEK. 2018. Dietary histories: tracing food consumption practices from childhood through adulthood using stable isotope analysis, in P. Beauchesne & S. Agarwal (ed.) *Children and childhood in bioarchaeology*: 262–93. Gainesville: University Press of Florida. https://doi.org/10.5744/florida/9780813056807.003.0009

MILLER, M.J., Y. DONG, K. PECHENKINA, W. FAN & S. HALCROW. 2020. Raising girls and boys in early China: stable isotope data reveal sex differences in weaning and childhood diets during the Eastern Zhou era. *American Journal of Physical Anthropology* :1-19. https://doi.org/10.1002/ajpa.24033

MINAGAWA, M. & E. WADA. 1984. Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between δ^{15}N and animal age. *Geochimica et Cosmochimica Acta* 48: 1135–40. https://doi.org/10.1016/0016-7037(84)90204-7

MOOK, W.G., & H.T. WATERBOLK. 1985. *Radiocarbon dating*. Strasbourg: European Science Foundation.

NGUYEN, P.H., K.C. NGUYEN, B. LE MAI, T.V. NGUYEN, K.H. HA, C. BERN, R. FLORES & R. MARTORELL. 2006. Risk factors for anemia in Vietnam. *The Southeast Asian Journal of Tropical Medicine and Public Health* 37: 1213–23.

ORTNER, D.J. 2003. *Identification of pathological conditions in human skeletal remains*. London: Academic.

ORTNER, D.J. & M.F. ERICKSEN. 1997. Bone changes in the human skull probably resulting from scurvy in infancy and childhood. *International Journal of Osteoarchaeology* 7: 212–20. https://doi.org/10.1002/(SICI)1099-1212(199705)7:3<212::AID-OA346>3.0.CO;2-5

ORTNER, D.J., E.H. KIMMERLE & M. DIEZ. 1999. Probable evidence of scurvy in subadults from archeological sites in Peru. *American Journal of Physical Anthropology* 108: 321–31. https://doi.org/10.1002/(SICI)1096-8644(199903)108:3<321::AID-AJPA7>3.0.CO;2-7

ORTNER, D.J., W. BUTLER, J. CAFARELLA & L. MILLIGAN. 2001. Evidence of probable scurvy in subadults from archeological sites in North America. *American Journal of Physical Anthropology* 114: 343–51. https://doi.org/10.1002/ajpa.1046

OXENHAM, M.F. 2000. Health and behaviour during the Mid-Holocene and Metal Period of northern Vietnam. PhD dissertation, Northern Territory University.

– 2006. Biological responses to change in prehistoric Vietnam. *Asian Perspectives* 45: 212–39. https://doi.org/10.1353/asi.2006.0025

- 2016. *Bioarchaeology of Ancient Northern Vietnam.* British Archaeological Reports (BAR) International Series 2781. BAR Publishing Oxford: Hadrian Books.

OXENHAM, M.F. & K.M. DOMETT. 2011. Paleohealth at Man Bac, in M.F. Oxenham, H. Matsumura & N. Kim Dung (ed.) *Man Bac: the excavation of a Neolithic site in northern Vietnam: the biology*: 78–93. Canberra: ANU Press. https://doi.org/10.26530/OAPEN_459363

OXENHAM, M.F. & A. WILLIS. 2017. Towards a bioarchaeology of care of children, in L. Tilley & A.A. Schrenk (ed.) *New developments in the bioarchaeology of care: further case studies and expanded theory*: 219–36). Cham: Springer. https://doi.org/10.1007/978-3-319-39901-0_11

OXENHAM, M., H. MATSUMURA, & D.K. NGUYEN. 2011. *Man Bac: the excavation of a Neolithic site in northern Vietnam: the biology*. Canberra: ANU Press. https://doi.org/10.26530/OAPEN_459363

OXENHAM, M., H. MATSUMURA, K. DOMETT, N.K. THUY, N.K. DUNG, N.L. CUONG, D. HUFFER & S. MULLER. 2008a. Childhood in Late Neolithic Vietnam: bio-mortuary insights into an ambiguous life stage, in K. Bacvarov (ed.) *Babies reborn: infant/child burials in pre- and protohistory* (British Archaeological Reports International Series 1832): 123–36. Oxford: Archaeopress.

– 2008b. Health and the experience of childhood in Late Neolithic Vietnam. *Asian Perspectives* 47: 190–209. https://doi.org/10.1353/asi.0.0001

PAPADIMITRIOU, A. 2016. The evolution of the age at menarche from prehistorical to modern times. *Journal of Pediatric and Adolescent Gynecology* 29: 527-30. https://doi.org/10.1016/j.jpag.2015.12.002

PFEIFFER, S., L.E. DOYLE, H.K. KURKI, L. HARRINGTON, J.K. GINTER & C.E. MERRITT. 2014. Discernment of mortality risk associated with childbirth in archaeologically derived forager skeletons. *International Journal of Paleopathology*, 7: 15-24. https://doi.org/10.1016/j.ijpp.2014.05.005

PIMENTEL, L. 2003. Scurvy: historical review and current diagnostic approach. *The American Journal of Emergency Medicine* 21: 32–32. https://doi.org/10.1016/S0735-6757(03)00083-4

POPOVICH, D., A. MCALHANY, A.O ADEWUMI & M.M. BARNES. 2009. Scurvy: forgotten but definitely not gone. *Journal of Pediatric Health Care* 23: 405–15. https://doi.org/10.1016/j.pedhc.2008.10.008

REID, D. & M.C. DEAN. 2000. The timing of linear hypoplasias on human anterior teeth. *American Journal of Physical Anthropology* 113: 135-39. https://doi.org/10.1002/1096-8644(200009)113:1<135::AID-AJPA13>3.0.CO;2-A

– 2006. Variation in modern human enamel formation times. *Journal of Human Evolution* 50: 329–46. https://doi.org/10.1016/j.jhevol.2005.09.003

REYNARD, L. M., & N. TUROSS. 2015. The known, the unknown and the unknowable: weaning times from archaeological bones using nitrogen isotope ratios. *Journal of Archaeological Science* 53: 618-25. https://doi.org/10.1016/j.jas.2014.11.018

SANDBERG, P.A., M. SPONHEIMER, J. LEE-THORP, D. VAN GERVEN. 2014. Intra-tooth stable isotope analysis of dentine: a step toward addressing selective mortality in the reconstruction of life history in the archaeological record. *American Journal of Physical Anthropology* 155: 281–93. https://doi.org/10.1002/ajpa.22600

SAWADA, J., N.K. THUY & N.A. TUAN. 2011. Faunal remains at Man Bac, in M.F. Oxenham, H. Matsumura & N.K. Dung (ed.) *Man Bac*: 105–16). Canberra: ANU Press. https://doi.org/10.22459/TA33.05.2011.09

SCHOUR, I. & M. MASSLER. 1940. Studies in tooth development: the growth pattern of human teeth, part II. *The Journal of the American Dental Association* 27: 1918–31. https://doi.org/10.14219/jada.archive.1940.0340

SCHURR, M.R. 1998. Using stable nitrogen-isotopes to study weaning behavior in past populations. *World Archaeology* 30: 327–42. https://doi.org/10.1080/00438243.1998.9980413

SEAR, R. & R. MACE. 2009. Family matters: kin, demography and child health in a rural Gambian population, in R. Mace & G. Bentley (ed.) *Substitute parents*: 50–76. New York: Berghahn.

SELLEN. D.W. 2001. Comparison of infant feeding patterns reported for nonindustrial populations with current recommendations. *The Journal of Nutrition* 131: 2707-2715. https://doi.org/10.1093/jn/131.10.2707

SKINNER, M.F. & J.T.W. HUNG. 1989. Social and biological correlates of localized enamel hypoplasia of the human deciduous canine tooth. *American Journal of Physical Anthropology* 79: 159–75. https://doi.org/10.1002/ajpa.1330790204

SNODDY, A.M.E., S.E. HALCROW, H.R. BUCKLEY, V.G. STANDEN & B.T. ARRIAZA. 2017. Scurvy at the agricultural transition in the Atacama Desert (*ca*. 3600–3200 BP): nutritional stress at the maternal-foetal interface? *International Journal of Paleopathology* 18: 108–20. https://doi.org/10.1016/j.ijpp.2017.05.011

SNODDY, A.M.E., H.R. BUCKLEY, G.E. ELLIOTT, V.G. STANDEN, B.T. ARRIAZA & S.E. HALCROW. 2018. Macroscopic features of scurvy in human skeletal remains: a literature synthesis and diagnostic guide. *American Journal of Physical Anthropology* 167: 1-20. https://doi.org/10.1002/ajpa.23699

STEWART, C.P., L. IANNOTTI, K.G. DEWEY, K.F. MICHAELSEN & A.W. ONYANGO. 2013. Contextualising complementary feeding in a broader framework for stunting prevention. *Maternal & Child Nutrition* 9: 27–45. https://doi.org/10.1111/mcn.12088

STUART-MACADAM, P. 1985. Porotic hyperostosis: representative of a childhood condition. *American Journal of Physical Anthropology* 66: 391–98. https://doi.org/10.1002/ajpa.1330660407

TEN CATE, A.R. 1994. *Oral histology: development, structure, and function*. St. Louis (MO): C.V. Mosby.

TILLEY, L. & M.F. OXENHAM. 2011. Survival against the odds: modeling the social implications of care provision to seriously disabled individuals. *International Journal of Paleopathology* 1: 35–42. https://doi.org/10.1016/j.ijpp.2011.02.003

TOIZUMI, T., N.K. THUY & J. SAWADA. 2011. Fish remains at Man Bac, in M.F. Oxenham, H. Matsumura & N.K. Dung (ed.) *Man Bac*: 117–26). Canberra: ANU Press. https://doi.org/10.22459/TA33.05.2011.10

TSUTAYA, T., & M. YONEDA. 2014. Reconstruction of breastfeeding and weaning practices using stable isotope and trace element analyses: a review. *American Journal of Physical Anthropology* 156: 2-21. https://doi.org/10.1002/ajpa.22657

WILLIS, A. & M.F. OXENHAM. 2013a. A case of maternal and perinatal death in Neolithic Southern Vietnam, *c*. 2100–1050 BCE. *International Journal of Osteoarchaeology* 23: 676–84. https://doi.org/10.1002/oa.1296

– 2013b. The Neolithic demographic transition and oral health: the Southeast Asian experience. *American Journal of Physical Anthropology* 152: 197–208. https://doi.org/10.1002/ajpa.22343

VLOK, M., M. F. OXENHAM, K. DOMETT, T. T. MINH, N. T. MAI HUONG, H. MATSUMURA, H. T. HIEP, T. HIGHAM, C. HIGHAM, T. H. NGHIA & H. BUCKLEY. In Press. Two Probable Cases of Infection with Treponema pallidum during the Neolithic Period in Northern Vietnam (~2000-1500B.C.) *Bioarchaeology International.*

WOOD, L. 1996. Frequency and chronological distribution of linear enamel hypoplasia in a North American Colonial skeletal sample. *American Journal of Physical Anthropology* 100: 247–59. https://doi.org/10.1002/(SICI)1096-8644(199606)100:2<247::AID-AJPA6>3.0.CO;2-U

WRIGHT, L.E. & H.P. SCHWARCZ. 1999. Correspondence between stable carbon, oxygen and nitrogen isotopes in human tooth enamel and dentine: infant diets at Kaminaljuyú. *Journal of Archaeological Science* 26: 1159–70. https://doi.org/10.1006/jasc.1998.0351

YONEDA, M. 2008. Dietary reconstruction of ancient Vietnamese based on carbon and nitrogen isotopes. *Paper presented at the Man Bac Symposium, Institute of Archaeology, Hanoi, Vietnam.*

ZANOLLI, C., L. BONDIOLI, F. MANNI, P. ROSSI & R. MACCHIARELLI. 2011. Gestation length, mode of delivery, and neonatal line-thickness variation. *Human Biology* 83: 695–713. https://doi.org/10.3378/027.083.0603

ZELLER, A.C. 1987. A role for children in hominid evolution. *Man* 22: 528–57. https://doi.org/10.2307/2802504