



A regional investigation of subadult dietary patterns and health in late Iron Age and Roman Dorset, England

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ABSTRACT

This is the first regional analysis of the impact of Romanisation on subadult dietary patterns and related health parameters in Britain. A sample of 200 subadults from late Iron Age (LIA) and Romano-British (RB) Dorset were examined for dental health and specific metabolic diseases, and a sub-sample of 29 individuals were selected for nitrogen and carbon isotope analysis. The results showed that dental health declined in the Romano-British period and the incidence of scurvy and rickets rose. Increased consumption of marine foods in the RB period is indicated by an increase in $\delta^{13}\text{C}$ between the LIA and RB subadults. After early childhood, there was no age-dependent variation in dietary protein in the RB and LIA populations from Dorset. We propose that these changes related to the introduction of urban living, Romanised diets and population migration.

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1. Introduction

The impact of cultural, social and environmental change following the Roman conquest of Britain in AD 43 is most frequently known as Romanisation, a phrase that has been subject to much criticism and re-definition in recent years (Mattingly, 2006; Webster, 2001). Therefore, in our study we have followed Terrenato's (1998:20) guidance and applied the term "...in its weakest sense, as a convenient denomination covering the events involved in the creation of Roman [Britain], with no cultural implications taken for granted."

The Romanisation of Britain has been particularly studied in respect to changes in material culture, funerary rites and the landscape (Mattingly, 2006), but in recent years our understanding of the transformations that took place within the local and wider environment has been invigorated by new studies examining the evidence for foodways and agriculture (Cool, 2006; King, 1999a, 2001; Locker, 2007; van der Veen et al., 2007, 2008). This research has demonstrated that multiple foodways existed within Roman

Britain, as the Romans did not seek to forcibly impose their dietary habits on colonies or conquered peoples (Alcock, 2003; Williams, 2000); the army also allowed the continuity of ethnic foodways, as attested by evidence presented by King (1999b) and Cool (2006). Such diversity was recognised during the Roman period, with changes in habits noted and discussed, particularly in relation to social change (Purcell, 2003). The results of stable isotope analyses of diet using human and animal remains in Roman Britain have supported and enhanced these findings, and allowed researchers to identify and examine differences at the individual, site, city and regional level (e.g. Chenery et al., 2010; Cummings, 2008; Leach et al., 2009; Müldner and Richards, 2007; Redfern et al., 2010).

The Romanisation of Britain also had health consequences for the existing and migrant populations, particularly because the Roman invasion saw the introduction of towns and urban life-styles to previously rural and tribal communities (Mattingly, 2006). The incorporation of late Iron Age (LIA) communities into the Roman Empire had negative health impacts, particularly with respect to a decline in dental health and an increase in the prevalence of infectious and metabolic diseases (Redfern, 2008; Redfern and DeWitte, 2011; Roberts and Cox, 2003). Our understanding of how subadults responded to these changes is very limited (Redfern, 2007; Redfern and DeWitte, 2011), and is made all the more difficult because we lack knowledge about their daily activities in the

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preceding LIA (Karl, 2005). Bioarchaeological evidence suggests that Romanisation negatively impacted subadult health, as Dorset data show an increase in the prevalence of infectious and metabolic diseases, a decline in growth and evidence for direct trauma (Redfern, 2007; Redfern and DeWitte, 2011). In contrast to the LIA, our knowledge of subadult life in Roman Britain has rapidly improved in recent years through bioarchaeology, stable isotope analysis and funerary studies (Gowland, 2001; Gowland and Redfern, 2010; Lewis, 2010). These have demonstrated that childhood was a culturally defined period of the life course, but one subject to regional heterogeneity and temporal variation. Woolf's (2005) research into family life in the northwest provinces of the Empire has shown that little epigraphic evidence is available, but suggests that the nature of the family and its relationship to wider kinship and power networks would have been subject to considerable regional differences, in addition to variation in the adoption/adaptation of Roman culture and concepts of family life (Rawson, 1986, 2003; Revell, 2005). Consequently, it is necessary to assume that the life-ways of Romano-British children were highly variable and subject to inter-family and inter-generational differences in care, diet and health (Baker, 2010; Gowland and Redfern, 2010).

Currently, the majority of published stable isotope analyses have studied single cemetery or town-specific adult dietary patterns in the Roman period (e.g. Müldner and Richards, 2007), or evidence for weaning in either LIA or RB populations (e.g. Fuller et al., 2006; Jay et al., 2008). As such, these studies were only able to capture dietary information on the last five years to several decades of a person's a life (Hedges et al., 2007) which, as isotope evidence for diaspora has shown, may also include pre-migration foodways (Müldner et al., 2011).

By way of contrast, subadult individuals provide an excellent source of data on changing diet and health, because our ability to more accurately determine their age-at-death using the sequence of dental eruption allows us to examine changes over the short-term compared to adults. Therefore, this study sought to complement previously published adult data from Dorset County, England (Fig. 1) concerning the effects of Romanisation upon diet and health (Redfern, 2008; Redfern and DeWitte, 2011; Redfern et al., 2010) by using subadults recovered from funerary contexts to test the hypothesis that the Romanisation in Dorset altered infant feeding practices, including the onset of weaning and post-weaning diet, and negatively impacted health, as evidenced through changing stable isotope profiles, and supplemented by bioarchaeological data on dental health and the metabolic diseases of scurvy and rickets to provide a holistic understanding of the stable isotope data.

2. Archaeological background

Research published by Redfern et al. (2010) presented and discussed the environmental and material culture evidence for Romanisation in LIA and RB Dorset. In summary, the materials on which this and the earlier study were based were recovered in the vicinity of Dorchester, southwest England, in the former territory of the Durotriges, who had likely occupied the region since the early Iron Age (9th to 7th centuries BC) (Cunliffe, 2004; Gale, 2003). By the LIA (1st century BC to 1st century AD), the Durotriges were a close-knit tribal confederacy centered upon modern Dorset (Cunliffe, 2005). The region was conquered during the early phases of the Roman invasion (circa AD 43/44) and Dorchester – Roman *Durnovaria* – was established circa AD 65–70 as a *civitas peregrina*, or native administrative centre (RCHME, 1970; Sharples, 1991; Woodward et al., 1993). *Durnovaria* was a “Roman-style town”, with the buildings organised using a street grid (Putnam, 2007; Woodward et al., 1993). Outside *Durnovaria*, the evidence for Romanisation is more varied. Roundhouses continued to be built

and occupied across Dorset, with Roman-style rectangular buildings later added in some outlying settlements (Hingley, 1989; Putnam, 2007). The construction of villas in Dorset follows the pattern of urban growth, with the 3rd and 4th centuries AD a time both of increasing villa numbers and architectural opulence. These farm complexes were likely home to *civitas* administrators and other functionaries, both native and Roman (Putnam, 2007).

The former Durotrigian territory has produced myriad evidence of the LIA and RB diet. Evidence for the LIA importation of wine and perishable commodities such as figs, corn and chamomile was recovered at Hengistbury Head and imported pottery types recovered at the Poundbury Camp hillfort likely contained olive oil, most probably for elite consumption (Darvill, 1995; Gale, 2003; Sparey Green, 1987:143). The evidence for cereal crops includes hulled barley, emmer wheat and oats (Hinton, 1999; Jones, 1981), while faunal remains indicate exploitation of a wide variety of wild and domesticated animals, including wood pigeons, curlew, red/roe deer, hares, geese, chickens and goats (Harcourt, 1979; Wyles, 1997). An emphasis on a dairy economy is suggested by pottery residue analyses, with the majority of samples having dairy fats present (Copley et al., 2004).

Food importation increased in the RB period and new food-stuffs, such as cherries, grapes, hazelnuts, cabbage and peas/beans, were introduced. The range of cereals being exploited shows continuity from the LIA but evidence from grain driers indicates barley, oats and bread wheat were now grown (Bryant, 1990; Ede, 1993). The faunal evidence continues to show an emphasis upon dairy farming, though evidence for the breeding of pigs and egg production in Dorchester has also been found (Hamilton-Dyer, 1999; Maltby, 1993; Sidell, 2001). Hathaway's (2005) research has demonstrated that estuaries and natural harbours were utilized for the production of salt in the LIA and RB period; this commodity was facilitated the curing and storing of food. The level of freshwater and marine resources increased in the Romano-British period, and the species identified – periwinkles, cockles, limpets, eel, bass, sea-bream and chub – were most probably caught from the local coast and rivers (Allen, 1993a,b; Hamilton-Dyer, 1993, 1999). The manufacture of *allec* – a sauce with bones produced by the fermentation of very small fish – is attested to by a deposit of herring and sprat bones from Dorchester, and the consumption of shellfish is supported by the discovery of a double-ended two-pronged cutlery item that may have been used to eat molluscs (Hamilton-Dyer, 2001).

2.1. Romanisation: subadult perspective

The study of subadults presents different opportunities compared to adult individuals. Macroscopic analysis of their skeletons can provide more detailed information on the biological aspects of the life course compared to adult individuals, as clinically established age-related changes in dentition, skeletal fusion and growth allow us to more accurately estimate their biological age (Scheuer and Black, 2000:4–17). It is also possible to achieve more nuanced perspectives of health using subadult samples, as they have high bone turnover which enables bone responses to be identified earlier in the disease process than with adults. This, combined with our ability to more precisely age them, allows us to examine disease onset and longevity (Lewis, 2007).

Research by Gowland (2001) has demonstrated that the funerary treatment of subadults can provide important information on their status and role in RB society. The rite practiced by the Durotriges was one of only three funerary traditions in Britain that included the consistent interment of a portion of the population in a given tribal area (Cunliffe, 2005; Whimster, 1981). Inhumation persisted in this area after the Roman conquest, while other areas of



Fig. 1. Location map of the county of Dorset within Great Britain.

Britain either continued their use of the pre-Roman 'invisible rite' or adopted the Roman rite of cremation (Cunliffe, 2005; Philpott, 1991). Regardless of the nature of the rite performed, Roman law mandated that human remains be placed outside the official and religious boundary of a town or city (Hope, 2009). This placement,

which sought to avoid the ritual pollution of the community, had a single exception – newborn infants, whose remains were often interred within settlements (Adkins and Adkins, 1998). These patterns and proscriptions are evident in mortuary patterning across Britain (Scott, 1999; Pearce, 2008).

Hamlin's research (2007:261) found that, after considerable LIA inter-cemetery variance, the ratio of subadult:adult burials in Dorset became more uniform across cemeteries in the RB period (25–30% subadults, 70–75% adults). Further, the marked LIA inter-cemetery variation in subadult:adult grave good distribution patterning gave way in the RB period to a consistent pattern in which adults were more likely to receive grave goods than subadults (Hamlin, 2007: 276). Together, these data provide strong evidence for changing concepts of age identity in post-conquest Dorset.

2.2. Late Iron Age and Romano-British subadult dietary patterns

Our knowledge of subadult diet in Britain during both periods is strongly reliant upon stable isotope data since it provides information in the absence of material culture evidence in the pre-literate LIA (Cunliffe, 2005). In the Roman period, it provides evidence independent of the primary literary sources, which are strongly biased towards Mediterranean communities (Harlow and Laurence, 2002:41–2; Jackson, 2000:100–4). In both periods, authors (e.g. Cool, 2006; Watts, 2005) have attempted to associate infant health and feeding practices, particularly the onset of weaning, with the prevalence of enamel hypoplastic defects. However, the bioarchaeological literature (cf., Lewis, 2007:106–7) clearly demonstrates that such defects have a multifactorial origin and cannot be reliably associated with the weaning period.

For the British Iron Age, Jay et al.'s (2008) study of the subadults from Wetwang Slack (Yorkshire) demonstrated that by the age of 2.5 years, they were consuming foods that were isotopically equivalent to adults. Greater evidence for subadult diets in Roman Britain is present. This includes feeding vessels (Fildes, 1985, 1988; Tubbs, 1947) that are frequently recovered from infant burials. These vessels, according to Soranus' writings, were used for dispensing water or diluted wine (Soranus 2.21). From excavations in *Durnovaria*, we know that a wet-nurse lived in the *civitas*, as a flagon has the inscription 'NUTRICIS' – property of *Nutrix*, which

translates as wet-nurse – indicating the presence of wet-nurses there (Tomlin, 1993:284). Roman medical texts, such as Soranus and Celsus, recommended that weaning took place between the ages of three months and three years (Rawson, 2003:7–30, 126). However, as in the LIA, the majority of RB information is derived from stable isotope analysis. Within Britain, Fuller et al. (2006) demonstrated that at Queenford Farm (Oxfordshire), weaning started before the end of the first year of life and was complete by the age of 3 or 4 years. Variations are seen in other parts of the Empire, with results from Rome suggesting that weaning was complete by 2.5 years (Prowse et al., 2008) and in Egypt by 3 years of age (Dupras et al., 2001). The quantity and quality of the foods consumed are socially and culturally determined and has been demonstrated to significantly impact child health and development (Rousham, 1999; Rousham and Humphrey, 2002), but stable isotope information cannot inform about this aspect of infant nutrition (see Jay, 2009).

3. Materials and methods

3.1. Bioarchaeological investigations

In order to investigate post-conquest changes in infant feeding practices, the onset of weaning and post-weaning diet, and their impact on health, bioarchaeological data concerning dental health and the metabolic diseases scurvy and rickets were included in our study to understand the stable isotope signatures.

The bioarchaeological data was gathered from 72 LIA and 128 RB individuals aged between preterm to less than 20 years old (see Tables 1 and 4), who were considered to have observable cortical bone (stages 0–3) (Buikstra and Ubelaker, 1994: 98) and had been excavated from burial contexts in Dorset. As the RB subadult sample from Poundbury Camp was too large to be recorded in its entirety (Redfern, 2007), a sub-sample of 80 randomly selected individuals from the RB phases were recorded (Redfern, 2006, 2008).

Table 1
List of sites and number of individuals included in the study, presented by date (M-LIA, mid-to-late Iron Age; LIA, late Iron Age; RB, Romano-British period), total N of individuals and age-group (Buikstra and Ubelaker, 1994:9).

Date	Reference	Site	Total N	Fetal (<birth)	Infants (birth–3 years old)	Children (3–12 years old)	Adolescents (12–20 years old)
M-LIA	1	Gussage All Saints	21	19	–	1	1
LIA	2	Dorchester Bypass	5	1	1	2	1
	3	Kimmeridge	1	1	–	–	–
	4	Maiden Castle hillfort	0	2	5	–	2
	5	Manor Farm, Portesham	3	–	–	–	3
	6	Poundbury Camp	27	24	1	1	1
	7	Rope Lake Hole	1	–	–	1	–
	8	Tolpuddle Bypass	3	–	1	1	1
	9	Whitcombe	2	–	1	–	1
		Total	72	47	9	6	10
RB	10	Albert Road	10	8	–	–	2
	11	Alington Avenue	13	3	4	3	3
	12	County Hall	6	–	6	–	–
	13	Dorchester Bypass	14	2	1	5	6
	14	Fordington Old Vicarage	6	3	1	1	1
	15	Greyhound Yard	8	8	–	–	–
	16	Hod Hill	2	2	–	–	–
	17	Little Keep	3	–	1	1	1
	18	Poundbury Camp	55	–	37	14	4
	19	Poundbury Pipeline	1	–	–	1	–
	20	Tarrant Hinton	8	8	–	–	–
	21	Tolpuddle Bypass	2	1	1	–	–
		Total	128	35	51	25	17
		Total: both periods	200	82	60	31	27

References: 1 Wainwright (1979); 2 and 12 Smith et al. (1997); 3 O'Connell (unpublished report); 4 Wheeler (1943); 5 Valentin (2003); 6 and 18 Farwell and Molleson (1993); 7 Maw (1976); 8 and 21 Hearne and Birkbeck (1993); 9 Aitken and Aitken (1991); 10 Stacey (1987); 11 Davies et al. (2002); 12 Smith (1993); 14 Startin (1982); 15 Woodward et al. (1993); 16 Richmond (1968); 17 Egging-Dinwiddy (2010); 19 Davies and Grieve (1986); 20 Graham (2007).

Table 2
Samples and results of isotopic analyses.

Site	Excavation reference	Period	Age	Midpointage	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	%N	%C	C/N
Gussage All Saints	GAS139.4	LIA	38 wks	−0.04	9.68	−19.56	9.7	28.8	3.4
Poundbury Camp	PC1376	LIA	38–40 wks	−0.04	10.58	−19.47	12.5	36.3	3.4
Fordington Bottom	FB4093	LIA	37–42 wks	−0.01	9.54	−19.95	9.4	27.4	3.4
Poundbury Camp	PC1392	LIA	40 wks	0.0	9.75	−20.60	8.4	25.0	3.5
Poundbury Camp	PC1214	LIA	2 yrs	2.0	10.35	−20.07	9.7	28.4	3.4
Flagstones	FL77 ^a	LIA	3–4 yrs	3.5	8.39	−20.49	12.7	37.9	3.5
Fordington Bottom	FB4377	LIA	8–16 yrs	12.0	8.17	−19.95	14.4	40.1	3.3
Gussage All Saints	GAS31.6	LIA	12 yrs	12.0	8.24	−20.53	12.2	35.3	3.4
Poundbury Camp	PC522	LIA	13–14 yrs	13.5	9.10	−19.90	12.5	35.2	3.3
Fordington Bottom	FB2264 ^a	LIA	15y ± 36 mo	15.0	8.49	−19.94	11.7	33.0	3.3
Whitcombe Farm	WF8	LIA	15 yrs	15.0	9.82	−20.28	13.5	38.3	3.3
Portesham Manor Farm	MF527	LIA	14–18 yrs	16.0	8.84	−20.01	12.1	34.2	3.3
Flagstones	FL73 ^a	LIA	16–17 yrs	16.5	8.87	−20.57	12.6	36.9	3.4
Alington Avenue	AA1103	RB	2–4 mo	0.3	10.01	−20.41	14.7	40.6	3.2
Poundbury Camp	PC765	RB	18 mo ± 6 mo	1.5	10.32	−20.12	14.4	40.0	3.2
Poundbury Camp	PC124	RB	2 yrs	2.0	9.52	−20.56	13.9	38.7	3.2
Alington Avenue	AA1066	RB	4–6 yrs	5.0	9.47	−19.52	12.7	36.2	3.3
Alington Avenue	AA1169	RB	4–6 yrs	5.0	9.82	−19.04	15.2	41.5	3.2
Poundbury Camp	PC209	RB	5 yrs	5.0	10.79	−19.26	12.5	35.3	3.3
Poundbury Camp	PC1114	RB	6 y ± 24 mo	6.0	8.60	−19.80	14.5	40.3	3.2
Alington Avenue	AA1156	RB	6–8 yrs	7.0	9.04	−19.15	13.6	38.2	3.3
Poundbury Camp	PC287	RB	12 y ± 36 mo	12.0	8.00	−19.48	14.2	39.8	3.3
Albert Road	AR20	RB	13–15 yrs	14.0	7.91	−18.95	15.5	42.8	3.2
Poundbury Camp	PC743	RB	15 y ± 36 mo	15.0	8.73	−19.81	13.3	37.4	3.3
Albert Road	AR50	RB	14–17 yrs	15.5	10.49	−19.02	12.5	34.9	3.3
Maiden Castle Road	MCR72	RB	18–19 yrs	18.5	9.13	−19.99	14.6	40.5	3.2
Maiden Castle Road	MCR98	RB	17–20 yrs	18.5	8.70	−19.43	14.2	39.5	3.2
Maiden Castle Road	MCR90	RB	18–20 yrs	19.0	9.09	−19.14	12.3	34.9	3.3
Maiden Castle Road	MCR43	RB	19–20 yrs	19.5	9.00	−19.14	12.6	35.9	3.3

^a data based on one measurement rather than three replicate measurements.

The skeletal remains and health variables were recorded using the protocols and methods described by Buikstra and Ubelaker (1994). Biological age was determined using eruption of the deciduous and permanent dentitions (Ubelaker, 1989), long bone length and epiphyseal fusion (Scheuer and Black, 2000); the age-groups described by Buikstra and Ubelaker (1994:9) were employed in the study. The biological sex of subadult individuals was not estimated as these methods are of low accuracy (Lewis, 2007:48).

Specific metabolic diseases are caused by maternal deficiencies transmitted to very young individuals and in older subadults by long-term dietary/environmental deficiencies. Rickets is caused by a deficiency in vitamin D, the majority of which is created by the body, initiated by exposure to sunlight. Lesser quantities are absorbed from the diet, particularly fish oils. This disease was diagnosed using the methodology published by Brickley and Ives (2008:97–114). Scurvy is caused by a deficiency in vitamin C, indicating a diet with little to no fruit or green vegetables. In the case of full-term individuals and infants, scurvy should only develop after 4–10 months post-partum, after the protective store of ascorbic acid present at birth has been exhausted (Lewis, 2007: 126–127). Scurvy was diagnosed using the criteria published by Brickley and Ives (2008:54–71).

Dental health evidence for diet was assessed by examining the deciduous and permanent dentition for evidence of carious lesions

and calculus. Carious lesions have a multifactorial origin, as they may be produced by factors such as poor oral hygiene and their prevalence influenced by tooth morphology (Powell, 1985). However, they frequently result from the action of bacteria in the dental plaque fermenting dietary food sugars, causing destruction of the crown and/or root structures; and the amount of destruction is dependent upon the length of time an individual sustained a lesion (Hillson, 1998:269–70). Calculus is one of the most frequently encountered dental diseases it is produced by the mineralization of plaque, and its presence influenced by oral hygiene practices. It particularly affects dentition located nearest to the salivary glands and is also associated with periodontal disease (Hillson, 1998:254–59). These pathologies are commonly used to investigate diet, as they are able to shed light on the inclusion of carbohydrates and sugars, such as through the consumption of different cereals and types of sugar (Hillson, 1998:276–83).

3.2. Isotopic investigations

Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios in bone collagen are informative about the diet of past people, primarily their protein intake (Katzenberg, 2008). In a British context these isotopes allow us to distinguish between marine food sources with high $\delta^{13}\text{C}$ (average −17 to −18‰), and terrestrial and freshwater food sources with low $\delta^{13}\text{C}$ (average −26 to −27‰). Nitrogen isotopes allow further differentiation because at each step in the food chain there is an increase of 3–5‰ in $\delta^{15}\text{N}$, and in long aquatic food chains this raises $\delta^{15}\text{N}$ to much higher values for the top carnivores than in terrestrial ecosystems. This variation in $\delta^{15}\text{N}$ allows differentiation of human diets with protein mainly derived from meat or fish (high or very high $\delta^{15}\text{N}$) from those where protein derives from plants (low $\delta^{15}\text{N}$). Each trophic level of the food chain also sees an enrichment of about 1‰ in $\delta^{13}\text{C}$, but bone collagen is offset from the bulk body value by about 4‰, and is therefore about

Table 3
Statistical comparisons.

Comparison		$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
Age-groups	LIA	$H = 3.00, p = 0.23$	$H = 6.35, p = 0.04$
(<2, 2–20, >20)	RB	$H = 5.42, p = 0.07$	$H = 2.9, p = 0.24$
Period	All subadults	$U = 40, p = 0.005$	$U = 98.5, p = 0.83$
groups (LIA, RB)	Subadults	$U = 12, p = 0.001$	$U = 49.5, p = 0.41$
	over the age of 1		

Table 4
Subadult health: skeletal pathology displayed by crude prevalence rate in percent (*n*), data presented by period, age-group and variable. Dental disease data for deciduous and permanent dentition as percentage of teeth affected (*n*), data presented by period and variable (no dental count data are available from the LIA sample from Manor Farm Portesham).

Period	Age-group	N	Carious lesions	Calculus	Rickets	Scurvy	Scurvy and Rickets
Late Iron Age	Fetal (<birth)	47	–	–	–	–	–
	Infant (birth – 3 years old)	9	–	–	11.1 (1)	–	–
	Child (3–12 years old)	6	16.7 (1)	16.7 (1)	–	–	–
	Adolescent (12–20 years old)	10	40 (4)	90 (9)	–	–	–
	Deciduous dentition	226	–	–	–	–	–
	Permanent dentition	276	1.4 (4)	54.1 (149)	–	–	–
Romano-British	Fetal (<birth)	35	–	–	–	–	–
	Infant (birth – 3 years old)	51	–	–	7.8 (4)	–	2.1 (1)
	Child (3–12 years old)	25	12 (3)	12 (3)	–	4 (1)	–
	Adolescent (12–20 years old)	17	58.9 (10)	58.9 (10)	–	–	–
	Deciduous dentition	377	0.3 (1)	4.2 (16)	–	–	–
	Permanent dentition	475	1.5 (7)	26.9 (128)	–	–	–

5‰ above diet, though there is some variability. Breastfeeding infants are deriving their nutrition from their mother's protein and so they exhibit an elevation of both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ above their mother's values. This 'nursing effect' appears very rapidly after birth and the values decline slowly as the weaning process gradually supplements and replaces breastmilk with solid foods (Waters-Rist and Katzenberg, 2009). The rate of decline in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values depends on the weaning practices involved, but it is difficult to estimate precisely the ages of onset and completion of weaning (Millard, 2000). However, it is possible to detect differences in weaning practices between populations by comparing the size and duration of the nursing effect without the need to quantify weaning age (e.g., Jay et al., 2008).

A sample of rib bone was taken from 15 LIA and 14 RB subadults derived from 12 burial locations in Dorset (Table 2) These samples were selected to reflect the funerary types present in both periods and include individuals from each age-group represented (see also Redfern et al., 2010). Samples of rib bone from each human burial were physically cleaned and chemically processed to a purified protein at the Rafter Laboratory, New Zealand, according to the methodology in Beavan-Athfield and Sparks (2001). All surfaces were either mechanically abraded with a Dremmel™ drill or pared with a scalpel to remove bone surfaces that had contact with the burial environment and/or appeared degraded. Each sample was then pulverised in a Retsch mill to <450 μm and then chemically treated with 0.5 M HCl while stirred at room temperature until fully demineralised. Insoluble collagen was filtered from the solution, rinsed and dried in a vacuum oven at 40 °C. Up to 80 mg of collagen was gelatinised with 0.01 M HCl in a nitrogen atmosphere at 90 °C for 16 h. The soluble gelatin was then double-filtered through Whatman™ GF/C and 0.45 μm Acrodisc™ filters, and lyophilised to weigh yields.

The carbon and nitrogen isotopic and % elemental content were measured using a Europa Geo 20-20 isotope ratio mass spectrometer, interfaced to an ANCA-SL elemental analyser in continuous flow mode (EA-IRMS). Approximately 1.5 mg of freeze-dried gelatin was weighed in triplicate into tin capsules for automated combustion. The carbon dioxide and nitrogen gases were resolved using gas chromatographic separation on a column at 60 °C and analysed simultaneously for isotopic abundance as well as total organic carbon and nitrogen. Standards and blanks were included during the run for internal calibration. All results are reported with respect to VPDB and N-Air, normalized to internal standards of Leucine (–22.7‰ for $\delta^{13}\text{C}$, 1.8‰ for $\delta^{15}\text{N}$), GNS Bone Collagen (–20.85‰ for $\delta^{13}\text{C}$, 9.41‰ for $\delta^{15}\text{N}$) and EDTA (–30.6‰ for $\delta^{13}\text{C}$, 0.4‰ for $\delta^{15}\text{N}$). The typical analytical precisions for these

measurements are $\pm 0.1\text{‰}$ for $\delta^{13}\text{C}$ and $\pm 0.3\text{‰}$ for $\delta^{15}\text{N}$. The precisions for the analysis of the Dorset project runs were $\pm 0.04\text{‰}$ for carbon and $\pm 0.08\text{‰}$ for nitrogen, indicating a precision better than the typical analytical precision.

3.3. Data analysis procedures

Comparisons were made of variations in isotope values by age within each period and between periods for each age-group. Homogeneity of variance was tested by Levene's test before applying a Kruskal–Wallis test (with correction for ties) for within-period age comparisons and a Mann–Whitney test for between-period comparisons. Non-parametric tests were used as there is no expectation of a normal distribution for isotope ratios. All statistical calculations were performed in PAST: the Palaeontological Statistics Package (Hammer et al., 2001).

Comparisons between age-groups within a period were designed to detect changes in diet with weaning and between subadults and adults, with the data grouped as up to 2, 2 to 20 and over 20 years. Data for the over 20 years old age-group from the sites studied here from Redfern et al. (2010) was combined with data from Richards et al. (1998) on adults from Poundbury Camp. Previous work had found no difference between sexes for adult diets in the LIA and only small differences in the RB period (Redfern et al., 2010).

Comparisons between periods were made for subadults, initially with all subadults, and then with those under 2 years old excluded in order to compare childhood diets without the influence of any changes in infant feeding practices. With only four and two infants less than 2 years of age in the LIA and RB periods, respectively, small sample sizes precluded statistical testing for differences within this age-group.

4. Results

4.1. Stable isotope results

Table 2 and Fig. 2 present the stable isotope results, while Table 3 summarises the statistical analysis of the data. When tested against the collagen quality criteria of van Klinken (1999), no samples were rejected as all fell within the acceptable ranges of 26–44 %C, 5–16 %N and C/N ratio of 3.1–3.5.

Within the compilation of adult data, it was noticeable that Poundbury Camp individual PC1391 had an extremely high $\delta^{15}\text{N}$ value (11.9‰) compared to the range of the other LIA individuals (7.8‰–10.4‰) but this value would fit within the Roman range.

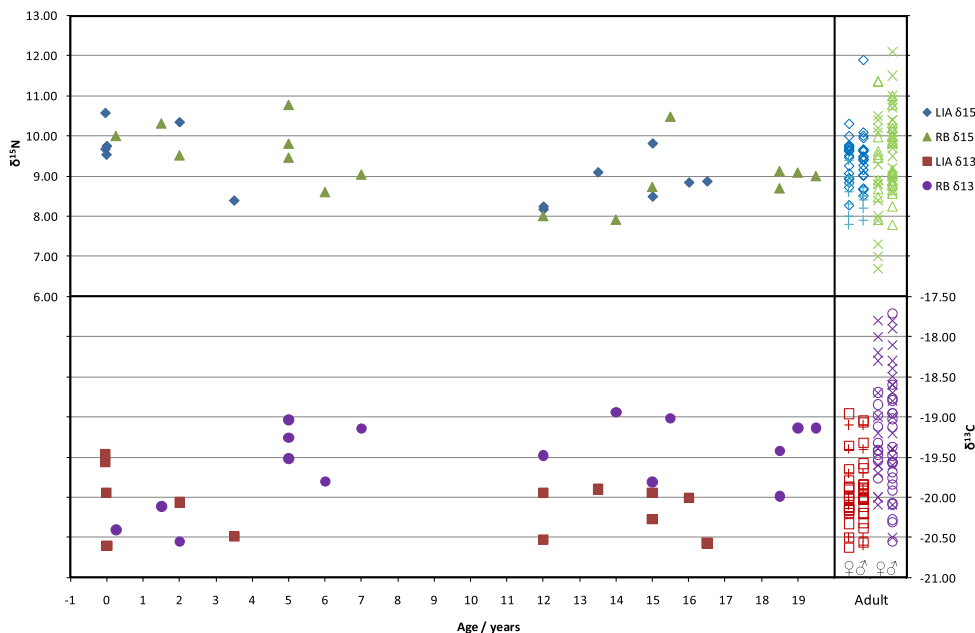


Fig. 2. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for LIA and RB Dorset populations plotted against age. Open symbols represent adult data from Redfern et al. (2010). Crosses represent Richards et al. (1998) data for Poundbury Camp adults.

Farwell and Molleson (1993:301) described this burial as part of a 'LIA/early Roman burial group' and the grave-goods date to the mid 1st century AD. There is evidence that graves were inserted into this area from the early through late Roman period (Farwell and Molleson, 1993:13), so this burial cannot be definitively attributed to the LIA and the nitrogen isotopes suggest it may be Roman. Given the ambiguous period and outlying nature of the $\delta^{15}\text{N}$ value, PC1391 was omitted from statistical comparisons.

Fig. 3 depicts our data plotted with previously published data from the RB cemetery at Queenford Farm (Oxfordshire) (Fuller

et al., 2006), LIA Wetwang Slack (Yorkshire) (Jay et al., 2008; Jay and Richards, 2006), and Imperial-period Isola Sacra (Rome) (Prowse et al., 2008). To facilitate inter-site and inter-period comparison of the effects of breastfeeding and weaning, the deviation of individuals from the adult female mean was used.

Two statistically significant differences were found. Firstly, between age-groups for $\delta^{15}\text{N}$ in the LIA, for which post-hoc pairwise Mann–Whitney tests indicated that it was the <1 age-group that differed from the others. Secondly between the $\delta^{13}\text{C}$ of LIA subadults and RB subadults.

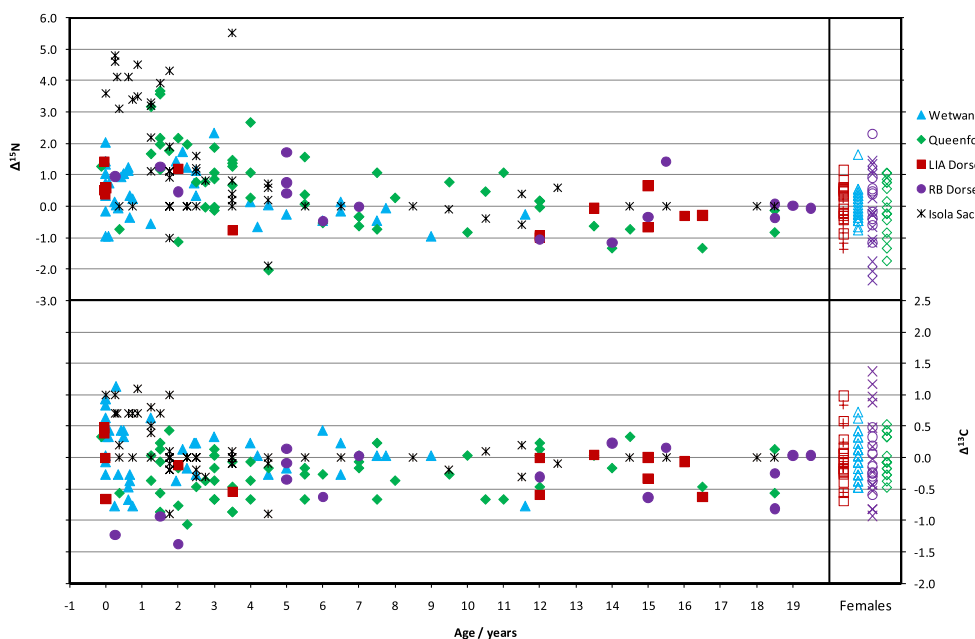


Fig. 3. Deviation of isotope values from the adult female mean. Comparative data from LIA Wetwang Slack, East Yorkshire (Jay et al., 2008; Jay et al., 2009), RB Queenford Farm, Oxfordshire (Fuller et al., 2006), and Isola Sacra, Rome (Prowse et al., 2008). Open symbols represent adults. Dorset adult female data are from Redfern et al. (2010). Crosses represent Richards et al. (1998) data for Poundbury Camp females. Adult data from Isola Sacra is not published in tabular format and could not be plotted.

4.2. Skeletal and dental pathology

The dental data showed clear age-related differences (Table 4), which is a normal and expected result reflecting the progressive nature of dental disease (Hillson, 1998). The number of individuals and teeth affected by carious lesions and calculus was low in both periods, and this small number precluded statistical analysis. In the LIA, carious lesions and calculus were only observed in the permanent dentition, with calculus affecting more teeth (54.1%), and the adolescent age-group data included the majority of affected individuals ($n = 9$). In contrast to the preceding period, the deciduous dentition of RB subadults were affected by carious lesions and calculus. Although the prevalence rate for dental diseases decreases in this period for children and the permanent dentition, the number of individuals and teeth affected increases. As in the LIA, the highest prevalence rates were observed for the dental disease calculus.

Metabolic diseases were observed in both periods (Table 4), but the majority of affected individuals were observed in the RB material. In the LIA, an infant (11.1% of sample) was identified with active rickets, while in the RB period one child had active scurvy (1%) and four infants had skeletal changes indicative of active rickets (7.8%); the changes observed and the bones affected by this disease are described in Redfern (2007).

5. Discussion

5.1. Stable isotope perspectives

Our dataset demonstrated a statistically significant difference in $\delta^{13}\text{C}$ between the LIA and RB subadults. This parallels previous findings of differences in $\delta^{13}\text{C}$ but not $\delta^{15}\text{N}$ in adult diets between these periods (Redfern et al., 2010) and is indicative of the increased consumption of marine foods in the RB period. Fig. 3 also depicts the uniformity of the values of subadults over the age of 6 years in both the LIA and RB samples. The $\Delta^{15}\text{N}$ values were between -1.5 and $+1.5$, and $\Delta^{13}\text{C}$ was between -1 and 0.5‰ . This indicates that, after early childhood, there was no age-related variation in dietary protein in the LIA and Roman populations from Dorset, Oxfordshire, Yorkshire and Rome.

Numerous studies have shown that $\delta^{15}\text{N}$, and to a lesser extent $\delta^{13}\text{C}$, are elevated in suckling infants (Waters-Rist and Katzenberg, 2009). Variation was seen between samples in this enrichment (Table 5). For LIA and RB Dorset, there was significant elevation of $\delta^{15}\text{N}$ in the four LIA infants, as expected. Surprisingly, the RB subadult sample showed no significant change in $\delta^{15}\text{N}$ and clear

evidence for lower $\delta^{13}\text{C}$ in subadults under 3 years of age compared to those over 4 years (Mann–Whitney test, $U = 0$, $p = 0.0036$), with the latter having comparable values to adults. Had there been a lack of significant difference in both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$, this might have been attributed to the small sample size rather than a genuine lack of suckling enrichment in this population. However, we observed a significant change in $\delta^{13}\text{C}$ in the *opposite* direction to the expected suckling effect. A similar reduction in infant $\delta^{13}\text{C}$ was observed at Queenford Farm (Fuller et al., 2006), but to a lesser extent than in our data, as can be seen in Fig. 3. No such effect was found at Isola Sacra, near Rome. This may indicate that in Roman Britain, but not in Italy, there was a special weaning diet for infants or a special diet for breastfeeding mothers; in either case, the special diet was lower in marine foods than the normal diet of later childhood and adulthood. Dietary advice specific to nursing females of this period is very limited, with the majority found in medical texts. Interestingly, these texts recognised the relationship between maternal health, diet and milk quality. Soranus' advice about wet-nursing does not specifically state if a special diet should be eaten by nursing mothers, only that they should avoid wine (Soranus, 1991: 2, 18–20). Other texts recommended that wet-nurses should have a good stomach, eat all kinds of foods, and that their diet should be adequate and not cause stomach upsets or constipation (Aly, 1996). Even if there was a special diet for breastfeeding mothers, this would be unlikely to cause a detectable shift in the isotope ratios of adult females because the adult skeleton retains an influence from adolescent diet well into adulthood (Hedges et al., 2007) and the period of breastfeeding will represent only a fraction of adult life.

Following the approach of Jay et al. (2008), Table 5 shows various measures which were indicative of the size of the enrichment due to breastfeeding, comparing LIA and RB Dorset to a range of other studies. Although the definition of 'adult' in these studies is variable (over 20 years of age in this study and at Queenford Farm, but over 12 for Wetwang Slack and over 15 for Isola Sacra) and was sometimes not stated, the broad trends were clear: the data for both LIA and RB Dorset showed low values of all the isotopic difference measures. The possible causes of low $\delta^{13}\text{C}$ in the Roman period were discussed above, and the same explanations could apply to $\delta^{15}\text{N}$. In the LIA the infants' small enrichments in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ may simply be due to a small sample size, though it is conceivable that there was some continuity in infant feeding practices between the LIA and RB periods, with the increased presence of marine foods in Roman diets showing up as a decrease in the already small enrichment. It is also important to remember that the sample sizes were very small and that these explanations must therefore remain tentative.

Table 5
Comparison of isotope values of 0–1 year olds to adult females in various populations.

Population	Carbon isotopes			Nitrogen isotopes				
	$\Delta^{13}\text{C}_{\text{C}_{\text{max}}-\text{F}_{\text{mean}}}$	$\Delta^{13}\text{C}_{\text{C}_{\text{max}}-\text{F}_{\text{sd}}}$	Fraction 0–1 year olds below female mean	$\Delta^{13}\text{C}_{\text{C}_{\text{mean}}-\text{F}_{\text{mean}}}$	$\Delta^{15}\text{N}_{\text{C}_{\text{max}}-\text{F}_{\text{mean}}}$	$\Delta^{15}\text{N}_{\text{C}_{\text{max}}-\text{F}_{\text{sd}}}$	Fraction 0–1 year olds below female mean	$\Delta^{15}\text{N}_{\text{C}_{\text{mean}}-\text{F}_{\text{mean}}}$
Various listed in Jay et al. (2008)	0.8 to 3.8	-0.7 to 2.9	0–80%	-1.3 to 1.7	2.6 to 5.9	1.6 to 5.1	0–55%	0.0 to 3.3
Wetwang (Jay et al., 2008)	1.1	0.8	7/13 (54%)	-0.1	2.4	1.9	2/13 (15%)	0.5
Queenford (Fuller et al., 2006)	0.3	0.0	2/3 (67%)	-0.2	3.2	2.3	1/3 (33%)	1.2
Isola Sacra (Prowse et al., 2008)	1.1	0.8	0/9 (0%)	0.8	4.8	3.7	0/9 (0%)	4.0
Dorset LIA	0.5	0.1	1/4 (25%)	0.0	1.4	0.8	0/4 (0%)	0.7
Dorset RB ^a	-0.9	-1.6	2/2 (100%)	-1.1	1.3	0.0	0/2 (0%)	1.1

Δ values are given between the highest value for a child below 1 (C_{max}) or mean of all subadults below 1 year old (C_{mean}) and the mean of all adult females (F_{mean}) or the adult female mean plus one standard deviation (F_{sd}).

^a Individual PC765 aged 18 ± 6 months is included in the Dorset RB 0–1 year olds.

5.2. Bioarchaeological perspectives

The work of Redfern and DeWitte (2011) and Redfern (2007, 2008) has demonstrated that Romanisation had a deleterious effect on the mortality risk and health of those living in RB Dorset. Mortality modelling demonstrated that males and young children had a higher risk of death during this period when compared to the preceding one, and these results were considered to reflect urbanism, population migration and the use of Mediterranean childcare practices.

The bioarchaeological analysis of the health variables included in this study supports these findings. The dental health of subadults showed that the prevalence of disease increased in the RB period for carious lesions, a result which matched the adult sample which displayed an increase of carious lesions (Redfern, 2008:173–5, 181). We consider that this result also provides insight into age-related changes in diet in both periods. During the LIA, it may well be that post-weaning subadult diets were comparable to those of 'adult' individuals, while in the RB period the foods that subadults had access to or were allowed to eat were more closely associated with life course changes, such as the social attainment of adolescence (Harlow and Laurence, 2002). Although the isotopes do not corroborate this change, it must be remembered that isotopic data primarily reflect protein sources and can differentiate marine and terrestrial protein sources, and to a lesser extent vegetable and animal protein. On the other hand, caries rates will reflect the sources and amounts of carbohydrate in the diet (Hillson, 1998:278). Our combination of data on caries frequencies and isotope ratios therefore points to changes in the carbohydrate component of diet between subadults and adults in the RB period rather than the protein component.

Skeletal evidence for dietary deficiencies was present in both periods, and the young ages of the individuals affected emphasize the inter-relationship between culture, maternal/carer health and infant outcomes (Redfern and Gowland, 2011). In LIA Britain, only a few cases of specific metabolic diseases have been reported, with only four IA subadults from Yorkshire and Worcester exhibiting evidence for scurvy (Caffell and Holst, 2005; Roberts, 1987). On current evidence, this is the first case of rickets identified from LIA Dorset. In contrast, a greater number of RB subadults with metabolic diseases have been identified, particularly from London (Gowland and Redfern, 2010; Roberts and Cox, 2003: 143). In the LIA, because of the lack of current evidence for residual rickets in the adult population (Redfern, 2006), it is considered that in this case it is unlikely that cultural practices influenced its development. Perhaps the infant was suffering from another disease and was kept indoors, which prevented them from the metabolising of sufficient quantities of vitamin D, or because of maternal death and the inability/absence of other lactating women to feed them, the infant was solely reliant on animal milk (e.g. cow) which contains very little vitamin D (Brickley and Ives, 2008: 77–80, 86, 144).

Following the Roman conquest, the development of *Durnovaria* as an urban centre and increased population movement resulted in cultural and settlement changes that provided greater opportunities for metabolic diseases to impact subadult health. Urban environments contain a number of risk factors, including variable living conditions, poor sanitation and pollution (Brickley and Ives, 2008:94–5). As shown in the material culture and funerary evidence, RB Dorset was culturally diverse, which in current societies is known to result in heterogeneous childcare and feeding practices (Abel et al., 2001; Ramji, 2009). In RB Dorset, greater numbers of carers may have employed the Roman tradition of swaddling, which would have prevented babies from effectively using sunlight in vitamin D metabolism, and cultural differences in the type, quality and quantity of weaning foods may have impacted

health (Brickley and Ives, 2008:92–5), although the 1st–2nd AD Roman doctor Soranus did attribute limb deformities in Roman children to poor nurturing and hygiene by their mothers (Rajakumar, 2003). Alternatively, their birth-mother or wet-nurse may have been vitamin D deficient and their poor health would have directly affected the infant (Brickley and Ives, 2008:86; see also, Redfern and Gowland, 2011).

Data collected by Brickley and Ives (2008:144–145) and Roberts and Cox (2003:143) showed that the number of individuals with vitamin D deficiencies increased during the Roman Empire, reflecting the development of urban centres and cultural practices which, in some areas and for particular status-groups, promoted poor health (e.g., swaddling or female dress).

6. Conclusions

The analysis of regional data concerning subadult health, diet and Romanisation validated our hypothesis that infant feeding practices in Britain changed following the Roman conquest in AD 43. Analysis of the selected health and dental variables demonstrated a decline in dental health and an increase in metabolic disease post-conquest, which was paralleled by isotopically attested changes in diet. These data indicate that infant feeding practices changed from the LIA to RB period, and it is likely that a special weaning diet was used in Roman Britain that differed both from its LIA counterpart and the weaning diet of Roman Italy. Weaned children showed a statistically significant difference in $\delta^{13}\text{C}$ values between periods, paralleling the difference previously observed in adults (Redfern et al., 2010). Interestingly, no age-dependent variations in isotope ratios were observed after weaning in either period, a result which contrasts to that from Isola Sacra (Prowse et al., 2008). The absence of intra-cemetery dietary differences in the RB subadults contrasts with the adult results from the region (Redfern et al., 2010), but may be a consequence of small sample size rather than a lack of dietary diversity. Overall, the change in diet and health in the RB sample supports findings from London (Gowland and Redfern, 2010) and indicates that the cultural, social and economic transformation of British life directly impacted the lives of children throughout the province.

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