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The role of infant life histories in the construction of identities in death: An incremental isotope study of dietary and physiological status among children afforded differential burial

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ABSTRACT

Objectives

Isotope ratio analyses of dentine collagen were used to characterize short-term changes in physiological status (both dietary status and biological stress) across the life course of children afforded special funerary treatment.

Materials and Methods

Temporal sequences of $\delta^{15}N$ and $\delta^{13}C$ isotope profiles for incrementally-forming dentine collagen were obtained from deciduous teeth of 86 children from four early-medieval English cemeteries. Thirty-one were interred in child-specific burial clusters, and the remainder alongside adults in other areas of the cemetery. Isotope profiles were categorized into four distinct patterns of dietary and health status between the final prenatal months and death.

Results

Isotope profiles from individuals from the burial clusters were significantly less likely to reflect weaning curves, suggesting distinctive breastfeeding and weaning experiences. This relationship was not simply a factor of differential age at death between cohorts. There was no association of burial location with stage of weaning at death, nor with isotopic evidence of physiological stress at the end of life.

Discussion

This study is the first to identify a relationship between the extent of breastfeeding and the provision of child-specific funerary rites. Limited breastfeeding may indicate the mother had died during or soon after birth, or that either mother or child was unable to feed due to illness. Children who were not breastfed will have experienced a significantly higher risk of malnutrition, undernutrition and infection. These sickly and perhaps motherless children received care to nourish them during early life, and were similarly provided with special treatment in death.

Archaeological investigations of cemetery sites throughout the world have revealed that children were frequently distinguished in death from adults. However, a combination of poor preservation of immature remains and child-specific funerary practices that render their remains archaeologically invisible has led to limited investigation of variation in child[1] burials. Children's graves may be located in different cemeteries to those of adults (Lillehammer, 2011; McKerr, Murphy & Donnelly, 2013) or in clusters within cemeteries (Bedford, Buckley, Valentin, Tayles & Longga 2011; Sayer 2014). Their remains may also be placed in forms of burial container exclusive to their age group (Carroll, 2012; Halcrow, Tayles & Livingstone, 2008) or accompanied by different grave goods to adults including esoteric items such as amulets and curated objects (Carroll, 2012; Kay, 2016) or items which might be interpreted as toys or playthings (Andrushko, Buzon, Gibaja Oviedo & Creaser, 2011; Harlow, 2013; Martin-Kilcher, 2000). In some cases, child-specific burial rites were provided to most individuals of a certain age at death, as with perinates interred at Romano-British settlement sites (Moore, 2009), while, in other cases, only a proportion of children were buried in unusual ways and others received more 'adult' treatment. Between the 8th and 12th centuries A.D. in England, some children who died before the end of their second year are found in burial clusters surrounding church buildings, but others are interred with adults in other parts of the cemetery (Craig-Atkins, 2014), highlighting that the decisions behind the provision of child-specific funerary rites were not based solely on age at death.

Variation in child-specific funerary practices might be explained in terms of the child's biological and social identity, the events that characterized their lives and deaths, or the perceptions and decisions of the individuals or communities that created their graves (e.g. Baxter, 2005; Millett & Gowland, 2005; Murphy 2011; Sofaer, 2006). However, evaluation of the relative importance of these factors to past societies has proved challenging, and thus

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[1] Various attempts have been made to define a shared terminology with which to discuss the lives of immature individuals in the past (e.g. Halcrow and Tayles 2010). The terms perinate, infant and young child are used here as biological age categories, established for past individuals through assessment of their skeletons, and refer to individuals of ages c. 40 weeks gestation-1 month; 2 months-1 year; and 2-5 years respectively. The term child/children is used to reflect the early period of life without specific reference to any category of biological maturity, but rather in a general sense to reflect the complex biological and social factors that demark the early life course.

received limited attention. Isotopic analysis of the collagen of incrementally-forming dentine can reveal dietary and physiological status throughout childhood, illuminating important biocultural thresholds such as the initiation of breastfeeding, introduction of supplementary foods, weaning and periods of biological stress related to undernutrition and disease (Beaumont & Montgomery, 2015; 2016). Yet despite the potential for incremental isotope data to provide detailed insight into childhood life histories, they have still to be integrated into examinations of motivations for child-specific funerary provision. This paper capitalizes on the continuous record of diet and health during early life provided by incremental isotope analysis of δ^{15}N and δ^{13}C to explore associations between childhood lifeways and wellbeing and the provision of differential burial. The findings shed new light on the brief life experiences of children who died in their early years, enabling an exceptionally detailed evaluation of the potential motivations behind their funerary treatment and mark a new direction in the study of child-specific burial practices using innovative archaeometric techniques.

Using isotope evidence to study the childhood life course

Analysis of the stable isotopes of nitrogen and carbon from dentine and bone collagen has become a widespread means by which key dietary transitions during childhood can be investigated (Tsutaya & Yoneda, 2015). Dietary isotope studies have been employed to illuminate the onset and exclusivity of breastfeeding and the timing and duration of weaning (e.g. Jay, Fuller, Richards, Knüsel & King, 2008; Haydock, Clarke, Craig-Atkins, Howcroft & Buckberry, 2013; Nitsch, Humphrey & Hedges, 2011), as well as to evaluate sources of dietary protein and carbohydrate (Mays & Beavan, 2012; Müldner & Richards, 2005). Tooth dentine isotope values reflect the period of dental growth and formation during childhood, whereas bone isotope values reflect an average of the diet over a period prior to death dictated by bone turnover rates (Hedges, Clement, Thomas & O'Connell, 2007). The traditional method of bulk sampling dentine and bone reveals diet across the life course in limited detail. Only an average diet during childhood can be determined through analysis of dentine, and only broad differences between childhood and adult diets can be examined through comparison of dentine and bone isotope data in adults. The analysis of incremental dentine provides a novel means of identifying continuous change in an individual's δ^{15}N and δ^{13}C values across the whole period of childhood with a previously unattainable degree of precision. The incremental method obtains isotopic data for multiple horizontal sections of tooth dentine, resulting in a profile of values which span the entire period of dental development – from the final prenatal months to early adulthood – and offer a finer-grained perspective on dietary change across childhood (Beaumont, Gledhill, Lee-Thorpe & Montgomery, 2013; King et al., 2018).

Incremental isotope profiles have been instrumental in generating new insights into past weaning practices, including clarification of the fundamental relationships between dietary change and δ^{15}N and δ^{13}C values (Beaumont, Montgomery, Buckberry & Jay, 2015; Eerkens, Berget & Bartelink, 2011; Fuller, Richards & Mays, 2003; Henderson, Lee-Thorpe & Loe, 2014). During exclusive breastfeeding the infant's only source of dietary protein is breastmilk, the consumption of which places them a trophic level above their mother and results in higher δ^{15}N values in infant than in maternal skeletal tissues. δ^{13}C values are also affected by a trophic level increase, albeit of lesser magnitude, but are additionally influenced by sources of dietary carbohydrate and therefore by the choice of supplementary foods offered from the first stages of weaning onwards (Fuller, Fuller, Harris & Hedges, 2006). Incremental profiles of δ^{15}N and δ^{13}C isotopes, evaluated in concert with a detailed understanding of the factors which affect their values in early life, can be used to examine the introduction, ubiquity and duration of breastfeeding and the timing of introduction of supplementary foods in a manner that conceptualizes weaning as a process rather than a single event (Figure 1).

[Insert Figure 1]

δ^{15}N and δ^{13}C values from skeletal tissues do not only respond to variations in the constituents of the diet, but also reflect periods of undernutrition during which recycling of the body's own tissues (catabolism) is employed to generate the nutrients needed to survive (Beaumont & Montgomery, 2016; Mekota, Grupe, Ufer & Cuntz, 2006; Neuberger, Jopp, Graw, Püschel & Grupe, 2013). The importance of undernutrition as an influential factor in dentine isotope profiles has recently been demonstrated in a study of the Great Famine in Ireland (1845-1852 A.D.) which revealed prolonged nutritional and physiological stress resulting from insufficient sustenance among inmates of the Kilkenny Union Workhouse, and confirmed that similar isotopic profiles to those from modern clinical contexts can be identified in archaeological material (Beaumont & Montgomery, 2016). It is important to note the synergistic effects of different aspects of physiology on δ^{15}N and δ^{13}C profiles obtained from human skeletal remains. While the quality and quantity of nutrition available to fuel the body are reflected in isotope profiles, other processes that impact the homeostatic process of growth and renewal of tissues are also implicated. For example, δ^{15}N values have been found to rise when the body is taxed by periods of disease but may fall during periods of intensive growth (Beaumont et al., 2015; Waters-Rist & Katzenberg, 2010).

The interplay between δ^{15}N and δ^{13}C isotope values in early life enables a highly detailed picture of physiological status reflecting both diet and biological stress to be developed. Moreover, as teeth develop at a relatively consistent rate between individuals, this picture can be tied to ontogeny in a manner that facilitates age-specific exploration of these factors across the life course from the prenatal stage into early adulthood. The value of this perspective for funerary studies is that it illuminates lifeways and wellbeing in a manner that reflects the interconnected and cumulative nature of the life course, as opposed to focusing on certain discrete events, and enables more effective consideration of variation between children independent of their age at death (Agarwal, 2016; Gowland, 2006; 2015). In consequence, it is possible explore whether aspects of identity at any stage of life have impacted on social perceptions of the individual and the choice of funerary rites provided. Incremental isotope studies have, thus far, tended to focus on developing or testing methods as opposed to their application and, where the methods have been applied to an archaeological context, the sample sizes have been very small (for example, Eerkens and colleagues (2011) analyzed only six individuals). While researchers have utilized incremental isotope studies of $\delta^{15}N$ and $\delta^{13}C$ to assess biocultural behaviors such as sex-dependent features of weaning practice (Eerkens & Bartelink, 2013; Henderson et al., 2014), birth spacing (Jay et al., 2008) and parental investment (Eerkens et al., 2011), these have not conceptualized childhood physiological status within its socio-cultural context as a potential factor in the provision of child-specific funerary rites as this study does.

MATERIALS AND METHODS

The skeletal material analyzed in this study derives from four early-medieval English cemeteries (c. A.D. 700-1100) at which two different funerary responses to the death of the very young were employed: Raunds Furnells (Northamptonshire), Black Gate, Newcastle (Tyne and Wear), Cherry Hinton (Cambridgeshire) and Spofforth (North Yorkshire) (Figure 2). At these sites, some children were buried in clusters around buildings in central locations within the cemetery ('clustered') whereas others were interred among adults across a wider area ('dispersed'). The sample was selected with the aim of generating two comparable-sized cohorts of individuals with similar demographic structure: one from the burial clusters and a control sample of dispersed burials (Table 1). A single deciduous tooth was collected from 86 individuals aged between birth and eight years: 31 (36.0%) individuals were from child-specific clusters and 55 (64.0%) from burials interspersed with adults (Table 2). Stable isotope profiles for both $\delta^{15}N$ and $\delta^{13}C$ were produced for each. The following data were obtained for each site: burial location; age at death; $\delta^{15}N$ isotope profile and $\delta^{13}C$ isotope profile. Permission for scientific analysis was granted by the holding institutions of the four collections: Cambridge County Council and the Universities of Sheffield, Bradford and Hull.

[Insert Figure 2]

[Insert Table 1]

[Insert Table 2]

Materials

Raunds Furnells

The cemetery at Raunds Furnells, Northamptonshire included interments of 363 individuals surrounding a two-celled stone church (Boddington, 1996; Craig, 2005). Radiocarbon dates from eight individuals spanning the late-10th to early-12th centuries A.D. suggest that burial took place over a short period. The cemetery served a rural community, and was part of a manorial complex (Boddington, 1996). Immature individuals were well represented, comprising 44.9% (163/363) of the population. A group of 25 individuals were interred in a narrow strip of ground immediately surrounding the church foundations, and have been interpreted as ‘eaves-drip’ burials (Boddington, 1996; Craig-Atkins, 2014). Of these, 88.0% (22/25) died before the age of three years. Samples for isotope analysis were obtained from 16 individuals. Additional data for a further six individuals were available from previous research (Beaumont et al., In press) and are included here, resulting in a total sample of 22 individuals.

Black Gate

Excavations at the Black Gate cemetery recovered 663 articulated interments and many disturbed burials surrounding a stone-footed church. The site, which occupies a promontory on the northern bank of the River Tyne, Newcastle, has been associated with a documented early medieval monastic site (Nolan, 2010; Swales, 2010). The earliest burials were radiocarbon dated to the 8th century A.D. and interment continued into the 11th, with a few late burials made in the 12th century (Nolan, 2010). An area of the cemetery to the south of the church (area C) has a preponderance of burials of infants and young children. Within this zone, 32.0% (41/128) of interments were of individuals aged from birth to the end of their first year and a further 17.2% (22/128) were under six years at death. In the other cemetery areas, these demographic groups comprised only 7.7% (32/418) and 10.8% (45/418) respectively (Swales, 2010). Samples for isotope analysis were obtained from 20 individuals.

Cherry Hinton

The large cemetery at Cherry Hinton comprised 683 burials associated with a wooden building. Although no radiocarbon dates were obtained, stratigraphic relationships suggest that a substantial number were contemporary with the second phase of this building, which itself was dated to the latter part of the 8th to the 12th centuries A.D. based on site stratigraphy and associated pottery (McDonald & Doel, 2000). Cherry Hinton is recorded in Domesday Book in A.D. 1086 as a single estate under the control of a powerful local landowner. A cluster of perinates and infants were buried beneath the church eaves (McDonald & Doel, 2000). This zone contained 54 interments, of which 55.6% (30/54) were under the age of three years at death and a further seven burials (13.0%) were placed in graves so small that they most likely also contained the remains of infants, but no skeletal remains survived. At least 27.8% (30/108) of all infants at Cherry Hinton were buried in the cluster around the church. Samples for isotope analysis were obtained from 20 individuals.

Spofforth

Excavations of the early medieval cemetery at Spofforth recovered the remains of around 420 individuals from a heavily disturbed and truncated site (Craig, 2010; Northern Archaeological Associates, 2002). This burial ground, which was radiocarbon dated to the 7th to 9th centuries A.D., included the partial remains of a substantial structure which was located towards the north and west of the burial zone. Little is known about the landscape context of the Spofforth cemetery, and no associated settlement has been identified (Northern Archaeological Associates, 2002). Children are not well represented at this site: only 28.6% (120/420) of the population were immature. Nevertheless, a clear pattern emerges in the spatial location of the youngest dead. Nine of only eleven perinates (81.8%) were buried along the line of the building's southern wall. Samples for isotope analysis were obtained from 24 individuals.

Methods

Estimation of age at death

To ensure consistency across all four sites, age at death for all 86 individuals was reassessed using the London Dental Atlas (AlQathani, Hector & Liversidge, 2010). This method utilizes dental development and eruption patterns observed and tested on modern children to assign age at death into categories with medians from 30 weeks in utero to 23.5 years and has proved significantly more accurate than other frequently-used osteological methods of Uberlaker (1978) and Schour and Massler (1941) for all age categories over one year (AlQathani, Hector & Liversidge 2014). Once age at death had been assigned, all individuals were grouped for analysis into one of six age cohorts (<1 year; 1.0-1.9 years; 2.0-2.9 years; 3.0-3.9 years; 4.0-4.9 years; and 5-8 years).

Isotopic analysis

Incremental isotope sampling was undertaken at the University of Bradford Stable Light Isotope Laboratories. following the methods of Beaumont and colleagues (2013), using their sample preparation method 2. For each tooth, incremental dentine collagen was prepared from the full length of a single root or a full longitudinal root section using the modified Longin method (Brown, Nelson, Vogel & Southon, 1988). Following air-abrasion to remove surface debris, longitudinal sectioning and manual removal of the enamel, longitudinal dentine sections were demineralized in 0.5M hydrochloric acid at 4°C for c. 7-10 days. The demineralized dentine sections were then cut into transverse samples of 1mm thickness using a scalpel, commencing at the coronal dentine horn, placed into microtubes and denatured with a pH3 acidified water solution at 70°C for 24 hours. The resulting solution was centrifuged to separate contaminants to the bottom of the tube, frozen at -35°C and then freeze-dried overnight.

Samples were measured in duplicate by combustion in a Thermo Flash EA 1112 and introduction of separated N_2 and CO_2 to a Delta plus XL via a Conflo III interface. Both international standards (IAEA 600, CH3, N1 and N2) and laboratory standards (fish gelatin and bovine liver, calibrated against the international standards) were interspersed throughout each analytical run. The results for dentine collagen are expressed using the delta (δ) notation in parts per thousand (‰) relative to the international standards Vienna-PDB for $\delta^{13}C$ and AIR for $\delta^{15}N$. Analytical precision was ± 0.2‰ (1 S.D.) or better for both $\delta^{13}C$ and $\delta^{15}N$.

Age at increment was assigned following the methods of Beaumont and Montgomery (2015). Estimated age at initiation was subtracted from estimated age at apex completion for each tooth to provide a period in years over which the tooth was forming. This value was divided by the number of increments obtained during the sample preparation stage (which varied depending on tooth type and length) to obtain an average duration for the growth of each increment. Each increment was then assigned an age at formation by cumulatively adding the average duration of each increment to the age at initiation until the age at completion was reached. Teeth that were partially formed at the time of death were divided into increments between age at initiation and developmental stage at death. Similarly, any teeth showing signs of resorption were assigned ages based on the remaining tissue.

Incremental isotope methods provide a much more precise indication of $\delta^{15}N$ and $\delta^{13}C$ values at any given age than bulk-sample methods, but a minimal amount of time-averaging still takes place. Growth bands in the teeth, particularly the roots, are oblique whereas the incremental samples are obtained as horizontal sections. Therefore, each slice comprises parts of more than one growth band. Time-averaging across increments results in isotopic profiles that are artificially smoothed and rapid changes in diet may appear, from the isotope data, to have occurred over a longer time frame. Overall trends in isotope values will not be obscured (Beaumont et al., 2013; Eerkens, et al. 2011). All teeth sampled for this study were deciduous. Incremental layers from the deciduous dentition reflect the period of life from -0.3 years ± 0.5 months (initiation of cusp development of deciduous incisors 1 and 2) to c. 3.5 years ± 6 months (completion of root apex of deciduous canine and molars 1 and 2), whereas the permanent dentition reflect a longer period from 0.4 years ± 1.5 months (initiation of cusp development of permanent molar 1) to c. 23 years ± 6 months (closure of root apex of permanent molar 3) (AlQahtani et al., 2010; Beaumont & Montgomery, 2015). Thus increments of equal size from deciduous teeth reflect a shorter period of life than those from adult teeth but provide greater precision, which is of particular benefit to the present study. The 1mm samples prepared in this study resulted in a maximum of 17 δ^{15}N and δ^{13}C increments per tooth (fewer for shorter teeth and where teeth were still developing), which when associated with an age-at-increment provide isotopic values at intervals of as little as 0.9 months. Additional benefits of focusing on deciduous teeth include better survival and resolution of dentine laid down in the prenatal period than in the permanent teeth, which is also often lost due to attrition of the cusps (Beaumont et al., In press).

Statistical analysis

The comparatively large sample of isotope data obtained for this study permitted the use of inferential statistical testing. The Chi-Square test was used to examine associations between categorical variables, and replaced with Fisher's Exact test where sample sizes were below accepted limits (Fisher, 1934; Cochran, 1952). Effect size was measured using Cramer's V and z-scores. Results of the former range from 0 (weak association) to 1 (strong association) and Z-scores were significant where z = ±1.96. Mann-Whitney U and Kruskal-Wallis H tests were utilized for the analysis of ordinal age at death data as they are more powerful than Chi-Square and can be used with ordinal data (Gibbons, 1993).

Interrelationships between multiple variables (isotope profile, burial location, age at death, site) were assessed using multivariate logistic regression analysis. While regression models are widely used to predict an outcome variable from a series of predictor variables, they can also serve as an exploratory approach to evaluate the interrelationships between the outcome variables themselves. This is because the coefficient of each predictor variable in a regression equation explicitly describes the relative contribution of that variable to the outcome variable, automatically controlling for the influences of the other predictor variables. A binary model was chosen as the outcome variable was dichotomous (clustered vs dispersed burial), logistic regression was employed as the predictor variables were categorical and the variables were entered simultaneously into the analysis, in one block, to avoid making any assumptions about the relative influence of each variable. The quality of the model was determined to be adequate on the basis of three accepted criteria (Bagley et al., 2001). First, there were sufficient 'events' per variable: in this case the ratio of the number of clustered burials to predictor variables (31/3=10.3) was greater than the accepted threshold of 10. Second, there was no evidence of collinearity among the predictor variables, which might reduce the overall significance reported for the model (pair-wise inter-variable associations: isotope profile vs age Cramer's V = .358, $p = 0.005$; isotope profile vs site Cramer's V = .374, $p<0.001$; and age vs site Cramer's V = .363, $p = 0.003$). Finally, validation of the model using various measures of goodness of fit produced no significant results, suggesting the model was viable (Cox and Snell R Square p = .252; Hosmer and Lemeshow test Chi-Square = 9.828, $p = 0.199$). The model was interpreted in two ways. First, by comparing its predictive accuracy to a null model in which individuals were allocated randomly to clustered and dispersed burial groups. Second, by examining the results of Wald's tests and odds ratios, both of which indicate whether each predictor variable made a significant contribution to the model.

RESULTS

Demography

Although there were too few burials at any one site to generate a sample with exactly equal numbers of clustered and dispersed burials, variation in the proportions of the two burial types at each of the four sites was not statistically significant (Fisher's Exact Chi-Square = 5.780, p=0.116). Site-specific variation in population demography affected the sample available for this study. Perinates and infants were rare at Cherry Hinton (1 individual, 5.9% of <1 year cohort) and an over-representation of the same age group at Spofforth (7 individuals, 41.2% of <1 year cohort) was identified (H (Kruskal-Wallis) = 8.976, p = 0.030). There was also a disproportionately high number of perinates and infants among child-specific clusters (13 individuals, 76.5% of <1 year cohort) compared to other child burials (4 individuals, 23.5% of <1 year cohort) (U (Mann-Whitney) = 518.0, p=0.002). This demographic discrepancy reflects the tendency for burial in clusters to be afforded to the very youngest individuals (Craig-Atkins, 2014). The potential for this demographic patterning to confound the interpretation of the incremental isotope data is considered throughout the following analysis.

Overall isotopic values

The $\delta^{15}N$ and $\delta^{13}C$ data for the whole sample are presented in Table 3. The overall mean $\delta^{15}N$ for immature individuals from the four sites in this study is 2.4‰ higher than the adult mean value of Black Gate (MacPherson, 2005) and 2.8‰ higher than the adult mean value of Raunds Furnells (Haydock et al., 2013). The overall mean $\delta^{13}C$ for immature individuals from the four sites in this study is 0.7‰ higher than the adult mean value of Black Gate but similar to the adult mean value of Raunds Furnells. This trend in both $\delta^{15}N$ and $\delta^{13}C$ is broadly consistent with the impact of a trophic level rise associated with consumption of breastmilk, which would be expected to be present in isotope values corresponding to the earliest months of life in our dataset.

The intra-individual ranges reflect periods of δ^{15}N enrichment during early life, but of substantially greater magnitude than that reported in some other studies (Fuller et al., 2006), suggesting the combined impact of trophic level effects and other factors, such as biological stress, in at least some individuals. The lower intra-individual range for δ^{13}C is consistent with suggestions that a smaller trophic level effect of c. 1‰ is seen in δ^{13}C values during the early years (DeNiro & Epstein, 1978; Bocherens & Drucker, 2003).

[Insert table 3]

Assessment of isotope profiles

The 86 δ^{15}N and δ^{13}C incremental isotope profiles obtained were visually evaluated and assigned to one of four groups based on their shape and relationship across the life course (Figure 3). Assignment in the present study did not consider differences between individuals in the absolute values of either δ^{15}N or δ^{13}C. Individuals were classified with no foreknowledge of their funerary provision to avoid bias. Group 1 represents the standard weaning profile in which δ^{15}N and δ^{13}C undergo a covariant rise and fall during the first two years of life reflecting the trophic level shifts associated with breastfeeding and weaning practices (Beaumont et al., 2015; Eerkens et al., 2011; Fuller et al., 2003; Henderson et al., 2014; Nitsch et al., 2011). Group 2 represents profiles that do not show a clear trophic level rise in either δ^{15}N or δ^{13}C, or both. The absence of a peak in both δ^{15}N and δ^{13}C implies no overall dietary change from birth, indicating an absence of successful breastfeeding which would have elevated the infant's δ^{15}N and δ^{13}C above that of the mother in the immediate post-natal period (Fuller et al., 2006). The absence of a rise in δ^{15}N values accompanied by a peak in δ^{13}C values suggests limited breastfeeding alongside supplementary foods with less negative δ^{13}C values than the mother's diet. Where a peak in δ^{15}N is found alongside a flat $\delta^{13}C$ profile, several explanations may be considered. The lack of elevated $\delta^{13}C$ implies that breastfeeding was limited, in which case elevated $\delta^{15}N$ could result from physiological stress-induced catabolism. Group 3 represents individuals where $\delta^{15}N$ and $\delta^{13}C$ show opposing covariance, which always manifests as an increase in $\delta^{15}N$ alongside a decrease in $\delta^{13}C$. This pattern may result from physiological stress (Beaumont & Montgomery, 2016), with rapid increase in $\delta^{15}N$ reflecting catabolism of protein and rapid decrease in $\delta^{13}C$ reflecting catabolism of fats (Mekota et al., 2006; Neuberger et al., 2013). The averaging of isotope values across incremental layers exaggerates the apparent duration of perturbations, so catabolism need not have continued over months or years to account for such prolonged isotope signals (Beaumont & Montgomery 2016). Opposing covariance may also arise from introduction of breastmilk from a non-maternal source (for example a wet nurse) or changes in maternal diet post-partum (in particular, introduction of protein sources such as fish) (Burt, 2015; King et al., 2018). However, high perinatal $\delta^{15}N$ values alongside lower-than-average female values recorded in a medieval population from Fishergate House, York (Burt, 2015), suggested that dietary preferences among women were not the most likely explanation for elevated $\delta^{15}N$ in infants. Group 4 represents profiles which show a sudden drop in $\delta^{15}N$ following birth, often accompanied by no overall change in $\delta^{13}C$. Although it has been argued that an initial postnatal drop in $\delta^{15}N$ values may relate to increased metabolic activity due to growth, this should only last for the first few weeks of life. The profiles assigned to group 4 present a drop in $\delta^{15}N$ more substantial than would be expected from a peak in normal growth (Waters-Rist & Katzenberg, 2010) and more likely reflect failure to breastfeed.

[Insert Figure 3]

There were no individuals from the four sites whose profiles did not fit comfortably into one of the four groups, but a few of the most varied $\delta^{15}N$ and $\delta^{13}C$ profiles could have been assigned to more than one group (Figure 4). A total of 15.1% (13/86) of individuals presented varied profiles that conformed to two or more of the groups at different points in the life course. In all these cases, there was a period of opposing covariance of δ^{15}N and δ^{13}C immediately before death. For analysis, these individuals were initially assigned to the profile that characterized the longest period of their lives, which was the period prior to the onset of opposing covariance. In a secondary stage of analysis they were reassigned to the opposing covariance group to evaluate the impact on the results. This had no effect on the results presented below.

[Insert Figure 4]

Comparisons between clustered and dispersed child burials

Assignment of the individuals from clustered and dispersed burials to the four isotope profile groups is presented in Table 4. Overall, 53.5% of individuals presented standard weaning profiles, and the rest provided evidence of some dietary or biological stress experience. Flat profiles were the second most common (33.7%), followed by opposing covariance (9.3%). Very few individuals (3.5%) presented evidence of a rapid drop in δ^{15}N; all three of these individuals came from Black Gate and died during the first year of life. A Fisher's Exact test confirms that there is a strong and statistically significant association between burial type and isotope profiles (Fisher's Exact = 21.010, $p<0.001$, Cramer's V = .477, $p<0.001$). Standard weaning profiles are significantly rarer among children in clustered burials (z = -4.3) compared to the dispersed burials, and both flattened profiles (z = 2.6) and profiles with a rapid drop (z = 2.3) are more commonly represented.

[Insert table 4]

Individuals presenting standard weaning profiles were present among both clustered and dispersed burials, albeit in significantly smaller numbers among the former. It is therefore possible to evaluate whether weaning status at death varied between those buried in clusters and those not. Examination of the 46 standard weaning profiles enabled assignment to one of three stages of the weaning process at death: exclusive breastfeeding; mixed diet comprising breastmilk and supplementary foods; and fully weaned (see Fig. 1, Table 5). There were no statistically significant differences in the proportions of individuals who died at the three weaning stages between clustered and dispersed burials (Fisher's Exact Chi-Square = 6.005, p=.132). This suggests that the stage of weaning at death was not associated with the decision to bury children in clusters.

[Insert table 5]

The binary logistic regression model using isotope profile, age at death and site as the predictor variables correctly predicted the funerary rite of 82.6% of individuals, compared to the null model which predicted only 64.0% of cases correctly (Table 6). Wald tests indicated that only isotope profile made a significant contribution to the model (W = 11.032, p = 0.001). Odds ratios indicated that the association of clustered burial with isotope profile (OR = 3.770) was substantially greater than with age at death (OR = 1.371) or site (OR = 1.198). This evidence suggests that isotope profile is the main determinant of whether an individual is interred in a burial cluster, rather than age or site. The result also confirms that the age bias identified in the two funerary cohorts and between the four sites is not primarily responsible for the patterns seen in the isotope profiles between these groups.

[Insert table 6]

DISCUSSION

The four incremental isotopic patterns identified here illuminate variation in dietary protein and carbohydrate intake over the infant life course, in addition to periods of biological stress of potentially diverse origin. Two non-standard weaning isotope profiles were significantly over-represented among individuals buried in child-specific clusters: flat profiles characterised by no evidence of the trophic level effect expected among breastfeeding infants and profiles in which a sudden drop in $\delta^{15}N$ followed birth accompanied by no overall change in $\delta^{13}C$. Both profiles indicate that these children struggled to obtain sufficient nutrition from breastmilk and, in some cases, may not have been breastfed at all. Children with standard weaning profiles were more likely to be interred in graves alongside adults, regardless of whether they died while exclusively breastfeeding, during weaning or after cessation of breastfeeding. The following discussion will provide a context for these data by exploring the causes of failure to breastfeed, their implications for infant wellbeing and identity, and the reasons why such children might be distinguished in death.

Failure to breastfeed: causes and impact on infant wellbeing and identity

Breastfeeding provides nutritional and immunological support for the newborn and helps to facilitate a strong mother-infant bond (Riordan & Wambach, 2010). Human milk provides the infant with highly bioavailable nutrients to support rapid growth and development, facilitating successful transition from intra- to extra-uterine environments (Donovan, 2009). Colostrum, the milk produced during the first few days after birth, also confers vital early immunological protection against gastrointestinal infections, diarrheal diseases and respiratory diseases, much of which extends into adulthood (Donnet-Hughes, Schiffrin & Walker, 2009). Modern clinical data suggest that breastfeeding success is highly dependent on maternal health (both mental and physical), with depressed, sick or undernourished women experiencing a greater failure rate in breastfeeding (WHO, 2009). Additional factors that influence breastfeeding practices include separation of the mother from infant, such as post-partum maternal mortality, a heavy maternal workload away from the home, or the fosterage or abandonment of infants by their biological parents. A combination of documentary sources sheds light on these factors in early medieval Europe. Orphans could be offered safe homes with family or friends, but biographical accounts regularly report foster families who failed to fulfill their duties (Shahar 1992). Law codes prescribing punishment for various crimes indicate that abandoned children were often placed into the care of the Church and Canon Law of the 8th century implies illegitimate children could also be given over in the same manner (Boswell, 1988). After several years under the care of the Church, these children could be fostered into families or into religious communities, but some will not have survived to independence.

Cultural practices can also be highly influential in infant feeding decisions (Fildes, 1995; Shahar, 1990). For example, ethnographic evidence suggests a widespread and longstanding distrust of colostrum among traditional societies, who believe it to be dangerous, dirty, bitter or stale (Morse, Jehle & Gamble, 1990), and a similar sentiment is expressed in the Classical medical texts that circulated throughout medieval Europe (Fildes, 1986). Although breastfeeding by the mother is generally preferred for the first months of life, wet-nursing is also documented in many pre-industrial societies and widely practised today. The breastfeeding of a child by other women appears to have been adopted both through necessity and choice, and has nutritional advantages for the infant over hand-feeding (Coates, 2010). Wet-nursing was practised during the medieval period among higher-status families and the 7th-century Laws of Ine of Wessex, suggest that a thegn should include among his retinue a *childfestran*, which can be translated as ‘nourisher of the child’ (Crawford, 1999). For poorer women, it was unlikely that wet-nursing was so readily available, but other, undocumented nursing arrangements may have existed.

An infant who does not receive sufficient breast milk from mother or wet-nurse, for whatever reason, requires alternative sustenance to survive. In both past and contemporary societies without access to artificially formulated infant milks, the first foods offered to babies often include paps or gruels made from a combination of liquids such as water or animal milk and starchy ingredients such as cereals. These are mixed into a paste which is easy to ingest (Coates, 2010; Fildes, 1986). One ethnographic study of 120 traditional societies suggested that similar foods, including milk, sugarwater and teas, are also fed to neonates in the first few days of life while they are kept from the breast to prevent them consuming colostrum (Morse, 1990; Semega-Janneh, Bøhler, Holm, Matheson & Holmboe-Ottesen, 2001). Historical and archaeological evidence has revealed several potential means of artificially feeding infants, including milk directly from the teat of an animal (although it was widely known, at least from the 11th century, that animal milk consumed in this way carried disease) and various liquid foods through modified animal horns or purpose-made vessels (Didsbury, 1992; Fildes, 1986).

Although there were clearly means of feeding infants known to past societies, these foods would have conferred none of the immunological benefits of colostrum, provided only a fraction of the required nutrition of breastmilk, and exposed infants to food-borne pathogens prior to sufficient maturation of their immune systems. In modern developing countries, it has been estimated that poor breastfeeding, especially the introduction of solid foods before six months of age, results in 1.4 million deaths and 10% of the disease burden in children under five years (Lauer, Betrán, Barros & de Onís, 2006; WHO, 2009). Infants who are not breastfed are six to ten times more likely to die in the first months of life. Moreover, both inadequate complementary feeding and early cessation of breastfeeding are considered key determinants of infant malnutrition in the modern world (Stewart, Ianotti, Dewey, Michaelsen & Onyango 2013; WHO, 2015).

Even if the mother was fit and able, the physical condition of the infant may have been a barrier to breastfeeding. Premature or stressful birth, illness and congenital abnormality (e.g. palate defect, tongue-tie, heart or kidney condition) are the main factors contributing to poor feeding among modern children (WHO, 2009) and are likely to have been similarly influential in the past. Weaning age also shows a strong relationship with pathogen stress (Quinlan, 2007), such that sickly children tend to cease breastfeeding earlier than healthier children. It can be difficult, however, to unpick whether an infant was weaned earlier than usual because they were sickly, or was sickly because they were weaned early (Simondon, Simondon, Costes, Delaunay & Diallo, 2001).

Conclusions

This study is the first to demonstrate the utility of applying incremental isotope analysis methods to generate data with which to test hypotheses about the provision of child-specific funerary practices in the past. The detailed understanding of early life history required for this study could not have been obtained without the incremental isotope method and its ability to reveal trends in dietary status and physiological status across the whole of early life rather than just at the point of death. The benefits of extending such analysis to investigate the motivations behind the provision of funerary rites during different periods and in various geographic locations would be great.

The infants who did not successfully breastfeed identified in this study tended to be buried in clusters. They are likely to have shared certain life experiences that affected their wellbeing and care needs, and thus influenced the perception of their identities by others. A substantial number may have lost their mothers during birth or the first few days of their lives, or had mothers who suffered from postnatal illness ~~or depression~~ who were unable to nurse. Others may have been premature or underweight births, had congenital anomalies that inhibited feeding, or been abandoned by their parents. They will all have faced higher risk of malnutrition, undernutrition and infection, and so may have matured more slowly and experienced more frequent and severe bouts of sickness than other infants. The survival of some of these children beyond infancy suggests that alternative care was actively sought and could be at least partially successful, but failure to breastfeed will have left children poorly buffered against nutritional and infectious insults later in life and may have contributed greatly to increased levels of mortality among this cohort, not just in their first few months, but throughout their early years.

~~It is widely argued that~~ Prior to this study, the burial of infants in clusters around churches during the early medieval period has been explained in several ways. Their location adjacent to the sacred focus of the church building and holy relics within implies special care in their interments, but why special care was necessary is debated (Craig-Atkins, 2014). It has been hypothesized that water running from the church roof could have provided reinforcement of baptismal ritual for those who died unbaptized (Boddington, 1996). Alternatively, it has been suggested the children may have died in an epidemic (Willmott, In Prep.) or that their interments were clandestine additions to cemeteries (Crawford, 2008). The evidence presented here, which indicates that many of the children buried in clusters around churches had the worst start in life – lost their mothers at or around the time of birth, lacked a safe means of sustenance and nurturing in their early years or could not be supported through the first key dietary threshold in life – provides a new dimension to this debate. These children likely included orphans and foundlings under the direct care of the church at the time of their deaths. It would be appropriate for the additional care these children received in life, when ultimately unsuccessful, to be extended beyond death through the provision of a funerary practice that reinforced the role of the church in their lives and afforded them special status among the community of the dead.

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FIGURE CAPTIONS

Figure 1. Expected changes in δ^{15}N and δ^{13}C during infancy and early childhood reflecting normative breastfeeding and weaning (After Nitsch et al. 2011: Fig. 1).

Figure 2. Locations of cemetery sites included in this study.

Figure 3. Examples of four individuals from the study cohort typifying the four isotope profiles assigned. Cherry Hinton 4008 – a standard weaning profile with evidence, in this case, of the individual having completed weaning; Spofforth 380a – a flat profile in which no elevation of δ^{15}N and δ^{13}C due to trophic level effects is evident; Spofforth 295 – opposing covariance of δ^{15}N and δ^{13}C; Black Gate 529 – rapid drop in δ^{15}N and δ^{13}C.

Figure 4. Raunds 5310. An example of an individual with a profile consistent with more than one isotope profile. The profile initially presents elevated δ^{13}C but a flat profile in δ^{15}N which would be classified as flat profile. Towards the end of life, an increase in δ^{15}N accompanied by a decrease in δ^{13}C would be classified as opposing covariance.

Table 1. Clustered and dispersed burials from the four early medieval English cemeteries included in the sample for incremental isotopic analysis.

		Burial location		Total
		Dispersed	Clustered	
Site	Black Gate	10 (18.2%)	10 (32.3%)	20 (23.3%)
	Cherry Hinton	17 (30.9%)	3 (9.7%)	20 (23.3%)
	Raunds Furnells	13 (23.6%)	9 (29.0%)	22 (25.6%)
	Spofforth	15 (27.3%)	9 (29.0%)	24 (27.9%)
Total		55 (64.0%)	31 (36.0%)	86 (100%)

Table 2. Age at death distribution for individuals from clustered and dispersed burials.

	Age at death (years)						Total
	<1	1-1.9	2-2.9	3-3.9	4-4.9	>5	
Dispersed	4 (4.7%)	5 (5.8%)	21 (24.4%)	13 (15.1%)	2 (2.3%)	10 (11.6%)	55 (64.0%)
Clustered	13 (15.1%)	2 (2.3%)	9 (10.5%)	3 (3.5%)	1 (1.2%)	3 (3.5%)	31 (36.0%)
Total	17 (19.8%)	7 (8.1%)	30 (34.9%)	16 (18.6%)	3 (3.5%)	12 (13.9%)	86 (100%)

Table 3. Descriptive data for incremental δ^{15}N and δ^{13}C from this study with comparative data from published research. Analytical error was 0.2‰.

[1.] MacPherson 2005; [2.] Haydock et al. 2013; * calculated from published supplementary data in Haydock et al. 2013.

	No. individuals	No. values	δ^{15}N (‰)					δ^{13}C (‰)				
			Mean	Std. Dev.	Min	Max	Mean intra-individual range	Mean	Std. Dev.	Min	Max	Mean intra-individual range
Raunds Furnells	22	127	14.2	1.5	11.1	17.7	2.2	-19.3	0.5	-20.3	-18.1	1.0
Black Gate	20	124	14.0	1.3	11.2	17.1	2.5	-19.9	0.7	-21.3	-18.4	0.8
Cherry Hinton	20	134	14.7	1.5	10.8	18.4	2.4	-19.3	0.5	-20.5	-18.3	0.9
Spofforth	24	137	12.6	1.2	9.4	16.8	1.7	-20.7	0.5	-21.9	-19.4	0.6
All four sites	86	522	13.8	1.6	9.4	18.4	2.2	-19.8	0.8	-21.9	-18.1	0.8
Adult rib data – Raunds Furnells[2]	20	-	11.0*	0.8*	9.5	12.5	-	-19.8*	0.2*	-20.3	-19.4	-
Adult rib data – Black Gate[1]	24	-	11.4	0.7	10.5	12.6	-	-20.5	0.5	-21.2	-19.1	-

Table 4. Distribution of the four isotope profiles among clustered and dispersed burials.

	Weaning profile	Flat profile	Opposing covariance	Rapid drop in $\delta^{15}N$	Total
Dispersed	39 (45.3%)	13 (15.1%)	3 (3.5%)	0 (0.0%)	55 (64.0%)
Clustered	7 (8.1%)	16 (18.6%)	5 (5.8%)	3 (3.5%)	31 (36.0%)
Total	46 (53.5%)	29 (33.7%)	8 (9.3%)	3 (3.5%)	86 (100%)

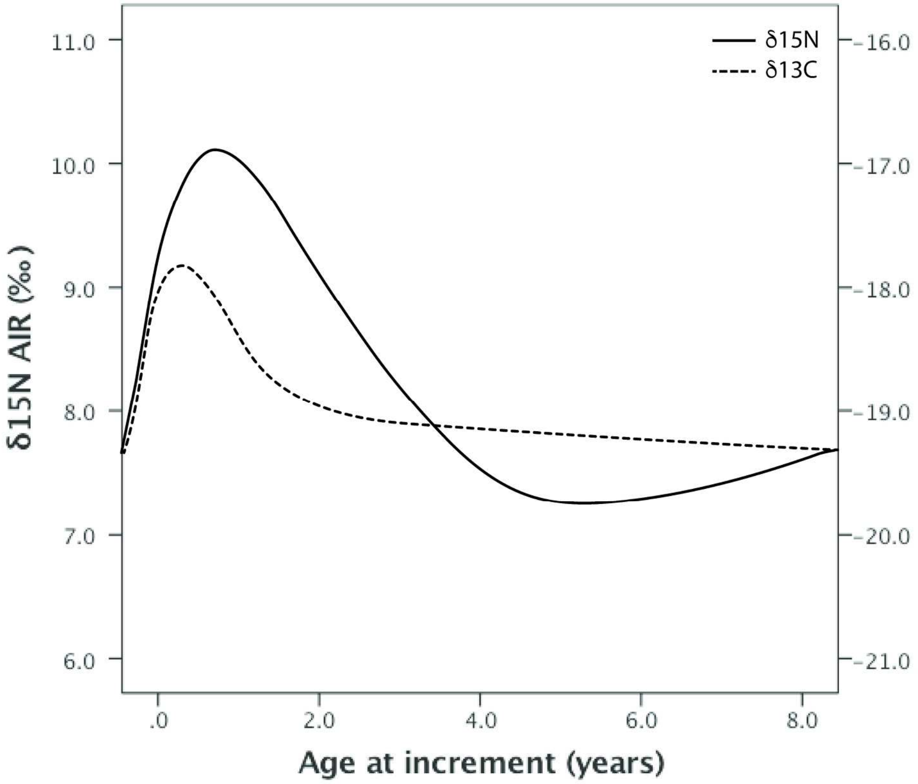
Table 5. Weaning status at death of individuals with standard weaning profiles from clustered and dispersed burials.

	Exclusive breastfeeding	Supplementary foods	Weaned	Total
Dispersed	0 (0.0%)	21 (45.7%)	18 (39.1%)	39 (84.4%)
Clustered	1 (2.2%)	4 (8.7%)	2 (4.3%)	7 (15.2%)
Total	1 (2.2%)	25 (54.3%)	20 (43.5%)	46 (100%)

Table 6. Binary logistic regression analysis of clustered and dispersed burials.

1. As these variables make a negative contribution to the model, the reciprocal of the odds ratio has been provided so its magnitude can be directly compared with that of isotope profile, which makes a positive contribution to the model.

	Coefficient	Standard Error	Wald Test P Value	Odds Ratio	Odds Ratio CI lower limit	Odds Ratio CI upper limit
Isotope profile	1.327	0.235	0.001	3.770	1.723	8.249
Age at death	-0.316	0.174	0.069	1.371[1]	0.976[1]	1.927[1]
Site	-0.180	0.235	0.587	1.198[1]	0.755[1]	1.898[1]
Constant	-1.339	1.066	0.209	--	--	--
Regression model		**Log (p clustered/p dispersed) = -1.339 + -0.316*age + -0.180*site + 1.327* isotope profile**				

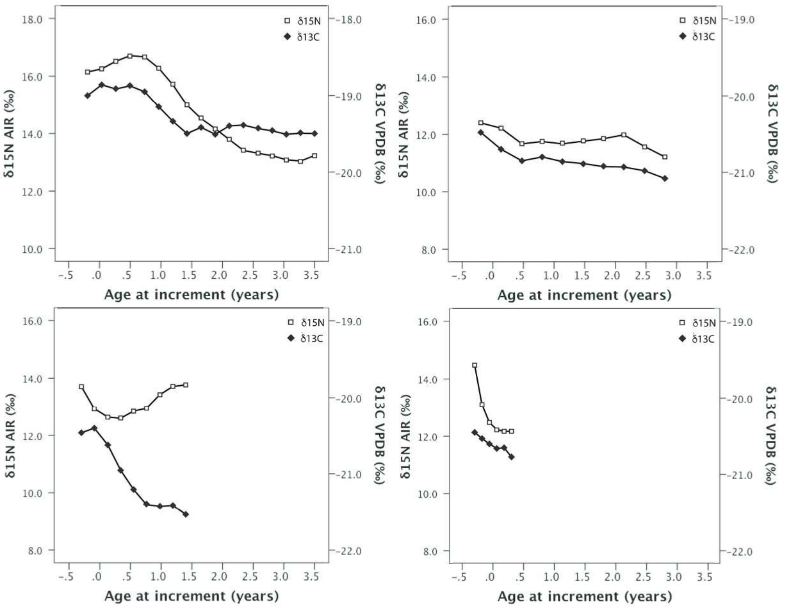


Expected changes in δ15N and δ13C during infancy and early childhood reflecting normative breastfeeding and weaning (After Nitsch et al. 2011: Fig. 1).

101x81mm (600 x 600 DPI)

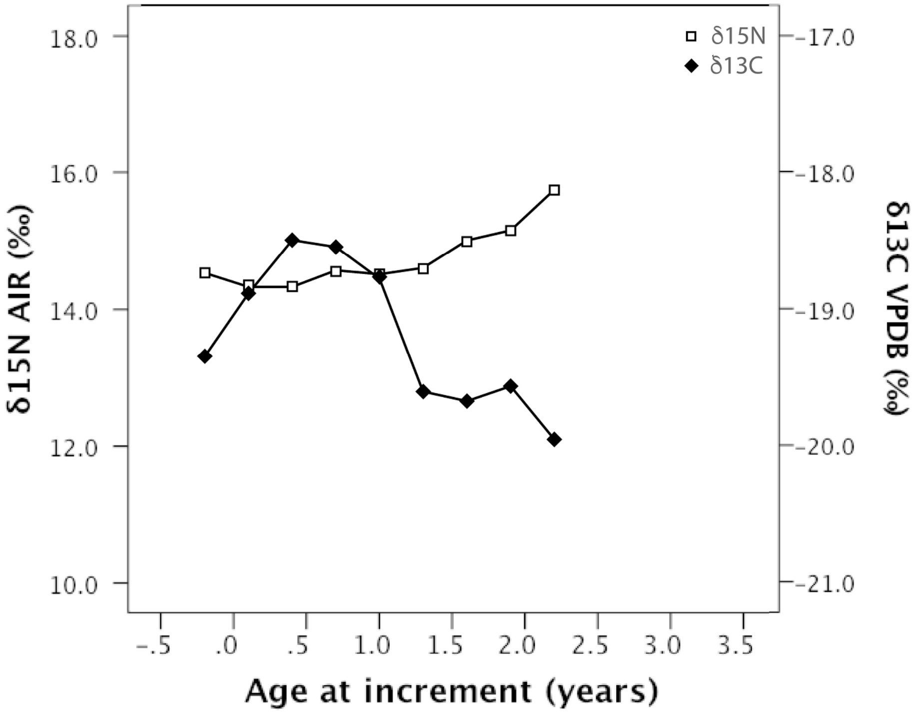
Locations of cemetery sites included in this study.

152x217mm (600 x 600 DPI)



Examples of four individuals from the study cohort typifying the four isotope profiles assigned. Cherry Hinton 4008 – a standard weaning profile with evidence, in this case, of the individual having completed weaning; Spofforth 380a – a flat profile in which no elevation of δ15N and δ13C due to trophic level effects is evident; Spofforth 295 – opposing covariance of δ15N and δ13C; Black Gate 529 – rapid drop in δ15N and δ13C. ‼ †

188x134mm (300 x 300 DPI)



Raunds 5310. An example of an individual with a profile consistent with more than one isotope profile. The profile initially presents elevated δ13C but a flat profile in δ15N which would be classified as flat profile. Towards the end of life, an increase in δ15N accompanied by a decrease in δ13C would be classified as opposing covariance. ‼ ┼

110x88mm (600 x 600 DPI)