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The prevalence of periodontal disease in a Romano-British population c. 200-400 AD

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IN BRIEF

- Describes the prevalence of periodontal and other dental disease in an ancient British population from the examination of dried skulls.
- Estimates that the prevalence of established periodontitis in this population was around 5%, considerably lower than prevalence estimates for modern humans.

RESEARCH

Objective The aim of this study was to investigate the prevalence of moderate to severe periodontitis in an ancient British cohort c. 200-400 AD. **Design** Observational study to assess periodontal and other oral disease parameters. **Setting** Natural History Museum, London. **Subjects and methods** 303 skulls from a Romano-British burial site in Poundbury, Dorset were examined for evidence of dental disease. **Main outcome measures** The primary outcome measure was presence of moderate to severe periodontitis. Secondary outcomes included: amount of horizontal bone loss; prevalence of ante-mortem tooth loss; and presence of other dental pathologies. **Results** The overall prevalence of moderate to severe periodontitis was just greater than 5%. The prevalence rate remained nearly constant between ages 20 to 60, after which it rose to around 10%. The number of affected teeth increased with age. Horizontal bone loss was generally minor. Caries was seen in around 50% of the cohort, and evidence of pulpal and apical pathology was seen in around 25%. **Conclusions** The prevalence of moderate to severe periodontitis was markedly decreased when compared to the prevalence in modern populations, underlining the potential importance of risk factors such as smoking and diabetes in determining susceptibility to progressive periodontitis in modern populations.

INTRODUCTION

Periodontal disease is perhaps the most common disease of humans. It is the result of a chronic inflammatory response to the accumulation of dental plaque. Although the severity of disease is associated with poor oral hygiene, it is now well recognised that despite the ubiquitous nature of plaque and very high prevalence of gingival inflammation, the majority of the population is not affected by progressive chronic periodontitis that is sufficiently severe to result in periodontal morbidity and tooth loss. Thus, the major determinants of susceptibility to moderate-to-severe chronic periodontitis include factors such as tobacco smoking, genetic factors and systemic factors, particularly diabetes mellitus.[1]

Thus, studies of the epidemiology of periodontitis in different populations are useful, not only for determining the prevalence, extent and severity of disease, but also in describing the natural history of the condition and possibly for identifying aetiological factors for the disease. In a landmark study, Loe and co-workers reported the results of examining a group of Sri Lankan tea workers with no access to dental care.[2] Despite the fact that most of this cohort had high levels of plaque, calculus and gingival inflammation, they reported that about 8% of the population had rapid progression of disease (mean loss of attachment 9 mm by age 35), 81% moderate progression (about 4 mm) and 11% were largely free of periodontitis (less than 1 mm attachment loss at age 35). In addition, a comparison with a study by a group of academics from Oslo, Norway showed much reduced overall levels of disease although they were dealing with a similar range of high, moderate and low risk groups.

Current epidemiological studies suggest the prevalence of moderate to severe periodontitis of around 15-30% of most adult human populations, and in some recent studies even higher than this.[3-6] In addition, despite the reported improvements in plaque control and consequent reduction in mild disease, this has not necessarily resulted in similar reductions in the prevalence of severe periodontitis.[7] The reasons for this may be complex and almost certainly partly related to changes in the criteria dentists use for extractions and the effects of an aging population. However, these results also suggest that the aetiology of the condition is not solely related to levels of plaque control.

Hujoel and co-workers have proposed that there has been an epidemic of progressive periodontitis in the twentieth century fueled by tobacco smoking.[8] Smoking may increase the risk of severe periodontitis by a factor of 3-5, and the authors of this study suggest that in the absence of smoking the historical level of progressive periodontitis may have been low.

A number of studies have described the prevalence of periodontal disease in ancient populations.[9-13] Such studies, as well as being of general anthropological and archaeological interest, may also contribute to our understanding of the epidemiology and natural history of the disease. Studies of periodontitis in ancient populations rely on the examination of collections of dried skulls and pose some technical challenges. Firstly, a diagnosis of periodontal disease depends on the estimation of attachment levels from examining the hard tissues only, and thus are not really suitable for the application of standardised case definitions of disease used in current studies, such as those proposed by Page & Eke.[14] In addition simple measures of

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attachment loss from the cemento-enamel junction (CEJ) to the alveolar bone crest cannot reliably be used to estimate attachment loss, owing to extensive passive eruption associated with occlusal attrition.[15-18]

There are sporadic reports of skulls showing signs of periodontal disease dating back to the early hominids. Alveolar bone loss and exposure of furcations have been reported in early hominid remains, the Australopithecines, that lived approximately 2.5-3 million years ago in Southern Africa.[18] It has been reported that a juvenile *Australopithecus africans* might have suffered from a form of periodontitis suggested to be a case of pre-pubertal periodontitis.[19] Pathological loss of alveolar bone has been reported on the jaws of a Neanderthal male from Krapina in the former Yugoslavia. The mandible shows that the individual had suffered extensive alveolar bone loss, though the teeth were only slightly worn and there were no signs of pulpal or other pathology.[20] Evidence on the antiquity of periodontal disease has also been found from examinations on mummified remains in Egypt[21] and writings by the Babylonians, Assyrians and Sumerians as well as the early Chinese.[22] There are, however, wider variations in the reported prevalence of periodontal disease in collections of skulls of different origins, which may vary as much due to the methodologies used to identify the disease as to the different origins of the skulls.

In the study reported here we investigated the prevalence of periodontitis in a Romano-British collection of human skulls. Our aim particularly was to assess the prevalence of moderate-severe periodontitis and to describe the distribution of disease along with other dental pathologies present.

MATERIALS AND METHODS

Study material

Three hundred and three skulls were used in the study from a total of 1,200 remains of a Romano-British burial ground in Poundbury, Dorset dating back to 200-400 AD. The majority of the inhumations were originally in simple wooden coffins and many of the remains were well preserved. The collection is held by the British Museum (Natural History) and stored at the Natural History Museum in Kensington, London. The collection had been previously catalogued by Natural History Museum scientists, including burial details and estimates of age and gender.[23] This information was used in the study for the purpose of estimation of age. The Poundbury collection has been previously described in detail and has also been the source material for a number of studies including some previous dental research.[24,25] The skulls were selected from 700 consecutive skulls and all those considered usable were included in the study. Exclusions were mainly due to extensive post-mortem damage or multiple fractures that had occurred post mortem. In addition only skulls catalogued as over the age of 16 were included.

Data collection

All data were collected by the same examiner, author TRM. The data recorded from each skull are shown in Table 1. All teeth present in their sockets were recorded including third molar teeth, although these were not used in the data analysis. Teeth judged to have been lost before death included areas where the alveolar bone had covered the site of a tooth and empty sockets showing bone fill and rounding of the socket walls. Assessment for teeth lost post mortem was made with relative ease because the teeth lost after death had left sharp edged sockets in the alveolar bone.

Alveolar bone surrounding the teeth on all surfaces was studied carefully for signs of vertical bony lesions. The criteria for these lesions were a clear vertical loss or destruction of the alveolar bone adjacent to a tooth surface. Both sharp edged ragged lesions and more rounded defects with even and smoother bony surfaces were recorded. Hu-Friedy® UNC 15 periodontal probes with 1 mm gradations were used for the measurements. The measurement was carried out from the deepest part of the lesion within the alveolar bone up to the surrounding bone crest. Defects of ≥3 mm and ≥5 mm were recorded separately.

Where possible, estimation of horizontal bone loss was carried out by measuring the distance between the alveolar bone crest and the CEJ on the approximal surfaces of teeth in all areas. The CEJ was used as a reference point to get accurate readings and to avoid having to estimate allowance for biologic width while working on the skulls. The measurements were carried out by using Hu-Friedy® UNC 15 periodontal probes and recorded in millimetres. For the assessment of horizontal bone loss a previous study of this same collection has demonstrated a linear relationship between age and over-eruption due to attrition by measurement of the distance between mental foramen (as a fixed reference point) and alveolar crest height.[25] Thus, a sample showing horizontal bone loss equal to two or more millimetres above the mean for the appropriate age was considered to be affected with periodontitis. The threshold of two millimetres to qualify for this type of bone loss was chosen to allow for possible variance within the expected rate of continuous eruption.

Table 1 Data collected from each skull
Teeth present
Teeth lost ante mortem
Teeth lost post-mortem
Estimated horizontal bone loss
Infra-bony pockets (>3 mm and >5 mm)
Dehiscences, fenestrations and developmental bony defects
Caries
Overall toothwear
Teeth lost due to periodontal disease
Any other diagnoses and pathologies
Presence of calculus
Any other comments

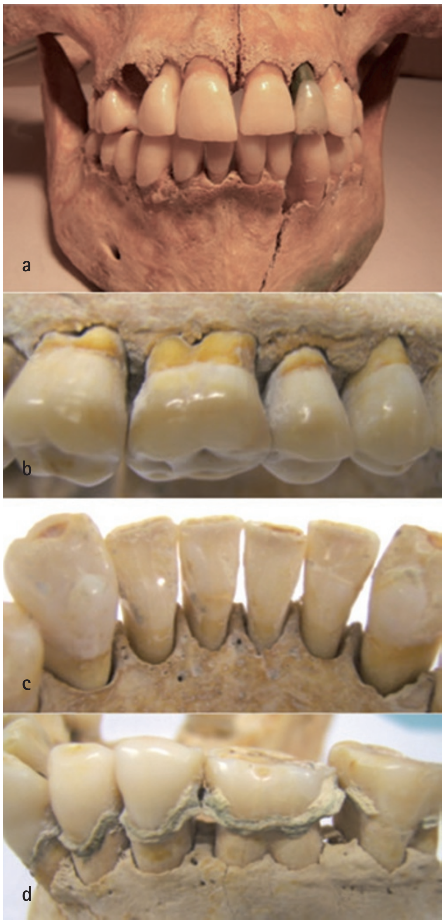

Fig. 1 (a) 25-year-old female, buried around 350 AD. Periodontally healthy but some post-mortem damage evident. She had been buried with a copper coin in her mouth resulting in the tooth discolouration seen in upper left second incisor. (b), (c) Periodontally healthy samples with normal crestal alveolar bone contour and intact cortical plates. (d) Extensive calculus deposits. Note also single infra-bony defect mesial to lower second molar

Teeth judged to have been lost due to periodontitis were identified by summarising data from evidence of periodontitis elsewhere and lack of other obvious pathology such as caries.

Bony dehiscences were recorded buccally and lingually for all teeth manifesting bony recession. The measurement was recorded

Fig. 2 Examples of periodontitis cases

Fig. 3 Other notable findings. (a) Extensive generalized attrition. (b) Pulpal exposure as as a result of attrition. Note resultant extensive apical bone loss on buccal root. (c) Large apical bony defect on disto-buccal root of first molar, consequent to tooth wear-associated pulpal exposure. (d) Bony dehiscences on lower canine an first molar teeth. (e) Buccal cervical carious cavity

as the distance between the point furthest away from the CEJ at the deepest part of the dehiscence to the CEJ. Fenestrations were recorded on the comments and other diagnoses section of the study sheet. Caries was recorded when clear cavity formation was present to visible examination.

An assessment of the overall wear of the occlusal surfaces was noted for each individual. The wear was scored as follows:

0 none
1 visible
2 flattened cusps
3 extensive with dentine exposure

Furcations as well as the presence of calculus, visible periapical lesions and other pathologies were noted.

Reproducibility

To assess intra-operator reproducibility of data recording 20 samples randomly selected throughout the whole sample were re-examined on a different occasion. In addition, to assess inter-operator reproducibility an additional 20 samples were examined by author FJH and data compared with the original data-recording.

Analysis of data

The sample was divided into six groups according to age. The groups were:

- Under 25-year-olds
- 25-34-year-olds
- 35-44-year-olds
- 45-54-year-olds
- 55-64-year-olds
- Over 65-year-olds.

Teeth considered to be affected with periodontitis were selected according to total vertical dimensions of bone loss. If the bone loss exceeded 5 mm in total, the tooth was considered to be affected. For example a vertical bony lesion of 5 mm, a vertical bony lesion of 3 mm together with 2 mm or more of horizontal bone loss as described above, or horizontal bone loss in excess of 5 mm above age average would qualify as a tooth affected by periodontitis. Prior to commencement of the study we defined the criteria for a case of periodontitis for different age groups as listed:

Under 25s	2 or more teeth affected
25-34-year-olds	3 quadrants affected
35-year-olds and older	4 quadrants affected.

These rather robust criteria were selected in order to find cases of periodontitis with an extent of disease serious enough for a case in the appropriate age group, and which in a modern clinical environment may have been diagnosed as moderate or severe periodontitis. In the oldest age group tooth loss was expected, and it was decided to include individuals even if they did not have affected teeth in all four quadrants.

In addition to the analysis of prevalence of periodontitis using the case definition determined *a priori,* a post-hoc recalculation of this data was undertaken using a second definition of three or more affected sites with at least 5 mm bone loss, independent of number of quadrants affected.

RESULTS

The sample of 303 skulls consisted of dry, brittle bones. The majority of the samples were very well preserved and anatomical structures, as well as periodontal phenomena such as calculus, were clearly visible. Post-mortem damage was common and hindered the making of measurements for the whole mouth in some cases. Fractures of pieces of bone were the most common type of post-mortem damage. Relatively often maxillae had become separated from the base of the skull. Teeth that had become loose after death were mostly intact and in one piece.

Infra-bony defects presented as visible craters and discontinuation of the alveolar bone next to root surfaces. They varied from large open defects to small less obvious ones between two teeth. The bone surface could be smooth and even, or ragged and sharp.

Calculus was seen in the vast majority of the individuals. The amount and location of calculus deposits varied throughout the dentitions. Few cases presented with little or no calculus, and several had very large deposits. Some calculus deposits had obviously become detached from the surfaces of teeth leaving behind tiny particles of darker colour attached to the surfaces of teeth.

Occlusal attrition was very common even in the youngest individuals of the Poundbury population. Mostly occlusal wear affected the entire dentition of an individual but several cases of uneven wear were seen. This uneven wear could affect one or a number of teeth; three young men presented with heavy wear on one side of the mouth and occlusal calculus with no wear on the other.

Most individuals of the Poundbury population appeared substantially periodontally healthy. The alveolar bone in these healthy specimens was solid with an intact cortical plate. A large number of dehiscences were recorded in the specimens. These appeared as subtle thinning of the alveolar bone away from a prominent root surface. Post-mortem fractures of the buccal alveolar bone were seen commonly among the samples. In addition a number of samples showed evidence of caries and some showed evidence of periapical pathology associated with either caries or apparently secondary to pulpal exposure due to toothwear. In addition one sample had evidence of a large cyst or tumour in the region of the lower left third molar. Representative photographs of specimens are showed in Figures 1-3.

The study sample of 303 individuals consisted of 166 females, 132 males and 5 whose gender was unidentified. The age, gender and mean teeth present is shown in Table 2. The whole sample consisted of 2,743 teeth in the maxilla and 3,293 teeth in the mandible totalling 6,036 teeth altogether. In some of the samples only the maxilla or mandible was available, which affected the average numbers of teeth present per individual examined in the study.

Table 3 lists the teeth lost during life. The percentage of individuals with ante-mortem tooth loss in each age group and the average number of lost teeth are described. Even the youngest age group presented with teeth that appeared to have been lost during life. The number of lost teeth increases steadily with age, and all the individuals in the oldest age group had suffered with tooth loss averaging 16.5 teeth in total. In addition, the number of teeth lost that were judged to have been lost due to periodontitis is also shown in Table 3.

Table 2 Age, gender and mean number of teeth present of samples examined

Age in years	No. of individuals	Males	Females	Teeth present
Under 25	36	7	27	25
25–34	75	30	46	23.4
35–44	65	40	25	21.3
45–54	74	37	35	17.4
55–64	34	13	21	14.7
Over 65	19	5	14	8.9

Table 3 Teeth lost during life. The percentage of subjects with ante-mortem tooth loss, and the average number of teeth these cases had lost both from all causes and those judged likely to be as the result of periodontitis

Age	Tooth loss (all causes)%	Number of teeth lost	Tooth loss (perio)%	Average number of teeth lost
Under 25	11.11	2.0	0	0
25–34	41.8	2.4	4.0	2.3
35–44	75.4	3.0	9.2	2.6
45–54	90.5	5.6	5.4	3.75
55–64	91.2	9.6	8.8	8.0
Over 65	100	16.5	10.5	20

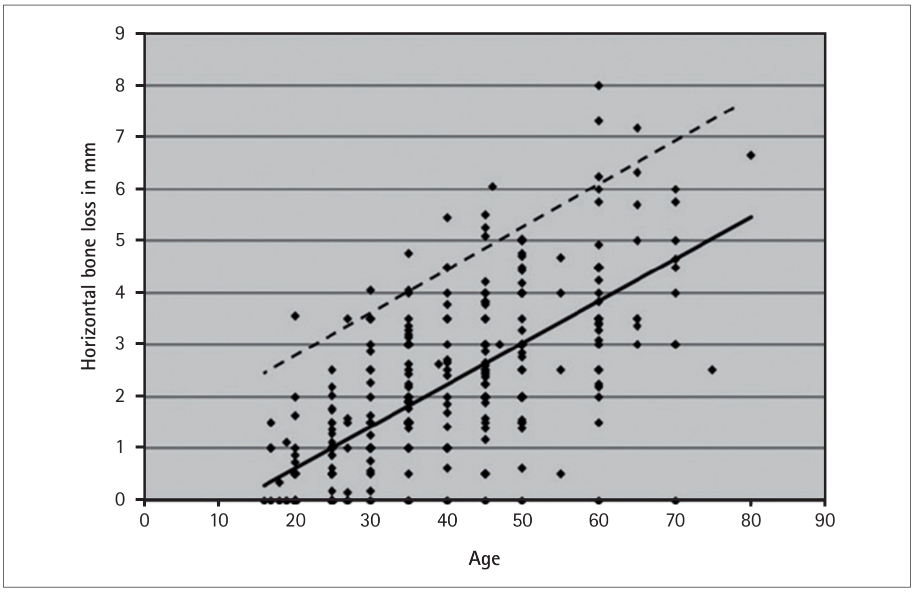

Fig. 4 Distribution of average horizontal bone loss and age for each sample examined. Cut off point of 2 mm greater than average bone height shown as broken line

Table 4 Horizontal bone loss in age groups

Age group	Number of individuals	% individuals with bone loss
Under 25	1	4.0
25–34	5	6.7
35–44	6	9.2
45–54	4	5.4
55–64	4	11.8
Over 64	2	10.5

Table 5 Cases with periodontitis and percentage of the age cohort, as estimated by the case definition determined a priori, and using the post hoc case definition 2, based on having a minimum of three teeth with 5 mm attachment loss

Age group	Number of affected individuals	Number affected by case definition 2
Under 25	2 (5.5%)	2 (5.5%)
25–34	4 (5.3%)	4 (5.3%)
35–44	4 (6.2%)	5 (7.7%)
45–54	3 (4.0%)	4 (5.4%)
55–64	2 (5.9%)	3 (8.8%)
Over 65	2 (10.5%)	2 (10.5%)

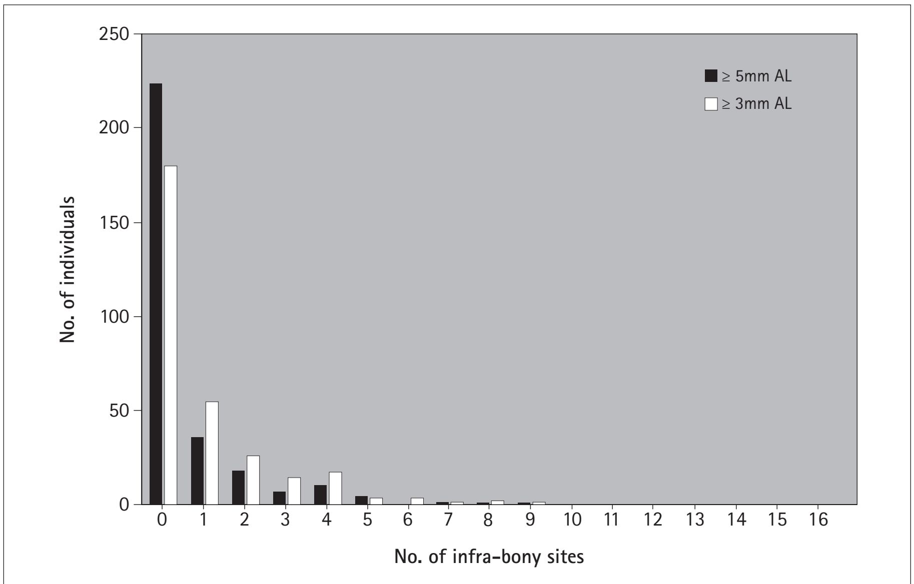

Fig. 5 Frequency distribution of number of individuals with infra-bony defects ≥3 and ≥5 mm

Table 6 Age and number of affected teeth and quadrants in periodontitis cases

Age	Number of teeth affected	Quadrants affected
20	2	1
20	2	2
27	3	3
30	5	3
30	6	4
30	6	3
35	4	4
35	5	4
35	4	4
35	4	4
45	11	4
45	9	4
45	11	4
55	5	4
60	11	4
65	3	2

Horizontal bone loss

Based on measurements between the CEJ and the alveolar bone crest a figure for the average distance between the two was counted for each age. When individuals presented with the equal of or more than two millimetres of bone loss than the expected value for their age they were considered to suffer with horizontal bone loss due to periodontitis. Twenty-two individuals presented with more bone loss than average for their age. This equated to 7.3% of the population. Figure 4 describes the relationship of average bone loss and age. Table 4 lists the individuals with periodontal bone loss divided in age groups. Because of the selected criteria and the phenomenon of continuing eruption these results need to be viewed with caution.

Cases of periodontitis

The criteria described in the material and methods section were applied to the whole sample to identify those individuals who qualified as cases of periodontitis. In total 17 individuals out of the whole sample of 303 were judged to qualify as cases of periodontitis. This equated to 5.6% of the entire group. Table 5 describes the number and the percentage of affected individuals in each age group. Table 6 shows the age, number of affected teeth and number of quadrants affected for those individuals judged to have suffered with periodontitis. It can be seen that the two individuals in the oldest age group had only three affected teeth in two quadrants. All these were affected by periodontitis and the other teeth were lost due to periodontitis. Hence they are included as cases. Ten of the 17 cases (7.6%) were seen in males and 7 (4.2%) in females, although this was not significantly different (P = 0.33 Fisher's Exact test). In addition, Table 5 also shows the post-hoc alternate case definition of periodontitis, as determined by three teeth with ≥5 mm attachment loss, and the total number of cases increased by 4 to 21 cases.

Table 6 shows the age and number of teeth and quadrants affected in periodontitis cases. After exclusion of the two oldest cases, where many additional teeth had been lost due to periodontitis, there is a strong correlation between age and number of affected teeth (R = 0.57, P = 0.0011, by linear regression).

In addition to the group assigned a diagnosis of periodontitis, isolated infra-bony defects were seen in a much larger number of subjects in the population who appeared to be otherwise periodontally healthy individuals. The total number of subjects affected by infra-bony defects and the number of defects they had are shown in the frequency chart in Figure 5. The total number of subjects with a single defect of ≥3 mm or >5 mm were 55 and 36 respectively.

Other features

The findings of attrition, caries and presence of bony dehiscences are shown in Table 7. The Poundbury population suffered with dental attrition from a young age. Use of the attrition index (0 = no attrition, 1 = visible, 2 = flattened cusps, 3 = extensive, dentine exposure) was not sufficiently sensitive to discriminate between age groups as even the youngest age group of under 25-year-olds typically presented with exposed dentine due to occlusal wear.

A relatively high percentage of individuals in each age group suffered from dental caries. The teeth with most decay were the first molars in all quadrants, followed by lower second molars. Analysis of which surfaces were most affected was not carried out. In addition, around 25% of the cohort were estimated to have pulpal exposure and/or periapical pathology as a result of either caries or extreme toothwear.

There was also a high prevalence of bony dehiscences seen in both upper and lower arches. Canines were the most frequently affected teeth followed by central incisors in the upper arch and first premolars in the lower arch. Upper and lower canines were as frequently affected. Due to post-mortem fractures and damage it is possible that the data presented in the table overestimates the prevalence of dehiscences in this population.

Reproducibility

In the intra-operator reproducibility study, 5 mm intra-bony defects were recorded as the same in 70% of cases, 20% were within one, and 5% differed by five defects. Horizontal bone loss was estimated to be the same or within 1 mm in 85% of cases and the remaining 15% within 2 mm. In the inter-operator study, 5 mm intra-bony defects were recorded the same in 87.5% of cases, 6.25% were within one and 6.25% case were within two defects. Horizontal bone loss was estimated to be the same or within 1 mm in 69.75% of cases, 25% within 2 mm and 6.25% within 3mm. Where discrepancies in recording were found these were resolved by re-examination of the sample by both operators together.

DISCUSSION

Although the prevalence of some periodontal disease is considered to be almost ubiquitous across modern adult human populations, it is clear that the prevalence of clinically significant progressive periodontitis (often grouped as moderate-severe periodontitis) is much less common, and affects only a minority of those with signs of some periodontal disease. It is thus of significant relevance to our understanding of the natural history and aetiology of periodontal disease to study its prevalence in a range of different settings, including those from ancient populations. We thus sought to determine the prevalence of moderate-severe disease in the Poundbury collection from a Romano-British burial ground from around 200-400 AD. Our results suggest that clinically significant periodontitis was uncommon in this population, despite the nearly ubiquitous presence of calculus and presumed absence of efficient oral hygiene measures.

The Poundbury cemetery population is thought to have consisted of residents of the local countryside as well as a more densely populated urban concentration. The people appear to have lived during a peaceful time and there may have been some immigration into the area. However, the size of the population is considered to have remained stable. It is thought that the country dwellers were likely to have enjoyed better growth and health than the people living in more densely populated conditions. Among the people who survived infancy, childhood illnesses and malnutrition into adulthood, the age at death appears to have peaked in the fourth decade. Infectious diseases are thought to have been a common cause of death. Young females would also have perished during childbirth.

Table 7 Summary of other significant findings. Attrition – mean toothwear index. Caries – % of subjects affected, and the mean number of teeth affected in those affected. Dehiscences: % of subjects affected and the mean extent in mm

Age	Attrition	Caries		Dehiscences			
		% affected	Mean teeth affected	Maxillary		Mandibular	
				% affected	Average (mm)	% affected	Average (mm)
Under 25	2.36	55.6	2.1	36.1	3.9	44.4	4.3
25-34	2.4	43.9	2.3	57.3	4.8	58.7	3.2
35-44	2.54	75.4	1.9	53.8	5.4	60.9	6.1
45-54	2.51	63.5	2	40.5	6.31	50	6.6
55-64	2.44	52.9	2.1	41.2	7.6	50	8.4
Over 65	2.53	66.7	1.5	57.9	9.7	57.9	8.9

There are a number of methodological problems inherent to this type of study on dried skulls. Firstly, inevitably, it is only possible to study hard tissue changes. Secondly, the estimation of periodontal disease by the measurement of clinical attachment level is complicated by the severe dental attrition and over eruption seen in even relatively young samples. In fact there was little sign of extensive horizontal bone loss, and indeed, even in those judged to have some horizontal bone loss, there was often little actual sign of periodontitis as judged by loss of cortical plate from the crestal alveolar bone. Thus, the estimation of periodontitis-associated horizontal bone loss has to be treated with caution, although it is likely that if anything we have over-estimated the amount of horizontal bone loss due to periodontitis.

A key feature of the data analysis is the use of age estimates previously carried out at the museum for cataloguing purposes. Two principal methods were used for age determination of the Poundbury collection. The first one was based on assessing the amount of dental wear[26] and the second by examining the pubic symphysis. Age-related changes to the vertebrae, cortical thickness and cell structure of bone were also examined. It was concluded that dental ageing gave the most reliable and consistent estimates for the age at death, although the authors think it possible that the dental ageing underestimates the actual age of the individuals.[23] The tendency to underestimate the age at death is thought to affect the older age groups in particular. Age estimation of the younger individuals is aided by, and more accurate due to, the development stages of the dentition and the eruption of teeth. Individual variation may play a larger role with increasing age, and from the fifth decade onwards age determination becomes more difficult. In particular, it is recognised that as age estimation is partly based on dental examination, there is the potential for a 'circular argument' when using this data for subsequent analysis of periodontal disease prevalence. However, as it is thought that the age at death assessments made on the Poundbury population may underestimate the actual chronological age of the individuals, the results presented in this study about the prevalence and severity of periodontitis may present a false picture of too much and too severe disease, especially in the older age groups whose ages are more likely to be underestimated.

Other potential concerns about our findings include case definitions for periodontitis (discussed further below), and the failure to be able to include missing teeth in periodontal diagnosis. This latter point has been considered but those teeth designated as likely to have been lost due to periodontitis will not significantly affect the number of cases overall, as the designation of 'lost due to periodontitis' was largely dependent on the presence of periodontitis in other teeth.

Our findings clearly suggest that, perhaps contrary to expectations, the prevalence of moderate-severe periodontitis was low and, specifically, considerably less than that seen in modern populations. In addition, the disease pattern and natural history of the condition appears to differ from that expected from current clinical observations. Overall the prevalence was just above 5% throughout most of the adult population, rising to up to 10% only in the small elderly cohort of those estimated to be over age 65. Thus, with this exception, the prevalence remained remarkably consistent throughout adulthood, although the number of affected teeth appeared to increase with age in a linear pattern.

Interestingly, a much higher proportion of this population were found to have single infra-bony defects but were considered to be otherwise periodontal healthy. We consider this to be suggestive of 'incidental periodontal attachment loss' rather than true periodontal disease, which is a condition affecting a number of teeth throughout the mouth. Although we can only speculate on the aetiology of these localised lesions it seems likely that they are the result of local factors such as lodging of food debris in the gingival margins, resulting in an acute local inflammatory episode.

Epidemiological reports of prevalence of a condition are highly dependent on how a 'case' of the disease is defined. Until, recent years there have been many different case definitions to define a 'case' of periodontitis, and little consensus on this important issue. In more recent years both the American Academy of Periodontology (with the US Centre for Disease Control–AAP/CDC),[14] and the European Academy of Periodontology[27] have proposed uniform case definitions of periodontitis. In particular, the AAP/CDC classification, proposed by Page & Eke, has become increasingly adopted.[14] Using this classification, moderate periodontitis is defined as at least two teeth with an interproximal site with clinical attachment loss of 4 mm or pocket depth of ≥5 mm; severe periodontitis is similarly defined as at least two teeth with an interproximal site with clinical attachment loss of 6 mm and one with pocket depth of ≥5 mm.

In setting our own case definition of moderate-severe periodontitis for this study, we deliberately set a definition *a priori* with sufficient stringency to avoid many false positive diagnoses. However, in recognition of the potential concerns about this we also reanalysed the data post-hoc with a case definition more akin to that of Page & Eke. For this we used a definition of three sites in different teeth with ≤5 mm. We chose to use three affected teeth rather than two, given the very high prevalence of 'incidental attachment loss' in this population, and 5 mm attachment loss rather than 4 mm CAL, as the measurement of true attachment level to bone margin on a dried skull is likely to be greater than the clinical attachment level measured in patients. Despite the use of two different case definitions in this study, the overall results were remarkably similar, supporting our findings of low prevalence of progressive periodontitis. In fact very subjectively, our direct impression was that cases of moderate-severe periodontitis were relatively easily recognised by direct visual examination, as the vast majority of samples examined were obviously largely periodontally healthy.

Previous studies of ancient populations have reported a wide range of different findings for the prevalence of periodontitis. For example, a number of studies of different collections report relatively high prevalence of periodontitis similar to modern prevalence rates, but have not particularly reported on prevalence of more severe disease. These studies include studies of a range of ancient populations back to prehistoric times (800 BC),[11,12] samples from 18th century burial site in Spitalfields, London,[10-13] and a Portuguese population from the 19-early 20th century.[28] However Clarke and co-workers, who studied a wide range of samples from both ancient and modern collections, reported that only about 10% of ancient populations were affected by periodontitis, compared with around 30% of modern samples.[9] Given that the use of height of distance from CEJ to crestal bone height is so problematic, Kerr described a five point scoring system for grading periodontal disease according to changes in the interdental bony septa, ranging from intact bony septum scoring 1, through to presence of an intrabony defect of at least 3 mm scoring 5.[10] However, we would question firstly, almost by definition, whether it is possible to identify gingivitis by bony changes, and also suggest that only a score of 5 within this scale (infrabony pocket of ≥3 mm) reflects clinically significant periodontitis.

In contrast to these studies, we have tried to apply a case definition of disease based on modern epidemiological measurements, and particularly to identify periodontitis of sufficient severity to be considered potentially clinically significant. Hence our reported prevalence figures may appear very different to many of the other studies of ancient populations. For example, in the study by Wasterlain in the 19-20th century Portuguese population,[28] the reported prevalence of periodontitis of around 70% would appear to reduce to somewhere between 2-3% if the Kerr Score 5 was adopted as a case definition for periodontal disease.

Other findings

In addition to the findings of periodontal disease prevalence, a number of other important findings were observed during the examination of these samples, including attrition, caries, evidence of apical infection and tooth loss. A rough and difficult-to-chew diet is thought to be responsible for the large amount of excessive wear in the teeth of the Poundbury population. According to the archaeologists the people of Poundbury appear to have lived on a diet high on cereals and grains. Rough milling would have left hard particles in the flour. When the grains were baked into dry bread it would have made people chew their food slowly to add moisture to the mixture and to be able to swallow the food. This long-lasting, slow chewing of a tough substance with lots of gritty material would have been very abrasive to teeth. Even the youngest age group presented with excessive amounts of wear and exhibited exposed dentine on the occlusal surfaces, and at times resulted even in pulpal exposure.

Dental caries was much more common than was initially expected. More than half of the population had carious lesions in their teeth, except the 25-34-year-old group. Boiling milled flour into porridge was the other form of cereals and grains it has been suggested was enjoyed by the population. A porridge mixture would have been less abrasive to teeth than bread, but may have caused an increase in the caries incidence. Root caries was uncommon.

Although ante-mortem tooth loss was very common, the vast majority of these missing teeth were not judged to have been the result of periodontal disease, as judged by lack of periodontal disease elsewhere. Obviously, this is slightly speculative, and the major causes of tooth loss can only be suggested by our general findings. Possible causes of tooth loss include incidental periodontal attachment loss, and long standing periapical infections, both of which were very common, and tooth fractures, which were less evident. Given the findings relating to pulpal and periapical disease and the likely chronic pain this might result in, it also raises the question of whether teeth were sometimes deliberately either self-extracted or perhaps more likely extracted by another individual.

CONCLUSIONS

Overall the study demonstrates the presence of significant and widespread oral disease, but low levels of moderate to severe periodontitis. It seems likely that gingivitis was widespread but we have no way of assessing this, and it is also possible that mild periodontitis was common, but owing to the methodological issues outlined this is not confirmed with any high degree of certainty. The pattern of disease distribution in the cohort is similar to that described in modern populations, in that only a relatively small proportion are highly susceptible to progressive disease, despite the absence of effective plaque control measures. However, the prevalence data suggests that the condition was much less common than today. These observations underline the importance of a range of aetiological factors which contribute to severe periodontitis. It is likely that the Poundbury population were genetically very similar to modern European populations. A recent study of calculus samples from German skulls with periodontitis from the Middle Ages has demonstrated very similar periodontal pathogens present to those seen in modern times, and does not support the idea that an increase in periodontitis may be due to changes in oral flora over time. Similarly it does not appear that the relatively poor diets of these people predisposed to periodontitis. However, this was a non-smoking population with likely very low levels of diabetes mellitus and these may be key factors in determining the prevalence of disease, consistent with Hujoel's hypothesis of a periodontitis epidemic in the 20th century fueled by smoking.[8]

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1. Papapanou P N. Epidemiology of periodontal diseases: an update. *J Int Acad Periodontol* 1999; **1:** 110–116.
2. Loe H, Anerud A, Boysen H, Morrison E. Natural history of periodontal disease in man. Rapid, moderate and no loss of attachment in Sri Lankan laborers 14 to 46 years of age. *J Clin Periodontol* 1986; **13:** 431–445.
3. Baelum V, Pisuithanakan S, Teanpaisan R *et al.* Periodontal conditions among adults in Southern Thailand. *J Periodontal Res* 2003; **38:** 156–163.
4. Holtfreter B, Schwahn C, Biffar R, Kocher T. Epidemiology of periodontal diseases in the study of health in Pomerania. *J Clin Periodontol* 2009; **36:** 114–123.
5. Norderyd O, Hugoson A. Risk of severe periodontal disease in a Swedish adult population. A cross-sectional study. *J Clin Periodontol* 1998; **25:** 1022–1028.
6. Konig J, Holtfreter B, Kocher T. Periodontal health in Europe: future trends based on treatment needs and the provision of periodontal services – position paper 1. *Eur J Dent Educ* 2010; **14 (Suppl 1):** 4–24.
7. Norderyd O, Hugoson A, Grusovin G. Risk of severe periodontal disease in a Swedish adult population. A longitudinal study. *J Clin Periodontol* 1999; **26:** 608–615.
8. Hujoel P P, del Aguila M A, DeRouen T A, Bergstrom J. A hidden periodontitis epidemic during the 20th century? *Community Dent Oral Epidemiol* 2003; **31:** 1–6.
9. Clarke N G, Carey S E, Srikandi W, Hirsch R S, Leppard P I. Periodontal disease in ancient populations. *Am J Phys Anthropol* 1986; **71:** 173–183.
10. Kerr N W. Prevalence and natural history of periodontal disease in a London, Spitalfields, population (1645–1852 AD). *Arch Oral Biol* 1994; **39:** 581–588.
11. Kerr N W. Prevalence and natural history of periodontal disease in prehistoric Scots (pre-900 AD). *J Periodontal Res* 1998; **33:** 131–137.
12. Kerr N W. The prevalence and natural history of periodontal disease in Britain from prehistoric to modern times. *Br Dent J* 1998; **185:** 527–535.
13. Kingsmill V. Chronic periodontitis in an eighteenth century population. *Br Dent J* 1991; **170:** 118–120.
14. Page R C, Eke P I. Case definitions for use in population-based surveillance of periodontitis. *J Periodontol* 2007; **78:** 1387–1399.
15. Whittaker D K, Griffiths S, Robson A, Roger-Davies P, Thomas G, Molleson T. Continuing tooth eruption and alveolar crest height in an eighteenth-century population from Spitalfields, east London. *Arch Oral Biol* 1990; **35:** 81–85.
16. Danenberg P J, Hirsch R S, Clarke N G, Leppard P I, Richards L C. Continuous tooth eruption in Australian aboriginal skulls. *Am J Phys Anthropol* 1991; **85:** 305–312.
17. Clarke N G, Hirsch R S. Two critical confounding factors in periodontal epidemiology. *Community Dent Health* 1992; **9:** 133–141.
18. Ripamonti U. The hard evidence of alveolar bone loss in early hominids of southern Africa. A short communication. *J Periodontol* 1989; **60:** 118–120.
19. Ripamonti U. Paleopathology in Australopithecus africanus: a suggested case of a 3millionyear-old prepubertal periodontitis. *Am J Phys Anthropol* 1988; **76:** 197–210.
20. Kelley J. Palaeoanthropology: Neanderthal teeth lined up. *Nature* 2004; **428:** 904–905.
21. Ruffer M A. *Studies in the paleopathology of ancient Egypt.* Chicago: University of Chicago; 1921.
22. Glickman I, Carranza F A. *Glickman's clinical periodontology.* 5th ed. Philadelphia: WB Saunders, 1979.
23. Farwell D E, Molleson T L. *Excavations at Poundbury 1966-1980 – Vol II: Cemeteries.* London: British Museum (Natural History), 1993.
24. Whittaker D K, Molleson T, Nuttall T. Calculus deposits and bone loss on the teeth of Romano-British and eighteenth-century Londoners. *Arch Oral Biol* 1998; **43:** 941–948.
25. Whittaker D K, Parker J H, Jenkins C. Tooth attrition and continuing eruption in a Romano-British population. *Arch Oral Biol* 1982; **27:** 405–409.
26. Brothwell D R. Digging up bone. London: British Museum (Natural History), 1963.
27. Tonetti M S, Claffey N. Advances in the progression of periodontitis and proposal of definitions of a periodontitis case and disease progression for use in risk factor research. Group C consensus report of the 5th European Workshop in Periodontology. *J Clin Periodontol* 2005; **32 (Suppl 6):** 210–213.
28. Wasterlain S N, Cunha E, Hillson S. Periodontal disease in a Portuguese identified skeletal sample from the late nineteenth and early twentieth centuries. *Am J Phys Anthropol* 2011; **145:** 30–42.