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High frequency of dental caries and calculus in dentitions from a British medieval town

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ABSTRACT

Objective: Dental pathology and tooth wear data can offer valuable insights into the diet and behaviour of past populations. This study aimed to investigate the presence of dietary continuity by examining different types of dental pathology and tooth wear in a medieval sample from the United Kingdom, comparing them to earlier and later samples from the same location.

Design: A comprehensive examination was conducted on 41 individuals (comprising 914 permanent teeth) retrieved from the medieval cemetery of St. Owens Church in Southgate Street, Gloucester, UK. The research focused on documenting and analysing various types of dental pathology and tooth wear, such as dental caries, calculus, and tooth chipping. The frequency of these specific pathologies and wear patterns was then compared to existing literature. Additionally, non-masticatory tooth wear was also evaluated as part of the study.

Results: The sample exhibits high levels of carious lesions and calculus (24 % and 74 % of teeth respectively). Anterior teeth also show an elevated chipping frequency, and along with occlusal notches on the maxillary central incisors suggest teeth were regularly used for non-masticatory purposes.

Conclusions: Caries frequency is similar to sites from later periods and may relate to the early adoption of consuming refined carbohydrates. However, remains from the same area, but the earlier Roman period, also shows high rates of caries and calculus, suggesting a continuation of consuming certain cariogenic foods, or certain behavioural/environmental factors, may instead be responsible for these pathology and wear patterns.

1. Introduction

Research has often focused on the frequency of dental pathology and tooth wear due to the insight these variables can give into the health and behaviour of past populations (e.g., Krogman, 1940; Hillson, 2001; Eshed et al., 2006; Keenleyside, 2008; Liu et al., 2010; Lee et al., 2019). When pathology/wear frequency and severity is investigated on a population level it is often possible to infer certain dietary and behavioural habits, particularly when evidence from isotopic, environmental, and cultural sources are also considered (Littleton & Frohlich, 1993; Lillie, 1996; Lillie & Richards, 2000; Bonsall, 2014; Bonsall & Pickard, 2015; Petersone-Gordina et al., 2018). To explore differences in dental pathologies at a population level for the present study, analyses were carried out on remains from a medieval cemetery from a port town in Southwest England. This location presents an opportunity to study diachronic changes in a small geographical area. Previous studies provide comparative pathological and dietary information for Neolithic (Hedges et al., 2008), Roman (Simmonds et al., 2008; Cheung et al., 2012), and medieval populations (Enright & Watts, 2002; Dawson & Brown, 2013) from Gloucestershire and the town of Gloucester itself. Therefore, this study aims to assess the continuity of diet in this area through time.

Literary and environmental sources suggest cereals were main components of the English medieval diet (Thomas et al., 1997; Woolgar et al., 2006; Connell et al., 2012). Excavations at St Mary Spital, an urban site in London, uncovered the remains of fruits, nuts, vegetables,

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herbs and spices, providing evidence for a wide variety of foods within urban environments (Connell et al., 2012). Pulses, dairy products, and different types of meat may also have been important dietary components (Wadsworth, 1992; Alberalla, 2006; Woolgar et al., 2006; Novak, 2015). Marine fish may have been commonly consumed in Gloucester during this period due to restrictions on freshwater fishing; however, some higher status groups had private fishponds (Schofield & Vince, 2003). The docks and location of the town of Gloucester would have enabled frequent trade and the town was a strategically placed defence post along the River Severn, where it had grown during the Roman period (Cheung et al., 2012).

The presence of dental caries and calculus is universal among human populations, with frequency and location on the dentition varying by diet and behaviour. Carious lesions form when bacteria, such as *Streptococcus mutans* and *Lactobacillus acidophilus*, demineralize dental tissue through the release of acids when sugars and starches are metabolized (Valm, 2019; Towle et al., 2022). Dental calculus is a biofilm that forms when bacteria along with organic and inorganic material adhere to a tooth surface as a plaque deposit that mineralizes over time (Lieverse, 1999). A variety of dietary factors influence calculus formation, making interpretations often more complex than for caries (Lieverse, 1999; Delgado-Darias et al., 2006; Novak, 2015). Diets with high levels of carbohydrates and proteins have been shown to have elevated frequencies of calculus (Littleton & Frohlich, 1989; Lillie, 1996; Lieverse, 1999; Lillie & Richards, 2000), but a diet high in carbohydrates and low in protein has been associated with high rates of both calculus and caries (Keenleyside, 2008; Šlaus et al., 2011). Ante-mortem dental chipping and non-masticatory wear can also give insight into diet and cultural practices (Belcastro et al., 2007; Scott & Winn, 2011). All primate species so far studied show dental chipping, with the chipping patterns across the dentition providing insight into the cause of the fractures (Towle et al., 2017; Fannin et al., 2020; Towle et al., 2022). In hominins, non-masticatory behaviour is often the focus of studies involving tooth chipping, with anterior teeth often showing a high frequency of fractures (e.g., Lous, 1970; Bonfiglioli et al., 2004; Belcastro et al., 2018).

In this exploratory study the frequency and severity of different types of pathologies and wear present on the dentitions of a medieval cemetery population from Gloucester are investigated. Through the examination of the frequency of caries, calculus, antemortem chipping and non-masticatory wear, a greater understanding of the lifestyles and diets of this port town population can be provided. Given that data are available in the literature on contemporary sites in other areas of the UK, as well as in the same area but for different time periods, this study aims to explore if this population retains a similar diet over time or if the period involved is the principal predictor of pathology/wear frequency and patterns. We propose a hypothesis based on previous research indicating higher prevalence of caries and calculus in this specific geographical area during earlier and later time periods, as compared to contemporary sites in other regions. Accordingly, it is anticipated that a similar high frequency of these dental conditions will be observed in the medieval sample under investigation.

2. Materials and methods

St Owens Church, in Southgate Street, Gloucester was a medieval cemetery (Fig. 1). The collection recovered from the site of St Owens and housed at Liverpool John Moores University contained 217 burials, of which 152 (70.09 %) were partial or complete adult individuals. Of those, any individuals which were unable to be assessed using a multivariate approach for age and sex (described below), and lacking dentition for assessment were excluded from the study. This resulted in 41 adult individuals (914 permanent teeth) being recorded for dental pathologies. The area was a Roman suburb before becoming part of Llanthony Priory in 1137 (Rawes, 1990). The church was founded by the first sheriff of Gloucester, Roger de Pitres, who held the position between 1071 and 1082 (Morris, 1918; Herbert, 1988). The church was

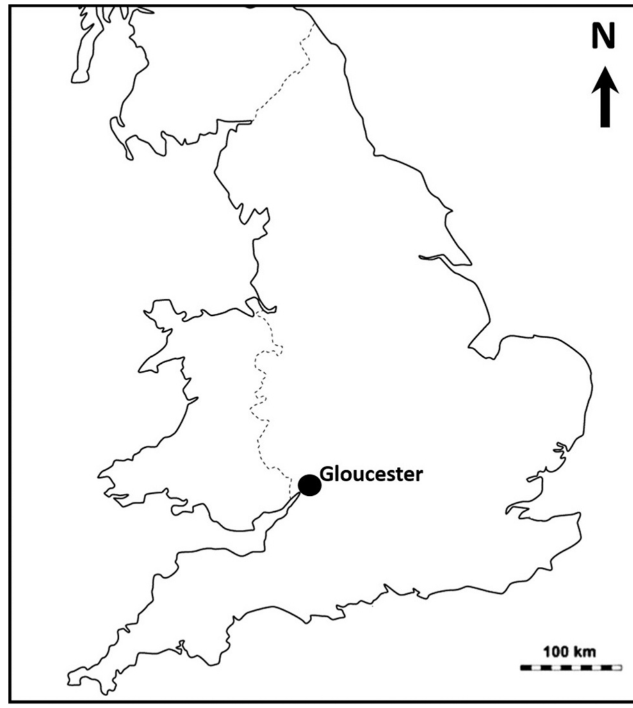

Fig. 1. Map showing the location of Gloucester, UK.

built outside the south gate of the city and served the parish of St Owens until 1643 when the area was cleared and fired prior to attack by the Royalist army during the siege of Gloucester. The parish of St Owens was merged with that of St Mary de Crypt in 1646. Although the Restoration in 1660 listed St Owens as a separate parish again, the church was never rebuilt, with the parishioners continuing to attend services at St Mary de Crypt (Herbert, 1988).

A biological profile was carried out on each individual using a multivariate approach (Lovejoy et al., 1985). Age was assessed using up to six morphological techniques from the skeleton where the element was present (Işcan et al., 1984; Işcan et al., 1985; Webb & Suchey, 1985; Meindl & Lovejoy, 1985; Brooks & Suchey, 1990). Sex was assessed using morphological techniques for the skull and pelvis (Phenice, 1969; Bass, 1995), along with metric measurements from the post-cranial remains (Stewart, 1979; Dwight, 1984; Berrizbeitia, 1989).

Each tooth was examined macroscopically under appropriate lighting with a 10x hand lens used to clarify certain features, particularly caries and chipping. The following variables were recorded: calculus, caries, antemortem tooth loss, occlusal wear, antemortem chipping and cultural tooth wear (e.g., notches). For each, the frequency was calculated by dividing the number of teeth with that variable (i.e., pathology or chipping), by the total number of teeth. Caries was recorded following the methods described in Towle, and Irish, Groote et al. (2021) and summarized here. A carious lesion was recorded if there was clear cavitation, with colour changes alone not recorded. Lesion severity was scored on a scale of 1–4 following Connell and Rauxloh (2003), with (1) enamel destruction only; (2) involvement of dentine but pulp chamber not exposed; (3) destruction of dentine with the pulp chamber exposed; (4) gross destruction with the crown largely destroyed. Lesion location was also recorded (e.g., distal, buccal, occlusal, lingual, mesial), and if it was not possible to ascertain the location of the lesion it was recorded as 'gross'.

Calculus presence and severity were recorded according to the criteria of Brothwell (1981). The three categories recorded were (1) slight: minimal and straight line; (2) moderate: up to 50 % of the tooth surface covered; (3) severe: more than 50 % of the tooth surface covered. A tooth was recorded as lost antemortem if the alveolar socket contained signs of bone resorption (Ortner, 2003; Novak, 2015).

Dental wear was marked according to Smith and Knight (1984) for anterior teeth on a scale of 1–8, and Scott (1979) for molars, on a scale of 1–10 for each of four occlusal quadrants. Notches and grooves on the dentition, caused by non-masticatory cultural activity, were also recorded following Bonfiglioli et al.'s (2004) three-point severity scale. Tooth chipping was recorded following the methods of Towle et al. (2017). A fracture was only recorded if there was further attrition evident on the chipped surface (i.e., the chip scar), to rule out post-mortem damage. Typically, this meant there were smoothed occlusal edges and uniform coloration of the fractured surface with other parts of the crown. Chip position was recorded as mesial, buccal, lingual, or distal, and the total number of chips per tooth was also recorded.

The interaction between different dental pathologies is often complex. It has been suggested that because caries can lead to antemortem tooth loss, a sample may not give a true representation of the overall effect of caries on that population. This possibility led to several proposed methods that help counteract any association (e.g., Lukacs, 1995; Duyar & Erdal, 2003). However, this study does not use corrective methods, and instead displays AMTL frequencies separately as an independent factor. This approach allowed direct comparisons with other samples. The number of postmortem lost teeth was also estimated. A chi-square test of significant was used to test for differences between teeth/groups (anterior vs. posterior teeth; older individuals vs. younger individuals; males vs. females) for the different variables under study (caries, calculus and AMTL), with significance set at the 0.05 alpha level.

3. Results

Table 1 presents the per tooth frequency for different pathologies and chipping divided by tooth type, jaw, sex and age. The frequency of ATML is 6 % for the sample as a whole. 80 teeth in the sample as a whole were considered to be lost postmortem, due to the corresponding alveolus showing no sign of resorption, suggesting the tooth would have been in occlusion at the time of death (55 anterior teeth and 25 posterior teeth). Dental wear is unexceptional, with older individuals commonly displaying occlusal enamel. The mean wear score for anterior teeth, here also including premolars, is 3.5 and molars 4.4 (Table 2). 17.6% of molar quadrants, and 12 % of anterior teeth (including premolars) have a wear score of 6 or above. Overall, mandibular molars are more worn than maxillary, with buccal quadrants of the former having higher wear than lingual (means: 4.8 vs. 4.48), whilst the opposite is true for maxillary teeth (means: 3.91 vs. 4.36 respectively).

Nearly 88 % of individuals exhibit at least one carious tooth, with 23.97 % of teeth affected ($n = 220/918$). Lesions are most common on interproximal surfaces (mesial: 26 %; distal: 25 %) followed by occlusal (19 %) and buccal/labial (15 %) surfaces (Fig. 2). Both sexes have similar proportions of caries in all four severity categories, with females exhibiting a slightly higher frequency of gross caries; however, this difference is not statistically significant ($\chi^2 = 0.54$, 1 df, $p = 0.46$). There are 259 carious lesions across the sample, with 39 teeth having two or more lesions (4.25 %). Only five individuals are caries-free, meaning that 87.8 % of individuals exhibit at least one carious lesion. Posterior teeth are significantly more affected than anterior ($\chi^2 = 54.02$, 1 df, $p > 0.05$), with percentages of 32.21 % and 10.96 %, respectively. Calculus is also common, with 74 % of teeth affected; of these, 5.4 % are severely affected (Brothwell grade 3; Table 1). Only one individual does not evidence calculus, although this individual had multiple antemortem teeth lost and gross caries.

All pathologies more commonly affected older individuals (Table 1). Caries and calculus frequency are not significantly different between the sexes; however, this is not the case for chipping and ATML, as males present higher rates of chipped teeth ($\chi^2 = 6.89$, 1 df, $p > 0.05$), and females more ATML ($\chi^2 = 5.01$, 1 df, $p > 0.05$). Calculus and chipping are more common on anterior teeth, whereas caries and ATML are more evident on posterior teeth (Table 1). Non-masticatory cultural notches are visible on eight maxillary central incisors from six individuals, i.e., two males, two females, and two for which sex could not be assessed. These notches are small, all graded as a 1 or 2 on the Bonfiglioli et al.

Table 2
Wear scores for individual teeth. Molar wear is based on Scott (1979), with teeth split into quadrants. The two buccal and lingual quadrants are combined to give UB (upper buccal), UL (upper lingual), LB (lower buccal), and LL (lower lingual). All other teeth are recorded following Smith and Knight (1984), with Is, Cs & PMs: incisors, canines and premolars respectively.

Wear score	Is, Cs & PMs	Molar quadrants	UB	UL	LB	LL
1	47	60	16	16	14	14
2	132	86	34	32	10	10
3	143	272	75	56	62	79
4	104	389	104	85	97	103
5	99	204	32	46	63	63
6	37	55	4	13	24	14
7	15	18	1	9	5	3
8	20	21	0	2	9	10
9	-	54	9	10	20	15
10	-	69	13	19	22	15

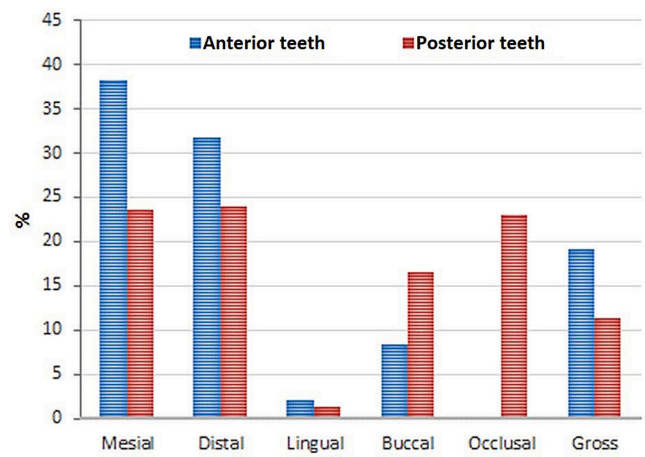

Fig. 2. Position of carious lesions as a percentage of teeth with caries. Teeth are split into anterior and posterior. 'Gross' is recorded if it is not possible to determine the surface the lesion originated due to its severity.

Table 1
Per tooth percentage (%) prevalence for each pathological condition present on the dentition; split by sex, age and tooth type.

Pathology	Sample grouped by								
	All Teeth	Position of dentition		Skeletal location		Sex		Age	
		Anterior	Posterior	Maxilla	Mandible	Male	Female	<35 yrs	>35 yrs
Caries	23.97	10.96	32.21*	23.96	23.97	25.33	28.71	20.63	32.93*
Calculus	74.3	79.66	70.89*	70.74	77.50*	82.37	77.45	71.11	82.93*
Chipping	6.7	10.14	4.49*	7.03	6.39	9.38	4.29*	4.93	11.52*
AMTL	6.06	2.13	8.67*	5.75	6.34	5.47	9.69*	3.94	11.81*

*Chi-square significant difference between variables at 0.05 level

(2004) three-point severity scale. Fig. 3 highlights an example of a tooth with a carious lesion and severe calculus (A) and an incisor displaying a notch (B).

4. Discussion

The rate of AMTL (6.06 % of all teeth) is not particularly high for this period, especially considering the high frequency of caries (Whittaker et al., 1998; Çağlar et al., 2007; Esclassan et al., 2009). The significantly higher frequency of ATML in females is most likely due to caries, given the higher rate of gross caries relative to males. This is in line with previous research in which a higher frequency of caries was found in females, with different behavioural, physiological and dietary explanations often used to explain sex differences (Lukacs, 1996; Walter et al., 2016). Non-masticatory dental wear is relatively common in archaeological samples (e.g., Irish and Turner 1997; Bonfiglioli et al., 2004; Scott & Winn, 2011). Notches in this sample are in individuals of a variety of ages and in both males and females, which likely relate to occupation or habitual behaviours. Gloucester was a port town, with a range of occupations that may have contributed to habitual behaviours causing this tooth wear (e.g., haberdashers, weavers, shoemakers and fishermen). Aside from merchants dealing in the import and export of goods, there would have been a workforce preparing the goods for sale.

Higher rates of chipping on anterior vs. posterior teeth may be suggestive that many fractures were the result of non-masticatory cultural/social behaviours (Bonfiglioli et al., 2004; Belcastro et al., 2007). The ratio of anterior to posterior chips is similar to that in other European samples from this time, in which food preparation and tool use have been proposed as likely causes (Belcastro et al., 2007; Scott & Winn, 2011). Males have significantly more chips per dentition than females, which may relate to using their teeth more for non-masticatory activities, though it could also reflect higher rates of violence or accidents. Despite sex differences, the overall chipping frequency is low compared to many other samples, including wild extant primates, fossil hominins and other archaeological humans (Bonfiglioli et al., 2004; Scott & Winn, 2011; Towle et al., 2017; Belcastro et al., 2018; Fannin et al., 2020; Towle and Loch, 2021). This suggests dental damage through tool use may not have been as common as in other archaeological samples (e.g., Turner and Cadien; Scott & Winn, 2011). The low rate compared to fossil hominins and extant primates also strongly suggests that hard foods were rarely masticated, supporting a diet containing cooked and cariogenic foods. More broadly, the lack of severe wear in most individuals at this site and presence of moderate wear, in even the oldest individuals, suggests their diet may not have been as abrasive as other contemporary sites (Hillson, 1996; Srejić, 2001; Esclassan et al., 2009).

The caries frequency is far higher than most other European medieval samples. It has been noted that the caries rate in medieval Europe varied widely [e.g., from 3 % to 17.5 % of teeth affected (Pap, 1986; Manzi et al., 1999; Vodanović et al., 2005; Çağlar et al., 2007; Belcastro et al., 2007; Esclassan et al., 2009; Meinl et al., 2010; Novak, 2015)]. Arce (2007) found that caries frequency in late medieval Southeast England varied between 4 % and 15 %. However, early medieval frequency is more uniform, ranging from 1 % to 5.6 %. Roman samples are similarly affected (5.9–10.6 %). These values fit with the interpretation that caries was prevalent in Roman Britain, falling to a low by early medieval and increasing again in late medieval times (Roberts & Cox, 2003). Caries frequency for this Gloucester sample is more like those of later sites in Great Britain (Mant & Roberts, 2015). An early adaptation of refined sugar and flour, perhaps made available due to its role as a port town, may help explain this high rate of lesions. Although the frequency of caries is high in this sample, the location of lesions is similar to contemporary populations, with posterior teeth and interproximal areas most affected (Varrela, 1991; Slaus et al., 1997; Watt et al., 1997; Srejić, 2001; Vodanović et al., 2005; Esclassan et al., 2009). Groups with higher attrition rates caused by abrasive and tough foods tend to have few occlusal caries and a far higher proportion of interproximal lesions (Maat and Van der Velde 1987; Meinl et al., 2010). Therefore, the fact that interproximal areas are most affected in the present study is likely explained by higher attrition than in later times; however, it may also be influenced by the high frequency of calculus-facilitated caries formation in these areas (Tomczyk et al., 2013).

The presence of calculus is harder to interpret in terms of diet (Delgado-Darias et al., 2006). Although oral hygiene, salivary flow and other non-dietary factors can influence calculus rates (Lieverse, 1999), diet is the main factor on a population level (Novak, 2015). This relationship is far from clear, however, with diets both high in carbohydrates as well as proteins showing similarly high levels of calculus (Littleton & Frohlich, 1989; Lillie, 1996; Lieverse, 1999). Calculus frequency varies drastically among medieval sites in Europe, from 27 % to almost 90 % (Manzi et al., 1999; Delgado-Darias et al., 2006; Belcastro et al., 2007; Slaus et al., 2010; Vodanović et al., 2012). Novak (2015) notes a high rate of calculus in a large sample of medieval Irish sites, but unlike the present study the rate of caries is low. Novak (2015) suggests both can be explained by incorporation of carbohydrates and dairy products. The calculus occurrence at this Gloucester site is greater than at most other British sites of this age yet, interestingly, it is similar to values for earlier Gloucester samples (Roman Gloucester: 66.7 % of teeth; 3.2 % at grade 3; Simmonds et al., 2008). This finding agrees with research that suggests during the Roman period different provinces differed markedly in diet, most notably with Southwest populations likely opposing new plant foods (van der Veen, 2008; Rohnbogner & Lewis, 2016). This supports the conclusion that populations in and around Gloucester were likely also consuming a diet substantially different from other areas of the UK during the medieval period, and may reflect difference in foods available but also potentially local cultural and cookery practices.

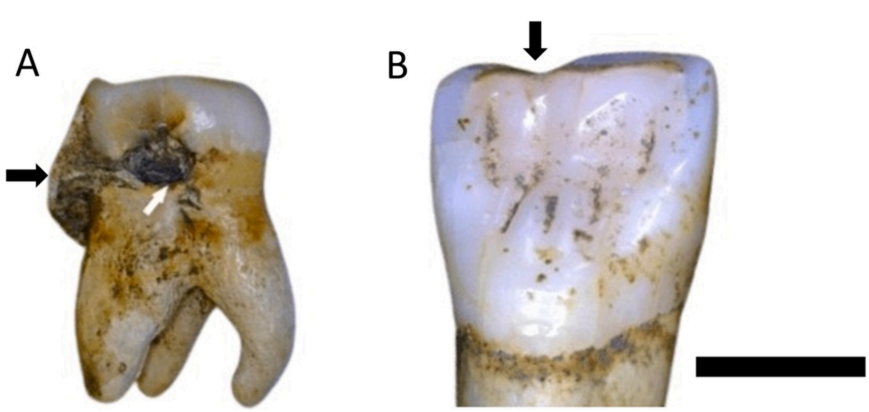

Fig. 3. Examples of dental pathology and wear, A) carious lesions (white arrow) and calculus deposit (black arrow), individual GM 81 (upper left first molar); B) Notch (white arrow), individual GM 76 (upper right central incisor). Scale bar is 5 millimetres.

Therefore, a diet high in certain carbohydrates is likely the cause for high rates of calculus and caries in this sample (Keenleyside, 2008; Šlaus et al., 2011). Since these rates are also high in the same area during the Roman period this may suggest a continuation of certain foods or behavioural practices or, more likely, Gloucester was a key port town throughout. The conclusion that Gloucester was a prosperous town with a diet high in 'luxury' foods such as meat and sugary carbohydrates is also supported by recent isotope analyses for this material. As part of a separate study, dental calculus samples from St Owens (n = 26) were sent for carbon and nitrogen stable isotope testing at the University of Nevada, Reno (Scott & Poulson, 2012; Poulson et al., 2013; Chamberlain et al., 2016; Poulson et al., 2016). The mean δ^{13}C values (−21.34 ± 0.79‰) for the St Owens chapel calculus samples were consistent with a diet focused on C_3 plants, which was supported by documented evidence of trade and agriculture in medieval Gloucester (Herbert, 1988). Mean δ^{15}N values (12.53 ± 0.19‰) are consistent with a 1–2 level trophic shift (6.72‰) above the herbivore baseline (5.81 ± 0.19‰, n = 51), indicating that the diet contained animal and marine sources, along with regular intake of omnivore or freshwater fish protein. Results from the present research and other multi-site analyses reveal that individual sites can vary dramatically during a given time particularly, as seen here, in the late medieval period.

Excluding early stage caries, which refers to lesions before visible cavitation occurs, may result in underestimating the actual frequency of caries. Nevertheless, in archaeological and paleontological contexts, the identification of incipient caries is challenging due to taphonomic processes that can obscure or be mistaken for lesions. Distinguishing between antemortem and postmortem effects often requires tooth sectioning or micro-CT scanning (Hillson, 2001; Towle et al., 2022). However, even with these techniques, accurately estimating the true frequency of caries in archaeological samples remains difficult. Therefore, limiting comparisons to cavitated lesions is currently justified, enabling broader comparisons with existing literature. While not accounting for antemortem tooth loss may also underestimate the impact of caries, determining how many of the lost teeth were actually caused by caries versus other factors, particularly attrition, is uncertain. It is important to note that both these limitations (excluding incipient caries and no corrective methods for antemortem tooth loss) result in underestimation of the impact of caries on the studied sample. Given the study's high caries rate, these limitations do not undermine the findings. Calculus also poses limitations, as the factors initiating mineralization are poorly understood, and deposits are frequently lost during burial, excavation, or subsequent collection storage. Hence, the frequency reported in this study should also be considered a minimum value. Despite this limitation, given the remarkably high values reported, the conclusions and inferences drawn remain robust. Additionally, typical limitations in similar archaeological studies, such as relatively small sample sizes compared to the entire populations under study and potential biases inherent in cemetery populations, should be acknowledged, and further research on other samples in the local area could be undertaken to explore these potential biases. Further analysis on the present sample could also lead to interesting findings, including microwear analysis of occlusal grooves, examination and analysis of entrapped remains within large calculus deposits, and the use of sectioning or Micro-CT techniques to investigate the progression of carious lesions.

CRediT authorship contribution statement

Ian Towle: Conceptualization (equal); Data curation (lead); Formal analysis (lead); Investigation (equal); Methodology (equal); original draft (lead); Writing - review and editing (equal). **Carole Davenport**: Conceptualization (equal); Data curation (supporting); Formal analysis (supporting); Investigation (equal); Methodology (equal); original draft (supporting); Writing - review and editing (equal). **Joel D. Irish**: Conceptualization (equal); Data curation (supporting); Formal analysis (supporting); Investigation (equal); Methodology (equal); original draft (supporting); Writing - review and editing (equal). **Isabelle De Groote**: Conceptualization (equal); Data curation (supporting); Formal analysis (supporting); Investigation (equal); Methodology (equal); original draft (supporting); Writing - review and editing (equal).

Declaration of Competing Interest

None.

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