Exploring the Relationship Between Dental Wear and Status in Late Medieval Subadults From England

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ABSTRACT Dental wear patterns were recorded on 458 deciduous molar teeth, of 142 subadults from late medieval (AD 1086–1539) England, to explore the relationship between dental wear and burial status of children. A new ordinal method for scoring dental wear stages on the deciduous molar teeth was devised. It was postulated that if a discernible relationship between dental wear stage and burial location could be seen then this could reflect a difference in diet between those receiving higher or lower status burial. The dental wear stages recorded were statistically similar for the dentitions of subadults from different cemeteries, as well as from different burial locations, indicating a comparable diet for the children studied. Am J Phys Anthropol 150:433–441, 2013. ©2013 Wiley Periodicals, Inc.

The analysis of rates of dental wear on the permanent dentition has been used as a way of aging adult skeletons (Murphy, 1959; Miles, 1963; Scott, 1979; Brothwell, 1981; Dreier, 1994) and as a means of interpreting diet and status for many decades (Molnar, 1971; Gilbert and Mielke, 1985). There are, however, no standard charts in the literature for recording wear on the deciduous teeth. The aims of this research were therefore to formulate a chart for recording this wear and to determine whether dental wear on the deciduous dentition has any relation to status.

The deciduous teeth begin to form at about 6 weeks in utero (Scheuer and Black, 2000: 148) with the lower first deciduous molar (dm1) commencing mineralization at 14.5–17 weeks and the lower second deciduous molar (dm2) at 16–23.5 weeks gestation. At birth the occlusal surface of dm1 is complete and the cusps of the forming enamel crown are joined to form a ring for dm2 (Lunt and Law, 1974). By 3 years of age the deciduous dentition is fully formed with the timing of emergence occurring between 14–18 months for dm1 and 23–31 months for dm2 (Scheuer and Black, 2000: 151–153). The enamel on the deciduous teeth tends to be thinner than that of the permanent dentition (Hillson, 1996: 148) suggesting that exposure of the dentin will occur at a faster rate than in the permanent teeth. It is for this reason that the use of recording methods designed for the permanent teeth may be inadequate when analyzing the deciduous dentition.

No published research appears to have been carried out to assess the possibility of using analysis of the dental wear on the deciduous teeth to explore the link between diet and status of children in the medieval period. Status, in this context, is defined in relation to the location in which a child was buried. Burial location will reflect both the social status of a child in general within society, and the wealth that those paying the burial cost (probably family members) had access to (Gilchrist and Sloane, 2005). Location of burial may be an important indicator of status with certain areas located within the church and cemetery being more desirable. Daniell (1997: 95) describes the late medieval church as a series of concentric rings of spiritual importance. The most holy area is the high altar at the east end of the church, the holiness lessening to the west end and out into the cemetery. All the consecrated ground would have been enclosed within the boundaries of the cemetery. In monastic complexes, intramural burials (within the church buildings) would have been reserved for those of the religious orders (usually closest to the east end), or to those able to afford such a privilege, with lay burial more usual away from the high altar.

Dental wear rates may be suggestive of different diets as the mastication of coarser foods will cause quicker rates of wear (Powell, 1985). Soft textured material such as refined foods and cooked meats create less dental wear than a diet high in grains (Papathanasiou, 2005), and these types of food would be more likely to be consumed by those of higher status in the late medieval period (Stone, 2006: 11; Woolgar et al., 2006: 273). This suggests that dental wear can be used to explore the status of individuals. In the past a coarse diet, along with inclusions such as small particles of grit in foodstuffs, caused significant dental wear, the patterns of which are easily recordable. The term "wear" includes both attrition, caused by direct tooth on tooth contact, and abrasion, caused by the contact of the tooth with an abrasive substance (Powell, 1985: 308). Wear is therefore possible as soon as the opposing teeth have erupted and are in occlusion in the jaw, regardless of the type of foodstuffs being consumed. Dental wear mainly occurs on the

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occlusal surface of the tooth, thereby making the molar teeth the most appropriate for which to record changes due to the larger surface area. Once a tooth has erupted and is in occlusion the processes of wear will commence. Initially, small planes or facets will appear on the tooth enamel as the cusp tips are worn; a flattening of the cusps subsequently occurs. Once the cusps have flattened, the enamel of the tooth will begin to wear exposing the dentin underneath. This process of enamel wear will continue over time until all the enamel of the tooth is worn away. Other authors have suggested that the rate of wear should be similar for individuals from the same population or environment if they are consuming a similar diet (Mays, 1998: 60; Roberts, 2009: 133).

The main measure of tooth wear in the clinical literature is based on the Tooth Wear Index of Smith and Knight (1984). However, methods are constantly being tested and revised (Al-Malik et al., 2001; Fares et al., 2009). In the modern world tooth erosion due to acidic foods (Millward et al., 1994) tends to be more of a problem than wear caused by abrasive foods, with secondary dentin exposure being uncommon in the deciduous teeth (Al-Malik et al., 2001). Socio-economic status has been found to have some positive correlation with permanent tooth wear in adolescents from an English living sample (Milosevic et al., 1994), although this was not seen in a similar sample of adults (Donachie and Walls, 1995). Males have been recorded as having higher mean wear scores in both young adult (Fares et al., 2009) and old adult samples (Donachie and Walls, 1995).

For most archaeological populations dental wear is seen to be much more severe than modern populations. Correlations between cultural factors, such as diet and food preparation techniques, and dental wear have been noted by numerous archaeological researchers (Molnar, 1971; Smith, 1972; Walker, 1978; Dreier, 1994), and several different dental wear charts have been formulated over the last 50 years for use with archaeological material (Murphy, 1959; Miles, 1963; Molnar, 1971; Scott, 1979; Brothwell, 1981; Dreier, 1994), mainly for use on adult dentitions. To be able to use these charts as a comparison across populations, it must be assumed that methods of food production, consumption and dental use are similar to those of the population originally studied in the formation of the chart. More recently Clement (2007) has used graphics software to take measurements of the area of exposed dentin, enabling continuous (as opposed to ordinal) data to be assigned to each tooth as a reflection of the area of wear.

Very little research appears to have been carried out on wear on the deciduous teeth with the exception of Bullington (1991), Skinner (1997), Prowse et al. (2008), and Clement and Freyne (2012). Bullington (1991) recorded microwear on the deciduous teeth of infants aged between 6 and 27 months from two prehistoric American groups (horticultural Middle Woodland period and the Mississippian agricultural period) using scanning electron microscopy. Although the age of onset of wear was similar between the groups she concluded that diets differed for the older and younger infants of both samples, and that the difference between the two groups indicated a harder diet in the Middle Woodland period.

Skinner (1997) recorded wear on the deciduous dentitions of European Middle and Upper Palaeolithic infants to determine if there were different weaning practices between the two populations. He used a series of wear stages to try and assess at what age infants began receiving dietary supplementation. From his results he concluded that the Upper Palaeolithic children were being moved onto solid foods sooner than those of the Middle Palaeolithic.

Prowse et al's. (2008) study utilized both isotopic and deciduous dental wear evidence to explore the feeding practices of infants and young children from the first to the third century in Rome. Both types of evidence complemented each other in suggesting that transitional feeding began by the end of the first year and that weaning occurred around the age of 2 years.

Clement and Freyne (2012) examined the dental wear patterns of 37 subadult individuals from Sudan using the quantitive method devised by Clement (2007). They concentrated on determining the pattern of wear seen for each tooth in relation to the whole dentition. They concluded that the anterior teeth were exposed to heavier amounts of wear during the first years of life and suggest that, while this may suggest early weaning practices, ceramic bottles and teething implements may be a contributing factor.

Richards et al.'s (2002) study of the isotope values of bone from the subadults from the medieval cemetery of Wharram Percy, Yorkshire found evidence that children between the ages of four and eight had a diet containing fewer animal products than older children. If this diet contained a larger proportion of coarsely ground grains then we may expect to see faster rates of dental wear occurring before the age of 8 years in this sample. This suggests that the relationship between dental wear and age at death is worth exploring and may contribute to an understanding of changes in diet related to age, something that may in turn be related to status. In the late medieval period, some children may have begun work apprenticeships from as early as 7 years of age (Fleming, 2001: 64). It could be that once in employment children were seen to require higher quality foods.

MATERIALS AND METHODS

All the dentitions analyzed for this study come from three medieval monastic cemetery sites from the south of England: the priory of SS Peter and Paul, Taunton, Somerset; the priory of St Oswald, Gloucester, Gloucestershire; and the priory of St Gregory, Canterbury, Kent (Fig. 1). The priory at Taunton was founded in the mid-12th century, and while there is no historical record of the lay cemetery until AD 1349 (Hugo, 1860) the archaeological evidence suggests a cemetery was in use before this time (Dawson, 2011: 113). The cemetery at the priory would have initially been used by all the parishioners of Taunton as it was the only consecrated cemetery in the area until AD 1446, when a cemetery at St Mary Magdalene church was provided. The two other sites were chosen, for comparison, as they are also composed of lay cemeteries attached to Augustinian priories with a likely mix of society buried within them. Like SS Peter and Paul's, St Oswald's was located on the outskirts of a town and was associated with a large parish including the less wealthy inhabitants of Gloucester (Schofield and Vince, 2003: 66). St Oswald's priory was founded in the mid-12th century and most of the burials analyzed for this study are from the early period around its foundation (Heighway and Bryant, 1999). St Gregory's priory was founded in AD 1086, although most of the burials excavated are related to the later period of its use (Hicks and Hicks, 2001). Located on the edge of

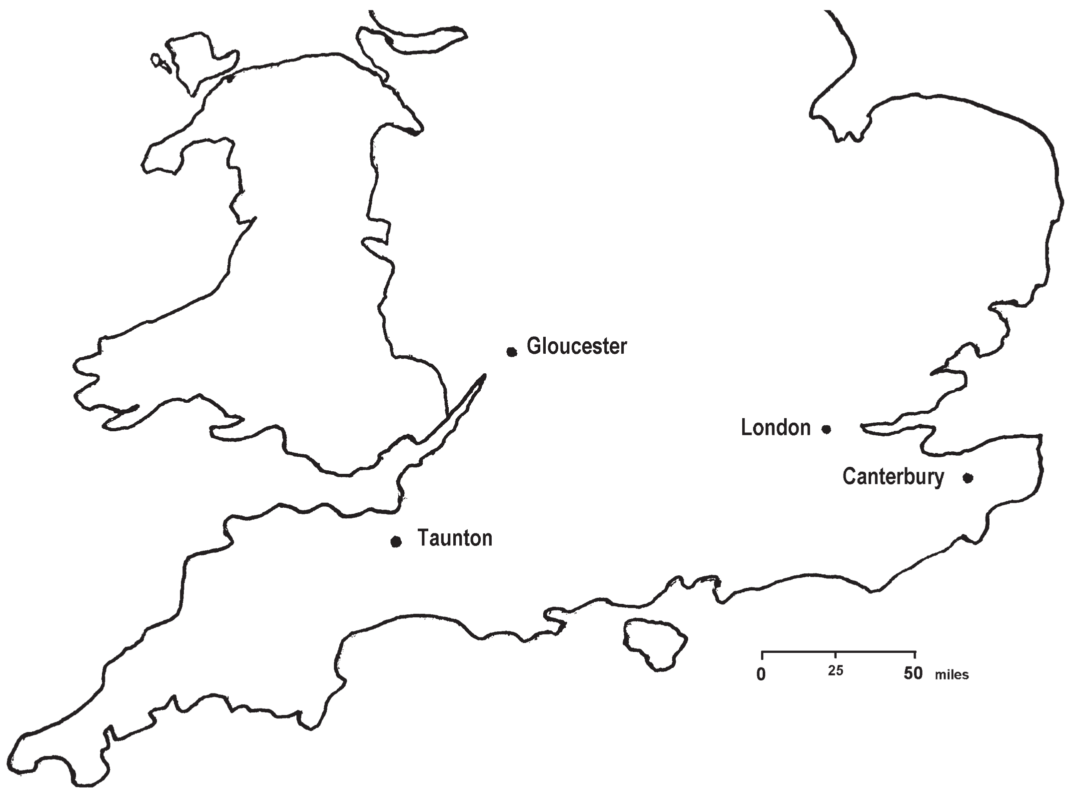

Fig. 1. Map showing location of cemeteries.

town this house was originally founded to administer to the infirm people of St John's hospital and to take care of their burial (Duncombe and Battely, 1785: 420). It also was the local cemetery for the parishioners of Northgate with an "extensive burying ground" (Brent, 1879: 241). Both the cemeteries at Taunton and Canterbury went out of use after the dissolution of monasteries in AD 1539, while the cemetery at St Oswald's continued in use, with the priory being converted into a small parish church (Heighway and Bryant, 1999: 22). The date range of the burials analyzed for this research is AD 1086–1539.

Dental age of each individual was assigned using the charts of Schour and Massler (1941). Each individual was assigned to a dental age in years, these do not signify actual ages but fall within an age range of ±6 months for the younger ages and up to ±24 months for those in the older age ranges. Only the first and second lower deciduous molar teeth (dm1 and dm2) were selected for dental wear analysis. Only the lower teeth were used for this study as some variation has been noted between wear on the upper and lower molars (Brothwell, 1981), with the upper molars tending to wear at a slightly slower rate (Powell, 1985; Prowse et al., 2008); mandibles also tend to preserve better archaeologically than maxillae. Molar teeth tend to be recovered in the jaw of individuals, whereas the anterior teeth often come loose. It was therefore felt that the lower molars would provide the best focus if the results were to be of use for future comparative studies. Four hundred and fifty-eight teeth from 142 individuals were analyzed for dental wear, comprising 216 first deciduous molars and 242 second deciduous molars. One hundred and fifty-four teeth (71 dm1 and 83 dm2) from 46 individuals were recorded from the priory of SS Peter and Paul, Taunton, 77 teeth (38 dm1 and 39 dm2) from 23 individuals from the priory of St Oswald, Gloucester, and 227 teeth (107 dm1 and 120 dm2) from 73 individuals from the priory of St Gregory, Canterbury.

Initially, the stages on a scale of 0–8 as described by Skinner (1997) were recorded, but, it was often the case that the wear pattern appeared to fall between the stages described. Two extra stages were created and a diagrammatic chart devised to enable a more accurate picture of the wear patterns to be recorded. A description of the stages is presented in Table 1, and a depiction of each of these stages is shown in Figure 2. Photographs of dentitions at different stages of wear are presented in Figure 3. Each lower deciduous molar was scored for dental wear, with any molar teeth badly affected by caries being excluded from the analysis.

Intraobserver and interobserver error tests were carried out by selecting 30 dentitions at random, from the 46 dentitions available from the Taunton skeletal collection, that had one or more deciduous molars present. The first named author scored dental wear at least 1 year after the initial scoring of the teeth, and the second named author scored the dentitions independently using the descriptions and the pictorial chart devised by the first named author. The scores were tested using the linearly weighted Cohen's kappa and the results are presented in Table 2. The strength of agreement between the scores for both the intra and inter observer tests are substantial (0.61–0.80), or in three cases (intra observer tests for Rdm1, Rdm2, and Ldm2) almost perfect (0.81–1.00), based on the criteria of Landis and Koch (1977).

TABLE 1. *Dental wear stage descriptions*

Stage	Description
0	No attrition visible. The teeth are either unerupted or have recently erupted with no sign of wear.
1	Enamel faceting. Attrition is visible as tiny planes or facets which reflect the light.
2	Enamel rounding. The cusps of the molars are slightly rounded and have lost their peaks and angular faceting.
3	Enamel flattening. The cusp tips of the molars are flattened and there is trace or no dentin exposure.
4	Dentin exposure (initial). One or two islands of dentin are exposed usually on one side of the tooth only (buccal).
5	Dentin exposure (middle). Three–five cusps have dentin exposure with islands on both sides of the tooth visible but are still quite small.
6	Dentin exposure (near complete). Dentin islands are visible on all or most cusps and are larger than at stage 5.
7	Dentin exposure (considerable). The dentin islands now resemble diamond shapes or rectangles as more dentin is exposed.
8	Advanced dentin exposure. At this stage there is coalescence of two or more islands of dentin even to the point where enamel is only seen at the center of the occlusal surface.
9	Enamel ring. The occlusal surface of the enamel is worn away leaving only a ring of enamel circumferentially. There may be darkly stained islands of secondary dentin.
10	Root involvement. At this stage the tooth is worn to the root. This stage was not seen in any of the teeth analyzed and it is probably a very rare occurrence for deciduous teeth to wear to this level before being exfoliated naturally.

This suggests the ease of use of this method and therefore its potential future applicability for the comparison of datasets between researchers.

For the analysis of status the location of burial was recorded as those buried within the church buildings or those buried within the cemetery. Statistical analyses were performed using Excel 2002 version 10, SPSS 2007 version 16, and MedCalc version 12.3.0.0.

RESULTS

Descriptive statistics for the dm1 and dm2 wear stages were calculated and data for the combined sites are depicted in Tables 3 and 4. The wear stages of the right and left molars of individual dentitions were analyzed to determine whether there was any significant difference. The wear stage of tooth 69 (Rdm1) was subtracted from that of tooth 62 (Ldm1), and tooth 70 (Rdm2) from tooth 61 (Ldm2). No correlation was seen for either dm1 or dm2 with most teeth being equally scored:

- dm1 by age: Spearman rho −0.136; *N* 86; *P*-value 0.213;
- dm2 by age: Spearman rho −0.049; *N* 106; *P*-value 0.617.

For dm1, the number of teeth equally scored was 64 (74.4%), those with a difference of one stage 20 (23.2%), of two stages 1 (1.2%), and of three stages 1 (1.2%). For dm2, the number of teeth equally scored was 75 (70.8%), those with a difference of one stage 28 (26.5%), of two stages 2 (1.8%), and of three stages 1 (0.9%). As the teeth from opposite sides of the dentition appear to be scored equally it is valid to use a tooth from either side as the wear stage attained. Where possible the left sided teeth have been used to define the wear stage for each individual for statistical purposes (if the left side was absent the right side has been used).

Initially, the data were tested using a Kolmogorov-Smirnov test on both age and wear stage to determine if the data were normally distributed. As the data were not normally distributed a series of nonparametric tests were used for the statistical analysis. First, the data were tested to see whether there was any significant difference in dental age by site, using a Kruskal Wallis test. Dental wear is strongly correlated to age, so any difference in the demography of each site could lead to a false significant difference if all wear stages were tested by site alone. No significance difference was seen in the age distribution between sites (dm1: chi square 1.776, df 2, p 0.411; dm2: chi square 3.287, df 2, p 0.193). Each site was then tested by wear stage to determine if the rate of wear from each cemetery analyzed was similar. No significant difference was seen for the wear stages assigned for dm1 (chi-square 1.935, df 2, p 0.380) but a significant difference was seen for dm2 (chi square 6.616, df 2, p 0.037). However, when using the Kruskal Wallis test to make multiple comparisons there is an increased risk of obtaining false significant results (Pallant, 2005: 200). The Bonferroni adjustment [$(n*(n-1))/2$ where n = the number of comparisons] was therefore applied reducing the significance value from 0.05 to 0.017. The three pairwise comparisons were then undertaken separately using the Mann–Whitney U test. No significant results were obtained suggesting that the wear stages obtained from the three sites are not significantly different.

The data indicate that, although dental wear increases with age, the amount of wear recorded on individuals from within each age category will differ. This can be seen in the range of wear stages recorded for dental age (Figs. 4 and 5). By analyzing the mean stages, the first molar seems to pass through stages at quite a regular rate. However, this is not so clear for the second molar where towards the older age ranges there are more 8-year-olds with higher wear stages than those aged to 9 years. This is likely to be a problem with the small numbers of teeth from these age categories; also analyzing the data by yearly age increments will undoubtedly mean that some children may be in the wrong age category, due to the slight timing differences in eruption and formation between males and females (Garn et al., 1958).

The amount of wear recorded appears to increase fairly steadily between 2 and 7 years of age but then flattens off, with wear stages between the ages of 8 and 10 becoming more similar as the deciduous teeth come towards the end of their period of use. The first permanent molar will erupt around the age of 6 years and this appears to have an effect on how the deciduous teeth are worn. It is likely that the larger surface of the permanent molar will be involved more in the mastication process from this time than the smaller deciduous molars. One individual from Gloucester still had a second deciduous molar retained at age 12 (SK 2), and this tooth scored stage 8 wear. This may suggest that the higher wear stage 9 is probably rarely reached even when the molars have been retained in the jaw for the longest possible time.

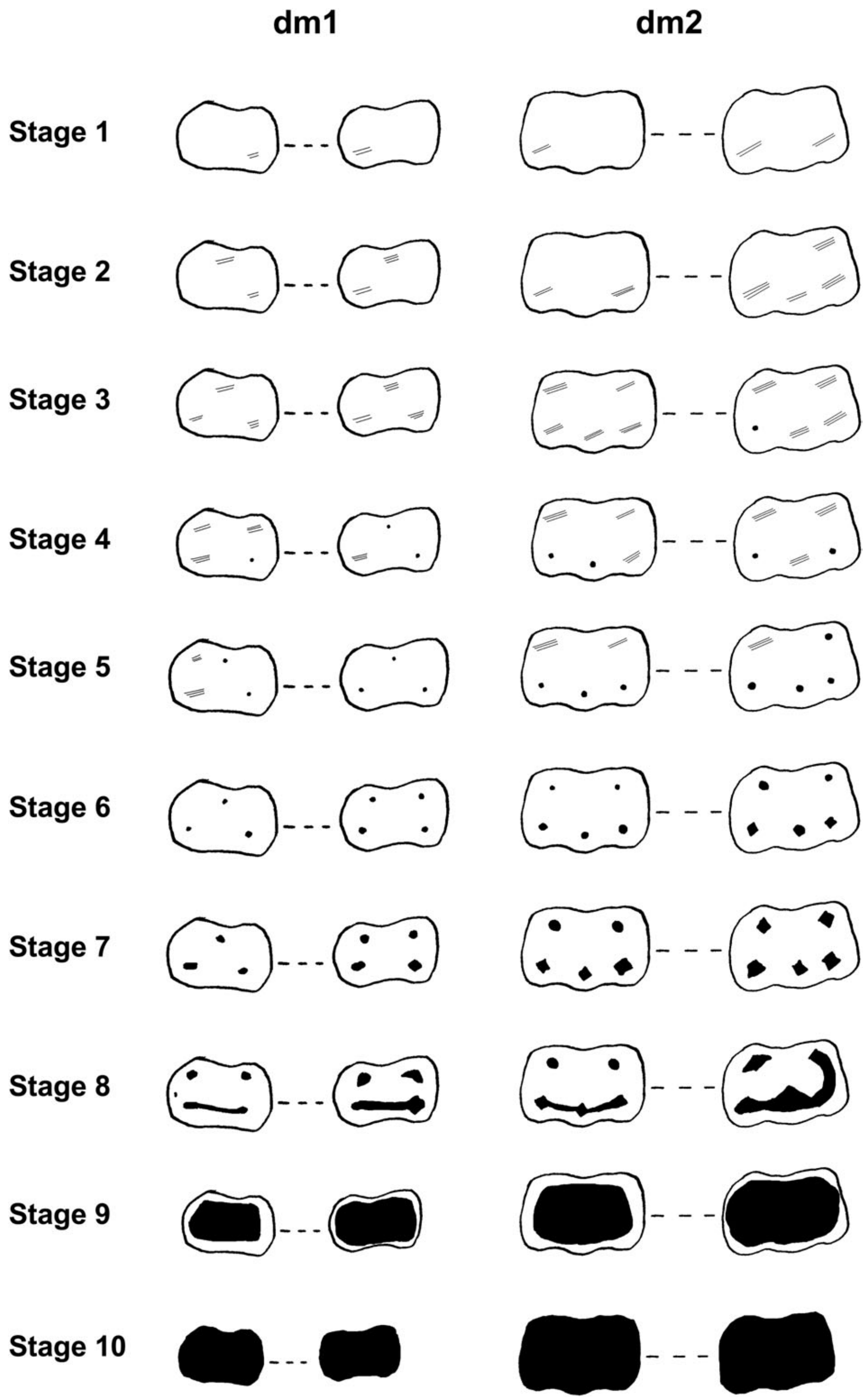

Fig. 2. Dental wear stages: dm1 = first deciduous molar; dm2 = second deciduous molar. On the diagrams white = no wear; hatching = enamel wear; dark = dentin. Two diagrams are depicted for each tooth at each stage; the left side diagram shows the least amount of wear recorded and the right side the greatest amount of wear recorded. No diagram is shown for stage 0, as at this point there is no wear present, and no dentitions analyzed for this study reached stage 10.

Relationship between dental wear stage and burial status

A Mann–Whitney U test was performed to see if there was any difference between burial location and dental wear, the suggested hypothesis being that only high status individuals would be buried within the church buildings and may therefore show less dental wear due to a softer diet. No significance difference was seen when the data from the three sites were pooled together (Z

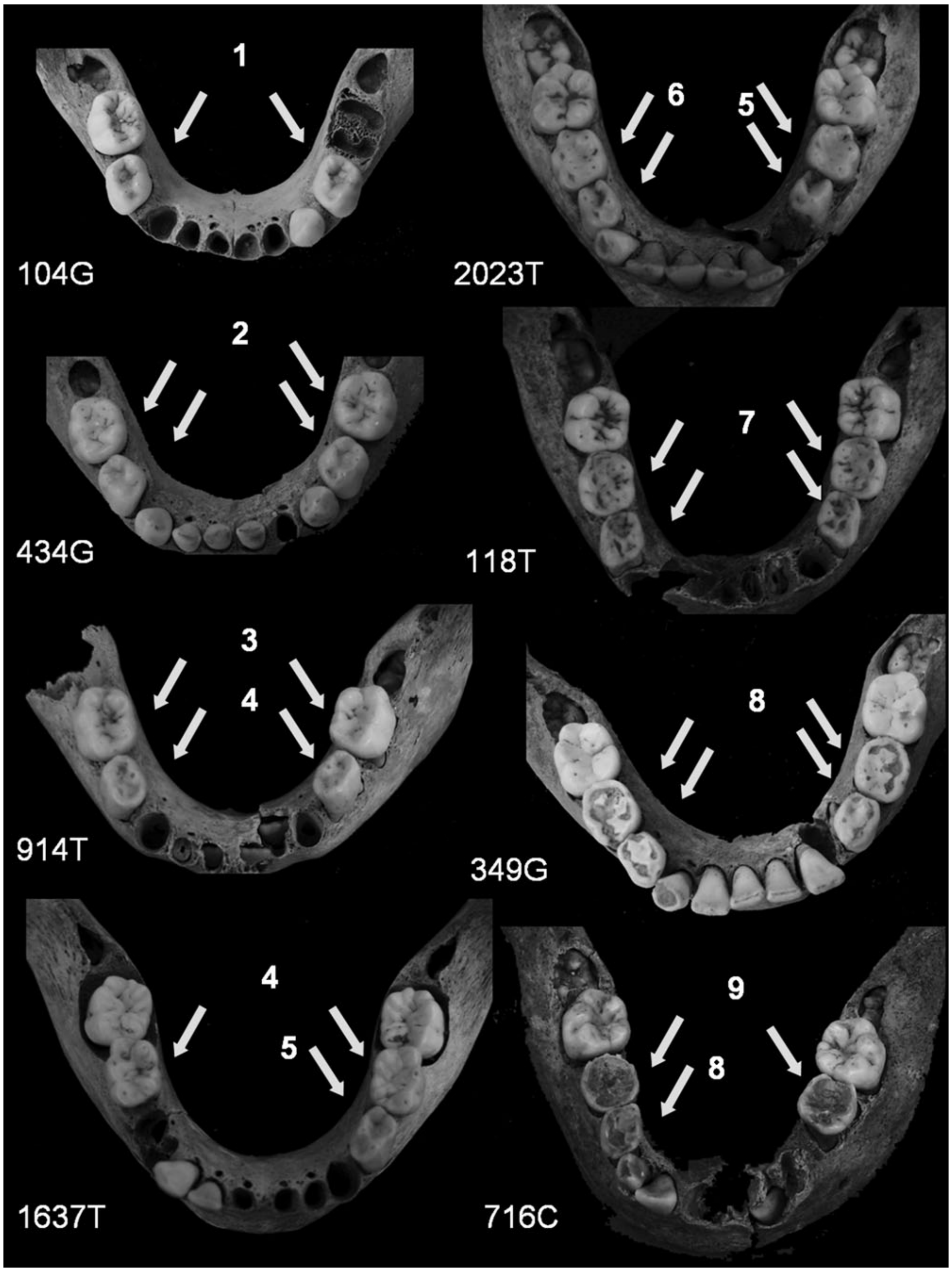

Fig. 3. Dental wear stages: the central numbers indicate the wear stage recorded with the arrow pointing to the associated tooth. The numbers in the lower hand corners are the skeleton numbers T = SS Peter and Paul, Taunton; G = St Oswald, Gloucester; C = St Gregory, Canterbury.

TABLE 2. Intraobserver and interobserver error results

	Intra observer error			Inter observer error		
Tooth	Kappa	SE	95% CI	Kappa	SE	95% CI
61 (Ldm2)	0.921	0.033	0.856–0.986	0.686	0.053	0.583–0.790
62 (Ldm1)	0.803	0.056	0.694–0.912	0.746	0.065	0.619–0.872
69 (Rdm1)	0.809	0.066	0.679–0.938	0.664	0.063	0.541–0.788
70 (Rdm2)	0.859	0.044	0.773–0.945	0.675	0.077	0.525–0.825

Kappa = weighted kappa; SE = standard error; 95% CI = 95% confidence interval.

TABLE 3. Descriptive statistics of wear stages recorded for dm1 (all sites combined)

Age (years)	N	Median	Mean	St Dev	Min	Max
1	12	1.00	0.92	0.51	0.00	2.00
2	24	2.00	1.83	1.09	1.00	5.00
3	15	4.00	3.47	1.77	1.00	6.00
4	15	4.00	4.00	1.13	2.00	6.00
5	16	5.00	4.81	0.98	3.00	7.00
6	12	5.50	5.25	1.06	4.00	7.00
7	12	6.00	6.25	1.36	4.00	8.00
8	6	6.50	6.67	1.21	5.00	8.00
9	13	7.00	6.62	1.41	4.00	8.00
10	3	7.00	6.67	1.53	5.00	8.00

−0.523, p 0.601). For the church burials $N = 10$ and the mean rank = 62.3, and for the cemetery burials $N = 126$ and the mean rank = 69.0.

Part of the problem when looking at the burials from within the church is that the numbers of individuals are very low when compared to the numbers recovered from the graveyards; only 10 individuals, with deciduous molar teeth present, were recovered from the church buildings. This will cause problems in being able accurately to interpret the data. To explore the significance of burial status in relation to dental wear in further detail in the future, sites which contain a much higher number of intramural subadult burials would need to be explored.

TABLE 4. Descriptive statistics of wear stages recorded for dm2 (all sites combined)

Age (years)	N	Median	Mean	St Dev	Min	Max
1	9	0.00	0.00	0.00	0.00	0.00
2	25	1.00	1.12	0.83	0.00	3.00
3	14	3.00	2.79	1.48	1.00	5.00
4	15	3.00	3.60	1.12	2.00	5.00
5	16	5.00	4.31	0.95	3.00	6.00
6	13	5.00	4.92	0.76	4.00	6.00
7	12	6.00	6.00	1.35	5.00	9.00
8	7	7.00	6.71	1.38	5.00	8.00
9	14	6.00	6.00	0.96	4.00	7.00
10	8	7.00	6.63	1.06	5.00	8.00

DISCUSSION

The recording of wear on the deciduous teeth is something that is rarely performed. Clement and Freyne (2012) have stated the need for an ordinal based system to be devised to allow the wear on deciduous teeth to be recorded consistently and rapidly for large collections. The morphology of the deciduous dentition is different to that of the permanent dentition and therefore the method provided here could be used as a new standard

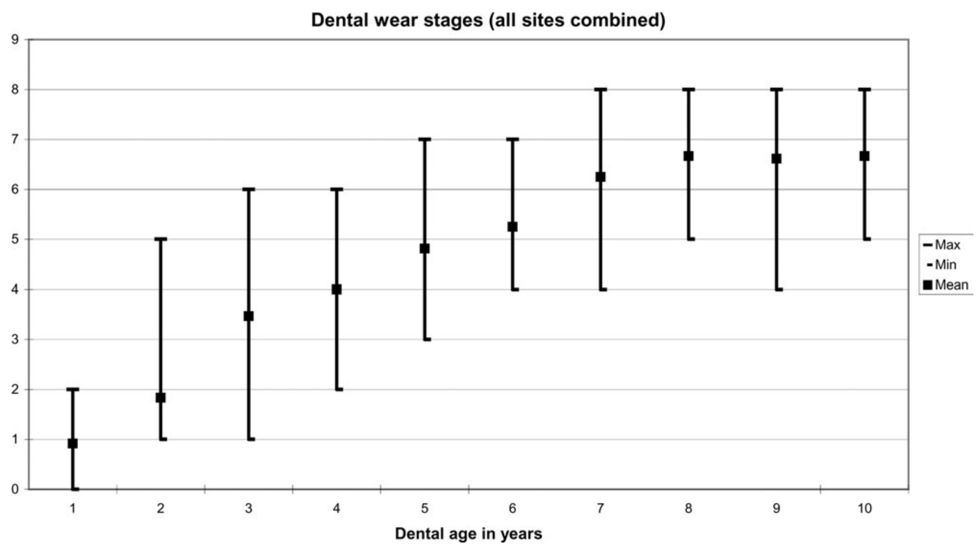

Fig. 4. Mean wear stages and range for all the sites combined (dm1).

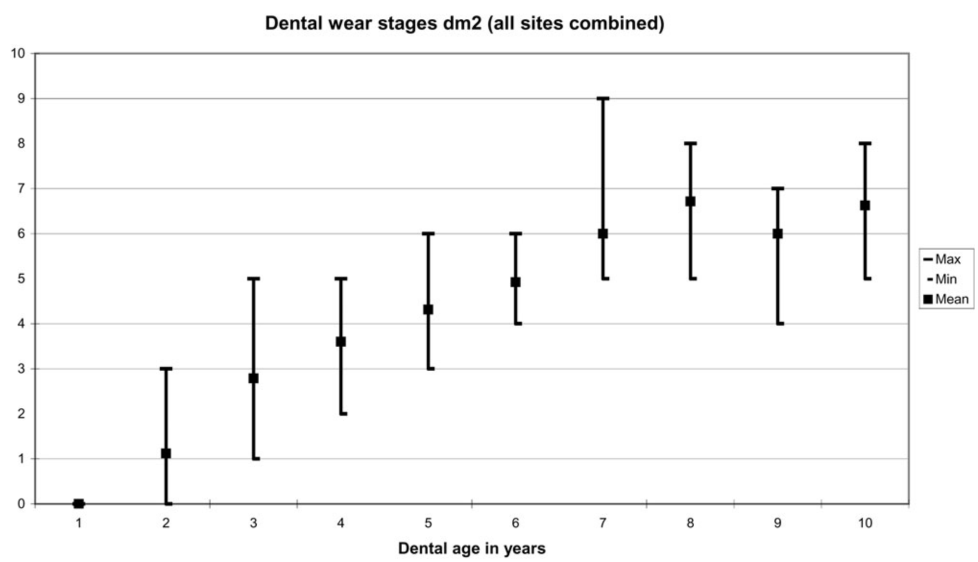

Fig. 5. Mean wear stages and range for all the sites combined (dm2).

to enable the comparison of data collected by researchers in the future. The good correlation shown between wear stage assigned from the intra and inter observer error tests suggests that this could be a useful method for researchers to use and suitable for the collation of comparison data.

In the case study presented deciduous dental wear was explored as a method for determining possible dietary differences associated with different cemetery sites and individuals of differing burial status. The deciduous molars from the dentitions of the late medieval children analyzed appeared to show similar stages of wear across sites, perhaps indicating similar diets. Comparable stages of wear were also seen for individuals whether they were buried within the church buildings or the cemetery, indicating that diets may have been similar for children regardless of burial status.

Although there are many advantages of using an ordinal method for recording dental wear there are also limitations. This method will be useful for recording the details of wear on deciduous teeth in a consistent way which is quick and easy to follow. However, by using an ordinal as opposed to a continuous scale, such as that utilized by Clement and Freyne (2012) the area of actual enamel removal cannot be deduced making it difficult to comment on the rates of wear on deciduous teeth over time. The reduction in dentin over time is also something that is neglected by this method but may be an important area for research in populations which experience heavy dental wear. Utilizing this method alongside the recording of measurements of tooth crown height could allow overall wear of both enamel and dentin to be explored more fully.

Expanding this study to include the analysis of dental wear stages on the permanent first molar for those individuals between the dental ages of 6 and 12 years will be an important avenue for future research, and provide useful comparisons to the wear recorded on the deciduous molars. Analysis of dental wear and crown height has previously been carried out on the first permanent molars of subadult individuals (Mays et al., 1995). This research focused on the use of crown height as an estimator of age at death in human remains, and a strong correlation was observed between these two factors in a Romano-British population.

The wear observed on the deciduous molar teeth allows insight into the abrasiveness of the diet in children too young to have erupted permanent molars, factors neglected if only the permanent teeth of a population are analyzed. This study has demonstrated how the recording and analysis of wear on the deciduous dentition may help to inform us about the diet of subadults in the past and aid us in comparisons of lifestyle factors between those of different social status and from differing populations.

CONCLUSION

This article has endeavored to demonstrate that the dental wear on the deciduous teeth of subadult individuals is a worthy subject for study. The presentation of a chart and the production of photographs for use in recording deciduous dental wear are intended to aid further exploration in this area by other researchers. The results obtained from the data presented have wide implications for the study of subadult remains. The similarity in wear stages recorded on the subadult dentitions, both from across geographical location and burial status, indicates a similar diet may have been provided for children regardless of their status or the community to which they belonged. It is hoped that this research will lead to others considering the potential of recording deciduous dental wear as a matter of course when analyzing subadult remains.

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