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Weaning at Anglo-Saxon Raunds: Implications for changing breastfeeding practice in Britain over two millennia.

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ABSTRACT

This study investigated stable-isotope ratio evidence of weaning for the late Anglo-Saxon population of Raunds Furnells, Northants., UK. $\delta^{15}N$ and $\delta^{13}C$ values in rib collagen were obtained for individuals of different ages to assess the weaning age of infants within the population. A peak in $\delta^{15}N$ values at c. two years old, followed by a decline in $\delta^{15}N$ values until age three indicates a change in diet at that age. This change in nitrogen isotope ratios corresponds with the prevalence of an osteological indicator of stress (cribra orbitalia) and the mortality profile from the site, as well as with archaeological and documentary evidence on attitudes towards juveniles in the Anglo-Saxon period. The pattern of $\delta^{13}C$ values was less clear. Comparison of the predicted age of weaning to published data from sites dating from the Iron Age to the 19th century in Britain reveals a pattern of changing weaning practices over time. Such a change has implications for the interpretation of socio-economic changes during this period of British history.

The age at which a child is weaned is an important cultural variable that has an impact on demographic factors such as the fertility rate and child mortality rate of a population (Katzenberg et al., 1996; Mays et al., 2002; Dupras and Tocheri 2007). Previous research has investigated weaning practices using stable isotope ratio analysis of nitrogen, as well as carbon in some studies. This study aimed to compare evidence of weaning age derived from carbon and nitrogen isotope ratio analyses with evidence of weaning practices taken from documentary sources for the later Anglo-Saxon period (c. 850-1066AD) in England, and then to place these results in the broader context of changing weaning practices over approximately 2000 years.

In the early Anglo-Saxon period (c.450-650 AD) children aged over two to three years were more likely to be buried in normal cemeteries than their younger contemporaries and were more likely to be buried with artefacts, including knives and occasionally weapons such as spear tips (Härke, 1992; Crawford, 1993, 1999; Lucy, 1994; Stoodley, 2000). This relationship has been interpreted as evidence that at this age children started to be viewed differently in society. Such a change corresponds with later Anglo-Saxon documentary evidence which reports the social transition from *unsprencende cild* (child without speech – believed to correspond with the Latin *infans*, or infancy) to the next stage of childhood, after which decisions about the future of the child (for example, whether they would go into the church) could be made (Crawford, 1999, 54). This evidence suggests that Anglo-Saxon children passed through an important age threshold around two to three years of age, one which altered their social – and possibly their legal – status. It has been argued that this may have been the age by which infants were fully weaned, and it corresponds with a peak in mortality in some populations (Hawkes and Wells, 1983; Crawford, 1999). The present study has used measurement of carbon and nitrogen isotope ratios to investigate the age of weaning of an Anglo-Saxon population, and thereby establish whether weaning age estimations derived by this chemical technique correspond with contemporary documentary and archaeological evidence.

The identification of trophic level shifts by the analysis of nitrogen isotope ratios in human bone can be utilised to study weaning age (Herring et al., 1998; Schurr, 1998; Fuller et al., 2006a). Trophic levels are the stages within food chains (i.e. producers, primary consumers, or secondary consumers) and stable isotope ratios vary between trophic levels due to the fractionation of isotopes within tissues. Isotope fractionation is the separation of the lighter and heavier isotopes of an element, and in this case the preferential excretion of the lighter isotopes from animals, leaving the body tissues enriched in the heavier isotopes (Pollard et al., 2007, 170). When a secondary consumer feeds, it ingests tissues which have already been enriched with the heavier isotope. Further fractionation occurs within that animal, leading to more isotope enrichment in its tissues. This fractionation mechanism continues up the food chain, with increases of around 3-6‰ in δ^{15}N and 1-1.5‰ in δ^{13}C bewteen each trophic level (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984; Bocherens and Drucker, 2003; Müldner and Richards, 2005; Hedges and Reynard, 2007).

When an infant is exclusively breastfeeding they are one trophic level above their mother, and this dietary difference is reflected in their nitrogen isotope signature, as has been shown in both modern (Fogel et al., 1989; Fuller et al., 2006a) and archaeological studies (Schurr, 1997; Herring et al., 1998; Dupras et al., 2001; Mays et al., 2002; Richards et al., 2002; Fuller et al., 2003; Prowse et al., 2008). δ^{15}N values in the infants' tissues will rise to be c. 2-4‰ higher than the mother, whilst the latter is breastfeeding, before gradually falling to the same level as the adults within the population (Jay et al., 2008; Katzenberg and Pfeiffer, 1995; Larsen, 1997, 284; Fig. 1). δ^{13}C values should follow a similar pattern, with an increase of up to 1‰ during breastfeeding, but with a more rapid decrease to the population mean once supplementary foods are introduced (Fuller et al., 2006a; Jay, 2009). This is because carbon occurs in all parts of the diet, whereas dietary nitrogen is derived almost exclusively from protein (Schoeller, 1999; Jim et al., 2006). The introduction of low-protein supplementary foods will thus affect $\delta^{13}C$ more than $\delta^{15}N$ (Fuller et al., 2006a; Jay et al., 2008).This study has used stable isotope analyses to investigate the weaning age of infants buried in the late Anglo-Saxon cemetery at Raunds Furnells, Northamptonshire, UK (Boddington, 1996). Nitrogen and carbon isotope ratios in the collagen of sub-adults of different ages were analysed, and then have been compared to the isotope ratio signatures of adult females of child-bearing age (young and middle adults, c. <46 years) from the same population.

Raunds Furnells

A small chapel was founded at Raunds in the 9th century, around which a cemetery was founded in the 10th century. The cemetery was almost completely excavated between 1977 and 1984 and it remains one of the most completely excavated churchyard cemeteries of the later Anglo-Saxon period. Importantly, the cemetery and chapel went out of use before the Norman Conquest (AD 1066) and thus there is little disturbance of the burials and the chronology of the cemetery is well understood. Radiocarbon dates for the graveyard give a date range of cal AD 978-1040 (cal to two sigma) (Boddington, 1996, 72). The graves were arranged in orderly rows, the burials were all supine and extended, orientated east-west with the head at the west end of the grave, and individuals were interred without grave goods – typical of cemeteries of this period. The cemetery is notable because of the large number of well-preserved skeletons (n=361), the use of stones within the graves to support the heads (and occasionally other areas) of the bodies, and the clustering of infants' graves around the church, in the so-called 'eaves-drip' area (Boddington, 1996, Hadley and Buckberry, 2005, Craig and Buckberry, 2010; Craig-Atkins in prep). The site is also well known for the large number (n=162) of well-preserved and accurately aged sub-adult skeletons, which made it ideal for our study. 17.2% of the entire population died in infancy (0 to 12 months); 8% in early childhood (1 to three years); 10.2% in middle childhood (four to seven years) and 4.7% in older childhood (8-12 years) (Craig, 2006, 115). Active cribra orbitalia, which can be an indication of physiological stress, had a higher true prevalence rate in individuals in the middle childhood category (Craig, 2006, 117; Table 1). This age distribution and pattern of pathology suggests that there was a physiological stress on the population that was severe enough to increase risk of death during middle childhood, which was not present for slightly older or younger children. One possible explanation is that this stress could be due to decreased immunity in children after weaning.

TABLE 1 HERE

MATERIALS AND METHODS

Samples were taken from the rib mid-shaft of 60 juveniles between birth and seven years-at-death (see Tables 2 and 3). An attempt was made to collect a similar number of samples for each 6-month age period within this range. The adult samples (n=20; also taken from the rib mid-shaft) are from females aged 18 to 45 years, with the majority belonging to the young or young/middle adult age categories in order to ensure they are females of child-bearing age. Data from a previous study of isotope ratios in adults from Raunds (Howcroft 2008) have been included in the data set.

Age was estimated by Craig (2006) using dental development and eruption, epiphyseal fusion and long bone length (Scheuer and Black, 2000a; Scheuer and Black, 2000b; Moorrees et al., 1963a,b; Ubelaker, 1989), with more reliance placed on the dental age estimates. For adults, sex was assessed using morphological traits of the pelvis and skull

(Buikstra and Ubelaker, 1994) and age was estimated using the pubic symphysis, auricular surface and dental wear (Brothwell, 1972; Brooks and Suchey, 1990; Buckberry and Chamberlain, 2002).

In order for stable isotope ratios in bone collagen to be used to estimate the age of weaning, the rate at which changes in the isotope ratios in the diet are incorporated and recorded in the bone must be taken into account. Bone turnover rates vary with physiological stress (Abrams et al., 1993; Weinbrenner et al., 2003), bone type (trabecular or cortical) and therefore skeletal element (Valentin, 2002), and also with age (Wild et al., 2000); the latter two factors are particularly important to this study. Trabecular and cortical bone remodel at similar rates during infancy; however, by the age of five years trabecular bone remodels at a relatively faster rate in comparison to cortical bone (Valentin, 2002). In this study, ribs were sampled, as they have a high proportion of trabecular bone and therefore a faster bone turnover than other elements. In addition, bone turnover will have been faster in the infants and young children than in the older individuals in the population (bone turnover is 300% per year for individuals aged birth to three months, 105% per year at one year of age, and 66% per year at five years of age; Valentin, 2002). This observation means that the lag between dietary change and its reflection in the bone collagen isotope signature will be minimal for children younger than or around weaning age. Trabecular bone in adults remodels at 10-25% per year (Valentin, 2002; Hedges et al 2007), meaning isotope ratio analysis of collagen extracted from ribs of the adults used as a baseline in the study will give a mean value that represents the diet over approximately the last four to ten years of life.

Rib samples were prepared using the Longin (1971) method, with modifications by Brown et al. (1988). 300-400 mg samples were cleaned using air-abrasion and demineralised in 0.5M HCl at 4°C for one to two weeks. The samples were rinsed, then heated to 70°C for 48 hours in a pH3 solution. The samples were filtered using an Ezee filter, then ultra-filtered using a Millipore membrane. The collagen produced was frozen overnight at -35°C, then freeze-dried over a 48 hour period. The samples were analysed in duplicate using a Delta-Plus XL continuous helium flow stable isotope ratio mass spectrometer, coupled to a Flash EA 1112 series elemental analyser, at the University of Bradford. Using a number of laboratory standards, analytical error was determined to be ±0.2‰.

RESULTS

Two measures of sample integrity were utilised in order to exclude any samples presenting evidence of excessive collagen degradation. DeNiro and Weiner (1988) show that modern collagen samples have a C:N ratio between 2.5-3.9, and that collagen samples with C:N ratios outside of this range have been substantially affected by degradation processes, and therefore are not suitable for analysis. The majority of samples from Raunds have C:N ratios between 3.22 and 3.59, indicating that they are sufficiently preserved. One replicated sample (R5343) produced an erroneous C:N ratio of 6.28 and was excluded from further analysis. Fresh bone has a collagen yield of approximately 22% by weight, which falls after burial (Van Klinken, 1999). The speed of this loss of collagen is dependent on burial conditions, and collagen yields under 1% are considered to be too diagenetically altered to provide accurate isotope ratio determinations. Ten samples from Raunds has collagen yields under 1%; of these, eight samples had collagen yields between 0.5% and 0.9%, and had C:N ratios consistent with non-diagenetically altered collagen, therefore these samples were not excluded (DeNiro and Weiner, 1988; Dobberstein et al., 2009). Samples from R5213 (adult) and R5322 (two to four years) had collagen yields of only 0.2%, and were excluded from further consideration in this study.

The carbon and nitrogen isotope ratio data for all individuals are summarised in Table 2. The juvenile and adult data together, including data by Howcroft (2008), have a range of δ^{15}N values from 8.46‰ to 15.82‰, with δ^{13}C values between -20.63‰ and -18.88‰. Figure 2 shows the isotope ratio values for the adults only, who have a narrower range of isotope ratio values than the non-adults: δ^{15}N values from 9.45‰ to 12.53‰, and δ^{13}C values between -20.33‰ and -19.37‰.

TABLE 2 HERE

In this study young adults (18 to 25 years), young middle adults (26 to 35 years) and old middle adults (36 to 45 years) have average δ^{15}N values of 10.92‰, 11.17‰ and 10.77‰, respectively; the mean δ^{13}C values were -19.80‰ (young adults), -19.83‰ (young middle adults) and -19.82‰ (old middle adults). There are no significant differences between the average δ^{15}N or δ^{13}C values for the female age groups (ANOVA; p=0.770 and p=0.971, respectively). The grouping of the adult isotope ratio data indicates that these individuals were all consuming a broadly similar C_3 terrestrial diet. The δ^{15}N and δ^{13}C values for Raunds adults are similar to those from the early Anglo-Saxon cemetery of Berinsfield, Oxfordshire (Privat et al., 2002), suggesting that inland populations at that time ate a diet of C_3 plants and terrestrial animals, with perhaps a small freshwater fish component. A more recent study of early Anglo-Saxon diet from 18 cemeteries supports these interpretations of adult diet at Raunds and Berinsfield, but noted small marine and freshwater components in coastal and riverine populations respectively (Mays and Beavan, 2012).

Raunds individuals aged less than six months have δ^{15}N values similar to those of adults, or values less than 1.5‰ above the maximum of the adult range. The δ^{15}N values from individuals who died between six months and 1.5 years were all more than 2.45‰ above the adult mean and at least 1.13‰ above the maximum adult value of 12.53‰. The highest δ^{15}N value was 15.82‰ (R5140, a 2-year old individual), which is 3.43‰ above the maximum adult value (see below). Individuals with a mean age of two years have a large spread of δ^{15}N values, from the maximum of 15.82‰ to one individual with a δ^{15}N value equivalent to the mean value obtained for the adults (11.01‰). By the age of three years the majority of the juvenile δ^{15}N values fall within the range of adult values (see Table 3). The wide range of δ^{15}N values in the Raunds juveniles relative to the adults suggests that the individuals in the age bracket birth to six years were consuming more varied diets than adult females from the same population (Fig. 3).

TABLE 3 HERE

The data for δ^{13}C values are varied, with a weak relationship between age-at-death and δ^{13}C value (Fig. 4). All individuals between six months and two years of age have δ^{13}C values above the adult mean, but several of these fall within the range of adult values. The highest δ^{13}C values were for individuals aged two years, although other two-year-olds had low δ^{13}C values. As expected, all of the juvenile age categories exhibit overlap with the adult δ^{13}C range, and even the peak value (-18.88‰, R5109, a 2-year old) is less than 1‰ above the mean adult δ^{13}C value (see Table 3). Although the carbon isotope ratio data does not show a clear relationship with age, the general pattern observed echoes that seen in the nitrogen isotope ratios for this population.

Interpretation – Breastfeeding at Raunds

The results of this study show an increase in δ^{15}N values in Raunds juveniles after birth of c. 3‰ compared with the adult baseline, reflecting the trophic level shift expected from the change between being nourished via the placenta in the womb to breast-feeding. δ^{15}N values remain high in all individuals between 0.5 and 1.75 years, reflecting the period of exclusive breastfeeding. Although the highest δ^{15}N value was exhibited by R5140 (aged two years), the data for the two-year old cohort is diverse, suggesting that complementary feeding had commenced before two years. It is possible that the high δ^{15}N for R5140 reflects prolonged exclusive breastfeeding of this individual, but increased fractionation caused by physiological stress should also be considered. The mean δ^{15}N values of individuals aged three and above fall within the range of adult values, indicating that breastfeeding had ceased by three years.

A series of *t*-tests (Table 4) show that the most significant differences ($p<0.005$) in mean δ^{15}N values occur between the age groups 0 years and 0.5 to one year old – a rise in δ^{15}N values related to breast-feeding after birth, and between 2.5 and three years. The latter result would suggest that after the age of 2.5 years, juveniles at Raunds Furnells were consuming a diet similar to that of the adult females in the population. The gradual introduction of complementary foods was unlikely to have produced statistically significant shifts in δ^{15}N values of bone collagen.

TABLE 4 HERE

R5023 (a three-year old) has a δ^{15}N value below the range of isotope ratios in the adult females, which is unexpected in a juvenile of this age. This anomaly may be due to a high proportion of plant material in the weaning diet of this individual relative to the diet of the general population. R5023 is also one of the juveniles with cribra orbitalia, a pathological condition that relates to physiological stress, potentially as a result of dietary deficiency such as anaemia; it is possible that a largely plant-based weaning diet could lead to malnutrition in some individuals.

DISCUSSION

Anglo-Saxon infants are thought to have been weaned relatively swiftly (Crawford, 1999, 73). Data from this study would support that interpretation, since the Raunds infants appear to have changed from being exclusively breast fed, to an adult diet in approximately one year. The final change to an adult diet between two and three years also corresponds with archaeological and documentary evidence of a change in the status and treatment of children aged over two to three years (Härke, 1992; Crawford, 1999, 70-73), perhaps reflecting the decreased risk of death during childhood after weaning was complete – a significant rite of passage in many societies.

Privat et al. (2002) briefly discuss weaning age at the early Anglo-Saxon cemetery of Berinsfield, Oxfordshire (5th to 7th century) as part of a larger dietary study. They found maximum δ^{15}N values of ~3‰ above the adult female mean in a 2-year old individual, followed by a general decrease in δ^{15}N values with age. Those data are very similar to the data for Raunds Furnells generated by this study. Isotope ratio data from the Anglo-Norman cemetery at Black Gate, Newcastle-upon-Tyne, UK (Macpherson et al., 2007) indicated that children were breastfed until at least six to nine months and were eating a low protein diet between three and six years. The sampling strategy of their study compared dentine in teeth that developed at different ages, which meant that a precise age for weaning could not be given.

How does the data from the Anglo-Saxon period compare with that from weaning studies of populations of different date in Britain? Data are now published that facilitate a comparison of weaning practices for the last two and a half millennia, such that changes to the practice of weaning can be examined, under the proviso that we assume that the populations under study are representative of their period. Weaning age at Iron Age Wetwang Slack, East Yorkshire, UK (Jay et al., 2008) was examined using both nitrogen and carbon isotope ratios. That study was not able to define a clear breast-feeding/weaning pattern in the isotope ratio signatures, because the infants did not appear to occupy a full trophic level above the adult females. Jay and colleagues (2008) suggested that the absence of a clear trophic level shift indicated restricted breast-feeding at Wetwang Slack, with infant diets supplemented by animal milk and plant gruels from an early age. The data from Wetwang Slack suggest that Iron Age weaning practices were significantly different to the weaning practices of later periods.

At the late Roman site of Queensford Farm, Oxfordshire (Fuller et al., 2006b), δ^{15}N values indicated that weaning had started before two years of age (a lack of infants under 18 months in this sample meant the age at which complementary feeding commenced could not be estimated accurately). δ^{15}N ratios were comparable to the adult mean once individuals were approximately four years old. Those data indicate that Romano-British infants started to be weaned at a similar age to infants during the Anglo-Saxon period, but that the duration of complementary feeding was longer.

Mays et al. (2002) analysed skeletal material from the medieval site of Wharram Percy, UK, which dates from the 10th to 16th century. The data from Wharram Percy suggest that weaning began at around one year, and was completed by age 2, which corresponds with documentary evidence of weaning practice for the medieval period (Mays et al., 2002). The age of weaning is younger and the duration of complementary feeding was shorter at Wharram Percy than at Berinsfield (5th to 7th century) and Raunds (10th to 11th century).

Carbon and nitrogen isotope ratio analyses of the 18th to 19th century population from Christ Church, Spitalfields, London, revealed that during the later post-medieval period, weaning commenced before one year of age, and complementary feeding ended before two years of age (Nitsch et al., 2011). A similar pattern was observed at the contemporary cemetery at Lukin Street, London (Beaumont et al., 2012). This isotope ratio based reconstruction of weaning age corresponds with documentary evidence of recommended weaning practices from the 18th century, which suggested that the process of weaning children should take place between the ages of six to 24 months (Maubray, 1730; Moss, 1781; both cited in Fildes, 1982).

The nitrogen isotope ratio evidence suggests that during the Romano-British and Anglo-Saxon periods in Britain, weaning commenced before c. two years of age, and the period of complementary feeding reduced from just over two years in the Roman-British period to approximately one year in the Anglo-Saxon period. By the medieval period, weaning was initiated at an earlier age and complementary feeding lasted just one year. This pattern of change in weaning practice continues in two post-medieval populations: complementary feeding commenced at an earlier age and was of shorter duration than during the medieval period. The reduction in both the age of commencement of weaning and the duration of complementary feeding could be related to the rise in urbanisation during the late Anglo-Saxon, medieval and post-medieval periods. Agricultural and hunter-gatherer populations tend to breast-feed for longer than urban populations, to increase birth spacing and control population size (Clayton et al., 2006). Cessation of breast-feeding at an earlier age would increase fertility rates and could therefore also be a factor in the population increase associated with rising urbanisation. The link between weaning, birth spacing and urbanisation should be investigated further.

CONCLUSION

Weaning age is an important cultural variable, which has an impact on morbidity and mortality patterns, as well as fertility rates, within a population. However, osteological indicators of weaning and increased mortality rates are also indicators of other physiological stresses. Stable nitrogen isotope ratio data suggests that complementary feeding at Raunds began around the age of 1.75 years old, and that infants ceased breast-feeding by three years. Following this event, there is a peak in mortality and in the prevalence of cribra orbitalia within this population. The Raunds data corresponds with the weaning age established at the Anglo-Saxon site of Berinsfield (Privat et al., 2002), as well as with documentary sources. Archaeological evidence indicates that this age was also marked by a change in social status, as evidenced by increased provision of grave goods to individuals aged over two to three years during the earlier Anglo-Saxon period. Together, these data suggest that age two to three years represented a significant milestone in the life of Anglo-Saxon children.

Comparisons to Romano-British, medieval and post-medieval populations indicate a change in weaning practices through time, leading to shorter periods of complementary feeding and an earlier age of the onset of weaning, possibly related to the rise of urbanisation across these periods. However, the determination of the nitrogen isotope ratios of a wider range of sites for these periods would allow for clarification of this pattern of change, and would contribute to greater discussion of changes in population size and the increase of urbanisation over the last two millennia.

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Figure Legends:

Figure 1: δ^{15}N values in infants and young children being breastfed and weaned (solid line). The dotted line represents adult females (from Jay et al 2008, based on a theoretical model by Millard 2000. Reproduced with permission).

Figure 2: δ^{15}N values plotted against δ^{13}C values for adult females from Raunds Furnells, including data from this study (grey circles) and Howcroft (2008; black triangles) with analytical error of ± 0.2‰.

Figure 3: δ^{15}N values of juveniles plotted against mean age (years). Solid lines are the mean and range of adult females of child-bearing age δ^{15}N values.

Figure 4: δ^{13}C values of juveniles plotted against mean age (years). Solid lines are the mean and range of adult females of child-bearing age δ^{13}C.

Table headers:

Table 1: Age-at-death and true prevalence rates of cribra orbitalia at Raunds Furnells.

Table 2: Raw data from carbon and nitrogen isotope ratio analyses.

Adult ages are given as ordinal categories: young adult (YA, c.18-25); young middle adult (YMA, c.26-35); old middle adult (OMA, c.36-45).

Table 3: Mean δ^{15}N and $\delta\ ^{13}$C values and standard deviation for all age groups.

Table 4: Results of t-tests measuring difference in $\delta^{15}N$ values between adjacent age groups.

Table 1: Age-at-death and true prevalence rates of cribra orbitalia at Raunds Furnells

Age Group	N	% of Population	TPR Cribra orbitalia
Infant (0-1 years)	62	17.2	0
Young child (1-3 years)	29	8.0	29.6
Middle child (4-7 years)	37	10.2	59.1
Older child (8-12 years)	17	4.7	46.2
Adolescent (13-17 years)	15	4.2	54.5
Sub-adult (<18 years)	2	0.6	0
Adult (>18 years)	199	55.1	30.2

Table 2: Raw data from carbon and nitrogen isotope ratio analyses.

Adult ages are given as ordinal categories: young adult (YA, c.18-25); young middle adult (YMA, c.26-35); old middle adult (OMA, c.36-45)

Skeleton Number	**Mean Age**	**Weight (mg)**	**Mass collagen (mg)**	**Collagen yield (%)**	**δ^{15}N (‰) Sample A**	**δ^{13}C (‰) Sample A**	**C:N Sample A**	**δ^{15}N (‰) Sample B**	**δ^{13}C (‰) Sample B**	**C:N Sample B**
5004	4.5	466	10.2	2.2	12.40	-19.69	3.26	12.31	-20.12	3.26
5005	3	482	16.6	3.4	10.39	-19.80	3.29	10.32	-19.64	3.26
5011	2.5	428	5.1	1.2	12.96	-19.58	3.38	12.85	-19.34	3.35
5012	2.5	395	19.7	5.0	12.36	-19.88	3.20	12.18	-20.18	3.22
5023	3	451	21.6	4.8	9.39	-19.79	3.21	9.41	-19.72	3.22
5032	5.5	399	18.4	4.6	10.26	-19.71	3.25	10.21	-19.90	3.25
5038	2.5	392	7.0	1.8	13.62	-19.52	3.29	13.63	-19.47	3.30
5070	5	328	3.5	1.1	13.58	-19.29	3.42	13.35	-19.68	3.44
5081	5	445	12.7	2.9	10.91	-19.54	3.23	10.41	-19.44	3.27
5082	1.25	334	3.6	1.1	14.38	-19.51	3.59	14.23	-19.25	3.59
5088	5	426	14.1	3.3	10.28	-19.23	3.27	10.23	-18.82	3.27

5091	5	309	6.9	2.2	12.54	-19.95	3.27	12.54	-19.76	3.25
5096	0.75	404	8.8	2.2	13.50	-18.86	3.30	13.42	-18.94	3.31
5097	0.75	419	12.3	2.9	14.44	-19.97	3.34	14.37	-19.60	3.34
5102	2.5	402	7.0	1.7	12.16	-19.28	3.28	11.90	-19.28	3.36
5109	2	374	15.7	4.2	12.58	-18.80	3.26	12.45	-18.96	3.28
5113	3	472	12.1	2.6	10.90	-19.78	3.25	10.86	-19.40	3.28
5121	4.5	494	5.4	1.1	10.34	-20.23	3.28	10.18	-20.07	3.30
5125	7	429	7.8	1.8	11.43	-19.98	3.34	11.43	-20.10	3.40
5131	4.5	339	4.5	1.3	10.24	-19.81	3.36	10.13	-19.67	3.37
5135	5.5	480	7.2	1.5	11.43	-19.74	3.34	11.22	-19.43	3.36
5140	2	407	12.7	3.1	15.85	-18.83	3.24	15.78	-18.97	3.28
5141	0	373	9.5	2.5	11.34	-19.57	3.28	11.27	-19.61	3.27
5143	0	361	8.6	2.4	11.61	-19.53	3.37	11.59	-19.65	3.31
5170	4	407	19.2	4.7	10.73	-19.53	3.21	10.65	-19.54	3.22
5174	3	403	16.5	4.1	12.18	-20.46	3.22	12.16	-20.30	3.23
5189	0	336	6.0	1.8	13.32	-20.29	3.35	13.27	-20.30	3.37

5191	4	426	3.0	0.7	12.27	-19.88	3.41	12.12	-20.08	3.43
5194	3.5	449	22.8	5.1	11.92	-20.06	3.23	11.95	-20.49	3.24
5199	3.5	401	4.7	1.2	11.42	-19.70	3.35	11.49	-19.76	3.35
5208	2.5	431	16.9	3.9	12.50	-19.69	3.22	12.42	-19.59	3.21
5212	4	475	13.7	2.9	10.55	-20.20	3.27	10.57	-20.00	3.27
5225	0	353	5.4	1.5	12.90	-19.19	3.38	12.78	-19.19	3.34
5244	2	371	3.1	0.8	14.03	-18.90	3.36	13.80	-19.00	3.36
5251	0	333	8.1	2.4	11.16	-19.89	3.33	11.14	-19.76	3.33
5264	3.5	307	12.1	3.9	13.73	-19.33	3.26	13.65	-19.39	3.30
5271	3.5	314	5.4	1.7	12.16	-19.58	3.28	12.11	-19.95	3.27
5273	2	278	2.1	0.8	11.03	-20.42	3.41	11.22	-20.64	3.38
5280	2.5	287	9.1	3.2	13.62	-20.02	3.26	13.46	-20.03	3.25
5292	2.5	337	17.7	5.3	12.83	-20.31	3.26	12.67	-20.02	3.24
5297	6.5	449	2.8	0.6	12.30	-20.01	3.42	12.34	-19.96	3.43
5302	2	444	7.2	1.6	11.71	-19.88	3.32	11.51	-20.19	3.34
5303	5.5	428	20.8	4.9	9.99	-19.32	3.21	9.92	-19.26	3.24

5304	0.5	308	6.6	2.1	13.84	-19.04	3.36	13.87	-18.94	3.34
5306	0	340	7.9	2.3	13.63	-19.24	3.27	13.45	-19.05	3.30
5310	1.25	470	9.6	2.0	14.75	-19.60	3.26	14.75	-19.86	3.28
5312	1.5	434	3.0	0.7	14.41	-19.52	3.55	14.65	-19.74	3.58
5316	0.75	420	7.6	1.8	15.32	-19.52	3.35	15.21	-19.24	3.31
5320	0.5	373	6.5	1.7	13.79	-19.23	3.32	13.89	-19.24	3.28
5329	0.75	401	5.8	1.4	13.60	-19.57	3.37	13.59	-19.66	3.33
5332	4.5	432	11.2	2.6	12.21	-20.64	3.29	12.15	-20.62	3.28
5336	1.25	419	6.4	1.5	14.87	-19.54	3.37	14.69	-19.65	3.36
5338	6	433	3.9	0.9	8.50	-20.10	3.32	8.43	-19.84	3.33
5339	5	347	4.1	1.2	12.91	-19.83	3.38	12.97	-19.69	3.37
5343	4	339	5.1	1.5	10.97	-19.75	3.33	10.82	-25.92	6.28
5345	3.5	378	5.6	1.5	10.27	-19.67	3.22	10.28	-19.80	3.21
5346	5.5	413	10.7	2.6	10.32	-20.05	3.22	10.26	-20.01	3.21
5349	4.5	223	10.1	4.5	10.86	-19.53	3.24	10.85	-19.62	3.23
5354	3.5	432	7.1	1.6	11.37	-20.20	3.36	11.36	-20.22	3.36

5018	YA	488	15.3	3.1	10.25	-19.50	3.29	10.11	-19.79	3.28
5021	YMA	340	4.9	1.4	10.26	-20.40	3.33	10.21	-20.27	3.34
5025	YMA	375	7.6	2.0	11.01	-19.80	3.29	11.03	-19.64	3.31
5027	OMA	359	14.0	3.9	10.98	-19.65	3.26	11.08	-19.44	3.25
5049	YA	280	12.8	4.6	11.36	-20.11	3.28	11.21	-20.05	3.28
5051	YMA	416	17.9	4.3	10.63	-19.93	3.24	10.76	-19.95	3.24
5056	YA	404	4.7	1.2	11.36	-19.90	3.30	11.38	-20.03	3.30
5093	YMA	458	11.2	2.4	11.08	-19.45	3.27	11.04	-19.47	3.30
5100	YMA	387	5.8	1.5	10.35	-19.64	3.36	10.27	-19.61	3.37
5106	YMA	405	7.9	2.0	11.82	-19.71	3.26	11.73	-19.94	3.28
5154	YA	308	12.2	4.0	11.51	-19.60	3.23	11.49	-19.61	3.25
5167	OMA	261	1.9	0.7	10.57	-20.33	3.40	10.46	-19.84	3.31
5187	YA	427	8.5	2.0	9.54	-19.88	3.25	9.36	-19.74	3.29
5209	YMA	347	4.8	1.4	11.98	-19.77	3.28	11.82	-20.01	3.31
5214	YA	455	11.4	2.5	10.46	-19.61	3.25	10.35	-19.93	3.29
5226	YA	398	12.1	3.0	11.88	-19.73	3.22	11.92	-19.74	3.26

5230	YA	261	1.3	0.5	9.88	-19.84	3.32	9.86	-19.71	3.32
5236	YA	327	5.8	1.8	12.35	-19.99	3.28	12.29	-19.71	3.31
5239	YMA	218	4.2	1.9	12.42	-19.71	3.29	12.37	-19.98	3.32

Table 3: Mean δ^{15}N and δ^{13}C values and standard deviation for all age groups

Age Group (Mean Years)	**No. of Individuals Sampled**	**Mean δ^{15}N (‰)**	**Standard Deviation δ^{15}N**	**Mean δ^{13}C (‰)**	**Standard Deviation δ^{13}C**
0	6	12.29	1.06	-19.61	0.43
0.5-1	6	14.07	0.67	-19.32	0.35
1-1.5	4	14.59	0.22	-19.58	0.15
2	5	13.00	1.90	-19.46	0.77
2.5	7	12.80	0.61	-19.73	0.34
3	4	10.70	1.15	-19.86	0.35
3.5	6	11.81	1.13	-19.86	0.33
4	4	11.10	0.74	-19.84	0.25
4.5	5	11.17	1.04	-20.00	0.41
5	5	11.97	1.43	-19.52	0.32
5.5	4	10.45	0.60	-19.68	0.30
6-7	3	10.74	2.02	-20.00	0.04
Young Adults	10	10.92	0.98	-19.80	0.15
Young Middle Adults	8	11.17	0.78	-19.83	0.26
Old Middle Adults	2	10.77	0.37	-19.82	0.38

Table 4: Results of t*-tests measuring difference in* δ^{15}*N values between adjacent age groups*

Age Groups (years) Being Compared	***T* value**	**Degrees of Freedom**	**P value**
0 and 0.5 to 1	3.493	10	0.0058
0.5 to 1 and 1 to 1.5	1.474	8	0.1787
1 to 1.5 and 2	1.641	7	0.1448
2 and 2.5	0.265	10	0.7964
2.5 and 3	4.1153	10	0.0021
3 and 3.5	1.603	9	0.1434
3.5 and 4	1.092	8	0.3066
4 and 4.5	0.105	7	0.9193
4.5 and 5	1.016	8	0.3394
5 and 5.5	1.967	7	0.0899
5.5 and 6+	0.273	5	0.7958

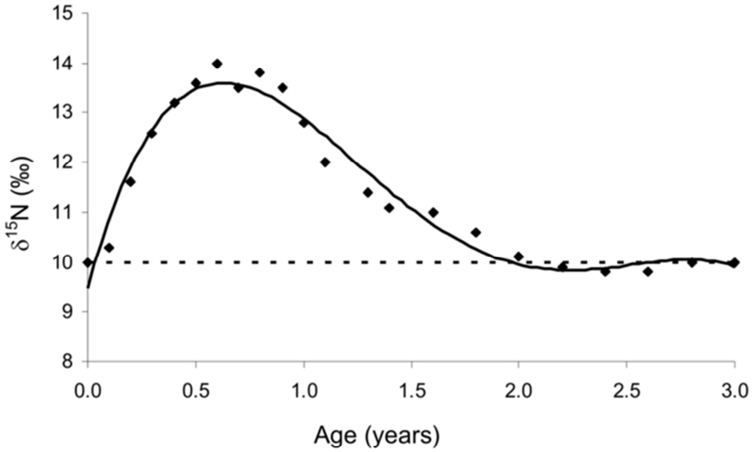

Figure 1: δ15N values in infants and young children being breastfed and weaned (solid line). The dotted line represents adult females (from Jay et al 2008, based on a theoretical model by Millard 2000. Reproduced with permission)
75x57mm (300 x 300 DPI)

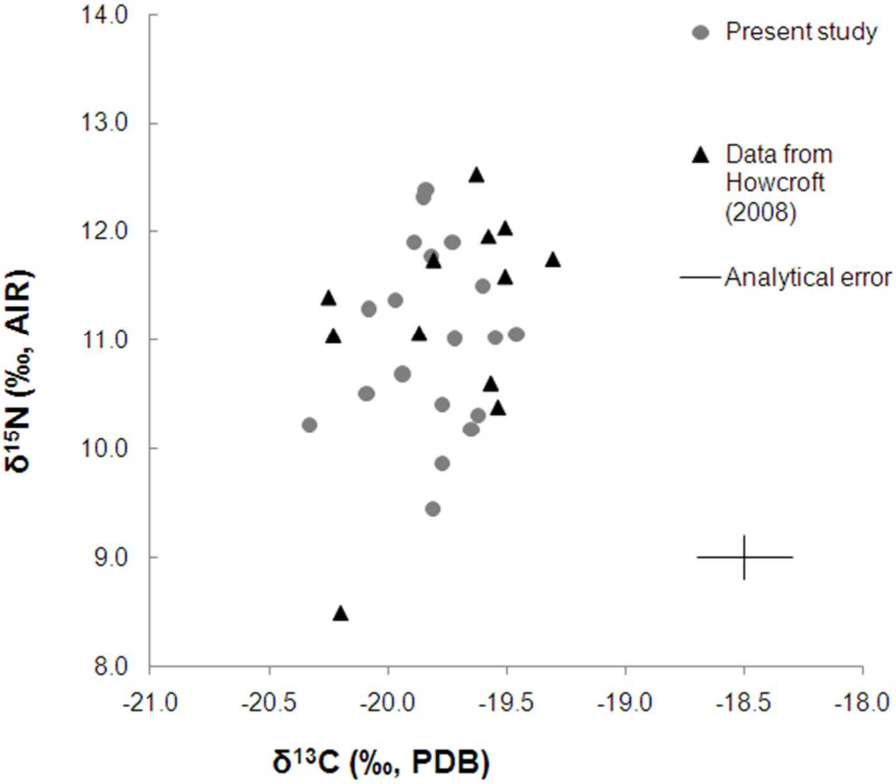

Figure 2: δ15N values plotted against δ13C values for adult females from Raunds Furnells, including data from this study (grey circles) and Howcroft (2008; black triangles) with analytical error of ± 0.2‰.
226x202mm (72 x 72 DPI)

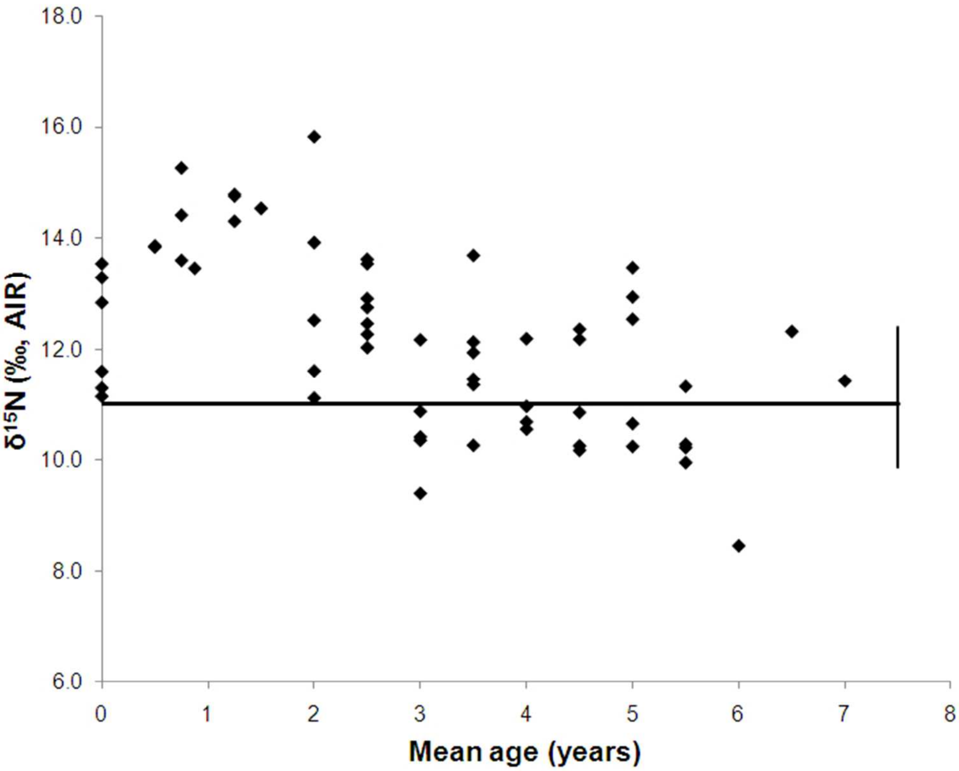

Figure 3: δ15N values of juveniles plotted against mean age (years). Solid lines are the mean and range of adult females of child-bearing age δ15N values.
258x209mm (72 x 72 DPI)

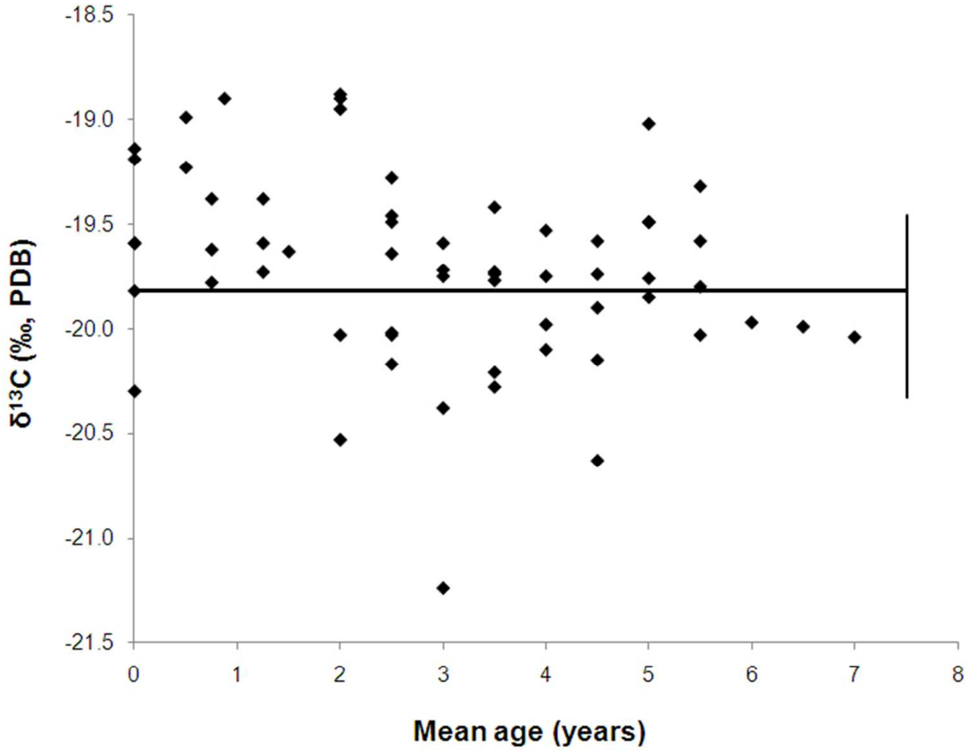

Figure 4: δ13C values of juveniles plotted against mean age (years). Solid lines are the mean and range of adult females of child-bearing age δ13C.
258x208mm (72 x 72 DPI)