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Urbanization, Economic Change, and Dental Health in Roman and Medieval Britain

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In modern populations, inequalities in oral health have been observed between urban and rural communities, but to date the impact of the place of residence on oral health in archaeological populations has received only limited attention. This meta-study analyses dental palaeopathological data to examine the relationship between place of residence and oral health in Roman, early medieval, and late medieval Britain. Published data on ante-mortem tooth loss, calculus, caries, dental abscesses, and periodontal disease were analysed from cemeteries in urban and rural locations from each period. The results indicate that the place of residence influenced oral health in Roman and late medieval times, with urban populations enjoying better oral health than rural populations in Roman Britain, but poorer oral health in the late Middle Ages. These findings may reflect changes in the nature of urban settlements and in their relationship with their rural hinterlands over time.

Keywords: oral health, palaeopathology, urban, rural, economy, Britain

Introduction

In modern populations, place of residence has been found to have a significant impact on oral health. In some societies this is believed to be due to differences in diet, with urban communities having greater access to the refined sugars responsible for dental caries, and therefore higher rates of oral pathologies than rural populations (Doherty et al., 2010; Ogunbobdede et al., 2015). However, in other societies diet does not appear to play a significant role in determining the relative oral health of rural and urban populations. A number of studies have found that rural populations tend to have higher rates of dental pathology than their urban counterparts (e.g. Skillman et al., 2010; Singh & Purohit, 2013; Shen et al., 2015); this appears to be due to the relative isolation and lower levels of income of rural populations, the higher proportion of older residents in rural communities, and difficulties accessing dental practitioners in rural areas (Ettinger, 2007). The impact of place of residence on oral health therefore appears to be strongly influenced by the social, cultural, and economic context of the populations examined.

Recent work has shown that differences in oral health between urban and rural populations can also be observed in past populations. Several studies of health in Roman Britain have identified such differences between urban and rural sites (Pitts & Griffin, 2012; Redfern et al., 2015) or between different types of urban sites (Bonsall, 2013). Pitts and Griffin (2012) observed significantly lower rates of oral disease in urban populations than in rural communities at this time, while Bonsall

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(2013) found lower rates of periodontal disease, caries, and dental abscesses in the more highly urbanized 'public towns' than in small towns in Roman Britain. Similar patterns have been observed in Roman Italy, where the higher rates of dental disease in rural settlements have been linked to the greater availability of meat in urban contexts (Manzi et al., 1999). The difference in diet between urban and non-urban settlements at this time is also supported by results from stable isotope analysis (Cheung et al., 2012; Killgrove & Tykot, 2013). Pitts and Griffin have suggested that the tendency towards better oral health in urban settlements in Roman Britain may be due to the economic effects of increasing urbanization and the incorporation of Britain into the Roman Empire. The redistribution of agricultural surplus by the Roman government to the urban centres is likely to have affected the diets of both urban and rural populations, with higher quality food more readily available in urban centres than in their rural hinterland. Access to dental treatment is also likely to have been greater in urban settings. It has therefore been proposed that a combination of a more diverse diet containing a higher proportion of meat and better access to dental care resulted in lower rates of dental disease in urban populations at this time. However, the findings of Redfern et al. (2015) of higher rates of dental disease in urban settlements in Roman Dorset suggest that the impact of place of residence on oral health may have varied within the province.

While the evidence suggests that place of residence influenced oral health in Roman Britain, it is unclear to what extent this affected the oral health of later populations, particularly given the substantial economic and social changes that took place in the centuries following the end of Roman rule. Studies from continental Europe have shown that there was a significant deterioration in oral health in the medieval period (Manzi et al., 1999; Slaus et al., 2011), and changes in diet have also been observed in analyses of stable isotope data, both in Britain and on the Continent (Müldner & Richards, 2007b; Lightfoot et al., 2012). This trend is, however, not consistently observed, with some regions showing little change in dental health (e.g. in the Molise region in central Italy; Belcastro et al., 2007) or indeed indicating that there was an improvement in oral health in the late medieval period (Watt et al., 1997; Gonçalves et al., 2015). This study therefore seeks to better understand the impact of urbanization and economy on British oral health over the longer term by determining the effect of place of residence on oral health in British populations from Roman to medieval times.

Materials and Methods

In order to gain an initial overview of oral health patterns across mainland Britain (Scotland, England, and Wales) from Roman to medieval times, this study sought to include as many sites as possible in a meta-study of oral health data, rather than focus on a smaller number of representative sites. Such an approach avoids having to select 'typical' sites for each period and urban/rural location, which may turn out to be unrepresentative. However, the size of the study precludes the analysis of conditions in the kind of detail that would be possible in a smaller study. Data on oral health from a sample of 124 urban and rural cemeteries located in mainland Britain are included here: thirty-eight are Roman, fifty-two early medieval, and thirty-four late medieval (Table 1). The selection was based on sites which contained at least twenty individuals, and for which data was available

Table 1. *Cemeteries selected for inclusion in this study, with sample sizes in brackets.*

Urban	Intermediate	Rural
Roman		
Cirencester[7] (407)	Alchester[33] (40)	Barrow Hills, Radley[34] (57)
Colchester[17] (575)	Ancaster[46] (327)	Bletsoe[20] (50)
Dorchester, Little Keep[40] (25)	Baldock 1[34] (191)	Boscombe Down[35] (37)
Dorchester, Poundbury[18] (1131)	Baldock 3[34] (145)	Cassington[34] (71)
Gloucester, Gambier-Parry Lodge[34] (94)	Baldock 4[34] (63)	Catterick[34] (28)
Gloucester, Kingsholm[34] (48)	Caistor, Talbot Inn[45] (22)	Chignall[29] (36)
Gloucester, London Road[47] (27)	Cambridge, Vicar's Farm[32] (21)	Dorchester, Tolpuddle Hall[34] (48)
Leicester, Newarke Street[34] (34)	Derby[34] (46)	Kempston[36] (92)
London, Giltspur Street[34] (124)	Dorchester-on-Thames, Queenford Farm[12] (92)	Owlesbury[34] (49)
London, Trinity Street[42] (44)	Dorchester-on-Thames, Queensford Mill[34] (81)	Radley[34] (33)
London, West Tenter Street[11] (112)	Dunstable[5] (116)	Stanton Harcourt[4] (36)
St Albans[34] (27)	Icklingham[2] (50)	
Winchester, Lankhills[3,46] (369)	Ilchester[6] (49)	
York, Trentholme Drive[34] (329)		
Early medieval		
Chichester, Apple Down[34] (125)	Andover, Portway[34] (68)	Addingham[34] (45)
Gloucester, Golden Minster[31] (139)	Bamburgh, Bowl Hole[43] (92)	Alton[34] (40)
Ipswich, School St[14] (95)	Barton-on-Humber, Castledyke[28] (200)	Ashstead, Goblin Works[15] (27)
Norwich, Farmer's Avenue[34] (91)	Bedford, St Paul's Square[34] (31)	Barrington, Edix Hill[30] (148)
Norwich Castle[34] (112)	Great Chesterford[34] (93)	Beckford A[27] (22)
Thetford, Red Castle[1] (85)	Kingsworthy, Worthy Park[34] (101)	Beckford B[27] (108)
Thetford 2[19] (81)	North Elmham Park[34] (206)	Berinsfield[21] (122)
York, York Minster[34] (60)	St Andrews, Hallow Hill[25] (93)	Binchester[34] (54)
		Brandon, Staunch Meadow[34] (158)
		Burgh Castle[16] (167)
		Caister-on-Sea[34] (139)
		Cannington[34] (542)
		Charlton Plantation[9] (45)
		Collingbourne Ducis[34] (29)
		Deal, Mill Hill[34] (75)
		Eastbourne, Ocklynge Hill[34] (23)
		Eccles[34] (166)
		Empingham[34] (153)
		Eriswell[34] (28)
		Filton[37] (51)
		Jarrow[38] (170)
		Monkwearmouth[38] (327)
		Norton[34] (125)
		Oakington[34] (23)

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Table 1. (*Cont*.)

Urban	Intermediate	Rural
		Pontefract, Tanners' Row[34] (178)
		Portchester Castle[34] (22)
		Raunds Furnells[23] (361)
		Ripon, Ailcy Hill[24] (27)
		Rivenhall[34] (46)
		South Acre[34] (119)
		Stretton-on-Fosse[34] (41)
		Ulwell[13] (49)
		West Heslerton[34] (132)
		Whitby Abbey[41] (122)
		Wicken Bonhunt[34] (222)
		Willoughby-on-the-Wolds, Broughton Lodge[34] (105)
Late medieval		
Bristol, St Bartholomew's Hospital[34] (30)	Aberdeen, Carmelite Friary[34] (68)	Abingdon Abbey[34] (589)
Canterbury, St Gregory's Priory[34] (91)	Bolsover, St Mary and St Lawrence[34] (28)	Barton Bendish, All Saints[34] (79)
Chester, Greyfriars[34] (49)	Chichester, St James and St Mary Magdalene[34] (351)	Brough, St Giles' Hospital[22] (37)
Lincoln, Pennell St[34] (79)		Chevington Chapel[34] (60)
Lincoln, St Mark's Railway Station[34] (31)	Dundee[26] (55)	Denbigh, Ysgol Twm or Nant[34] (170)
	Grantham, London Road[34] (53)	Hatch Warren, Brighton Hill South[34] (52)
London, Carter Lane[34] (58)	Guildford, Dominican Friary[34] (113)	Hulton Abbey[34] (24)
London, Holy Trinity Priory[34] (68)	Ipswich, Blackfriars Friary[34] (25)	Rivenhall[34] (70)
London, St Mary Graces[44] (100)	Merton, Merton Priory[34] (74)	Stratford Langthorne Abbey[10] (128)
London, St Mary Spital[34] (126)	Newark St Leonard's Hospital[34] (82)	
London, Spitalfields Market[39] (200)	St Andrews, St Mary's[34] (330)	
York, Jewbury[34] (475)	Taunton, Taunton Priory[8] (162)	
York, St Andrews Fishergate[34] (402)	Thetford[19] (149)	
York, St Helen on the Walls[34] (1037)		

Sources: [1]*Knocker, 1967;* [2]*Wells, 1976;* [3]*Clarke, 1979;* [4]*McGavin, 1980;* [5]*Matthews, 1981;* [6]*Leach, 1982;* [7]*McWhirr et al., 1982;* [8]*Rogers, 1984;* [9]*Davies, 1985;* [10]*Stuart-Macadam, 1986;* [11]*Whytehead, 1986;* [12]*Chambers, 1987;* [13]*Waldron, 1987;* [14]*Mays, 1989;* [15]*Poulton, 1989;* [16]*Anderson & Birkett, 1993;* [17]*Crummy et al., 1993;* [18]*Farwell & Molleson, 1993;* [19]*Stroud, 1993;* [20]*Denston and Duhig, 1994;* [21]*Boyle et al., 1995;* [22]*Cardwell, 1995;* [23]*Boddington, 1996;* [24]*Hall & Whyman, 1996;* [25]*Proudfoot, 1996;* [26]*Spalding et al., 1996;* [27]*Wells, 1996;* [28]*Boylston et al., 1998;* [29]*Clarke, 1998;* [30]*Malim & Hines, 1998;* [31]*Rogers, 1999;* [32]*Lucas, 2001;* [33]*Hawkes, 2003;* [34]*Roberts & Cox, 2003;* [35]*Wessex Archaeology, 2003;* [36]*Boylston & Roberts, 2004;* [37]*Cullen et al., 2005;* [38]*Cramp, 2006;* [39]*Arce, 2007;* [40]*McKinley, 2009;* [41]*Vincent & Mays, 2009;* [42]*Langthorne, 2010;* [43]*Groves, 2011;* [44]*DeWitte, 2012;* [45]*Keal, 2012;* [46]*Bonsall, 2013;* [47]*Jackson, 2013.*

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for at least one of the five oral health conditions under analysis: antemortem tooth loss (AMTL), calculus, caries, dental abscesses, and periodontal disease. In order to maximize the sample size, sites were examined by the broad period to which they belonged (Roman, early medieval, late medieval). It is, however, important to note that not all sites were occupied at the same time, and this could influence the results obtained. Furthermore, it is also possible that the populations examined here are not representative of the original living population, due to factors such as differential burial practices, incomplete excavation of some of the cemeteries included in the study, and the effects of the Osteological Paradox, where lesions will only appear in the skeleton of those who were able to survive a disease long enough for the skeleton to be affected (Wood et al., 1992). These aspects will need to be taken into consideration when interpreting the results.

The five oral health conditions chosen for analysis were those that are most frequently recorded in osteoarchaeological reports. Dental caries is associated with high carbohydrate diets and poor oral hygiene, and can therefore provide information about diet and dental health (Larsen et al., 1991). Calculus is calcified dental plaque, which can also provide information about the diet of the individual (Hillson, 1996). It has been suggested that the relative proportions of caries and calculus can be used to give an indication of the relative proportions of proteins and carbohydrates in the diet, although other factors such as oral hygiene and drinking water composition can also have an effect on calculus rates (Lieverse, 1999). Periodontal disease is also associated with dental plaque, and is caused by gum inflammation in areas of plaque accumulation, leading to the remodelling of the jaw and the loss of alveolar bone (Hildebolt & Molnar, 1991). Dental abscesses result from the localized resorption of bone due to infection of the tooth pulp, often caused by caries in the tooth crown or root. In osteoarchaeological contexts, it is often difficult to distinguish between dental abscesses and less severe periodontal lesions (Dias & Tayles, 1997). It is therefore likely that the figures for abscesses shown here include more minor lesions in addition to true abscesses. As this is likely to affect all sites equally, this is unlikely to significantly influence any patterns observed between sites. AMTL is commonly caused by oral pathologies such as caries, periodontal disease, or tooth wear, and can therefore provide useful information about diet, particularly when examined in conjunction with rates of caries and periodontal disease (Hillson, 1996). The analysis of data on these five oral pathologies with diverse aetiologies is therefore likely to provide insights into the dietary and health factors influencing oral health in urban and rural sites in Roman and medieval Britain.

Data were collected from published reports giving details of the remains from each site or from published summaries of palaeopathological data (see sources listed in Table 1). The use of secondary data for this study presents particular challenges. Because these data were recorded by different osteoarchaeologists, the data available varies between cemeteries and depends on such factors as the time available for analysis and the level of preservation of the remains. The impact of such variations has been minimized for this analysis by using true prevalence rates where possible. The true prevalence rate is the percentage of observable teeth or sockets affected by a specific pathology. This approach can be preferable when studying archaeological remains, as the level of preservation of the skeletons recovered varies and hence it is not always possible to assess all conditions in all parts of the mouth for every individual (Brickley, 2004). This can have an impact on the prevalence of each condition observed per individual, known as the crude prevalence rate. However, the use of true prevalence rates can also be problematic, as it is common for the same oral health condition to be present in multiple teeth from a single individual (Mays et al., 2004). If more teeth are preserved from some individuals than from others, this can bias the results. In this study, it was decided to use true prevalence rates where possible, as these are more commonly used for reporting dental diseases than crude prevalence rates. For the majority of sites under examination it was possible to calculate true prevalence rates for caries, dental abscesses, and AMTL; hence these rates were used rather than crude prevalence rates. However, for dental calculus and periodontal disease, it was not possible to calculate true prevalence rates from the data available. For these conditions, crude prevalence rates were therefore used.

Because of variations in the detail in which these conditions were reported in each publication, it was not possible to split the data from all sites by tooth type (permanent/deciduous or anterior/posterior). The data are therefore analysed as a single overall figure for each condition at each site. For the majority of sites, prevalences were calculated directly from the published figures for that site. In cases where figures were not available for the numbers of individuals/teeth affected and/or the number of individuals/teeth assessed, published prevalence rates were used instead.

Cemeteries were classified according to the nature of the nearby settlement as urban, intermediate, or rural. Major towns, as defined by Perring (2002) for Roman sites, and Palliser (2000) for medieval sites, were classified as urban; other towns or major settlements were classified as intermediate, and all other sites were classified as rural. The classification of some sites was, however, not always straightforward, especially in the case of Roman Britain, where the distinction between intermediate 'small towns' and rural settlements has been subject to debate (Brown, 1995). It is hoped that the inclusion of a number of sites of each type within each period will help minimize the impact of any potentially incorrect classification.

Differences in oral health between rural, intermediate, and urban sites were assessed using analysis of covariance (ANCOVA). As age and sex can also affect oral health, the age distribution and male:female ratio of each population were taken into account in the analysis. Because of the varying age categories used in the different reports, particularly for individuals aged over twenty-five, it was decided to focus on a comparison of the proportion of individuals aged over twenty-five as an indication of the age structure of the population. The proportion of adults aged over twenty-five and the male:female ratio were therefore included as covariates in each ANCOVA analysis.

In addition, to gain an overall picture of oral health per period, multidimensional scaling was used to visualize patterns in health between sites from each period. Multidimensional scaling was selected for this analysis because it plots the data according to shared characteristics, does not rely on any assumptions regarding the groups within the sample, and can be adapted for use with datasets containing missing data (Pechenkina & Delgado, 2006). To increase the reliability of the results, only sites with data for at least three of the conditions considered in this study were included in the analysis. A matrix of similarities between sites was produced for each period, with the similarities calculated using Gower's composite similarity index (Gower, 1971), using the average similarity index for all health indicators for which data were available at each pair of sites. The resulting matrix was analysed using the PROXSCAL function within SPSS (Statistical Package for the Social Sciences), to produce a plot according to the similarities in oral health between the sites under study, where the axes are Dimensions 1 and 2. The plots were then examined both visually and by using regression analysis to determine the factors underlying the distribution of the sites on the plot.

Results

Differences in oral health were observed between urban, intermediate, and rural settlements in all three periods (Table 2), with the relationship between oral health and place of residence appearing to change over time. In Roman Britain, a significantly higher true prevalence rate of abscesses occurred in rural settlements than in urban settings. Rural sites also tended to have a higher prevalence of calculus, periodontal disease, and AMTL, although these differences were not statistically significant. While the particularly high average rate of abscesses in rural settlements was influenced by the unusually high rate of abscesses at the Barrow Hills site in Oxfordshire (26 per cent), all the rural Romano-British sites included in this study displayed high prevalences of dental abscesses and the average prevalence remained high even after the data from Barrow Hills had been removed. In contrast, in late medieval Britain, urban settlements tended to have a higher rate of oral pathologies, although this pattern was only significant for periodontal disease after taking into account the sex and age compositions of the sites analysed. The main exception to this trend was dental caries, which occurred at a higher rate in rural populations in the late medieval period. The overall pattern of oral disease suggests that changes in the physical and social environment over this time may have affected urban and rural settlements differently, with urban environments being more beneficial to oral health in the Roman period. In contrast, rates of oral disease were similar in urban and rural settlements in the early medieval period.

No significant difference in age composition was observed between urban and rural sites in the Roman ($p = 0.991$) or early medieval ($p = 0.737$) periods. However, the proportion of individuals aged twenty-five or over was significantly higher in urban and intermediate sites than in rural sites in the late medieval period ($p = 0.044$). The greater proportion of older individuals in urban and intermediate sites at this time is reflected in the higher prevalences of AMTL, calculus, dental abscesses, and periodontal disease there. However, the higher rate of periodontal disease in urban populations appears to have also been influenced by factors other than age composition; indeed, after having taken into account the age composition at a given site using ANCOVA, the higher prevalence of this condition in urban sites remained significant.

The impact of place of residence on oral health observed here is supported by the results of the multidimensional scaling analysis. In Roman and late medieval times, the distribution of sites on the multidimensional scaling plot is strongly influenced by site type. In the Roman period (Figure 1), urban and intermediate sites tend to be located towards the bottom of the graph, with rural sites located towards the top. This association is significant after taking into account the sex and age composition at each site ($p = 0.044$). Sites towards the bottom of the graph (predominantly urban and

Table 2. *Average prevalences of oral pathologies in urban, intermediate, and rural populations from Roman, early medieval, and late medieval sites, with p values determined using ANCOVA taking into account the male:female ratio and proportion of adults over 25 years old in each population.*

Condition	Period	Urban (per cent)	Intermediate (per cent)	Rural (per cent)	*p* value
Antemortem tooth loss (true prevalence rate)	Roman	12	13	20	0.246
	Early medieval	7	8	8	0.985
	Late medieval	17	14	13	0.157
Calculus (crude prevalence rate)	Roman	39	34	44	0.444
	Early medieval	40	50	37	0.858
	Late medieval	68	59	39	0.870
Caries (true prevalence rate)	Roman	12	7	11	0.455
	Early medieval	5	4	4	0.115
	Late medieval	7	9	12	0.671
Dental abscesses (true prevalence rate)	Roman	1.8	3.5	13	0.003
	Early medieval	2.9	3.8	2.3	0.568
	Late medieval	2.7	4.6	1.6	0.135
Periodontal disease (crude prevalence rate)	Roman	41	37	45	0.531
	Early medieval	15	30	24	0.045
	Late medieval	66	33	29	0.022

intermediate sites) are associated with lower rates of dental disease than those at the top, particularly AMTL and dental abscesses. No significant association was observed between either Dimension and the age composition of the sites in this period. In the late medieval period (Figure 2), urban sites appear to the right of the graph relative to rural and intermediate sites. This association is, however, not statistically significant after taking into account the age and sex composition at each site ($p = 0.072$). In this plot, sites to the right of the graph (predominantly urban sites) are associated with higher rates of dental disease, particularly calculus and periodontal disease. No significant association was observed between either Dimension and the age composition of the sites in this period. This suggests that in Roman as well as late medieval times there is a relationship between overall levels of oral health for each population and the location of these communities, which is not primarily determined by the age composition of the site. No such association between the position of sites on the multidimensional scaling plot and site type could be observed for the early medieval group (Figure 3), a finding that is consistent with the results of the ANCOVA analyses.

The prevalence of oral disease in both rural and urban settlements also changes significantly between the Roman and late medieval periods (Figures 4 and 5). For the majority of conditions, urban populations in the Roman period show a lower rate of dental pathology than rural populations, but these differences either become much smaller or reverse in the early medieval period. Rates of caries and AMTL decrease significantly in all three settlement types at this time after taking into account the sex and age composition of each site, while dental abscesses increase in urban settings but decrease in intermediate and rural settlements. The gap in oral health between urban and rural sites increases in the late medieval period: rates of caries increase significantly in all settlement types, after taking into account the sex and age composition of each population, and rates of periodontal disease

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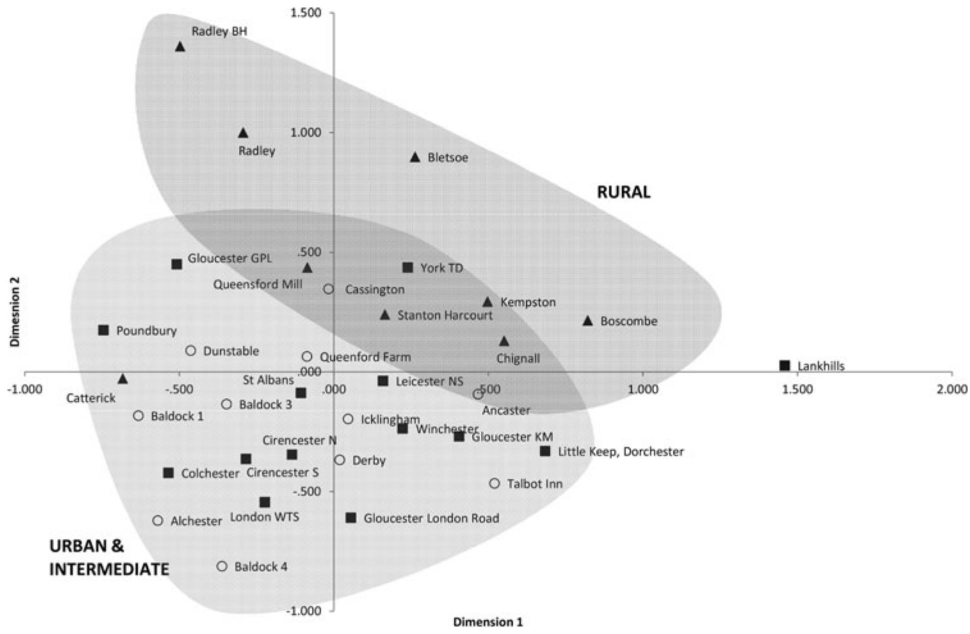

Figure 1. *Multidimensional scaling plot for oral health data from Roman Britain.* ■ *Urban;* ○ *Intermediate;* ▲ *Rural.*

increase in urban sites but decrease in rural sites. It therefore appears that both urban and rural contexts saw changes which affected the susceptibility of these populations to oral disease.

Discussion

The findings of this study suggest that the social and economic relationship between urban and rural sites may have had an important influence on oral health in Roman and medieval times. In comparison to the overall rates of dental disease in the Iron Age reported in Roberts and Cox (2003), there is an increase in the rate of oral diseases in the Roman period, and this is more marked among Romano-British rural populations than in their urban counterparts. One possible explanation is that the incorporation of rural settlements into the broader market economy at this time had a particularly detrimental effect on oral health in rural areas. The assimilation of rural communities into the imperial economy would be expected to have led to increased extraction and redistribution of rural surplus to the towns, associated with a concentration of the highest quality produce in the towns at the expense of the rural population. This process is likely to have had an impact on oral health, with rural communities becoming more reliant on a carbohydrate-rich diet with a high cereal content due to the lower availability of meat, as has been observed in Roman sites on the European continent (Manzi et al., 1999; Bonfiglioli et al., 2003). However, while the existence of dietary differences between urban and rural settlements is supported by isotopic evidence for urban and rural diets from both Britain (Cheung et al., 2012) and Italy (Killgrove & Tykot, 2013), the differences identified in these studies do not appear to result from variations in meat consumption between rural and urban

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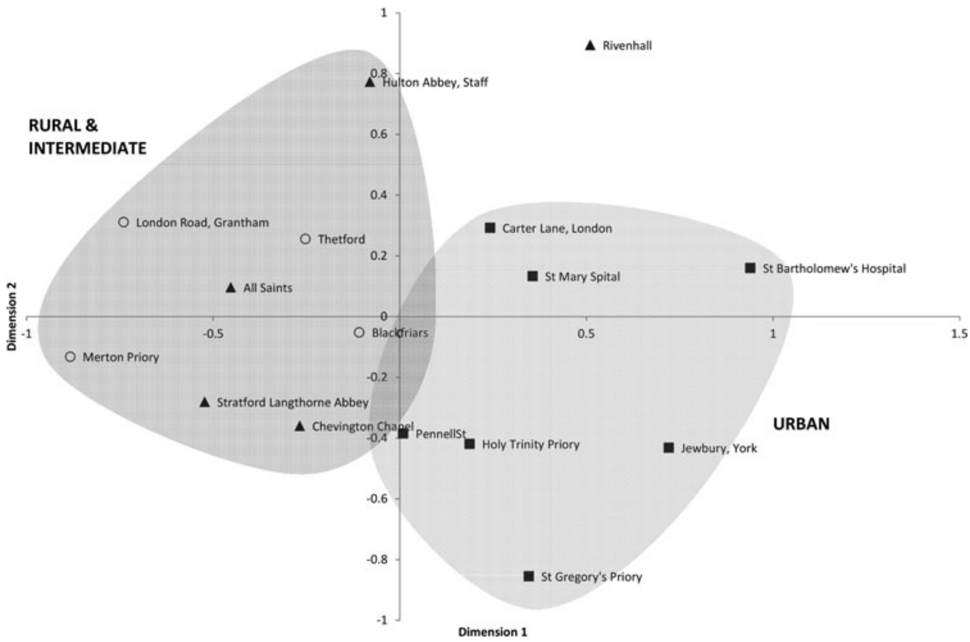

Figure 2. *Multidimensional scaling plot for oral health data from late medieval Britain. ■ Urban; ○ Intermediate; ▲ Rural.*

populations, but to more subtle differences in dietary composition. The isotopic evidence instead indicates that both urban and rural populations were consuming significant quantities of meat and dairy products (Cummings, 2009), though variations in diet also existed within populations (Redfern et al., 2010). Furthermore, archaeobotanical evidence shows that both urban and rural populations had access to a varied diet at this time, such variety not being limited to elite groups (van der Veen et al., 2008). Nevertheless, the presence of high rates of AMTL, caries, and calculus in both urban and rural settlements in Roman times suggests that urban as well as rural populations were consuming a diet that was high in carbohydrates. This is consistent with evidence from isotopic studies (Richards et al., 1998; Bonsall & Pickard, 2015) and with previous osteoarchaeological findings (e.g. Moore & Corbett, 1973; O'Sullivan et al., 1993). It may therefore be that comparatively subtle differences in the relative quantities of carbohydrates within urban and rural diets are reflected in the poorer oral health observed here.

Differences in the types of carbohydrate consumed may also have had an impact on the caries levels observed. For example, foods rich in sugars are more cariogenic than those containing starchy carbohydrates such as potatoes and grains, with starchy foods being more likely to cause caries when cooked than when consumed raw (Moynihan, 2005). It is possible that rural communities may have been consuming greater amounts of sugary carbohydrates such as fruit relative to urban populations, or a higher proportion of cooked starchy carbohydrates. In addition, there is evidence to suggest that the consumption of dairy products may help to protect against caries formation (Moynihan, 2005). If urban populations were consuming higher amounts of dairy produce than rural populations, this could

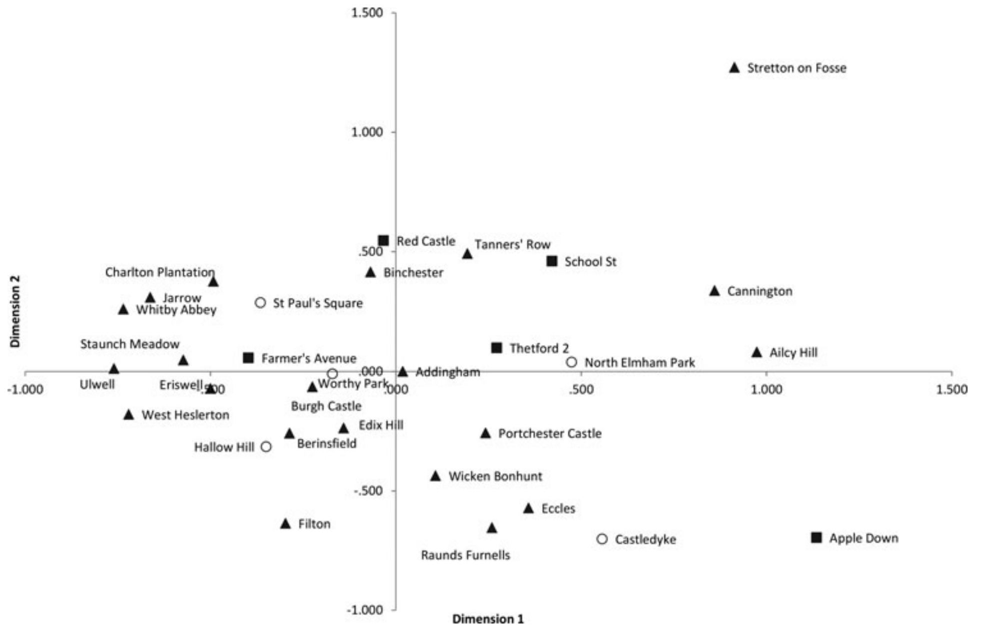

Figure 3. *Multidimensional scaling plot for oral health data from early medieval Britain.* ■ *Urban;* ○ *Intermediate;* ▲ *Rural.*

also potentially explain the lower rates of caries observed in urban sites. Further isotopic and archaeobotanical studies are needed to identify the nature of dietary differences between urban and rural Romano-British populations. It is also possible that the lower crude prevalence rates of dental diseases in urban populations reflect a higher level of mortality in urban settlements, with a greater proportion of individuals dying in childhood or early adulthood before these conditions would become visible in their dentition. The analysis of the age distribution of the urban and rural Romano-British sites included in this study has, however, found no evidence for a difference in childhood/young adult mortality between urban and rural sites. Furthermore, the poorer oral health observed at rural sites across numerous dental pathologies with different causes suggests that varying levels of mortality are unlikely to be the sole cause of this pattern.

The influence of economic factors on oral health in urban and rural populations is supported by the decreasing rates of oral pathologies in both urban and rural early medieval sites. The rates of caries and AMTL drop substantially in the early medieval period in both urban and rural populations, but the rate of calculus only changes slightly. The presence of high rates of calculus but low rates of caries may be indicative of a diet higher in protein, as calculus is associated with the consumption of both proteins and carbohydrates, while caries is primarily associated with high levels of carbohydrate consumption (Lieverse, 1999). This may reflect a shift to more localized distribution networks in the early Middle Ages, with trade on both urban and rural sites (Blair, 2000) and urban populations tending to consume produce from their local area rather than further afield (Britnell, 2000). This would allow rural as well as urban communities to consume a

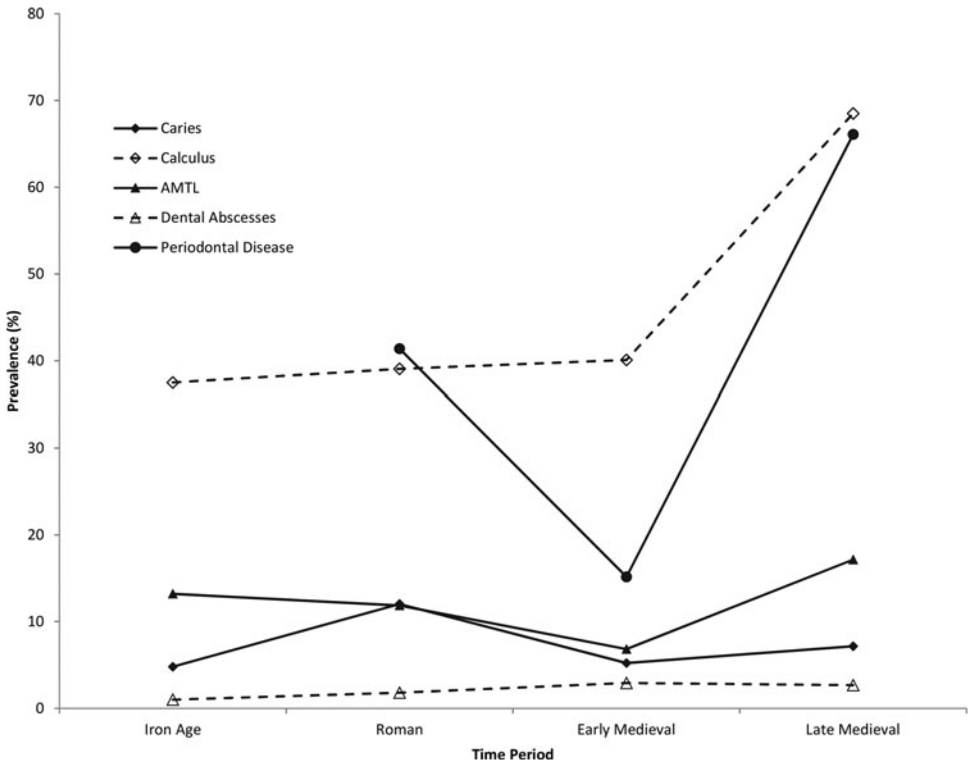

Figure 4. *Prevalences of oral pathologies in urban settlements from the Iron Age to the late medieval period (per cent). Figures are true prevalence rates for ante-mortem tooth loss, caries, and dental abscesses, and crude prevalence rates for calculus and periodontal disease.*

more diverse diet with a higher proportion of meat. This is consistent with the similarity in the diets of urban and rural populations observed in stable isotope data from this period (Mays & Beavan, 2012). However, the analysis of crude prevalence rates for calculus cannot capture potential variations in the severity of calculus, which would provide more nuanced information on oral health and diet at this time. Further detailed analysis of patterns in calculus severity may therefore help elucidate patterns in diet and oral health between urban and rural sites in the early medieval period.

The evidence for oral health in early medieval continental Europe is much more mixed, with some regions showing an increase in dental disease (Manzi et al., 1999; Slaus et al., 2011), but others showing a decrease at this time (e.g. Belcastro et al., 2007). This variation appears to be due to the differing impact of the dissolution of the Roman Empire. In areas where oral health declines at this time, it has been suggested that this is due to the decreased availability of meat in settlements that had become economically more isolated, particularly in regions which had previously benefited from incorporation into the wider Roman economy. However in regions like Britain, which were net producers of food during the Roman period, separation from the Roman economy is likely to have increased the availability of meat, which would be consistent with the improvements in oral health observed here.

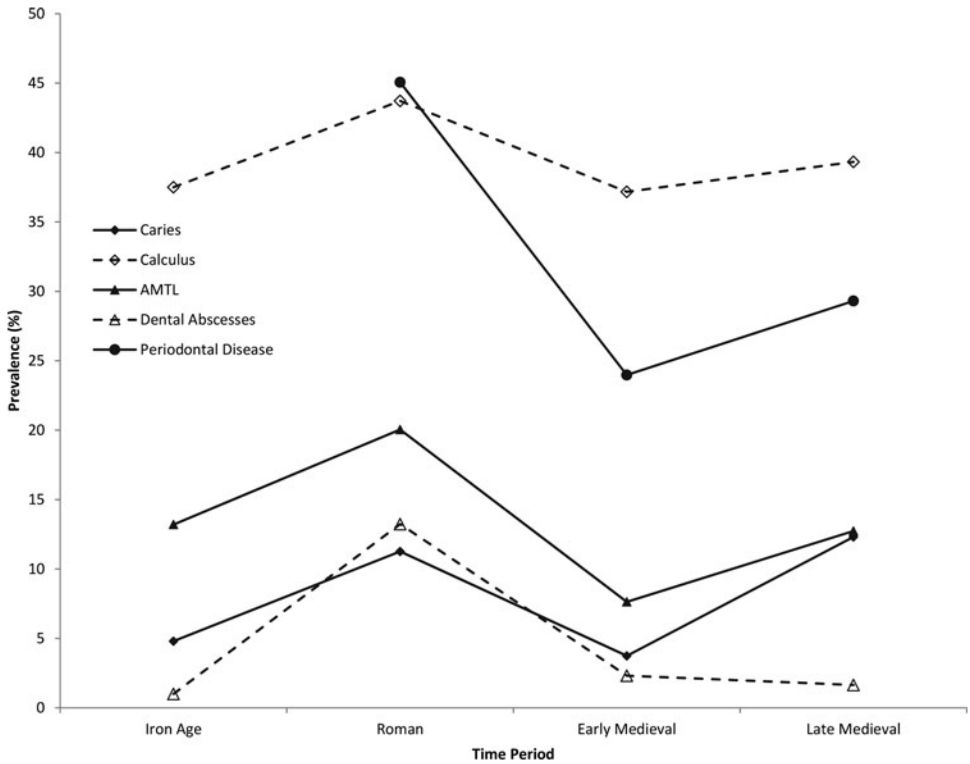

Figure 5. *Prevalences of oral pathologies in rural settlements from the Iron Age to the late medieval period (per cent). Figures are true prevalence rates for ante-mortem tooth loss, caries, and dental abscesses, and crude prevalence rates for calculus and periodontal disease.*

By contrast, the rate of oral pathologies in both urban and rural communities generally increases in the late medieval period, with most conditions increasing more markedly in the urban population, with the exception of caries where the increase is greater in rural populations. While other studies have observed decreasing rates of caries (Watt et al., 1997) and periodontal disease (Gonçalves et al., 2015) at specific sites at this time, the present study found evidence for worsening oral health across a wide range of sites and oral pathologies. This was particularly evident when data from urban and rural settlements were considered separately, with different patterns in dental disease observed within these two settlement types across the period under consideration. The higher rates of oral disease in urban populations are likely to have been strongly influenced by the higher proportion of older individuals in urban sites relative to rural settlements. In particular, this urban age profile may be contributing to the much greater increase in rates of periodontal disease and AMTL relative to caries. Periodontal disease and AMTL are both more strongly associated with age than caries, and are therefore likely to be more common in populations with a higher proportion of older individuals. In addition, the presence of rising levels of AMTL is likely to have had an impact on observable caries levels, as teeth lost ante-mortem as a result of caries will no longer be visible in the archaeological record, potentially reducing the apparent rate of caries in that population. The age distribution of the sites, however, does not appear to be the only factor influencing dental disease prevalence in these populations. After taking into account the different age and sex distributions, urban and intermediate sites were found to have a significantly higher rate of periodontal disease than rural sites. This suggests that the higher number of older individuals at urban sites is not the sole cause of the higher rates of oral disease in urban settlements.

While sugar became increasingly available in the later Middle Ages, it is unlikely that this is the primary cause of the increase in oral pathologies, given that the observed rate of caries is greater at rural sites, and not at urban sites where sugar is likely to have been more plentiful. During this period, towns grew in significance, as central places for the economic activity of both rural and urban populations, although substantial amounts of trade were still conducted away from towns, to avoid the regulatory requirements and tolls associated with many urban markets (Palliser, 2000). Meat and other produce was in high demand, and often had to be imported to the towns from further afield (Astill, 1983), which may have led to a greater reliance on cereals as the mainstay of the diet of the urban poor. Furthermore, this period is characterized by a high level of inequality within urban settlements. It is thus likely that urban elites were able to consume a greater proportion of the available meat than the urban poor, although rates of meat consumption appear to increase generally in the latter part of the Middle Ages (Dyer, 1998). It is also possible that the consumption of dairy products was higher among elite groups. As these would have only made up a small proportion of the overall urban population, it is likely that the overall oral health status of each cemetery population reflects more closely the health of the non-elite, except where there is evidence for bias towards more affluent burials within a given cemetery. It therefore seems likely that the generally poorer oral health observed in urban cemetery populations at this time reflects a tendency for greater longevity in urban sites as well as a greater reliance on cereals in the diet of the urban poor.

In addition to potential differences in diet between urban and rural settlements, ease of access to dental treatment is likely to have also affected oral health. Dental practitioners are likely to have been more common in urban settlements, and access to such treatment outside urban centres potentially more limited. In late medieval towns, often only the most affluent citizens would have been able to afford dental treatment (Anderson, 2004b), limiting the benefits of such greater access to dental care to a narrow group within each community. This may have contributed to the high rates of most oral pathologies in urban sites in the later Middle Ages. By contrast, it has been suggested that in Late Roman towns in Britain a higher proportion of the population was made up of elite groups (Perring, 1991). It is possible that the lower rates of dental pathology in Roman urban populations are due to the greater relative affluence of those living in towns, with a larger proportion of the urban population able to afford dental treatment than in later periods. However, given the limited range of dental treatments available in Roman and medieval Britain (Anderson, 2004a, 2004b), it is unclear how significant the impact of such treatment would have been on overall rates of oral health.

The presence of monastic settlements among the sites included in the study, both in urban and rural settings, constitutes an additional factor that needs to be considered for the early and late medieval periods. Monastic settlements would have

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contained concentrations of individuals of higher status, who may have consumed greater amounts of meat than their less affluent contemporaries, and therefore would exhibit lower levels of dental disease. A comparison of health indicators in cemeteries associated with monastic orders with data from non-monastic settlements showed no significant difference in oral health between the two groups in either period (the p value range is 0.243–0.737 for the early medieval, 0.096–0.599 for the late medieval after taking into account the age and sex composition of each site). Although the number of monastic sites included in this study is small, this suggests that the diet of the monastic communities and that of the general populace were not substantially different, perhaps reflecting the fact that monastic settlements would also have contained significant numbers of servants and other lay people drawn from the non-aristocratic population. Such a finding is consistent with the evidence from isotopic studies (Müldner & Richards, 2007a). However, DeWitte et al. (2013) have found lower levels of mortality in monastic communities compared to non-monastic populations. It is therefore possible that the higher mortality of non-monastic populations is masking differences in oral health between these two groups, although no significant difference in age composition was observed between the monastic and non-monastic sites included in the present study. However, the absence of any observable difference in oral health between monastic and non-monastic cemeteries suggests that treating monastic settlements separately is unnecessary when examining the impact of place of residence on oral health.

The possibility that immigration, which could have influenced the patterns in oral health observed, took place between urban and rural areas constitutes a further potential limitation to this study. While there is considerable evidence for immigration from the countryside into the towns from the late medieval period, with 'the majority of residents [being] … newcomers' (Kermode, 2000: 458), it is difficult to ascertain what impact this had on health, as immigrants often cannot be readily identified from the archaeological record. In addition, many rural estates were associated with houses located in a nearby urban settlement (Hinton, 2000), suggesting regular movement between rural and urban contexts for the purposes of trade. Further isotopic studies of immigration patterns within medieval Britain may help elucidate the impact of migration on oral health at this time. Recent work by Eckardt (2010) has also provided evidence for a significant presence of migrants within Romano-British urban settlements. While this would have influenced the food consumed in Roman towns, with migrants potentially bringing dietary practices from their homeland to Britain, the isotopic evidence indicates that the majority of migrants adopted local foodways (Eckardt et al., 2014). It therefore seems unlikely that the presence of migrants would have significantly affected the overall oral health within urban settlements in Romano-British times.

The results may also have been influenced by the type of prevalence rate selected for each analysis. The crude prevalence rates used may have been affected by the absence of teeth or jaws from some individuals at a given site, while the true prevalence rates may be unrepresentative of the prevalence within the whole population if the teeth and jaws of some individuals were better preserved than those of other individuals at that site. Be that as it may, the trends observed do not appear to show any patterns with respect to the type of prevalence rate used, with both crude and true prevalence rates showing similar results. It therefore seems likely that the trends observed are not strongly affected by the prevalence rate selected for each condition. It is also possible that the skeletal collections included here are not representative of the whole population at each site. However, the trends in oral health observed across multiple sites from each site type in each period suggest that any potential bias within individual sites is unlikely to be significantly influencing the overall results.

The inclusion in the datasets of each period of sites that were not occupied simultaneously may also have influenced the results obtained. If differences in oral health were present over time within a given period, this would make it more difficult to ascertain overall patterns in health within that period. Likewise, if the number of urban settlements varied with time, it may also be difficult to separate the impact of temporal changes in oral health from changes associated with settlement type. However, no such trend in site type was noted in any of the periods considered here. It therefore seems unlikely that this had a significant impact on the results obtained. It is also possible that the focus of this study on overall trends over a wide geographical area masks regional differences in health; indeed there is evidence from Roman Dorset that rates of dental disease were higher in urban sites there (Redfern et al., 2015). Further work on the influence of place of residence on oral health at the local level is needed to fully understand the implications of the broader patterns observed here.

Conclusion

The findings of this study indicate that place of residence may have had a significant impact on oral health in Roman and medieval Britain. While the same overall trends in oral health are visible in both urban and rural populations across this time span, the extent to which these communities were affected differed: the rural populations were more strongly affected by the increase in oral disease in the Roman period, and the late medieval urban populations were affected by increasing oral pathologies to a greater extent than their rural counterparts. These patterns appear to reflect changes in diet associated with the changing economic relationship between urban and rural settlements. However, it is likely that the effects of such overall changes would have been experienced differently at the regional level, depending on the nature of the economic and social ties between a given town and its rural hinterland. It is hoped that this study will provide a stimulus for further investigation into disparities in oral health in town and country at a regional level and contribute to a better understanding of the changes that affected the population of Roman and medieval Britain.

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Biographical Notes

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Urbanisation, évolution de l'économie et santé bucco-dentaire en Grande-Bretagne à l'époque romaine et médiévale

L'étude de la santé bucco-dentaire des populations d'époque moderne a révélé des inégalités entre les populations urbaines et rurales mais jusqu'à présent l'influence du milieu sur la santé dentaire de populations provenant de contextes archéologiques n'a reçu que peu d'attention. L'étude méta-analytique présentée ici se base sur des données paléo-pathologiques et a pour but de déterminer les rapports entre le lieu de résidence et la santé bucco-dentaire en Grande-Bretagne au cours de l'époque romaine et pendent le haut et le bas Moyen âge. Cette étude consiste en un examen diachronique des données publiées concernant la perte des dents avant décès, le tartre, les caries, les abcès dentaires et les maladies parodontales relevés dans les nécropoles et cimetières en milieux urbains et ruraux. Il en ressort que le lieu de résidence a eu un effet sur la santé bucco-dentaire à l'époque romaine ainsi que pendant le Moyen âge : la santé dentaire des populations urbaines romaines était meilleure que celle des communautés rurales contemporaines ; par contre ces populations urbaines souffraient plus au bas Moyen âge. Ces résultats reflètent probablement des transformations plus profondes dans la nature de l'habitat urbain et dans les relations que les villes entretenaient avec leur arrière-pays rural au cours des âges. Translation by Madeleine Hummler

Mots-clés: santé bucco-dentaire, paléo-pathologie, milieu urbain, milieu rural, économie, Grande-Bretagne

Urbanisierung, Wirtschaftswandel und Zahngesundheit im römischen und mittelalterlichen Großbritannien

Studien von modernen Bevölkerungen haben gezeigt, dass es Ungleichheiten in der Zahngesundheit von städtischen und ländlichen Gesellschaften gibt, aber der Einfluss des Wohnortes auf die Zahngesundheit von archäologisch dokumentierten Gemeinschaften hat bisher wenig Aufmerksamkeit erregt. In der *vorgelegten Meta-Analyse werden paläopathologische Angaben ausgewertet, um die Beziehungen zwischen Wohnort und Zahngesundheit im römischen, früh- und spätmittelalterlichen Großbritannien zu untersuchen. Die veröffentlichten Daten, die prämortaler Zahnausfall, Zahnstein, Karies, Abszesse und parodontale Krankheiten dokumentieren, wurden von Gräberfeldern und Friedhöfen in städtischen und ländlichen Bereichen in den verschiedenen Zeitabschnitten ausgewertet. Es ergibt sich, dass der Wohnort die Zahngesundheit in der Römerzeit und im Spätmittelalter tatsächlich beeinflusste: Die römischen Stadtbewohner hatten bessere Zähne als ihre ländlichen Zeitgenossen, aber im Spätmittelalter war die Zahngesundheit in den Städten schlechter als auf dem Lande. Diese Ergebnisse weisen wahrscheinlich auf zeitliche Entwicklungen im Städtewesen und in dessen Beziehungen zu seinem ländlichen Hinterland hin.* Translation by Madeleine Hummler

Stichworte: Zahngesundheit, Paläopathologie, Stadtbereich, Landumgebung, Wirtschaft, Großbritannien