ORIGINAL PAPER

Migration and cultural integration in the early medieval cemetery of Finglesham, Kent, through stable isotopes

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Abstract

Debate over migrations to Britain during the fifth and sixth centuries AD is still rampant in archaeological discourse. Stable carbon, nitrogen and oxygen isotope values from multiple tissues in individuals buried at Finglesham in Kent during the first millennium AD demonstrate not only migration of individuals to the region but also highlight community integration through foodways and refute previous models of 'invasion' and replacement. This case study community suggests gendered differences in mobility into early medieval England, with males more likely to be migrants from cooler regions than women. It also challenges traditional narratives of social status in these furnished cemeteries being linked to diet or migrant status with no clear correlations found between funerary treatment and isotopic signatures. This multi-tissue and multi-isotope study tracks dietary changes in this multi-origin community throughout their lives and shows that they may have even changed their diets to adapt to Christianising influences in the region.

Keywords Early medieval · Kent · Isotopes · Diet · Mobility · Identity

Introduction

Combining isotopic signatures from different tissues gives powerful insight into patterns of diet and mobility throughout the life course. This paper combines carbonate signatures from human tooth enamel, with carbon and nitrogen from bone and dentinal collagen of the same individuals to investigate how one community in Kent changed and adapted during the highly dynamic period of the fifth to eighth centuries AD.

The period covered here spans the '*Adventus Saxonum*' (or 'coming of the Saxons') (Hills 2013b, 2015; Michelet 2017), the Late Antique Little Ice Age (c. 536 to 660AD, LALIA) (Büntgen et al. 2016, 2017; Di Cosmo et al. 2017; Fei et al. 2007; Helama et al. 2017; Loveluck et al. 2018; Luterbacher et al. 2016), the Plague of Justinian (c. 541–750 AD) (Keller et al. 2019; Mordechai et al. 2019), and the Christian mission of St Augustine to Kent (597 AD). It is therefore not surprising that there were major cultural and socio-economic changes during this period, namely changes in burial practice and grave goods, farming practices and trade, although the relationships between all factors is highly complex. The impact and scale of these events are much debated, the '*Adventus*' in particular, and other isotopic studies claim to show evidence for contemporary migrant populations to those proposed here (Hughes et al. 2014, 2018).

The '*Adventus*' theoretically occurred at the end of the Roman occupation in Britain in the fifth century AD and resulted in large material-cultural changes in England, particularly in funerary rites and grave goods. Cemeteries in Kent are frequently cited as key evidence in the debate around the '*Adventus Saxonum*' due to distinctive female dress-styles which are seen by some as definitive proof of incoming groups (Brookes and Harrington 2010; Härke 2011; Richardson 2005; Sorensen 1999). The main historical sources for this migration are Bede, Gildas and the Anglo-Saxon Chronicle which all state that groups of people migrated from parts of what is now the Netherlands, northern Germany and the Jutland peninsula to Britain

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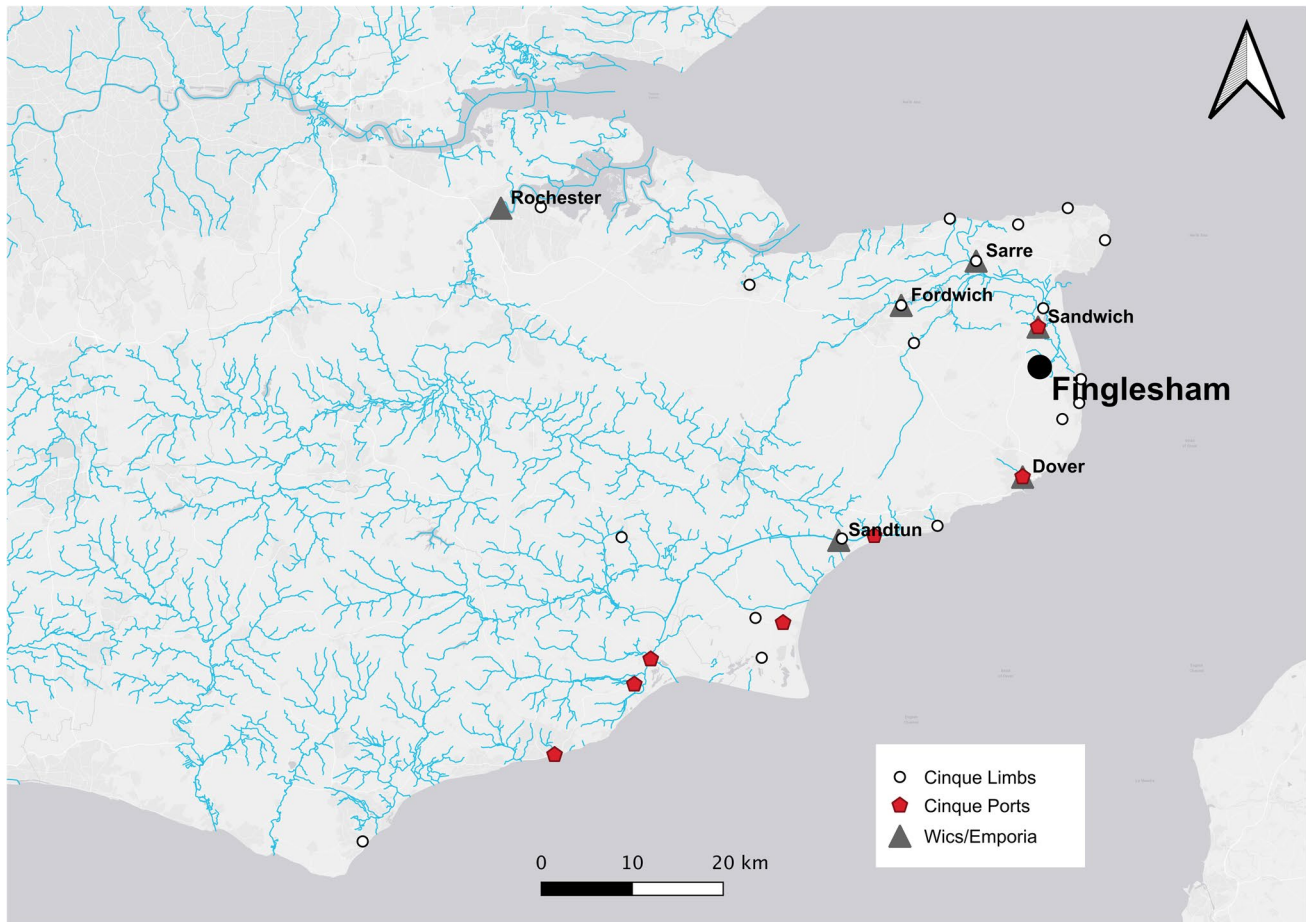[2] School of Archaeology, University of Oxford, Oxford, UK

Fig. 1 Map of Kent and East Sussex showing the location of Finglesham (large black circle) and other sites mentioned in text (figure by S. Leggett)

(Gildas 2010; The Venerable Bede 2009; Unknown 2008).[1] Scholarship on post-Roman migration(s), particularly to England, has shifted between elite replacement models with top-down cultural change, models of large-scale migration over several generations and anti-migrationist thought from the 1990s onwards (Hamerow 1997; Härke 2003, 2004, 2011; Hills 2013a, 2013b, 2015; Pattison 2008; Thomas et al. 2006, 2008).

Previous isotopic studies on early medieval communities have shown that there was likely a large amount of movement around Europe throughout the first millennium AD but identifying 'non-locals' and outliers in datasets still proves difficult (Brettell et al. 2012a, b; Evans et al. 2012; Groves et al. 2013; Hakenbeck 2013; Hemer et al. 2013; Krzewińska et al. 2018). However, taking a life course approach with isotopic data to investigate not only if a cemetery includes

migrants, but their cultural integration via foodways, alongside grave goods and other factors is as yet underutilised in early medieval cemeteries, especially in England. This is the largest study utilising multi-tissue multi-isotope analyses for any single cemetery in early medieval England and therefore goes a long way towards a better understanding of the nature and impact of early medieval migrations in England in post-Roman Britain, and other major transitions, like Christianisation.

Background

Location and early medieval archaeology of Finglesham and its surrounds

Finglesham is located in eastern Kent (51° 14′ 5.9994″, 1° 20′ 24″; see .

Figure 1) at approximately 12 m above sea level on a mixture of Cretaceous chalk, Palaeogene alluvium, sand, gravel, silt, and diamicton (British Geological Survey

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[1] It is important to note here that these sources whilst medieval are not contemporary with the events they describe, the closest is Gildas (c. sixth century) and then Bede's *HE* (*Historia Ecclesiastica Gentis Anglorum* – The Ecclesiastical History of the English People) which post-dates the migrations by c. 300 years (written c. 731 AD).

n.d.; Chadwick Hawkes and Grainger 2006). The $\delta^{18}O_{MAP}$ (modelled annual precipitation) value calculated for the site using the OIPC (online isotopes in precipitation calculator) is −6.9‰ (Bowen 2019; Bowen and Revenaugh 2003; Leggett et al. 2021; Lightfoot and O'Connell 2016).

Kent is well placed for cross-channel and North Sea trade, with several wics/emporia established by the eighth century, including Rochester, Sarre, Fordwich, Sandwich, Dover and Sandtun (Brookes and Harrington 2010: 83; Hill and Cowie 2001; Leggett 2017; Pestell 2011). Finglesham is close to several of these trading ports, and their limbs (see .

Figure 1) so therefore was likely well linked into coastal trade which may have facilitated migration of people as well as the importation of luxury and foreign goods found in some of the graves (Brookes and Harrington 2010; Chadwick Hawkes and Grainger 2006; Soulat 2013, 2018).

Grave goods of Frankish origin are not uncommon in Kent but are almost absent in other parts of England, suggesting that Kent and Francia had special trade relationships in the early middle ages (Brookes and Harrington 2010: 46–47; Chadwick Hawkes and Grainger 2006; Sorensen 1999; Soulat 2013, 2018). This unique cross-channel relationship also included royal marriages such as King Æthelberht of Kent's marriage to the Frankish princess Bertha; this alliance is what is often credited as the conduit for the Christian conversion of the 'English' in the late sixth and early seventh century (at least by Bede) (Stenton 1971: 59–60; Blair 2003: 27–28, 116–117; The Venerable Bede 2009: 39–41; Brookes and Harrington 2010: 44,69–70).

In the seventh and eighth centuries, a large shift occurs in funerary practices across western Europe, generally termed the 'final phase' of furnished burial (Brownlee 2020; Welch 2011). Finglesham is one of the cemeteries where these shifts can be seen. It, like other cemeteries in Kent, sees extremely elaborate graves with large grave markings and barrows (elite female graves being especially well furnished) appear alongside an increasing number of individuals with little to no grave goods. However, compared with the rest of England furnished burial continues later in Kent (Brownlee 2019: 185).

These marked shifts in funerary displays are also coupled with large differences in stature between women and men in the fifth/sixth centuries which seem to disappear by the seventh/eighth (Richardson 2005: 100–102, 252). This is used by Richardson and Härke (2011) to argue for men and women coming from different ethnic groups during the '*Adventus*', but it could of course be due to a number of other factors such as differences in nutrition, as investigated further below.

Kent's particularly well recorded processes of religious conversion and cross-cultural contact during the early medieval period make it somewhere we would expect to find individuals of mixed childhood origins, and see the impact of migration, religious conversion, trade and exchange on food-ways. Consequently, Finglesham, as a large fifth to eighth century cemetery, close to the coast is an exciting case study through which these cultural shifts can be explored.

Finglesham was first excavated by Stebbing and Whiting in 1928–1929, with further excavations by Sonia Chadwick Hawkes between 1959 and 1967. Hawkes excavated 216 inhumation graves, 201 of which were osteologically analysed (Chadwick Hawkes and Grainger 2006). Forty-six individuals were selected for primary isotopic analyses (see graves highlighted in Fig. 2).

The cemetery was in use from approximately the fifth to the eighth century AD and seems to represent a 'normal' burial population in its age and sex profiles (Chadwick Hawkes and Grainger 2006: 15, 324). The majority of burials are aligned W-E with heads to the west, but there are some variations on this, as seen in Fig. 2. The site also boasts many tumuli/barrows and graves with post holes and other wooden structures alongside plain earth-cut graves.
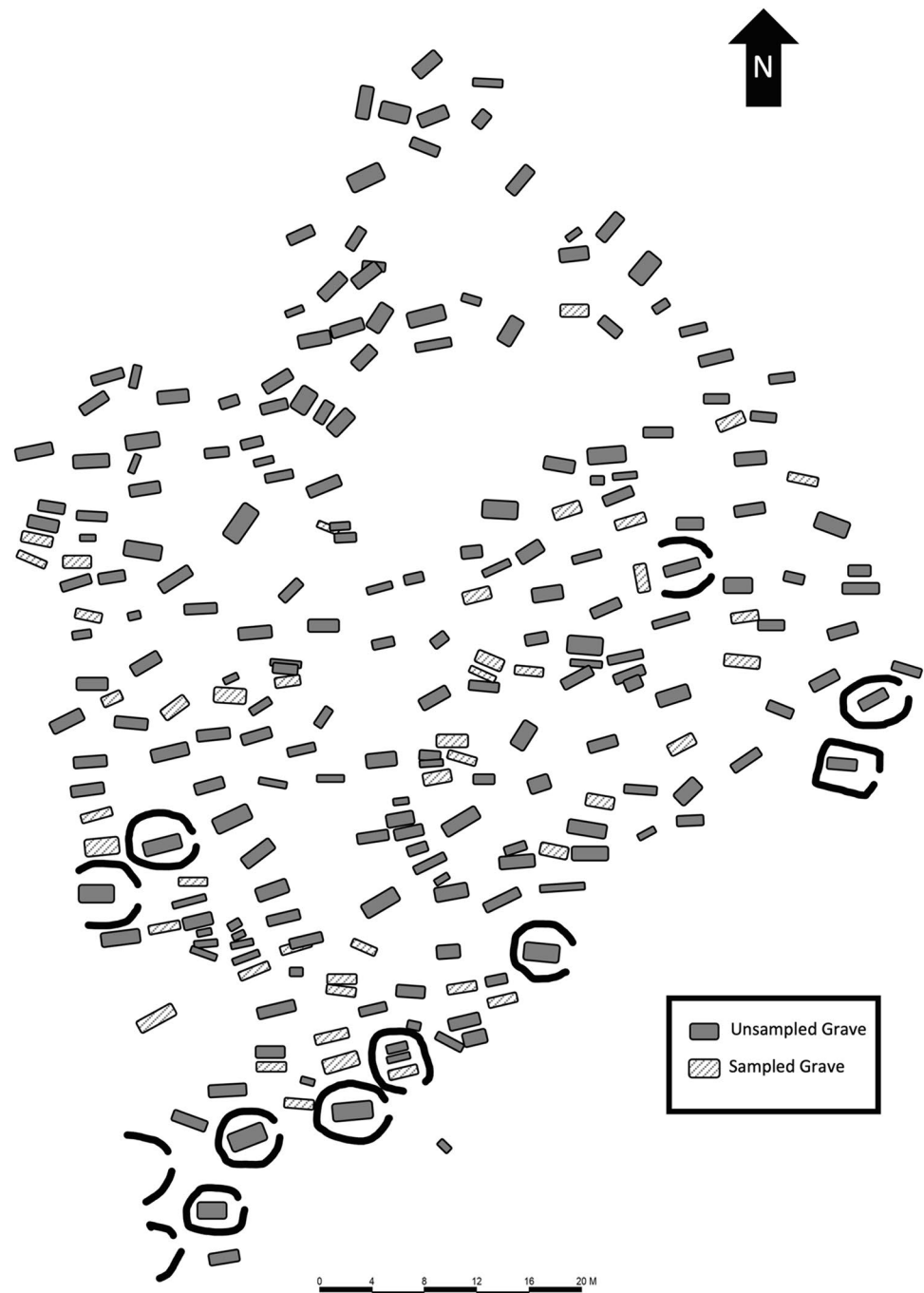
The choice of Finglesham as a case study cemetery for the region was clear—it has the largest sample size for all three tissues (bone, dentine and enamel) in Kent to date (Leggett et al. 2021). This enabled more robust analyses which would not be possible for cemeteries with fewer individuals, or with only one tissue analysed. It is also a well-known, well-excavated and well-documented cemetery that has a good balance between female and male graves and variation in levels of grave provisioning so as to not overly bias the dataset with unbalanced sample sizes between social or biological groups (e.g., more men than women, more richly furnished individuals). See 'Statistical analyses' section below for implications).

Stable isotope analyses

Chemical techniques are now relatively commonplace in bioarchaeological studies which investigate diet and mobility in the past. There is a growing trend for multi-tissue and multi-isotope studies at individual and populational levels (Bond et al. 2016; Gregoricka et al. 2017; Lamb et al. 2012; Ryan et al. 2018; Zhu and Sealy 2019).

Quantifiable isotopic variations in water (caused by climate), geologies and different kinds of food and drink underpin stable isotope methodologies (Gannes et al. 1998). Due to differences in tissue turnover rates, different bones reflect the average isotopic composition of food and drink consumed, and the environment these foods were sourced from as those tissues were being formed and re-modelled throughout an individual's life (Hedges et al. 2007; Pederzani and Britton 2019). Similarly teeth (which do not remodel during life) reflect the period of consumption and environmental conditions during their formation (Beaumont et al. 2013; Pederzani and Britton 2019). Differences in the

Fig. 2 Site plan of the early medieval cemetery at Finglesham, Kent, with burials sampled for stable isotope analyses filled with stripes, and unsampled graves in solid grey, redrawn by S. Leggett from Chadwick Hawkes and Grainger (2006)

Collagen (bone and dentine)—carbon and nitrogen

The use of stable carbon and nitrogen isotopes for dietary reconstruction in archaeology is a well-established technique (Ambrose 1986; Bocherens and Drucker 2003; Kellner and Schoeninger 2007).

environmental variation of different isotopes and dietary routing into various bodily tissues are briefly explained below.

Carbon stable isotope ratios can discern between diets based on C_3 plants (e.g. most vegetables, wheat, barley, oats, rye), C_4 (mainly drought adapted grasses, e.g. millet, sorghum, amaranth) and CAM (e.g. succulents and cacti) plants due to differences in their photosynthetic pathways causing isotopic fractionation (Farquhar et al. 1989; Hoefs 2018: 63–65; O'Leary 1988). In early medieval England (where we do not expect to see any C_4 or CAM plant consumption (Alt et al. 2014; Ganzarolli et al. 2018; Hagen 2006: 23, 33, 38–39; Hakenbeck et al. 2017)), they

are also useful in differentiating between marine versus terrestrial food resources (O'Leary 1988). Nitrogen stable isotope ratios indicate trophic level and are generally assumed to increase ~ 3–5‰ per level of the food chain, with controlled diet studies suggesting diet-collagen spacing can be as high as ~ 6‰ (Ambrose 1986, 1991; Bocherens and Drucker 2003; Hedges and Reynard 2007; O'Connell et al. 2012). They are therefore useful in indicating plant versus animal protein intake, as well as consumption of marine and freshwater resources when combined with carbon isotope values (Bocherens and Drucker 2003; Lucy et al. 2009). δ^{15}N in humans and animals can also be altered by factors such as breastfeeding/weaning, and pregnancy/lactation (Beaumont et al. 2015; Fuller et al. 2005, 2006; Haydock et al. 2013; Richards et al. 2002).

Collagen in bone and dentine is composed of both essential and non-essential amino acids, and thus reflects diet but also other metabolic processes and nutrient pools in the body. The carbon and nitrogen in collagen derives primarily from dietary protein but nitrogen in particular can be impacted significantly by periods of nutritional stress, and carbon in collagen can also be drawn from carbohydrates and fats which can be from the consumer's own body (France and Owsley 2015; Fuller et al. 2005; Hedges 2003; Lee-Thorp et al. 1989; Makarewicz and Sealy 2015; O'Connell et al. 2012).

Due to differences in structure between trabecular and compact bone it is assumed that trabecular bone (e.g. majority of rib bone and hence its use in this study) has a much faster tdurnover rate and thus represents a shorter window for diet, while long bones largely made of compact bone have far longer turnover periods; however exact rates are still elusive (Hedges et al. 2007; Sealy et al. 1995; Smith and Rennie 2007). Unlike bone, dentine usually does not remodel once formed, so turnover rates are not a concern in the same way, however, dietary routing and changes to metabolism (e.g. stress events) are. Dentine reflects diet during the period of tooth root formation which begins after completion of the crown, usually a snapshot of 1–3 years depending on the tooth selected (Scheid 2007: 328).

Bioapatite—oxygen and carbon

Bioapatite is the mineral portion of biologically formed tissues, here analysed from tooth enamel carbonate. Enamel, like dentine, does not remodel during life. Therefore, it represents a fixed point in early life (often an average over a few years depending on the tooth selected) for the incorporation of those elements into the tissue matrix. Hence it is a useful tool for mobility and diet studies (Brown and Brown 2011: 100–101; Chenery et al. 2012; Evans et al. 2012; Pederzani and Britton 2019; Price and Burton 2012: 91–92, 95–98).

Slightly different to the routing of carbon in collagen, the carbon in bioapatite is derived from blood bicarbonate, which in turn derives from respiration and therefore is thought to represent whole diet (Ambrose and Norr 1993; Hedges 2003; Howland et al. 2003; Passey et al. 2005; Tieszen and Fagre 1993; Zhu and Sealy 2019). Enamel carbonate therefore gives us a window into whole diet in childhood for the period of crown formation and mineralisation. This is a useful tool to combine with the largely protein-derived δ^{13}C values of collagen by creating bioapatite-collagen offsets. Tissue offsets are however not straightforward, especially in omnivores (i.e. humans). A recent feeding study on pigs suggests that the introduction of marine resources into the diet can substantially change nutrient pooling and dietary routing of amino acids and thus change the $\Delta^{13}C_{whole\ diet-tissue}$ relationship that holds well in terrestrial contexts (Webb et al. 2017). However, Webb et al. (2017) did not collect enamel carbonate samples in their study, so it is hard to interpret how this plays out in bioapatite versus proteinaceous tissues (collagen) to attempt corrections and better understand the whole diet-apatite relationship in omnivores. Although their work does suggest that $\Delta^{13}C_{bioapatite-collagen}$ values in humans (and other animals) may not always reflect trophic level, looking at a combination of the ecological literature and work done on Jomon period Japanese populations, suggests that $\Delta^{13}C_{bioapatite-collagen}$ values can give a suggestion of trophic-like relationships, in particular for disentangling proportions of mixed marine/terrestrial/freshwater protein discrimination (especially in otherwise C_3 environments) (Clementz et al. 2007, 2009; Clementz and Koch 2001; Kusaka 2019; Kusaka et al. 2015). Although caution is needed as more feeding studies and work on modern populations (both animals and people) is needed to better understand underlying dietary routing and isotopic composition of all portions of foodstuffs.

The δ^{18}O values of bioapatite are determined by the isotopic composition of body water in mammals, which is derived from consumed oxygen sources such as inhaled air, drinking water and oxygen components of food (structural oxygen and food water), in a mass balance with excretions (e.g. water vapour through breath or sweat, water in waste products and exhaled carbon dioxide) (Pederzani and Britton 2019).

An extensive review of archaeological applications of isotope analyses using oxygen and the underlying principles has been recently published by Pederzani and Britton (2019). Variation in δ^{18}O baselines is due to the hydrological cycle where water is continuously rained out and evaporated. During this cycle, proximity to coast (continentality), seasonality, temperature, altitude, amount of rainfall and humidity all play a role in δ^{18}O variability (Bowen and Revenaugh 2003; Lightfoot and O'Connell 2016; Pederzani and Britton 2019;

Rozanski et al. 1992, 2013). Thus, $\delta^{18}O$ values vary in relatively predictable patterns geospatially and climatically. $\delta^{18}O$ fractionation is largely driven in natural systems by evaporation, whereby the preferential evaporation of the lighter to the heavier isotope, leaves bodies of water which are either large, or in hot climates, enriched in ^{18}O (Bowen and Revenaugh 2003; Iacumin et al. 1996; Longinelli 1984; Pederzani and Britton 2019; Rozanski et al. 1992, 2013).

Cooking, brewing and stewing

Humans are unique in their consumption of artificially altered beverages and foods in high abundances. The 'brewing and stewing' effect is a confounding factor in some archaeological stable isotope studies using oxygen and is difficult to correct for (Brettell et al. 2012a, b; Pederzani and Britton 2019).

The heating processes involved in making drinks such as teas or worts, alcoholic distillation or stewing cause liquid evaporation which leaves the product enriched in the heavier isotope (Brettell et al. 2012a, b; Pederzani and Britton 2019). Mammalian milk has also been shown to be enriched compared to body water and drinking water values (Lin et al. 2003; Pederzani and Britton 2019). Brettell et al. (2012a, b) estimated that $\delta^{18}O$ values may be enriched by as much as $+2.3‰$ or possibly more, given the historical and archaeological evidence. In essence, enriched ^{18}O values can point to foodways which involve a significant amount of brewing and stewing as shown with King Richard III (Brettell et al. 2012a, b; Lamb et al. 2014; Pederzani and Britton 2019).

Materials and methods

Materials

As per Leggett et al. (2021) selection of individuals was based on skeletal preservation as initially assessed from site reports as well as the condition of the skeletons at the point of sampling in the Duckworth Laboratory collection. Where possible, individuals with both suitable ribs and surviving teeth were preferred. Adults were preferentially sampled with some late sub-adults being chosen due to cultural perceptions of adulthood in the Early Middle Ages with adulthood, at least in part, starting in the mid-to-late teens as seen life stages marked by different grave assemblages which is reflected in their age categories assigned here (Crawford 2018; Leggett et al. 2021; Stoodley 2011). Good bone and enamel preservation were also key factors for selection. Individuals whose bones might have low collagen yields or tissues otherwise affected by diagenesis, and thus might complicate the interpretation of results, were avoided. This was assessed visually and physically by the texture and

appearance of the bone (e.g. was it crumbling or discoloured, were there significant signs of microbial activity, were there any signs of petrification in the bones, etc.). After preservation and availability of skeletal elements, sampling as evenly as possible spatially across the site (see Fig. 2) with roughly equal numbers of females and males was attempted. Both males and females were included irrespective of grave provisioning so long as they met the above preservation criteria to avoid sampling based purely on richness of graves or the skewness this brings to both chronology and gendering of graves (Bayliss et al. 2013; Brownlee 2019; Leggett et al. 2021). This has meant a mixture of furnished and unfurnished graves, with adults largely at life stages 4/5, dating primarily to phases B–D, but more radiocarbon dating on this site is forthcoming (see Table 1 and Leggett et al. 2021 for a breakdown of individuals and their categorisations).

Ribs were preferred for bone specimens (Hedges et al. 2007; Lucy et al. 2009). Permanent second premolars or second molars were preferred due to their similarity in development timings and because they represent a post-weaning signature in both enamel and dentine (Beaumont et al. 2015; Evans et al. 2012; Scheid 2007: 326–334). Some individuals did not have teeth suitable for sampling (e.g. could not easily extract the tooth, or too carious or worn on inspection), but the priority was to limit damage to skeletons, so if a tooth could not be easily extracted, only bone was taken.

Of the 46 individuals sampled for stable isotope analyses, 45 individuals had rib fragments available for analysis (Table 1). Forty of those individuals had loose teeth or teeth loose enough to extract without damaging the maxilla/mandible to analyse both dentine and enamel from the same tooth. Forty of the 46 individuals analysed have more than one tissue with isotopic data, and 38 have all three tissues with data included here as summarised in Table 1.

Individuals sampled range from date category B (450–580 AD) to E (690–790 AD), with more individuals from periods C/D (c. 580–690 AD) and D (630–690 AD), and slightly more males than females in the sample. The phasing of these individuals was based on assessments in the original excavation report and subsequent radiocarbon dating (Bayliss et al. 2013; Chadwick Hawkes and Grainger 2006; Leggett et al. 2021). Full details on phasing can be found in the data paper by Leggett et al. (2021).

Forty-one of the 46 individuals had skeletal stature estimates available, and these range between 145 and 183 cm (Chadwick Hawkes and Grainger 2006); female skeletons range from 145 to 169 cm, and males 165–183 cm which agrees with the analysis of Kentish stature more broadly undertaken by Richardson (2005: 100–102, 252). Numbers of grave goods within the Finglesham subsample range from 0 to 13, with a maximum of two foreign items (as specified in the original report) in one grave (gr 57).

Table 1 Carbon, nitrogen and oxygen stable isotope data, and collagen quality indicators for human samples from Finglesham

Grave	Gendered age category	Phase from Leggett et al. (2021)	Bone sampled	Tooth	Bone collagen						Dentine						Enamel			
					$\delta^{13}C$	$\delta^{15}N$	%C	%N	C/N	% Coll	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C/N	% Coll	$\delta^{13}C$	$\delta^{18}O_{PDB}$	$\delta^{18}O_{PO4\ VSMOW}$	$\Delta^{18}O_{dw-MAP}$
6	M5	B	Rib	Lower M3 R	−20.3	8.6	39.7	14.5	3.2	4.4	−20.1	9.2	43.8	16.5	3.1	7.0	−13.6	−5.5	16.4	−1.5
8	F5	D	Rib	Upper C R	−19.7	9.4	43.2	15.8	3.2	6.7	−20.0	9.5	44.9	16.6	3.2	7.8	−14.0	−5.9	16.0	−2.2
15	M5	B	Rib	Upper C L	−20.9	9.5	33.9	11.5	3.4	1.5	−20.2	10.1	46.4	17.2	3.1	16.6	−14.2	−6.8	15.0	−3.7
16	F5	C/D	Rib		−20.5	9.0	33.9	12.0	3.3	3.0										
18	M4/5	B/C	Rib	Upper M2	−21.3*	8.1*	20.1*	6.0*	3.9*	1.3*	−19.9	9.8	46.3	17.0	3.2	12.0	−12.8	−6.0	15.9	−2.4
21A	M4/5	C/D	Rib	Lower C L	−20.0	9.7	45.2	16.5	3.2	8.1	−19.5	9.7	45.3	16.8	3.1	11.4	−13.7	−5.0	16.9	−0.8
21B	F4	C/D	Rib	Upper PM1 L	−20.3	9.7	39.5	14.6	3.2	2.6	−20.4	11.7	45.5	16.8	3.2	8.4	−14.4	−2.9	19.1	2.6
26A	M4/5	C/D	Rib	Upper M3 L	−19.7	9.7	41.9	15.6	3.1	5.9	−19.4	10.3	45.8	17.1	3.1	16.2	−12.7	−5.8	16.0	−2.1
30	M4	B/C	Rib	Lower M3 R	−20.3	8.8	43.9	16.2	3.2	9.3	−20.0	9.6	46.1	17.2	3.1	13.6	−13.7	−4.1	17.9	0.7
47B	F6	C/D	Rib	Lower PM1 R	−19.8	9.3	52.0	19.2	3.2	8.3	−19.8	10.5	43.2	16.2	3.1	8.2	−13.5	−5.7	16.2	−1.9
48	M4	C/D	Rib	Upper M2 L	−20.0	9.7	43.3	15.8	3.2	4.0	−19.9	10.6	42.5	15.3	3.2	5.0	−14.1	−5.6	16.2	−1.8
57	F5	C/D	Rib	Lower PM2 R	−20.1	9.0	44.6	16.5	3.2	4.7	−20.1	9.6	37.5	13.9	3.2	5.6	−14.4	−5.5	16.4	−1.6
61	F4	D	Rib	Upper PM2 L	−20.0	8.8	46.1	16.9	3.2	5.3	−19.8	9.1	45.3	16.7	3.2	12.6	−13.8	−5.8	16.1	−2.0
62B	F4	C/D	Rib	Upper PM2 L	−20.4	8.9	34.9	12.5	3.3	4.0	−20.2	12.6	42.6	15.7	3.2	6.0	−14.5	−6.0	15.8	−2.5
63	F4	C/D	Rib	Upper M2 L	−20.2	10.0	43.5	16.1	3.2	7.9	−19.8	11.9	44.4	16.3	3.2	6.8	−13.9	−4.3	17.6	0.3
64	F5	C/D	Rib	Upper PM2 R	−19.7	10.0	49.8	18.3	3.2	18.5	−19.7	11.2	43.4	16.2	3.1	13.4	−14.0	−3.8	18.2	1.2
72	M6	D	Rib	Upper M2(?)	−19.8	9.0	39.8	14.8	3.1	4.2	−19.4	7.8	45.7	16.9	3.2	10.5	−12.9	−6.0	15.8	−2.4
73	M4	D	Rib	Lower M2 L	−20.1	9.1	38.4	14.3	3.1	3.9	−19.6	9.3	45.6	17.1	3.1	15.9	−12.9	−4.3	17.6	0.4
82	M4	C	Rib	Lower M2 R	−20.4	10.9	42.7	15.8	3.2	20.5	−20.0	11.9	45.5	17.0	3.1	9.8	−14.0	−5.8	16.0	−2.1

Table 1 (continued)

Grave	Gendered age category	Phase from Leggett et al. (2021)	Bone sampled	Tooth	Bone collagen δ¹³C	δ¹⁵N	%C	%N	C/N	% Coll	Dentine δ¹³C	δ¹⁵N	%C	%N	C/N	% Coll	Enamel δ¹³C	δ¹⁸O$_{PDB}$	δ¹⁸O$_{PO4}$ VSMOW	Δ¹⁸O$_{dw-MAP}$
84	F5	C/D	Rib	Upper M2 L	−20.1	9.2	43.2	16.1	3.1	15.1	−20.4	9.0	39.7	14.4	3.2	4.9	−13.8	−6.2	15.6	−2.8
105	M4/5	D	Rib	Upper M2 L	−20.0	9.5	42.0	15.4	3.2	11.6	−20.1	8.7	45.6	17.1	3.1	12.1	−12.9	−3.7	18.3	1.3
106	M5	C/D	Rib		−20.2	10.6	41.2	15.1	3.2	10.9										
113	F4/5	C/D	Rib	Lower PM1 L	−20.1	10.5	43.1	15.9	3.2	15.9	−19.7	12.2	34.1	12.7	3.1	5.3	−14.0	−5.5	16.4	−1.6
116	M4	C/D		Lower M2 R							−19.5	11.3	45.3	16.9	3.1	6.9	−15.3	−4.3	17.6	0.3
118	M5	B/C	Rib		−20.0	9.5	42.5	15.7	3.2	6.2										
121	F5/6	C/D	Rib	Upper M1 R	−19.9	9.4	43.6	15.9	3.2	10.2	−19.6	8.5	46.7	17.4	3.1	16.2	−13.2	−3.4	18.7	1.9
123	M5	C	Rib	Lower C L	−20.1	9.7	40.0	14.8	3.2	2.7	−20.2	12.3	41.4	15.5	3.1	5.3	−13.4	−5.3	16.6	−1.3
124	F5	D	Rib	Upper M2(?) R	−20.1	8.8	43.5	16.1	3.2	15.1	−20.1	8.9	44.0	16.1	3.2	12.4	−14.4	−5.5	16.4	−1.6
125A	M5	B/C	Rib	Lower M2 R	−20.1	9.9	42.0	15.5	3.2	5.1	−20.4	11.3	30.6	11.2	3.2	3.0	−14.7	−5.9	15.9	−2.3
129A	M4	C/D	Rib	Upper M3 R	−20.4	9.3	42.9	15.6	3.2	11.1	−20.3	9.1	28.0	10.3	3.2	5.4	−14.0	−5.0	16.9	−0.8
129B	M5	B/C	Rib	Lower M2 R	−19.8	10.1	35.9	13.2	3.2	5.2	−20.0	8.6	44.3	16.5	3.1	10.5	−13.2	−5.9	16.0	−2.2
133	M4	B	Rib		−20.1	9.9	42.2	15.7	3.1	16.1										
135	M4	B/C	Rib	Upper M2 L	−20.1	8.4	42.3	15.6	3.2	10.6	−19.8	8.9	18.6	6.7	3.2	3.3	−13.4	−6.7	15.1	−3.6
138	F4	D	Rib	Upper M1 R	−20.2	9.2	43.4	16.0	3.2	16.9	−20.1	10.3	44.7	16.6	3.1	18.4	−15.40	−3.7	18.3	1.4
144	M4	D	Rib	Lower M2 L	−20.0	9.6	39.5	14.5	3.2	4.5	−19.8	9.7	34.3	12.6	3.2	3.8	−14.2	−6.3	15.6	−2.9
145A	M4	E	Rib	Lower M2 L	−20.1	9.1	42.4	15.5	3.2	11.4	−19.9	8.4	31.0	11.5	3.1	4.0	−14.0	−6.2	15.7	−2.7
150	F4	C/D	Rib	Lower M2 L	−20.2	8.5	41.6	15.1	3.2	7.2	−20.0	8.8	37.2	13.8	3.1	4.0	−15.0	−5.3	16.6	−1.3
158	M5	B/C	Rib	Lower M3 L	−20.0	9.4	42.4	15.8	3.1	3.4	−19.7	10.4	36.3	13.4	3.2	3.9	−14.4	−5.6	16.2	−1.8

Table 1 (continued)

Grave	Gendered age category	Phase from Leggett et al. (2021)	Bone sampled	Tooth	Bone collagen						Dentine						Enamel			
					$\delta^{13}C$	$\delta^{15}N$	%C	%N	C/N	% Coll	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C/N	% Coll	$\delta^{13}C$	$\delta^{18}O_{PDB}$	$\delta^{18}O_{PO4\ VSMOW}$	$\Delta^{18}O_{dw\text{-}MAP}$
165	M5	C/D	Rib	Upper M1 R	−20.4	9.3	40.2	14.9	3.2	3.4	−19.3	8.7	36.1	13.2	3.2	5.6	−13.9	−5.8	16.1	−2.1
168	M5	B-D	Rib		−20.2	9.1	43.4	16.0	3.2	10.3										
175	F5	C/D	Rib	Lower PM1 L	−20.4	9.6	41.7	15.5	3.1	6.3	−20.2	10.8	41.7	15.5	3.1	18.2	−15.1	−3.4	18.6	1.9
179	M5	C/D	Rib		−19.8	9.8	42.6	15.7	3.2	7.8										
180	F5	D	Rib	Lower PM2 L	−20.3	8.7	43.3	16.2	3.1	14.5	−20.0	9.5	42.9	15.9	3.1	19.6	−13.9	−3.6	18.4	1.5
193	M4	D	Rib	Upper M2 R	−20.2	8.6	37.5	13.6	3.2	3.9	−20.0	8.4	42.4	15.5	3.2	8.3	−14.0	−6.2	15.7	−2.7
199	M4	D	Rib	Upper M2 R	−19.9	10.1	42.1	15.4	3.2	7.0	−19.8	9.6	26.1	9.6	3.2	3.4	−13.2	−6.0	15.8	−2.4
208	M4	C/D	Rib	Upper M2 R	−19.9	10.6	37.3	13.8	3.1	3.6	−19.8	11.0	39.9	14.9	3.1	7.5	−13.1	−6.2	15.6	−2.8

*Poor preservation and sample was excluded from analysis. Chronological phasing: A = c. 200 BC–450 AD, B = 450–580 AD, C = 580–630 AD, D = 630–690 AD and E = 690–790 AD (Leggett et al., 2021).

Methods

All samples were prepared in the McDonald Institute for Archaeological Research, University of Cambridge and analysed on mass spectrometers housed in the Department of Earth Sciences, University of Cambridge. Full details on laboratory methods and protocols used, as well as the collation and standardisation of site context data and funerary practices are detailed in the metadata in Leggett et al. (2021), where the data are also fully accessible. The laboratory methods used are therefore briefly outlined below.

Bioapatite—enamel carbonate isotopic analyses

As detailed in Leggett et al (2021), tooth enamel powder was prepared for stable isotope analysis of bioapatite (carbonate) following the Balasse method (Balasse et al. 2002). Treated enamel powder was analysed in single aliquots at the Godwin Laboratory, Department of Earth Sciences, University of Cambridge, using a Gas Bench II coupled to a Delta V mass spectrometer for isotopic analysis. The enamel carbonate samples are reported with reference to the VPDB standard, calibrated through the NBS19 international standard for carbon and VSMOW (Vienna Standard Mean Ocean Water) for oxygen and analytical error for the carbonate samples is $\pm 0.08‰$ for $\delta^{13}C$ and $\pm 0.10‰$ for $\delta^{18}O$ as calculated through these international standards and in-house Dorothy Garrod Laboratory standards of homogenised prehistoric animal tooth enamel called standard 2 ($\delta^{18}O - 4.9$, $\delta^{13}C - 13.0$) and 3 ($\delta^{18}O - 1.1$, $\delta^{13}C - 10.0$).

As detailed in Leggett et al. (2021), there are many different conversion and correction equations for oxygen isotope values from human tooth enamel; from carbonate to phosphate, from phosphate to drinking water, drinking water to temperature… and there is still much debate in the field surrounding this (Lightfoot and O'Connell 2016; Pederzani and Britton 2019). As the enamel here was analysed as carbonate, a variety of phosphate and drinking water conversions were calculated and reported in Leggett et al. (2021). The original carbonate $\delta^{18}O_{PDB}$ measurements are reported here alongside $\delta^{18}O_{PO4\ VSMOW}$ (phosphate) values converted from $\delta^{18}O_{PDB}$ using the Chenery et al. (2012) equation.

$\Delta^{18}O_{dw-MAP}$ was also calculated for each sample from $\delta^{18}O_{dw}$ calculated from $\delta^{18}O_{carb\ VSMOW}$ ($\delta^{18}O_{dw} = 1.59*\delta^{18}O_{carb\ VSMOW} - 48.634$) and the site MAP value given by the OIPC mentioned above ($-6.9‰$) (Bowen 2019; Bowen and Revenaugh 2003; Chenery et al. 2012; Leggett et al. 2021). This was done as a simplistic measure to complement traditional visual and statistical methods for the identification of outliers/migrants using $\delta^{18}O$ values by calculating the difference between the theoretical $\delta^{18}O_{MAP}$ values and the $\delta^{18}O_{dw}$ values calculated from human tooth enamel. The equation is extremely simple:

$$\Delta^{18}O_{dw-MAP} = \delta^{18}O_{dw} - \delta^{18}O_{MAP}.$$

This difference can be used as a guide to how much an individual's $\delta^{18}O_{dw}$ value deviates from their place of burial. Given the maximum estimated inter-laboratory and population variability is $\pm 2‰$ for $\delta^{18}O$, individuals with values within $\pm 2‰$ should be regarded as 'local' (Jay 2005; Lightfoot and O'Connell 2016; Pederzani and Britton 2019; Pestle et al. 2014; White et al. 2002, 2004). Values above $+ 2‰$ could be migrants but should have 'brewing and stewing' fractionation factors considered as part of interpretation, however those below $- 2‰$ are likely real migrants or people who lived during a climatic cooling event (such as LALIA) since there are not any known cultural processes which can alter $\delta^{18}O$ values in this direction (Brettell et al. 2012a, b; Pederzani and Britton 2019).

Collagen—bone and dentine carbon and nitrogen isotopic analyses

Collagen was extracted from bone and dentine samples following a modified Longin method (Leggett et al. 2021; Longin 1971; Privat et al. 2002; Richards and Hedges 1999). Aliquots of collagen were run in triplicate using an automated elemental analyser coupled in continuous-flow mode to an isotope-ratio-monitoring mass-spectrometer. Stable isotope values of bone collagen and dentine are reported relative to an internationally defined scale—VPDB ($\delta^{13}C$) and AIR ($\delta^{15}N$). Analytical error (1σ) for all collagen samples is $\pm 0.20‰$. As per the companion data paper Leggett et al. (2021) the standards used are IAEA standard of caffeine for carbon and nitrogen ($\delta^{15}N + 1.0/1.1‰$, $\delta^{13}C - 27.5‰$); in-house standards of nylon ($\delta^{15}N - 3.14‰$, $\delta^{13}C - 26.55‰$), alanine ($\delta^{15}N - 1.4‰$, $\delta^{13}C - 26.9‰$), 'new' alanine ($\delta^{15}N - 1.22‰$, $\delta^{13}C - 23.88‰$), protein 2 ($\delta^{15}N + 6.0‰$, $\delta^{13}C - 26.9/-27.0‰$) and EMC (Elemental Microanalysis Caffeine, $\delta^{15}N - 2.5/- 2.6‰$, $\delta^{13}C - 35.8/- 35.9‰$) for carbon, nitrogen and atomic C/N ratios.

Statistical analyses

Archaeological data often have large biases (e.g. large differences in sample sizes between groups) and these biases would lead to the violation of assumptions for common statistical approaches (e.g. assumption of equality of variance across groups) (Zuur et al. 2010). Furthermore, the sampling design was nested with varying numbers of sexes, genders and age groups as well as funerary treatments and date categories represented. Frequentist approaches tend to perform poorly with these kinds of unbalanced data structures. However, Bayesian and exploratory data analysis (EDA) get around some of these issues.

EDA is a state of flexibility which does not require statistical significance or probability, and therefore avoids the proliferation of type I and type II errors and other such problems, reducing the likelihood of making false archaeological interpretations (Tukey 1977: 794, 806; Zuur et al. 2010). On this vein, Bayesian thinking is preferable to a frequentist approach as it too is more flexible; it can take on non-parametric data and uncertainty without having to violate assumptions and commit statistical sins (Kruschke 2013, 2014; Kruschke and Liddell 2018; Lavine 2019; McElreath 2018: 2–4). Therefore, a Tukey-style EDA framework and Bayesian thinking was adopted in analyses. Data were explored graphically first before undertaking statistical analyses where appropriate (McElreath 2018; Tukey 1977; Zuur et al. 2010). This can be broadly summarised as 'New Statistics' which is underscored by using Open Science practices, embracing both explorative and planned statistical methods (Calin-Jageman and Cumming 2019; Collaboration 2015; Kruschke and Liddell 2018). Furthermore, no p-values will be reported here as per the American Statistical Association (ASA) guidelines (Wasserstein et al. 2019; Wasserstein and Lazar 2016).

Statistical analyses and graphics were conducted using Free and Open Source R version 4.0.4 and Rstudio version 1.4.1106 (R Development Core Team 2021; RStudio Team 2021). The code is freely available as part of the Supplementary Material ESM1, with data primarily drawn from Leggett et al. (2021), with additional and re-formatted data given in the article and in ESM2. Maps were created using the Free and Open Source QGIS version 3.10 unless otherwise attributed (QGIS 2020).

Data were visualised and explored with a range of plots including scatterplots, violin plots, and bagplots using R packages 'ggplot2', 'ggridges', 'ggExtra' and the geom_bag function (Attali and Baker 2019; Marwick 2018; Wickham 2019; Wilke 2020).

Bagplots are bivariate versions of boxplots. They show the depth median (the point with the highest possible Tukey depth) which is roughly analogous to the univariate median and visualised as a cross (e.g. Figure 7). Then, there is a darker shaded polygon around the cross that encloses 50% of the points around the depth median called the 'bag', analogous with the box in a box plot. Around the bag is another lighter polygon which is three-times the size of the bag called the 'loop', which is equivalent to the whiskers on a box plot. Any points outside the bag and loop are considered outliers and not automatically visualised (Marwick 2018; Rousseeuw et al. 1999; Wickham and Stryjewski 2012).

BEST (Bayesian Estimation Supersedes the *t*-test) tests were used as a Bayesian alternative to a student's t-test, to compare between two groups (Kruschke 2013, 2014). The BEST test uses Markov-chain Monte-Carlo (MCMC) sampling to generate posterior predictive distributions for group data. In Bayesian statistics posterior predictive distributions (PPDs), and therefore the means of these distributions, are distributions of possible unobserved values which have been predicted based on the observed or 'real' data put into the model (Kruschke 2013, 2014). An important point is that the results are drawn from the PPD generated from the MCMC and not the inputted data directly. These were run with R package 'BEST' (Kruschke 2013). The outputs of these tests can be found in ESM3 along with an infographic and additional guidance on how to interpret them.

The DetectingDeviatingCells (DDC) algorithm was used to detect outlying cells in the numeric data available for the Finglesham burials (i.e. isotopic values, stature, number of grave goods and grave orientation). This was done using the R package 'cellWise' (Raymaekers et al. 2020; Rousseeuw and Bossche 2018). DDC can only be used on numeric data and excludes observations with over 50% missing data, and variables which have low variation from the mean. DDC uses the entirety of the data matrix to determine if cells are higher or lower than expected given the rest of the dataset. It therefore tells us if certain individual burials are outliers and for which specific metrics, given the data for the rest of the cemetery (in this case). It produces a graph called a cell map (see Fig. 12) where red cells are higher than predicted, blue cells are lower, yellow is 'normal', with orange and purple forming a scale between the extremes. White cells indicate missing values. Black/grey dots next to the row (here columns, as the cell map is rotated for easier viewing) highlight individuals which have half or more cells flagged as outliers (at either end of the scale).

Results and discussion

The data as reported in Leggett et al. (2021) are summarised in Table 1 with additional quality indicators reported (%C, %N and % collagen yield for bone and dentine). Collagen preservation was good across the site (see Table 1), with all samples except the bone collagen from grave 18 meeting the established standards for collagen preservation, and many having preservation well within the range of modern samples (van Klinken 1999).

The δ^{13}C of the bone collagen samples range from -20.9 to -19.7‰, and δ^{15}N ratios of the same samples vary from 8.4 to 10.9‰, with respective means of -20.1 ± 0.2‰ and 9.4 ± 0.6‰. Dentine from the same individuals has δ^{13}C values from -20.4 to -19.3‰ (mean -19.9 ± 0.3‰), and δ^{15}N values of 7.8–12.6‰ (mean 10.0 ± 1.3‰). The $\delta^{13}C_{carb}$ values range from -15.4 to -12.7‰ with an average of -13.9 ± 0.7‰. The $\delta^{18}O_{PDB}$ values from Finglesham range from -6.8 to -2.9‰, with a mean of -5.3 ± 1.0‰.

Figure 3 shows the enamel $\delta^{13}C_{carb}$ and $\delta^{18}O_{phosphate}$ results for the cemetery, with multi-modality shown at the site,

particularly in $\delta^{18}O_{phosphate}$ values. The split in $\delta^{18}O_{phosphate}$ values occurs around 17.0–17.5‰, with values below 17.0‰ ($n=29$) being more numerous than those above ($n=11$), which might indicate a mixed-origin group drawing from at least two different water sources. This split in $\Delta^{18}O_{dw-MAP}$ values equates to 11 individuals with local or ^{18}O enrichment (possible brewing/stewing) and the other 29 with ^{18}O depletion (see Table 1). This suggests that two thirds of the analysed burials at Finglesham could have childhood origins in colder climates, such as northern Europe.

Despite this marked bimodality in enamel carbonate signatures, Fig. 4 and Fig. 5 demonstrate the relative homogeneity in dietary signatures in both bone and dentine collagen at Finglesham. However, this does not necessarily equate to homogeneity through the life course as indicated by the large dentine $\delta^{15}N$ standard deviation mentioned above.

For bone, Finglesham $\delta^{13}C_{coll}$ values have a range of 1.2‰, and $\delta^{15}N_{coll}$ values of 2.5‰ (as mentioned above). The ranges for dentine are similarly tight with $\delta^{13}C_{coll}$ having a range of 1.1‰, and $\delta^{15}N_{coll}$ 4.8‰. There is little variation in $\delta^{13}C_{coll}$ values for either tissue, but $\delta^{15}N_{coll}$ values in bone suggest at least two different trophic levels in the population. $\delta^{15}N_{coll}$ values in dentine show more variation which could be due to variability in the types of teeth analysed, although these do not appear to be systematically offset in anyway (predominantly PM2 and M2 but some other teeth were analysed, see Table 1). This is possibly due to the diversity of childhood origins in the population as suggested by the carbonate data above. Overall, the group has a C_3 based diet with little variation in the population, with no clear evidence for a substantial marine input into the diet.

There are no clear outliers in the Finglesham subsample identifiable in either Fig. 4 or Fig. 5. This is a population with mixed origins whose dietary habits throughout life are relatively similar to one another. This is not unexpected for a smaller community buried together, where we might expect more localised patterns of consumption on a small scale, especially in bone which is more likely to represent some or all of their time in and around Finglesham and its associated settlement(s).

In the following sections chronological change in migration, dietary change over the life course and tissue offsets, and isotopic differences between the sexes are considered before using the DDC algorithm to identify outliers statistically in the Finglesham population.

Chronological change

Due to the low variation within the $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values for bone and dentine in Finglesham, the relatively short time span the sampled burials represent and the skewed sampling towards those from date categories C and D, diachronic change for diet at the site was not explored. However, change through time in $\Delta^{18}O_{dw-MAP}$ values at the site was investigated to see if any particular migration waves are identifiable. Since this involved multiple group comparisons BEST tests were not appropriate here, so a visually comparative EDA approach was used instead. Figure 6 shows that even despite some small sample sizes for earlier dated graves, individuals with negative $\Delta^{18}O_{dw-MAP}$ values are present throughout the use of the cemetery. There are only a few individuals with positive $\Delta^{18}O_{dw-MAP}$ values, one in date category B/C and the others from c. 580 AD onwards. This shows that Finglesham is a community of migrant individuals to Kent in the earlier centuries from somewhere further

Fig. 3 Scatterplot of Finglesham tooth enamel $\delta^{13}C_{carb}$ and $\delta^{18}O_{phosphate}$ values with marginal density plots ($n=40$)
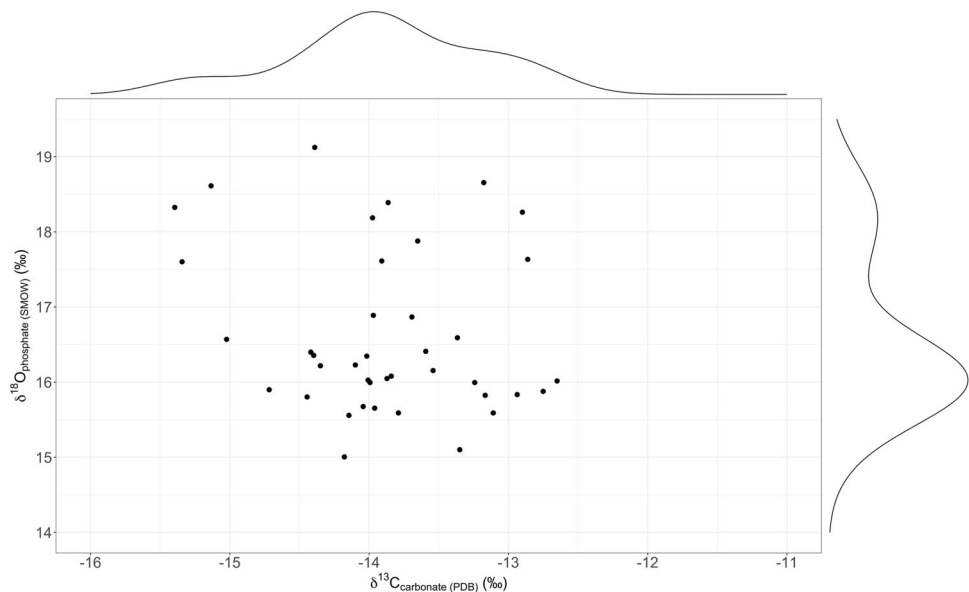
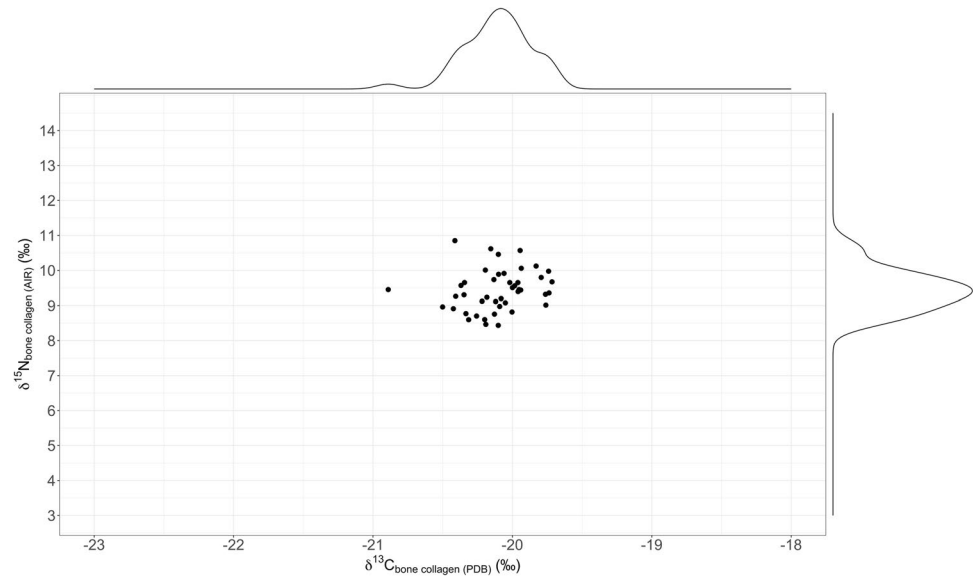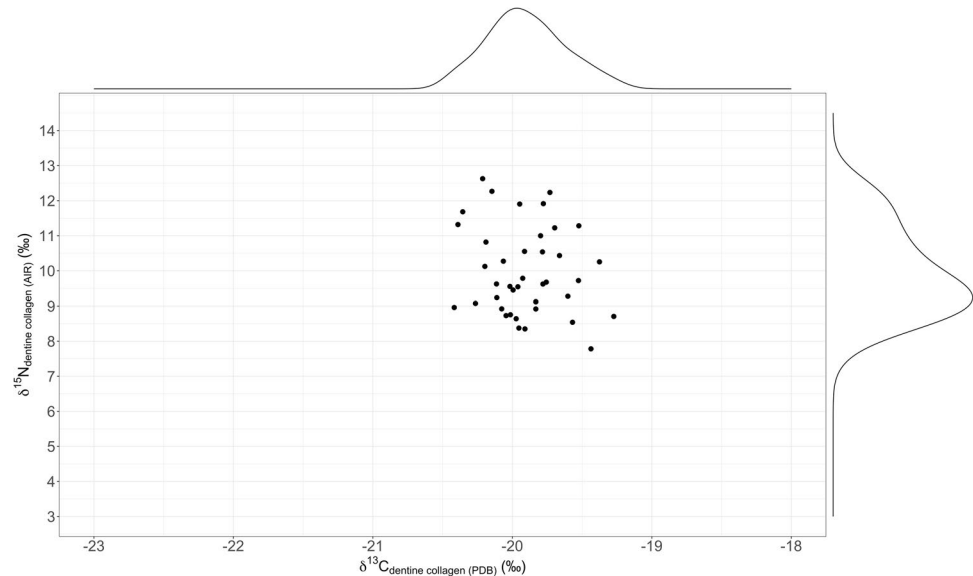**Fig. 4** Scatterplot of Finglesham human bone $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values with marginal density plots ($n = 44$)

Fig. 5 Scatterplot of Finglesham human dentine $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values with marginal density plots ($n = 40$)

north in Europe (probably Scandinavia). The later more 'local' and possible 'brewing and stewing' signatures which appear one or two generations after the founding of the burial ground are therefore likely the locally born descendants of the original group. This picture could change with more individuals included from the earlier graves, and there may be this bimodality in the earlier phases too, in which case Finglesham would be a fully mixed local and migrant burial community from its inception. There are three individuals whose $\Delta^{18}O_{dw\text{-}MAP}$ values are 1.9, 1.9 and 2.6‰. For these individuals 'brewing and stewing' effects or possible migration from somewhere further south in Europe cannot be ruled out, but without significantly different diets or strontium data it is impossible to say more.

Change through the life course

Bone and dentine $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values from individuals with both tissues analysed in Finglesham were compared, the results of which can be seen in Fig. 7. As with the bone and dentine scatterplots above, the ranges for $\delta^{13}C_{coll}$ are relatively small for both tissues (<2‰); however, the $\delta^{15}N_{coll}$ values in dentine are markedly higher. The degree of overlap between the bags and loops, and the proximity of their depth medians is reflected in the results of BEST tests comparing $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values between the tissues which found that they were very similar, with the starkest difference being the standard deviation for dentine $\delta^{15}N_{coll}$ (see supplementary material).

Fig. 6 Violin plots of Finglesham $\Delta^{18}O_{dw-MAP\ (Chenery)}$ values through time from c.450 to 790 AD (B = c. 450–580AD, E = c. 690–790AD; see Leggett et al. 2021 for details on chronological designations)
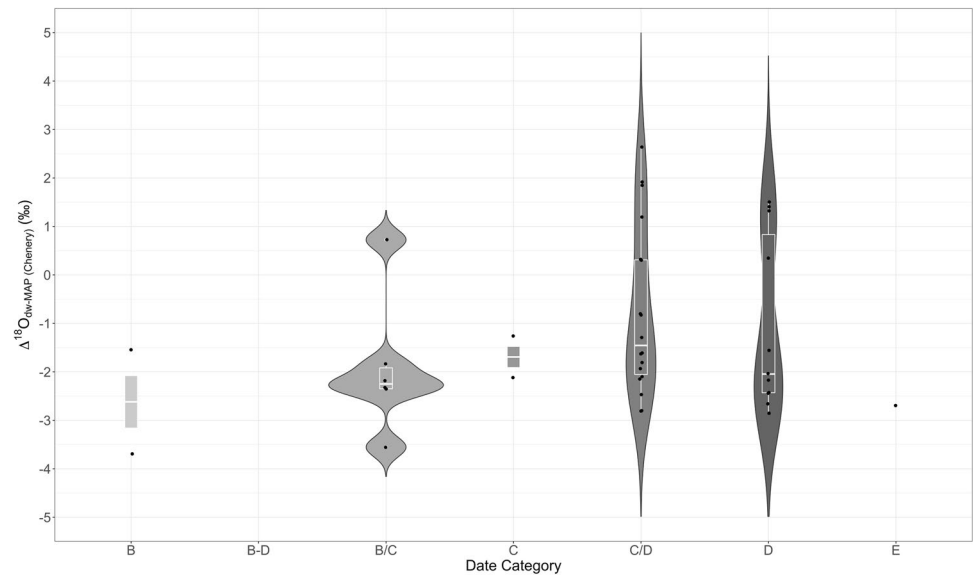
The isotopic niche for the Finglesham community in earlier life seen in dentine is far broader than that represented by bone, which is interesting, when considering the formation times for the tissues, and the fact that bone remodels. We may have expected the opposite since bone should reflect a larger time frame which could therefore have far more dietary variability. This is likely due to the high degree of mobility seen in the population. Therefore, the dentine represents C_3 diets from a variety of childhood origins. Whilst similar to the adult diets seen in bone, it has a broader isotopic niche due to the variety of environments these tissues were formed in during earlier life.

Figure 8 uses bone, dentine and enamel isotopic data to look at trophic position and tissue offsets/enrichment through the life course. There is remarkable consistency over the life course in $\delta^{13}C_{coll}$ values, with very little change seen in Fig. 8C, although the same graph shows there is more diversity in $\Delta^{15}N_{dentine-bone}$ in the population, which is as expected given the differences between the bag plots of bone and dentine discussed above. $\Delta^{13}C_{carb-dentine}$ values shown in Fig. 8A, B and D show the majority of individuals at Finglesham sitting around 6–7‰. This means that most of the sampled individuals at Finglesham have $\Delta^{13}C_{carb-dentine}$ values comparative to terrestrial and freshwater consumers on a scale from herbivory to omnivory (6‰ and up), with six individuals whose values indicate a higher trophic level ($\Delta^{13}C_{carb-dentine}$ values closer to 4‰) (Clementz et al. 2007, 2009; Clementz and Koch 2001). Figure 8A demonstrates that these higher trophic positions (~ 5‰ or below) do not correlate directly to $\delta^{15}N_{coll}$ values, but what Fig. 8B implies

Fig. 7 Bag plots of bone versus dentine $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ in Finglesham
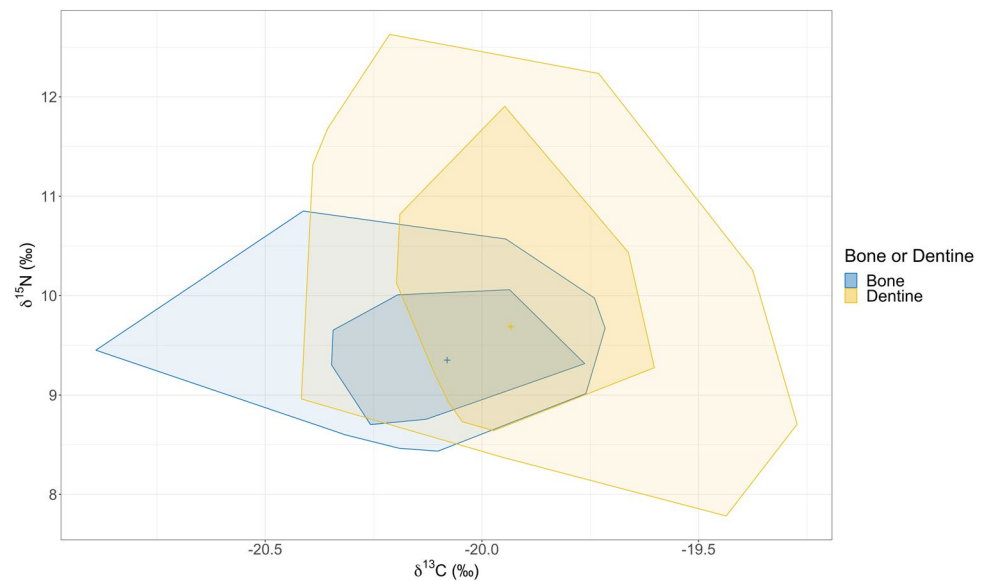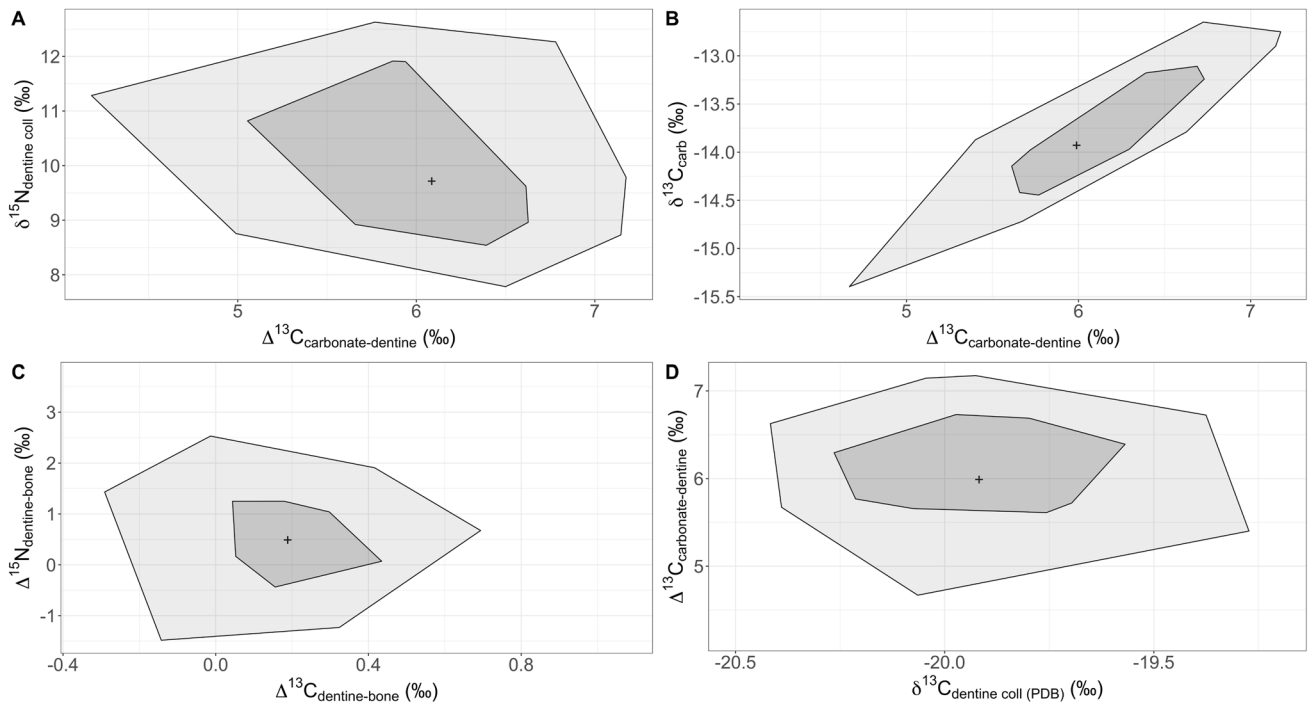
Fig. 8 Bag plots of Finglesham data. **A** $\Delta^{13}C_{\text{carb-dentine}}$ and $\delta^{15}N_{\text{dentine coll}}$. **B** $\Delta^{13}C_{\text{carb-dentine}}$ and $\delta^{13}C_{\text{carb}}$. **C** $\Delta^{13}C_{\text{dentine-bone}}$ and $\Delta^{15}N_{\text{dentine-bone}}$. **D** $\delta^{13}C_{\text{dentine coll}}$ and $\Delta^{13}C_{\text{carb-dentine}}$

is that in C_3 diets, lower $\Delta^{13}C_{\text{carb-dentine}}$ values correlate with low $\delta^{13}C_{\text{carb}}$ values. This indicates that higher trophic levels in individuals may be due to freshwater resources rather than terrestrial or marine protein.

Figure 8 highlights the variability in childhood $\delta^{15}N_{\text{coll}}$ values compared to the signatures in bone, and the C_3 nature of diets of people at Finglesham. Very few individuals had protein-heavy diets, those which do are a minority,

and this may be from freshwater resources. Since high $\delta^{15}N_{\text{coll}}$ values do not correspond with high trophic levels, as measured through tissue offsets, at Finglesham despite the faunal evidence from (high status sites) such as Lyminge (Knapp 2018), we need concerted efforts to form more appropriate faunal baselines for sites, and consider what other aspects of agriculture and diet may be at play such as plant values (Hamerow et al. 2020).

Fig. 9 Violin plot of Finglesham human tooth enamel $\Delta^{18}O_{\text{dw-MAP (Chenery)}}$ values coloured by osteological sex, females $n = 16$, males $n = 24$
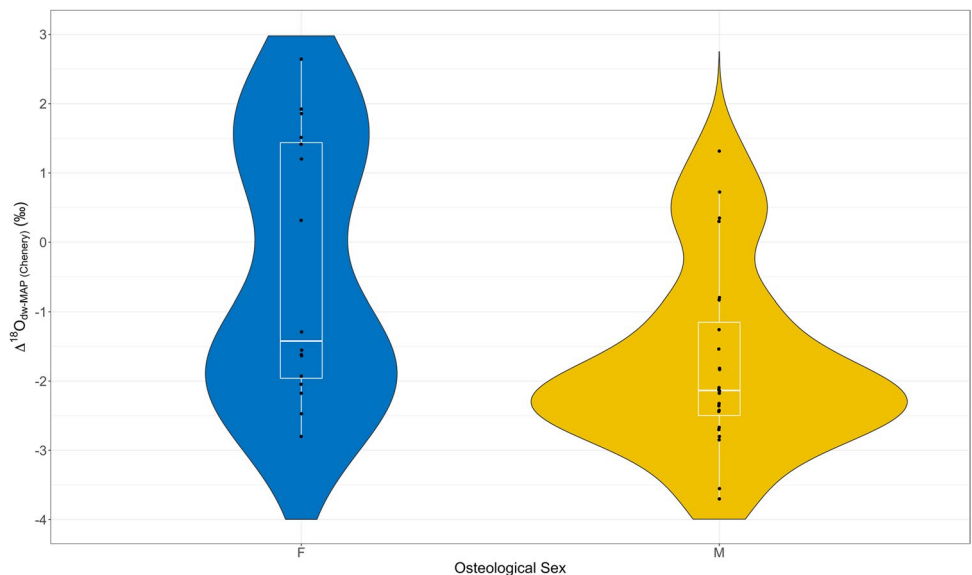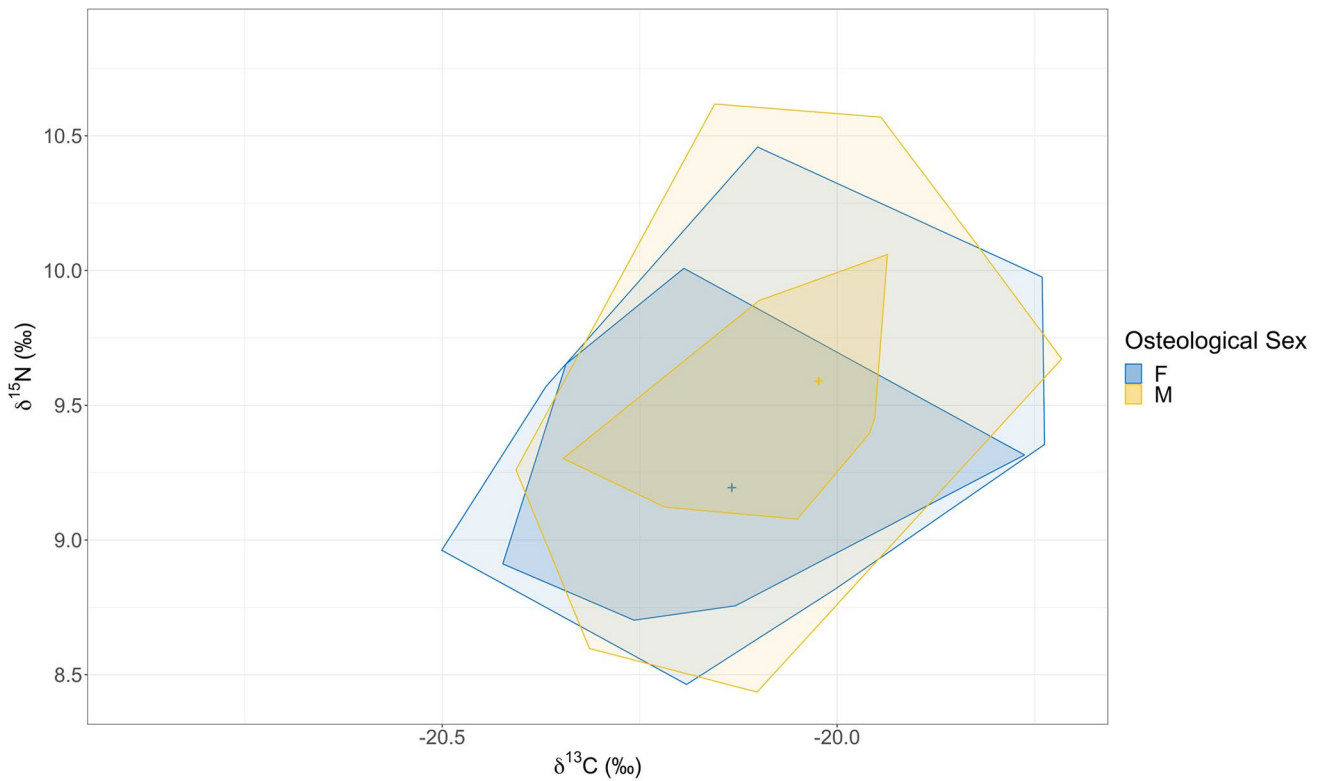
Fig. 10 Bag plot of female versus male bone $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values at Finglesham

Fig. 11 Bag plot of female versus male dentine $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values at Finglesham
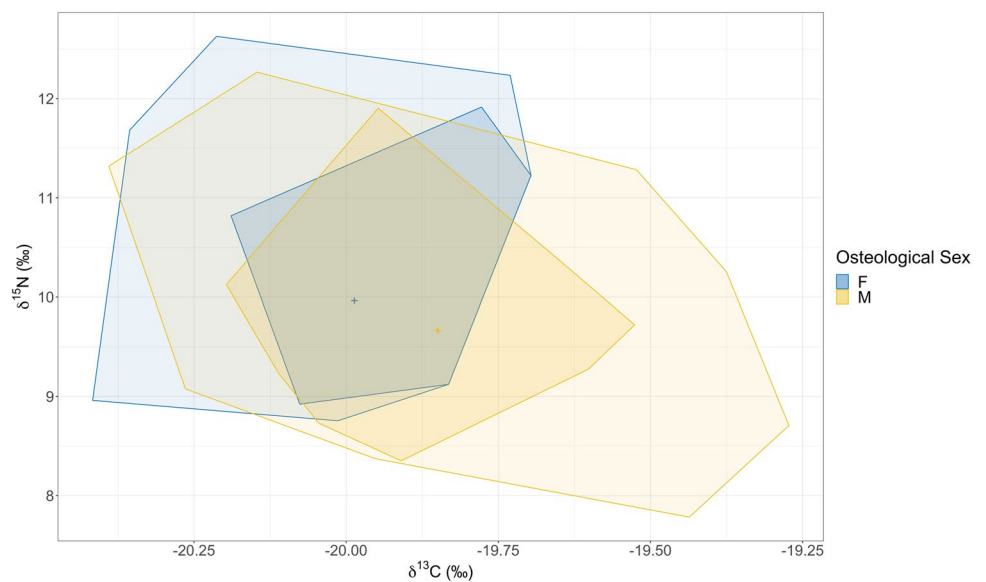
Sex-based differences

Given the stark differences in height at Finglesham between females and males, and the assertion by Härke and Richardson that this may reflect different communities of origin for males and females (Härke 2011; Richardson 2005), mobility or dietary differences between the sexes on this smaller community scale were tested.
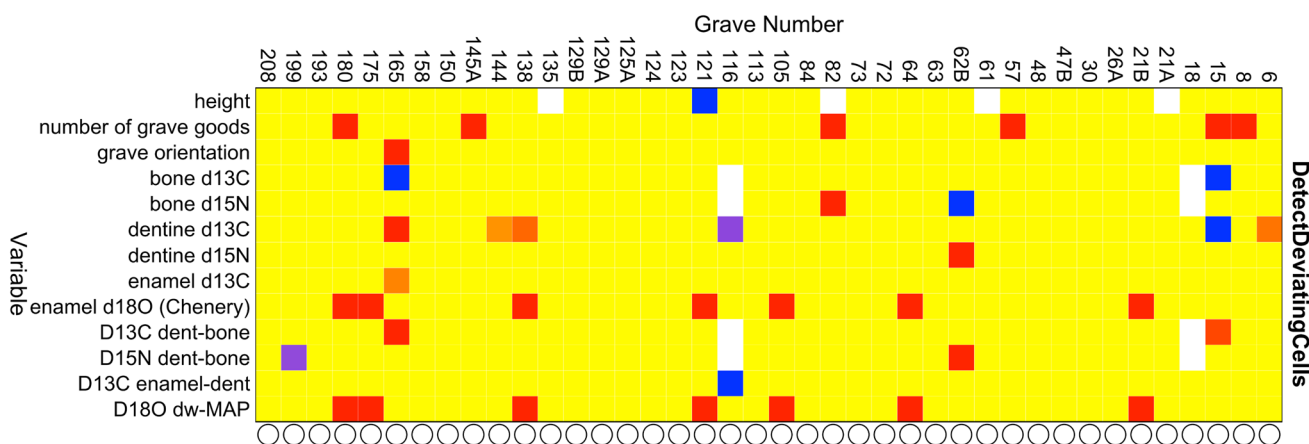
Fig. 12 DetectDeviatingCells cell map for Finglesham ($n=40$). Red cells = higher than predicted values, orange = slightly higher than predicted, blue = lower than predicted, purple = slightly lower than predicted, yellow = as predicted, white = missing value

Figure 9 compares $\Delta^{18}O_{dw-MAP}$ values between females and males, and, whilst bimodality is found in both groups, it is more evenly split in females who also have the highest values for the site. Both groups are skewed towards negative values and males have the lowest $\Delta^{18}O_{dw-MAP}$ values for the subsample. A BEST test showed no difference between the groups, however since this is largely based on means, it is perhaps not the best measure of the differences in distribution shapes seen above in Fig. 9 (see supplementary material). With a greater sample size from both sexes across the cemetery, this picture could change but it does show that there was a large portion of the population with 'non-local' signatures in both sexes. Given the diachronic changes above, perhaps marriage practices changed through time, or there were more local women and a gender imbalance during the seventh century in the cemetery, with males being buried elsewhere. This issue of a lack of male burials dated to later phases is a well-known problem in early medieval cemeteries, with a tendency to date 'male' grave goods such as weapons as significantly earlier than 'female' dress accessories which show more stylistic changes through time (Bayliss et al. 2013; Brownlee 2019).

Finglesham could therefore represent a largely immigrant population with incomers of both sexes, who may have practiced exogamy later in time with a mixture of 'local' and 'non-local' females and males present; however, a larger sample size from both sexes and better dates for male graves in particular would be needed to confirm this.

Do these sex-based differences in height and $\Delta^{18}O_{dw-MAP}$ values bear out in diet? Are these differences in height due to nutrition more so than genetics, given that many females had similar childhood origins to the males?

What Fig. 10 and Fig. 11 show is that there is an almost complete overlap in bone values between females and males, but this is not the case for dentine. Despite the high degree of overlap in bag plots between female and male bone $\delta^{13}C_{coll}$ and $\delta^{15}N_{coll}$ values, the inner bags are very different in shape. Diet in childhood, represented by dentine, is where the real differences lie with a high degree of overlap, but ~ 50% of males having less negative $\delta^{13}C_{coll}$ and slightly lower $\delta^{15}N_{coll}$ values than females. Males occupy a larger isotopic niche in childhood in the Finglesham subset. Therefore, the question is, are these differences due to dietary or physiological differences? Or are they so small that they may be biochemically ephemeral? The relatively small differences suggest it might be the latter and are consistent with offsets between the sexes found in modern Japanese individuals (Minagawa 1992).

Detecting deviants analysis

As outlined above DDC analysis looks for outliers on a cell-wise basis, meaning here that it flags variables for burials which stand out given their other contextual information (e.g. lower than expected dietary signatures given the number of grave goods they have or stature). Six individuals (graves 16, 106, 118, 133, 168 and 17) were removed by DDC due to having over 50% missing data, leaving 40 individuals suitable for DDC analysis. The results can be seen in Fig. 12.

Six individuals who stand out with three or more deviating cells are summarised in Table 2. There is a mixture of females and males, and there are no clear trends in what variables they deviate in or their contextual data. Four of the individuals are coffin burials or possible coffin burials, and all bar one of these individuals are aligned roughly W-E, however, as is clear in Fig. 2, most burials sampled are broadly on a W-E axis.

Table 2 Individuals from Finglesham with three or more deviating cells identified by DDC in Fig. 12

Grave no	Date category	Gendered age category	No. grave goods	No. foreign grave goods	Grave orientation	Body position	Interment style	$\delta^{13}C_{coll}$		$\delta^{15}N_{coll}$		$\delta^{18}O_{PO4\ VSMOW}$ (‰)	$\Delta^{18}O_{dw\text{-}MAP}$ (‰)
								Rib	Dentine	Rib	Dentine		
15	B	M5	9	0	WNW-ESE (105°)	Ext. supine	Earth cut grave	−20.9	−20.2	9.5	10.1	15.0	−3.7
62B	C/D	F4	6	1	W-E (90°)	Ext. supine	Coffin; double burial	−20.4	−20.2	8.9	12.6	15.8	−2.5
121	C/D	F5/6	0	0	W-E (99°)	Ext. supine	Planks/coffin	−19.9	−19.6	9.4	8.5	18.7	1.9
138	D	F4	7	0	WSW-ENE (80°)	Ext. supine	Coffin	−20.2	−20.1	9.2	10.3	18.3	1.4
165	C/D	M5	3	0	N-S (174°)	Ext. supine	Earth cut grave	−20.4	−19.3	9.3	8.7	16.0	−2.1
180	D	F5	9	0	W-E (93°)	Ext. supine	Coffin	−20.3	−20.0	8.7	9.5	18.4	1.5

Grave 15 and grave 165 should be highlighted in particular, as they have the most deviating cells (four and five respectively) for the site. Grave 15 is flagged for number of grave goods (high), their $\delta^{13}C_{coll}$ values (low) and therefore also $\Delta^{13}C_{dentine-bone}$ (high). Grave 165 was flagged for five variables (see above) and is a clear outlier for their community in terms of their N-S orientation but also their diet, especially in childhood, and the change between dentine and bone in terms of $\delta^{13}C_{coll}$ values. Both of these individuals, whilst not outliers in DDC for oxygen (due to the high proportion of migrants in the cemetery), have $\Delta^{18}O_{dw-MAP}$ values which suggest they are non-locals, so perhaps their deviance in diet is due to their foodways before coming to Kent. Using other methods, these individuals would not have been highlighted as particularly different from the rest of the group, so this certainly opens up avenues for further investigation.

It is interesting to note that the individuals who are outliers for oxygen (both $\delta^{18}O_{phosphate}$ and $\Delta^{18}O_{dw-MAP}$) in Fig. 12 stand out as higher than predicted for both values, and all are female, except grave 105. Their $\Delta^{18}O_{dw-MAP}$ values are all over $+1‰$, highlighting that the majority of the cemetery's population with negative values is seen by the algorithm as the 'norm'.

When this is compared with using the $\pm 2‰$ criteria for $\Delta^{18}O_{dw-MAP}$ values, there are 19/40 individuals who fall outside the 'local' range for Finglesham. Conversely these are mostly male burials (14/19), and the one outlier above $+2‰$ is the female grave 21B. Five of these burials are flagged by DDC as outliers for a variety of variables, but not necessarily for oxygen isotope values. There do appear to be some key underlying differences in enamel $\delta^{18}O_{phosphate}$ and $\Delta^{18}O_{dw-MAP}$ values between female and male burials at Finglesham, and a tension between what is 'normal' for the cemetery in terms of mobility signatures versus the underlying 'local' isoscapes. The DDC analyses have supported the fact that there does not seem to be any particular link between some aspects of burial practice, mobility or diet within this community. Dietary outliers are rarely also mobility outliers, and neither are particularly linked to other non-isotopic variables.

Conclusions

From these analyses, it is clear that Finglesham is a mostly migrant population where change in diet from childhood to later in life, particularly in males, is visible. This suggests that these people spent quite some time in the region for their bone isotopic signatures to become more homogenised to reflect 'Kentish' or perhaps Finglesham specific resources and foodways. Those who stand out in terms of bone values may be more recent incomers to the area. The migration pattern at Finglesham supports this as they seem to be gendered, with more males being identified as 'non-locals'.

These dietary patterns and male mobility support a model of incoming male migrants and their acculturation once in Kent, at least in terms of foodways. This suggests local resources and dietary syncretism/acculturation win out here over imported childhood foodways.

Furthermore, the suggestion of freshwater fish consumption in the isotopic signatures at Finglesham aligns with zoo-archaeological patterns seen at high status sites like Lyminge as they underwent Christianisation as per the laws of Wihtred of Kent (Knapp 2018; Thomas 2013; Thomas and Knox 2012; Whitelock 1994).[2]

It has been demonstrated here that the community buried at Finglesham in Kent were from a diverse range of origins, and that migration to the area was likely continuous throughout the first millennium AD. Migrants could have come from areas of the Mediterranean up to northern parts of Scandinavia, with brewing and stewing also a potential factor for some individuals. This diversity in origins does not appear to correlate with any particular number or style of grave goods. The debated expressions and changes in 'ethnic' identities theoretically signalled by certain objects like brooches have far more complex cultural meanings and processes of construction behind them and are not closely associated with individuals with any particular isotopic signatures.

The cemetery at Finglesham provides new evidence for the '*Adventus Saxonum*' and continuing migration from the Continent to Kent after the fifth and early sixth century AD. The isotopic data when combined with the other archaeological evidence from the cemetery demonstrate the cultural integration of these migrants into the community both in life and in death.

[2] The laws of Wihtred (c. 695 AD) state the following in regard to Christian dietary prohibitions: "If anyone gives meat to his household in time of fasting, he is to redeem both freeman and slave with *healsfang*. If a slave eat it of his own accord [he is to pay] six shillings or be flogged." (Whitelock, 1994).

Declarations

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