Dental Caries as a Measure of Diet, Health, and Difference in Non-Adults from Urban and Rural Roman Britain

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ABSTRACT Dental disease in childhood has the potential to inform about food availability, social status, and feeding practices, in addition to contributing to a child's overall health status. This paper presents the first comprehensive overview of carious lesion frequencies in 433 non-adults (1-17 years), and 6,283 erupted permanent and deciduous teeth from 15 urban and rural Romano-British settlements. Pooled deciduous and permanent caries rates were significantly higher in major urban sites (1.8%) compared to rural settlements (0.4%), with children from urban sites having significantly higher lesion rates in the deciduous dentition (3.0%), and in younger age groups with mixed dentitions. The differences in dental caries between urban and rural populations suggest disparities in maternal oral health, early childhood feeding practices, food preparation and access to refined carbohydrates. A richer, perhaps more 'Roman', cuisine was eaten in the urban settlements, as opposed to a more modest diet in the countryside. The effect of early childhood stress on caries frequency was explored using evidence for enamel hypoplasia. Co-occurrence of caries and enamel hypoplasia was highest in the major urban cohort (5.8%) and lowest in the rural sample (1.3%), suggesting that environmental stress was a contributing factor to carious lesion development in Romano-British urban children.

Child health is an understudied subject in the archaeology of Roman Britain. Most of what we know about growing-up in the province is derived from the Classical literature. While archaeological research has mainly focused on the architectural grandeur of the towns and high status villa settlements (Parkins, 1997; Millett, 2005; Mattingly, 2006; Pearce, 2008; Holbrook, 2015), rural settlements and their inhabitants have received scant attention ,preventing a more holistic view of life in Britannia (Taylor, 2007; McCarthy, 2013; Breeze, 2014; Fulford and Holbrook, 2014). Contrary to the long-held belief in the detrimental effects of the urban environment, recent bioarchaeological research has demonstrated that living in the Romano-British countryside also negatively affected health (Pitts and Griffin, 2012; Redfern et al., 2015). The late Romano-British villa economy may have provided health challenges for its workers, a subject yet to be fully explored. While non-adult skeletons are widely acknowledged to provide an intricate measure of population fitness in the past (Mensforth et al., 1978), comparisons of the morbidity and mortality of urban and rural Romano-British children have yet to be carried out. A child's diet would have reflected the cultural beliefs and social standing of his or her family. Carious lesion frequency can therefore provide valuable information on access to resources, eating habits, and food preparation practices.

In children, calcified plaque (calculus), and pathological conditions of the dentition such as periapical lesions, periodontal disease, and antemortem tooth loss are rare. Carious lesion frequencies in the deciduous and permanent teeth, therefore, provide the most effective measure for discussing past dental health during childhood (Halcrow et al., 2013). The presence of dental caries in children not only indicates the levels of carbohydrates consumed, but also informs on cultural practices such as pre-mastication, and sharing of foods or utensils (Nield et al., 2008). Carious lesions can cause considerable discomfort, resulting in intense pain, difficulty eating, reduced efficiency of the immune system (Baqain et al., 2004), and can affect speech development (Aligne et al., 2003). Dental studies that focus on children are rare in the palaeopathological literature and tend to focus on individual sites or have small sample sizes (e.g. Moore and Corbett, 1973; Whittaker et al.,

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1981; O'Sullivan et al., 1993; Clough and Boyle, 2010; Redfern et al., 2012). This study will provide an overview of carious lesion frequency in non-adults from 1st to early 5th century AD urban and rural settlements in Roman Britain. Due to the general absence of periodontal disease, periapical lesions, antemortem tooth loss, and calculus in the dentitions of children, this study relies on dental caries as the sole measure of childhood dental health. The aim of the study is to assess whether an urban or rural living environment impacted childhood dental health through the investigation on lesion frequencies of dental caries in the deciduous and permanent dentition.

Pathogenesis of dental caries in children

Dental caries is a progressive infectious disease of the deciduous and permanent dentition, with localised demineralisation of the dental hard tissues by organic acids (Larsen, 1997). *Streptococcus* and *Lactobacillus* bacteria in the oral cavity metabolise sugars and starches, which create an acidic environment and demineralise tooth enamel (Byun et al., 2004). Teeth are remineralised as soon as pH levels are restored to neutral. If, however, the pH is low for a prolonged period, the dynamic between de- and re-mineralisation is upset, resulting in a cavity (Gussy et al., 2006). *Streptococcus mutans*, the main cariogenic bacterium, is normally transmitted from the mother or other caregiver to the child through kissing or sharing implements (Nield et al., 2008). Colonisation with *S. mutans* can commence as early as six months old, although the highest risk for infection is at two years old. It takes around 13-16 months from colonisation for a lesion to develop (Kawashita et al., 2011).

'Early Childhood Caries' defined as caries in children aged 0-5 years, is a serious chronic condition in the modern world (Afroughi et al., 2010). Newly erupted deciduous teeth are particularly susceptible to dental caries due to incomplete maturation, large dental tubules and thinner enamel, which is insufficient in preventing the progression of carious lesions (Aligne et al., 2003; Schuurs, 2013). The area around the erupting tooth also provides favourable conditions for bacterial colonisation (Schuurs, 2013). Child saliva flow rate is slower than in adults, and has lower levels of secretory immunoglobin A (IgA) concentrations. While IgA begins to be produced after one month of life, its formation can be impaired by high levels of cortisol in the blood through stress. Stress could therefore have a caries-promoting function. It may manifest as enamel defects, i.e. hypoplasia, which in turn may increase the risk of dental caries (Boyce et al., 2010). Enamel hypoplasias may cause dental caries to progress more quickly due to higher acid solubility of defective enamel, and greater adhesion of cariogenic bacteria at the site of a defect (Hong et al., 2009). The presence of enamel hypoplasias in individuals with dental caries may therefore be a valuable indicator of early childhood stress in relation to dental decay, and it is of interest to evaluate their co-occurrence.

Using the jaws of modern children, Afroughi and colleagues (2010) showed that once a tooth is infected, dental caries continues to spread to the teeth on either side or above, often in a symmetrical pattern. Risk of lesion development was greater for maxillary posterior teeth than for anterior or mandibular teeth. Early childhood caries may take on a rampant virulent form, known as 'Severe Early Childhood Caries' (SECC), 'Nursing Caries' or 'Milk Bottle Syndrome'. The condition is characterised by rapid lesion development and dental decay primarily in the maxillary anterior dentition (Berkowitz, 2003; Azevedo et al., 2005). A probable case of SECC has recently been identified by Bonsall and colleagues (2015) in a 3-4 year old child from Roman Ancaster, Lincolnshire.

Diet is a crucial factor in the onset and proliferation of dental caries. Refined foods with a high carbohydrate and/or sugar content encourage the metabolic activity of oral bacteria and acid production, increasing the risk of lesion development (Powell, 1985; Prowse et al., 2008). A tough and fibrous diet has a cleaning effect, and vigorous mastication stimulates salivary flow, which is alkaline, buffering against plaque acids (Duray, 1992; Moynihan, 2000). Soft sticky foods and prolonged snacking or sipping of sweetened fluids pose a greater risk for acid development (Hallet and O'Rourke, 2003). Dental disease is usually described by the different surfaces of the tooth that are affected: the occlusal surfaces, smooth surfaces of the crown including the interproximal areas, or the root (Moore and Corbett, 1973). Each of these surfaces has different cariogenic potential, therefore, the location of carious lesions on the tooth may provide insight into changes in diet (Ortner, 2003). With the intensification of cereal agriculture, carious lesions at the root and cemento-enamel junction rise, and with the introduction of refined sugars, interproximal and fissure carious lesions increase, especially in children (Hillson 1996, 283).

The Romano-British diet

There are a number of historical sources that make reference to 'Roman' food and drink, including Apicius' collection of recipes, Pliny the Elder's Naturalis Historia or Galen's medical writings (Grocock and Grainger, 2006; Alcock, 2010). These sources reflect Mediterranean practices of the literate upper classes in the 1st and 2nd centuries AD, and it remains unknown how these are relevant for exploring diet in Roman Britain. When comparing literary evidence on diet to recent isotopic and osteological studies of populations from Rome (Rutgers et al. 2009; Killgrove and Tykot 2013), Velia (Craig et al. 2009), and Portus Romae

(Prowse et al. 2008), it transpires that a 'typical' Roman diet as described in Classical sources may not have been followed, or in fact existed.

Cereal products such as bread and porridge may have been the staple foods in Britain, although variation across the social and geographical strata is expected (Cool, 2006). Sugars would have been available as fructose from fruits, fruit juices, honey and syrups, or glucose in the carbohydrates consumed (Moore and Corbett, 1973; Bowman and Thomas, 1994; Cool, 2006; Bogdanov et al., 2008; Nassar et al., 2012). More advanced farming and plant cultivation techniques, alongside larger scale animal breeding, would have ensured a stable food supply for the army and non-producing urban population, whilst also putting increasing demands on the workers in the countryside (Mattingly, 1997; Dobney, 2001; Taylor, 2001; Pitts and Griffin, 2012; McCarthy, 2013; Redfern et al., 2015).

Studies by King (1984; 1999; 2001) and Cummings (2009) have demonstrated that access to meat and animal products was dependent on site type and status. Overall, marine and freshwater fish became increasingly fashionable, probably as a result of following Roman tastes (Locker, 2007). Isotopic studies on human bones (Richards et al., 1998; Redfern et al., 2010; Cheung et al., 2012; Müldner, 2013) and archaeobotany (van der Veen, 2008; van der Veen et al., 2007; 2008) have revealed temporal, cultural, social and sex differences in the consumption of terrestrial, plant, and aquatic foods at an inter-site and intra-site level. Richard and colleagues' (1998) study of Poundbury Camp in Dorset showed that animal protein and marine foods were only available to the few. Children are thought to have enjoyed more marine foods, and diet was more varied for the inhabitants of the towns (Redfern et al., 2010; Müldner, 2013). It also appears that marine and freshwater foods were primarily consumed in the urban environment rather than the surrounding villages, and that the male and female diet, at least within Roman Gloucester, differed (Cheung et al., 2012). To the benefit of Britons, a variety of new plant foods were introduced following the Roman conquest, improving the nutritional value of the Romano-British diet. Examples include cherries, carrots, or plum, also beet and cabbage, which are high in nutrients and vitamins (van der Veen et al., 2008). As a general pattern, plant foods were widely accessible and eaten in both town and country (van der Veen et al., 2007). It is of note that some areas of the province differed. Access to new plant foods was more restricted, or perhaps opposed, in the southwest (van der Veen et al., 2008).

In children, dietary experiences would have started at weaning with the gradual introduction of solid foods to supplement breastmilk. Galen's writings and Soranus' Gynaecology, both dating to the 2nd century AD, recommend the introduction of supplementary foods from around six months (Fildes, 1986; Temkin, 1991). Weaning would have been complete by 2-4 years old, a practice that has been supported by isotopic analysis of non-adults from England and Italy (Fildes, 1986; Fuller et al., 2006; Prowse et al., 2008; Prowse, 2011; Nehlich et al., 2011; Redfern et al., 2012; Powell et al., 2014). The Roman weaning diet comprised mainly of cereal foods, such as porridge, or bread mixed with milk, wine or honey (Temkin, 1991; Garnsey, 1999). Pre-mastication of foods for weanlings was warned to be harmful; however, the fact that the practice needed to be discouraged suggests it was a known method of infant feeding (Bradley, 1986; Temkin, 1991). Honey was also used as a popular medicinal aid. Soranus suggests rubbing honey on the gums of teething infants to soothe their pain (Temkin, 1991). Once weaned, the contents of the Roman early childhood diet are unknown. If diet was influenced by location and status, children would have been subjected to differential food allocation. Child dental disease rates may then also differ, depending on urban and rural site types, or high versus low status settlements. A large scale investigation of dental caries rates may therefore provide the first detailed evidence for cultural practices and dietary habits of children in Roman Britain.

MATERIALS AND METHODS

Site classification

The terms 'urban' and 'rural' are used to characterise the nature of the settlement rather than its geographic locale. In order to allow for a comparison of carious lesion frequencies between settlements under different levels of Roman influence, sites were divided into major urban (coloniae, civitates), minor urban (nucleated/small towns) and rural settlements (villages, farmsteads, villa estates). A common denominator for Romano-British towns, whether large or small, is the dependence on the hinterland for agricultural surplus to feed the non-producing urban population (Mattingly, 1997; Morley, 1997). 'Major urban' sites were defined as large legal and administrative settlements with a series of features including a grid layout for the street system and organised planning throughout, with public buildings, a forum and a spiritual focus (Wacher, 1974; Burnham and Wacher, 1990; Millett, 1990; Laurence et al., 2011). 'Minor urban' centres displayed some urban aspects, such as evidence for town planning and a market to facilitate local trade (Hingley, 1989; Burnham, 1993; 1995; Millett, 1995; Wilson, 2011). Rural sites were defined as undefended farmsteads, villages, or villa estates with a predominantly agricultural focus (McCarthy, 2013). Depending on their location, rural sites would have exhibited varying economic and socio-cultural dependence on nearby towns (Laurence et al., 2011; White, 2014). However, their agricultural focus still rendered them as rural in character and urbanisation of the countryside to the extent seen in Italy was not apparent in Roman Britain (Laurence, 2011). Current models on life in the Romano-British countryside consider villa economies as estates managed by landowners, with a peasant population that cultivates the land as tenants or freeholders, living either on the estate or surrounding villages (Taylor, 2001; Mattingly, 2006; McCarthy, 2013; Breeze, 2014).

There is a growing awareness of the difficulty in classifying Romano-British settlements (Mattingly, 1997; Millett, 1999; Burnham et al., 2001; Millett, 2001; Pearce, 2008; Rogers, 2011), and it is important to bear in mind that power in Roman Britain was not exclusively urban, as the elite often resided in the countryside or a town's immediate hinterland (Parkins, 1997; Pitts and Perring, 2006). In addition, not all urban cemeteries would have contained those living and dying exclusively within these large settlements, as many individuals may have been derived from the "urban periphery" (Goodman, 2007:1-2), or represent rural migrants (Griffin and Pitts, 2012; Redfern et al., 2015).

Materials

Dental caries was recorded in 433 non-adults (aged 1.1-17.0 years) and a total of 6,283 erupted teeth (deciduous n=2910; permanent n=3373) from 15 Romano-British sites dating from the 1st-5th centuries AD (Table 1, Figure 1). Infants (birth to 1.0 year) were excluded from analysis due to the scarcity of erupted teeth within this age group. The following age categories defined by Lewis (2002) were used: 1.1-2.5 years, 2.6-6.5 years, 6.6-10.5 years, 10.6-14.5 years, 14.6-17.0 years. Age ranges serve to minimise age estimation error, and allow for cross-site comparison while corresponding with developmental milestones (Lampl and Johnston, 1996; Scheuer and Black, 2004; Lewis, 2010).

Methods

Individuals were aged based on their dental development either through macroscopic assessment or, wherever possible, using radiographs (Moorres et al., 1963a,b). As non-adults were not sexed, male and fe-

TABLE 1. Study sites by settlement date and type

Site	Date (AD)	Type	Total non-adults	TPR by tooth count a/p (%)	CPR by Individual a/p (%)	Reference
Winchester (North, West, East)	1-4th century	Major Urban	39	11/559 (2.0)	6/39 (15.4)	Ottaway et al. (2012)
Kingsholm, Gloucester	2-4th century	Major Urban	9	9/135 (6.7)	4/9 (44.4)	Hurst (1985), (1986)
Gambier-Parry Lodge, Gloucester	2-4th century	Major Urban	6	0/76 (0.0)	0/6 (0.0)	Heighway (1980); Mullin (2006)
Trentholme Drive, York	3-4th century	Major Urban	17	2/262 (0.8)	2/17 (11.8)	Wenham (1968); Ottaway (2009)
Bath Gate, Cirencester	4th century	Major Urban	38	5/483 (1.0)	4/38 (10.5)	Viner and Leech (1982)
Butt Road, Colchester	4-5th century	Major Urban	80	22/1209 (1.8)	12/80 (15.0)	Crummy and Crossan (1993)
Baldock, Hertfordshire	2-4th century	Minor Urban	25	2/414 (0.5)	2/25 (8.0)	Stead and Rigby (1986); Burleigh and Fitzpatrick-Matthews (2010)
Queenford Farm/ Mill, Oxfordshire	3-4th century	Minor Urban	51	8/729 (1.1)	3/51 (5.9)	Durham and Rowley (1972); Chambers (1987)
Ancaster, Lincolnshire	3-4th century	Minor Urban	34	13/480 (2.7)	5/34 (14.7)	Todd (1975); Cox (1989)
Great Casterton, Rutland	3-4th century	Minor Urban	27	7/383 (1.8)	4/27 (14.8)	McConnell et al. (2012)
Ashton, Northamptonshire	4th century	Minor Urban	17	0/265 (0.0)	0/17 (0.0)	Dix (1983)
Dunstable, Bedfordshire	3-5th century	Minor Urban	12	7/201 (3.5)	4/12 (33.3)	Matthews (1981)
Owslebury, Hampshire	1-4th century	Rural	3	0/42 (0.0)	0/3 (0.0)	Collis (1968), (1977)
Cannington, Somerset	3-4th century	Rural	69	4/977 (0.4)	3/69 (4.3)	Rahtz et al. (2000)
Catsgore, Somerset	2-5th century	Rural	1	0/6 (0.0)	0/1 (0.0)	Leech (1982)
Bradley Hill, Somerset	4-5th century	Rural	5	0/62 (0.0)	0/5 (0.0)	Leech et al. (1981)
Total non-adults			**433**	**90/6283 (1.4)**	**49/433 (11.3)**	

Figure 1. Distribution of study sites (black: major urban, dark grey: minor urban, light grey: rural)

male tooth development stages were averaged. The cut -off point of 17.0 years was assigned when the roots of the third mandibular molar were complete but the apex remained open, giving an average age of 16.9 years old (Smith, 1991). When the apices of the available teeth were closed, an upper age estimate was derived using skeletal maturation and diaphyseal lengths (Ubelaker, 1989; Scheuer and Black, 2000; 2004). Individuals were excluded once the femoral head was fully fused, with completion estimated between 14-17 years in females and 16-19 years for males (Scheuer and Black, 2000; 2004). It is recognised that the cut-off age of 17.0 years reflects a biological rather than chronological age; however, it is based on the oldest, most accurate age estimate we currently have for non-adults (Lampl and Johnston, 1996). It is of course recognized that a biological age of 17.0 years would not necessarily have marked the end of childhood in Roman Britain. The lifecourse of Romano-British children is not fully explored; we therefore cannot use skeletal ages or age groups according to chronological ages that marked transitions in the lifecourse we are yet to define.

Only erupted teeth were included in the analysis, reflecting their susceptibility to dental caries. For teeth within the jaw, eruption was defined as those teeth in occlusion. The identification of loose teeth as erupted involved an assessment of root development stages (Moorrees et al., 1963a,b) and eruption patterns (Ubelaker, 1989), in addition to any evidence of wear or dental calculus (Buikstra and Ubelaker, 1994). As different teeth have varying degrees of susceptibility to dental caries, they were defined by type: deciduous or permanent, posterior (deciduous and permanent molars, permanent premolars) or anterior (deciduous and permanent incisors and canines) and location (i.e. root or crown). Carious lesion frequencies were reported accordingly. A lesion was recorded macroscopically when it perforated the tooth enamel. Statistical analysis was performed using a Pearson's chi-square test to evaluate the prevalence of lesions between the urban and rural sites, with a confidence limit set at 99.5% ($p=0.005$). Percent caries rates are presented as both crude prevalence rates (CPR) for the number of individuals observed and affected, or more precisely as true prevalence rates (TPR) determined by the number of teeth observed over those affected. The caries correction factor advocated by Lukacs (1995) was not applied as antemortem tooth loss is low in non-adult samples and loss of teeth through attrition was unlikely.

Enamel hypoplasia was recorded macroscopically when the tooth enamel was disrupted by circular or linear defects on two or more teeth on opposite sides of the dentition (Goodman and Armelagos, 1985; Goodman and Rose, 1990). This was done to avoid recording defects that may have resulted from localised trauma. The relationship between enamel hypoplasia and caries was quantified by Yule's Q.

RESULTS

Entire sample

The prevalence of dental caries for each site is listed in Table 1. For all sites and in the deciduous and permanent dentition combined, 11.3% (n=49/433) of individuals displayed caries, with a TPR of 1.4% (n=90/6283 teeth). Overall, 2.1% of posterior teeth were affected (n=79/3678 teeth) compared to only 0.1% (n=2/2586 teeth) of the anterior teeth, a significant difference ($X^2=51.29$, $p<0.001$, d.f.=1). No lesions at the cemento-enamel junction (or 'root caries') were reported. Carious lesions were predominantly found on the occlusal surface of posterior teeth (TPR 1.1%, n=39/3678 teeth). Fissure caries accounted for 49.4% (n=39/79 teeth) of lesions in posterior teeth.

When the deciduous and permanent caries rates were compared, TPR was marginally higher in the deciduous dentition at 1.5% compared to 1.1%, but not significantly so ($X^2=1.58$, d.f.=2) (Table 2).

Inter-settlement comparisons

Nine carious teeth in the minor urban cohort were derived from the Ancaster toddler with SECC (Bonsall et al., 2015). To prevent skewing of the data, this individual was removed from analysis. The prevalence of caries was highest in the major urban sites (CPR 14.8%, TPR 1.8%), followed by minor urban (CPR 10.3%, TPR 1.1%) and rural settlements (CPR 3.8%, TPR 0.3%). The rural TPR is significantly lower than those reported from the urban settlements (X^2=13.66, p<0.005, d.f.=2).

Lesion frequency in posterior teeth was significantly lower in the rural sites at TPR 0.6% (n=4/659 teeth; X^2=12.34, p<0.005, d.f.=2) compared to both the major and minor urban sites. Lesions in the anterior dentition were only found in two non-adults, both from a major urban site, affecting the deciduous canine in the maxillary dentition of a 2.6-6.5-year old from Kingsholm, Gloucester, and the mandibular deciduous canine of a 6.6-10.5-year old from the northern cemetery at Winchester (see Table 2).

In the deciduous teeth, significantly more lesions were recorded in the major urban cohort (n=32/1075 teeth) at TPR 3.0% (X^2=27.03, p<0.001, d.f.=2). Whereas no significant differences were observed for caries in the permanent teeth (see Table 2).

Interproximal caries affecting the crown surface, either mesially or distally, was observed in 29 posterior teeth or 1.0% of the total sample (n=29/3019 teeth), but only in the major and minor urban sites with a revised prevalence rate of 38.7% (n=29/75 teeth). Again, buccal caries was only observed in these urban cohorts with a prevalence of 10.7% (n=8/75 teeth).

Age differences

The prevalence of caries increased with age, albeit with a slight decrease in the 10.6-14.5 year age group (CPR 16.7%, TPR 1.3%), probably as a result of the shedding of the primary dentition. Caries was not apparent until 10.6 years in the rural sample, whereas lesions were observed in the youngest cohort (1.1-2.5 years) in the major urban sample. In the 6.6-10.5-year cohort, the frequency of carious lesions was statistically higher in the major urban sample at TPR 3.7% (n=20/539 teeth; X^2=11.36, p<0.005, d.f.=2) compared to both the minor urban and rural sites. Out of the total of 20 carious teeth within this major urban group, 17 (85.0%) were deciduous molars (Table 3).

Stress and caries

In the major urban group, 11.4% of teeth (n=309/2700 teeth) had dental enamel defects, compared to 9.6% (n=236/2460 teeth) in the minor urban cohort, and 4.5% (n= 49/1087 teeth) in the rural sample. The rural rate was significantly lower than those from both urban contexts (X^2=43.66, p<0.001, d.f.=2). The higher rates of enamel hypoplasia observed in major urban non-adults (TPR 11.4%) also matched the elevated rates of caries in these settlements. Overall, 39.6% (n=19/48) of the children with caries also had enamel hypoplasia. The Yule's Q statistic of 0.75 indicates that a moderate to strong relationship between the two conditions existed. This co-occurrence was highest in major urban sites at 5.8% (n=11/189) and lowest in rural children at 1.3% (n=1/78), although these differences were not significant (X^2=3.26, d.f.=2) (Table 4).

TABLE 2. Carious lesion frequencies by tooth type and individual

		Major Urban		**Minor Urban**		**Rural**		**Total**	
		Tth	Ind	Tth	Ind	Tth	Ind	**Tth**	**Ind**
Total	a/p	49/2724	28/189	28/2453* (37/2472)	17/165* (18/166)	4/1087	3/78	**81/6264* (90/6283)**	**48/432* (49/433)**
	%	**1.8**	**14.8**	**1.5* (1.5)**	**10.3* (10.4)**	**0.3**	**3.8**	**1.3* (1.4)**	**11.1* (11.3)**
Deciduous teeth	a/p	32/1075	14/125	10/1335	7/127	1/481	1/54	**43/2891**	**22/306**
	%	**3.0**	**11.2**	**0.7**	**5.6**	**0.2**	**1.9**	**1.5**	**7.2**
Permanent teeth	a/p	17/1649	14/124	18/1118	10/86	3/606	2/43	**38/3373**	**26/253**
	%	**1.0**	**11.3**	**1.6**	**11.6**	**0.5**	**4.7**	**1.1**	**10.3**
Anterior teeth	a/p	2/1100	2/171	0/1058	0/152	0/428	0/69	**2/2586**	**2/392**
	%	**0.2**	**1.2**	**0**	**0**	**0**	**0**	**0.08**	**0.5**
Posterior teeth	a/p	47/1624	28/185	28/1395	17/164	4/659	3/78	**79/3678**	**48/427**
	%	**2.9**	**15.1**	**2.0**	**10.4**	**0.6**	**3.8**	**2.1**	**11.2**

Tth = tooth count; Ind=individual count; a/p = number affected/number present; *corrected rates for the Ancaster child with SECC, uncorrected rates in brackets

TABLE 3. Carious lesion frequencies by age group and site type

		Major Urban		Minor Urban		Rural		Total	
Age (years)		Tth	Ind	Tth	Ind	Tth	Ind	**Tth**	**Ind**
1.1-2.5	a/p	1/394	1/38	0/571	0/49	0/193	0/21	**1/1158**	**1/108**
	%	0.3	2.6	0.0	0.0	0.0	0.0	**0.1**	**0.9**
2.6-6.5	a/p	12/555	7/50	7/774	4/56	0/254	0/22	**19/1583**	**11/128**
	%	2.2	14.0	0.9	7.1	0.0	0.0	**1.2**	**8.6**
6.6-10.5	a/p	20/539	8/35	4/393	4/27	0/112	0/8	**24/1044**	**12/70**
	%	3.7	22.9	1.0	14.8	0.0	0.0	**2.3**	**17.1**
10.6-14.5	a/p	11/883	8/44	11/520	5/25	1/315	1/15	**23/1718**	**14/84**
	%	1.3	18.2	2.1	20.0	0.3	6.7	**1.3**	**16.7**
14.6-17.0	a/p	5/213	4/20	6/195	4/8	3/351	2/12	**14/759**	**10/40**
	%	2.4	20.0	3.1	50.0	0.9	16.7	**1.8**	**25.0**

Tth = tooth count; Ind=individual count; a/p= number affected/number present

TABLE 4. Prevalence rates of enamel hypoplasia and co-morbidity

		Major Urban		Minor Urban		Rural		Total	
		Tth	Ind	Tth	Ind	Tth	Ind	**Tth**	**Ind**
Total	a/p	309/2700	54/214	236/2460	43/192	49/1087	12/105	**594/6247**	**109/511**
	%	11.4	25.2	9.6	22.4	4.5	11.4	**9.5**	**21.3**
Co-morbidity	a/p		11/189		7/165		1/78		**19/432**
	%		5.8		4.2		1.3		**4.4**

Tth = tooth count; Ind=individual count; a/p = number affected/number present

DISCUSSION

This study provides the first large-scale examination of carious lesion frequencies in non-adults from urban and rural settlements in Roman Britain. Dental caries is age-progressive and multifactorial, but can provide valuable insights into the cultural habits that affected non-adult diet, particularly where the characteristics of eating and drinking in childhood across Roman Britain are still largely unknown. This study is limited by the scarcity of skeletal and dental material from rural sites, a common problem within Romano-British bioarchaeology, and due to limited sample sizes it was also not possible to analyse variations in diet over time.

However, caries affected 11.3% of the Romano-British children, or 1.4% of all erupted teeth. Lesions were more frequent in children from major urban sites, where 14.8% of non-adults presented with caries. This is substantially higher than the non-adult rate reported at the Dorchester civitas (CPR 3.6%, Lewis pers. comm.), which is thought to represent a major urban settlement. Instead, the Dorchester rates are more comparable to the rural pattern (CPR 3.8%) (see Table 2, Table 5). The major urban TPR of 1.8% is, however, similar to that reported from the Lankhills cemetery for the Winchester civitas (TPR 1.7%) (Clough and Boyle, 2010).

When the deciduous teeth were examined, lesions were statistically more frequent in the major urban sample (TPR 3.0%), the only cohort to show individuals with caries in the anterior deciduous dentition. Higher rates of lesions in the deciduous compared to permanent dentition might be expected due to reduced enamel hardness and longer exposure to the oral environment (Hunter et al., 2000; Halcrow et al., 2013), although soft and carbohydrate-rich weaning foods further elevate early childhood caries (Temkin, 1991; Garnsey, 1999). Hence, the greater frequencies of deciduous caries in the major urban group suggest a prolonged exposure to cariogenic foods during early childhood (Veerkamp and Weerheijm, 1995; Berkowitz, 2003; Freeman and Stevens, 2008), while the presence of anterior deciduous caries may hint at the use of pacifiers (Azevedo et al., 2005). The significantly lower rate of deciduous caries in the rural settlements suggests a different early childhood diet or

TABLE 5. Previously reported caries rates in Romano-British non-adults

Study	Site and context	Date (AD)	CPR (%)	TPR (%)	Comments
Moore and Corbett (1973)	Various unknown Major urban, military	1st-5th century		4.2	Deciduous teeth
O'Sullivan et al. (1993)	Various unknown Not stated	1st-5th century		16.0	Deciduous molars
Redfern et al. (2012)	Various (Dorset) Major urban, rural	1st-5th century		0.3/1.5	Deciduous/ permanent teeth
Lewis (pers. comm.)	Poundbury Camp Dorchester Civitas	3rd-5th century	3.6	0.7/0.7	Deciduous/ permanent teeth
Clough and Boyle (2010)	Lankhills Winchester Civitas	4th century		1.7	Deciduous and permanent teeth
Caffell (2007)	Horncastle, Lincolnshire, Fort/minor urban	4th century		12.5/0.0	Deciduous/ permanent teeth

food processing techniques. Fewer carious lesions in the rural cohort may suggest that this part of the population was restricted in its consumption of agricultural products, which are high in carbohydrates. Perhaps this reflects the primary role of rural inhabitants in this period, who were expected to produce a surplus to provide for urban dwellers, the army, and the elite (de la Bédoyère 1993, 86; Jones 1996, 208; MacMullen 1987; Whittaker and Garnsey 1997), where rural families would have been hesitant to consume their primary source of income. In turn, rural weaning foods may have been chosen that were less economically important and also less cariogenic. Differences in the archaeobotanical record between rural sites, particularly in the southwest where the sample sites of the current study are located, and urban settlements across Roman Britain were observed by van der Veen and colleagues (2008), and strengthen the argument for biased food allocation between producer and consumer. A diet high in grit, with hard and abrasive fibrous foods or contaminants may have also been consumed in rural areas, limiting dental caries development (Duray, 1992; Moynihan, 2000). Further research into dental wear in the urban and rural groups may help elucidate this pattern.

While it is important to compare the results from this study with those that have gone before, this is challenging. Many of the studies that have discussed caries rates in Romano-British non-adults have very small sample sizes, and merged data without specifying which sites they included (Table 5). However, data for carious lesion frequency in non-adults is available for Rome itself. Killgrove (2010) reported true prevalence rates for 0-10 year olds, and 11-20 year olds. At Casal Bertone, a cemetery located close to the walls of the city of Rome, caries prevalence rates were 3.2% (0-10 year olds) and 2.9% (11-20 year olds), compared to 2.2% (n=33/1488 teeth in 1.1-10.5 year olds) and 1.5% (n=16/1096 teeth in 10.6-17.0 year olds) in the major urban cohort of the current study. Lesions were less frequent at the cemetery at Castellia Europarco which was located in an agricultural area of the suburbs of Rome. Just as in this study, no dental caries was reported in children under 10 years old; however, the sample was small (n=2/121 teeth) (Killgrove 2010). Although we cannot make inferences on the specific foods eaten in Rome and the major urban towns of Roman Britain from this comparison, dental disease rates from both locations highlight the pertinent differences in oral health between residents of the towns and country at the centre and the fringes of the Empire. Prowse and colleagues (2008) reported a TPR of 3.8% for carious lesions in the deciduous teeth of 1-12 year olds from the necropolis at Isola Sacra at urban Portus. Although the deciduous caries rates for major urban settlements (3.0%) in the current study are significantly higher than elsewhere in Roman Britain, it is below that of children living in Italy, even outside of Rome. Additional data for child caries rates comes from Kellis II in Egypt, where Shukrum and Molto (2009) reported a TPR of 8.9% for deciduous teeth and TPR 3.8% for the permanent dentition, again substantially higher than seen in the British province. Overall, refined carbohydrates and a more fortified diet may have been more readily available to major urban residents in Roman Britain, compared to those living in the countryside. Yet, access to rich foods was more restricted than in Rome, the Italian urban centres and other provinces closer to the centre of the Empire. However, we also have to assume that genetic and geographic factors, such as immunity and fluoride exposure may have influenced dental caries susceptibility between these different populations.

Although the exact pathophysiology of a relationship between enamel hypoplasia and carious lesion development remains to be explored, a total of 39.6% of children with carious lesions also displayed dental enamel hypoplasia. The result was anticipated, and is consistent with the caries-promoting function of stress. Stress may have elevated salivary cortisol levels, which in turn suppressed salivary IgA and enabled cariogenic bacteria to spread (Boyce et al., 2010). Not only will these children have experienced a greater spread of cariogenic bacteria, but the quality of hypoplastic teeth would have exacerbated this effect. In the affected children, bacteria adhere to the site of the defect, and the thinned or defective enamel is more acid soluble, both allowing for dental caries to progress quicker (Hong et al., 2009). Co-occurrence of caries and enamel defects was more frequent in the urban cohorts. More bacteria in the oral cavity, and thinned enamel as a result of non-specific stress may have contributed to the progression of caries in those children. Since hypoplastic enamel defects were more frequent in the major urban cohort than in the rural children, both diet and non-specific stress may have contributed to the significant differences in carious lesion frequencies. This would suggest that higher status of the major urban children was not necessarily a given.

The youngest individual reported with carious lesions was a 1.1-2.5-year old from Butt Road, Colchester with occlusal carious lesions on the deciduous maxillary second molar. The rise in caries TPRs from the youngest age group may reflect the timing of colonisation of the oral cavity with *S. mutans.* Carious lesions usually appear between 13-16 months after initial colonisation (Kawashita et al., 2011), suggesting the children in this study were affected at around one year of age. However, the administration of cariogenic foods and feeding habits may have occurred earlier, for instance between 6-12 months when infants start to sit up, develop better chewing and tasting mechanisms, and are eventually able to self-feed (Sheridan, 1991; Sellen, 2001; 2007; Carruth and Skinner, 2002; Delaney and Arvedson, 2008). Neither human breastmilk nor cow's milk are very cariogenic, but their caries-promoting properties are significantly increased when the infant is fed supplementary foods rich in carbohydrates such as fruits and honey (Moynihan, 2000; Azevedo et al., 2005; Kawashita et al., 2011). Today, *S. mutans* is mainly transmitted from the primary caregiver to the infant as soon as tooth surfaces have erupted (Gussy et al., 2006). In Rome, early child care was not only provided by the mother, but also by a nutrix or paedagogus among richer families (McWilliam, 2013), or by neighbours, friends and relatives for working women (Rawson, 2003a; Golden, 2011). It is likely similar practices were in place in Britain. For example, caries rates in Romano-British females are reported as 5.4% at Cannington (Brothwell et al., 2000), 3.9% at Butt Road, Colchester (Pinter-Bellows, 1993), and 5.4% at Bath Gate, Cirencester (Wells, 1982), higher than those observed in the non-adults from the same sites (TPRs of 0.4%, 1.8% and 1.0% respectively). The mechanism of *S. mutans* transmission may show that Romano-British care givers pre-chewed or tasted their infants' food, and shared utensils with them when administering food or drink (Fildes, 1986). Historical evidence for pre-mastication refers to it as a practice to be avoided (Bradley, 1986; Temkin, 1991), which indicates that it might have indeed occurred, and probably had an influence on the transmission of oral infections from caregiver to child.

Lesion frequencies were higher in major urban and minor urban children from 10.6-17.0 years, at almost four times the rate reported for the rural sites. It is possible that this pattern is reflecting a richer diet of fortified foods for these adolescents. The fact that the majority of carious lesions in both the major urban and minor urban samples were interproximal and occlusal further attests to a softer and more refined diet (Vodanović et al., 2005). There is archaeological evidence for the fine milling of cereals into white flour (Cool, 2006; Alcock, 2010) and following a Roman diet, refined sugar may have been accessed in the form of honey and syrups (Moore and Corbett, 1973; Bowman and Thomas, 1994; Cool, 2006; Carreck, 2008; Crane, 2013). Honey has antibacterial properties which inhibit *S. mutans* growth, but whether honey is primarily cariogenic or cario-protective is debatable (Bogdanov et al., 2008; Nassar et al., 2012). However, it would have been the main sweetener in this time period and therefore frequently consumed. Grape syrup known as defrutum, sapa or caroenum was made in Spain or southern Gaul and was shipped to Britain in distinctive amphorae (Cool, 2006). Evidence for these amphorae in Britain is scarce and dates mainly to the 1st and 2nd centuries AD. These syrups were therefore either imported in different vessels in the later centuries, became even more difficult to get hold of or, alternatively, ceased to be available in Roman Britain (Sealey and Davies, 1984; Sealey and Tyers, 1989; Monfort, 1998). However, defrutum could be made from boiling down any fruit juice in lead vessels, and would therefore have been widely available across Roman Britain (Farwell and Molleson, 1993; Roberts and Cox, 2003). In summary, carious lesion frequencies in children aged older than 10.6 years attest to dietary differences between those living in the towns and country, probably linked with the availability of more refined and softer foods in the urban centres.

CONCLUSIONS

This research has demonstrated the value of reporting carious lesion frequency in non-adults. Its use is further increased by considering the location and type of carious lesions, and the presence of early childhood stress. Higher rates of dental disease in urban environments suggest differences in diet between children in the countryside and the towns of Britannia. Elevated stress, measured as the prevalence of enamel hypoplasia, in the children growing up in urban settlements was accompanied by higher carious lesion frequency. However, we cannot currently estimate how exact the relationship between stress and enamel defects is to the incidence and severity of dental caries. Carious lesions in the deciduous dentition allow for inferences to be made on weaning and feeding practices that promote dental decay, such as the sharing of utensils and food between caregiver and child. The lower frequency of carious lesions in the rural sample suggests a simpler diet consumed by these children, possibly as a result of biased food allocation in response to economic pressures. Urban populations may have had more access to processed and sweetened foodstuffs whereby refined carbohydrates were more readily available.

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