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Dental Health of 19th Century Migrant Mineworkers from Kimberley, South Africa

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ABSTRACT Dental health may deteriorate in populations exposed to economic growth as a result of easier access to refined carbohydrates and sugars. Such changes affected migrant labourers working in Kimberley, South Africa, during the late 19th century. A rescue excavation salvaged several skeletons from pauper's graves dating from this period, and the purpose of the study was to assess their dental health to determine whether it concurs with historical statements suggesting that the skeletal population sample being investigated was migrant labourers with limited access to a healthy diet. According to historic sources their diets mainly consisted of ground carbohydrates and occasional meat.

The permanent dentition of 79 males and 13 females (majority between 20 and 49 years of age) were examined. Carious lesions were observed in 57% of males and 46.2% of females with an average of 2.7 and 3.8 carious teeth per mouth. The anterior teeth were significantly less affected than the posterior teeth. Periodontal granulomata ('abscesses') were observed in 17.7% of males and 15.4% of females, and periodontal disease affected 40% of those investigated. Antemortem tooth loss (AMTL) was recorded in 29% ($N = 27$) of the sample with an average of 3.5 teeth lost per mouth.

It was concluded that the prevalence of dental caries, periapical granulomata and periodontal disease as well as the pattern of AMTL observed concurs with dietary descriptions for paupers in historical documents. The relatively low prevalence of carious lesions can be ascribed to the limited time migrant labourers spent in Kimberley and the labour restrictions they had to comply with during their stay in the compounds.

Key words: migrant labour; Kimberley; dental caries; antemortem tooth loss; periapical granuloma; chronic abscesses; periapical cyst; periodontal disease

Introduction

Teeth are often recovered during archaeological excavations due to their hard and robust structure, thus becoming a valuable source of information during the investigation of skeletal material. Several characteristics can be investigated, such as the prevalence of carious lesions, antemortem tooth loss (AMTL), dental wear, enamel hypoplasia (EH) and supernumerary teeth, all of which add to our understanding of the diet, oral hygiene, stress levels and habitual activities of past populations (Hillson, 1979; Roberts & Manchester, 1995; Hillson 1998; Ortner, 2003).

Various studies have been conducted on the dental health of black South Africans, both on living and skeletal population samples. These studies indicated that, as would be expected, the prevalence of dental pathology changes as populations progressed from a very traditional hunter–gather diet, to an agricultural diet, and then to a diet high in refined carbohydrates and sugars (Staz, 1938; Cleaton-Jones, 1979; Morris, 1992; Steyn *et al.*, 2002; L'Abbé *et al.*, 2003; L'Abbé, 2005). It is thus clear that a decrease in dental health, specifically an increase in dental caries, is caused by changes in subsistence patterns, often associated with economic growth and industrial advances. Such an economic change resulting in the rapid availability of machine ground carbohydrates (maize meal in particular) and sugars to originally rural African communities also occurred in Kimberley, South Africa, during the late 19th century, with the discovery of diamonds.

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The discovery of diamonds on Colesberg Kopje in South Africa in 1871 resulted in many people rushing to mark their claims. By 1899 population numbers had increased dramatically and it was estimated to include 16 300 Europeans and 28 200 black individuals (Stoney, 1900).

It is stated in historical documents that the majority of black mineworkers in Kimberley were migrant labourers. Males left their families in the rural areas, within and outside the borders of South Africa, and came to Kimberley for a limited period of time to work on the diamond mines. During their stay they were housed in closed labour compounds (Turrell, 1984; Roberts, 1976; Worger, 1987). The compounds were developed to improve security and limit the theft of diamonds, while increasing productivity by restricting and controlling the movements of labourers. Although compounds were intended to provide adequate shelter and supply in the nutritional needs of all labourers, the living conditions in these camps were, in fact, poor (Turrell, 1984; Jochelson, 2001). After their labour contracts expired, workers returned to their rural families (Turrell, 1984; McNish, 1970; Roberts, 1976).

Several complete skeletons were exhumed from damaged, unmarked graves alongside the fenced Gladstone cemetery in Kimberley, South Africa in 2004. Historical documents indicated that these graves dated to between 1898 and 1900. They were pauper's burials of individuals who had passed away in the Kimberley and surrounding hospitals (Swanepoel, 2003). Several skeletal lesions suggestive of scurvy, tuberculosis, treponemal diseases, violent trauma and congenital abnormalities were observed during the investigation of the remains (Van der Merwe *et al.*, 2009a; Van der Merwe *et al.*, 2009b; Van der Merwe *et al.*, 2009c).

It can be assumed that food sources were initially very limited and low-cariogenic in nature when diamonds were first discovered in the district of Kimberley, since refined carbohydrates and sugars would have had to be brought all the way from large South African towns such as Durban and Cape Town. However, as the mining community grew economically, resources increased and Colesberg Kopje turned into a city. This probably resulted in much easier access to refined carbohydrates and sugars for the resident community, although this increased prosperity was probably slow to reach the migrant labourers. The aim of this study was therefore to assess the prevalence of dental caries, AMTL and EH as well as bony evidence of periodontal disease and periapical granulomata and -cysts in the population sample exhumed from the Gladstone site to determine whether their dental health is consistent with what is known about them from historical documents. This includes the fact that the majority of black individuals in Kimberley were migrant workers, housed in mining compounds, with restricted to no access to dietary products outside of their housing facilities. The diet of black labourers in Kimberley consisted mainly of machine ground carbohydrates (mealie meal) and occasional meat (Harries, 1994), as it was briefly described in historical documents, and they therefore experienced limited exposure to dietary factors, such as an increase in the consumption of refined carbohydrates and sugars, which may be associated with increased economic prosperity.

Materials and methods

A total of 86 males, 15 females and 6 individuals of unknown sex were available for study. Standard anthropological techniques such as the assessment of changes to the sternal ends of the ribs, changes to the pubic symphyses, external cranial suture closure as well as general cranial and pelvic morphology and discriminant functions were used to determine the age and sex of all individuals exhumed from the trench (e.g. De Villiers, 1968; Krogman & İşcan, 1986; Hillson, 1998; Oettlé & Steyn, 2000; Åsala, 2001; Franklin *et al.*, 2005).

The permanent dentition of 79 males and 13 females were examined under good lighting for signs of dental caries, AMTL and bony evidence of periapical -granulomata and -cysts, periodontal disease and EH. The 92 individuals examined comprised of 12 (13%) juveniles (11–19 years), 52 (57%) young adults (20–34 years), 25 (27%) middle aged adults (35–49 years), one (1%) old adult (50+ years) and two (2%) individuals who could only be described as being adult.

Due to the possibility of post-depositional damage to the teeth mimicking early stages of lesion development, a carious lesion was only recorded when a clear cavity was present. The location of carious lesions was recorded according to tooth type as well as to the surface of the tooth primarily affected by the lesion. Multiple lesions on one tooth were treated as a single occurrence.

Calculations described by Lukacs (1989) and Henneberg (1991) were used to analyse the dental caries data. The following was calculated:

(a) Individual caries frequency (the frequency of individuals presenting with carious lesions divided by the total number of individuals investigated).

(b) Caries intensity (the number of carious teeth observed divided by the total number of teeth investigated).
(c) Mean number of carious teeth per mouth (the total number of carious teeth observed divided by the total number of individuals presenting with teeth affected by dental caries).
(d) Caries intensity per tooth type (the number of carious teeth present on a specific type of tooth divided by the total number of that specific tooth observed).

Percentages were calculated separately for each sex.

Unfortunately the antemortem loss of teeth has a great influence on the accuracy of the intensity of dental caries within a population, and can cause the underestimation thereof (Lukacs, 1995). Therefore, using a method described by Lukacs (1995), AMTL was taken into account and a 'corrected' intensity for dental caries within this population was also calculated.

Further statistical analyses included χ^2 tests to determine if there were significant differences in the prevalence of carious teeth between males and females, between various specific types of teeth, between the observed caries intensity and corrected caries intensity, as well as to test for comparability with results obtained from other studies. Comparisons between population groups were only done for the data obtained for males in this study as so few females were present in the Gladstone population sample and significant difference exists between the dental health of males and females in other studies which will result in skewing of the data should it be pooled.

The prevalence of dental caries observed in the Gladstone sample was compared to results obtained by Oranje *et al.* (1935) and Staz (1938). Both investigated the difference in the prevalence of dental caries between living individuals following a traditional rural-, mine-based and urban diet. Although there are often difficulties in comparing results obtained from living and skeletal sample populations, these specific studies were well suited for several reasons. Firstly, they comprised of samples of young male individuals contemporary to the Gladstone skeletal sample. The studies were also cross sectional and the prevalence of dental caries was, just as in this study, calculated by determining the caries frequency, caries intensity and the average number of carious teeth per mouth in those affected by the condition and not using the DMFT index. Other comparative samples included skeletal remains from Maroelabult, Koffiefontein and Venda, of which only results obtained for young adult (19–40 years) males were used for comparison (Steyn *et al.*, 2002; L'Abbé *et al.*, 2003; L'Abbé, 2005).

AMTL can be recognised by the resorption of the alveolar bone tissue, socket filling and mesial drift (Turner, 1979; Lukacs, 1989). It should be kept in mind that teeth lost just before death will show no signs of alveolar resorption and therefore these will be interpreted to have been lost postmortem (Turner, 1979). Methods described by Lukacs (1989) and Henneberg (1991) to assess antemortem loss were used in this study. The following calculations were done:

(a) Individual AMTL frequency (total number of individuals who lost one or more tooth antemortem divided by the total number of individuals investigated).
(b) AMTL intensity (total number of teeth lost antemortem divided by the total number of teeth present in the sample before AMTL).
(c) Mean number of teeth lost antemortem per individual (total number of teeth lost antemortem divided by the number of individuals affected by AMTL).
(d) Prevalence of specific types of teeth lost antemortem (total number of a specific type of tooth lost antemortem divided by the total number of the specific teeth present before AMTL).

The frequency of bony evidence of periapical granulomata and -cysts, chronic periapical abscesses and periodontal disease was also documented. Although these pathological conditions do not by themselves inform investigators about specific issues under investigation, such as the diet of the population, they do add to the general picture of dental health of the sample being studied and can therefore often aid in explaining patterns observed in the prevalence of dental caries and AMTL observed in the study populations.

A periapical granuloma could be recognised by the formation of a small bony cavity around the apex of the tooth root. Bony lesions resulting from granuloma formation are rather small, approximately 2–3 mm in diameter with allowance made for the portion of the cavity which is filled by the root tip. Similar lesions, but larger in size, result from periapical cysts. These develop through the replacement of granulation tissue, present in the periapical granuloma, by fluid. When left untreated the bony cavity where the cyst is located will slowly increase in size. Chronic periapical abscesses were recognised by evidence of infectious bony cavity formation connected to the exterior bone surface or a sinus by a small fistula or sinus (Dias & Tayles, 1997).

Bony evidence of periodontal disease was characterised by loss of the height of alveolar bone surrounding the teeth due to resorption of the alveolar processes. This is often accompanied by an inflammatory bone response resulting in a limbus along the alveolar edges (Hillson, 1998; Dias & Tayles, 1997; Ortner, 2003)

Dental EH was recorded for each individual on all permanent teeth, whenever observed macroscopically to be present. EH can manifest as horizontal lines, vertical grooves, pits and areas of missing enamel (King *et al*., 2002). Therefore, the type of hypoplasia was also specified.

In cases where more than one defect was present on the tooth surface, it was still recorded as a single event. The frequency of EH (proportions of individuals displaying the defect in relation to the total number of individuals examined) was calculated. No attempt was made to calculate the intensity of EH per tooth type (the number of teeth affected by EH from a specific tooth type divided by the total number of that specific tooth type examined), or to measure the distance between the hypoplastic lesions and the cemento-enamel junction, as this fell beyond the scope of this study (Hillson & Bond, 1997; Reid and Dean, 2000).

Results

Dental caries

As can be seen in Table 1, 57 % of males and 46.2% of females showed signs of one or more carious lesion. An average of 2.7 and 3.8 carious teeth per mouth was calculated for males and females, respectively. It was concluded that an average dental caries intensity of 5.33% was present for males and 5.68% for females. No significant differences existed in the intensity of carious lesions between males and females ($\chi^2 = 0.085$, p-value > 0.5).

Using the method described by Lukacs (1995), a 'corrected caries intensity' was calculated for males and females to compensate for teeth lost antemortem due to dental caries. As a consequence, the caries intensity increased by 3% for males, totalling 8.3%, and by 1% for females, totalling 6.6%. A significant difference existed between the observed dental caries intensity and the corrected caries rate for males ($\chi^2 = 16.203$, p-value < 0.001), but not for females ($\chi^2 = 0.322$, p-value > 0.5). Since none of the comparative studies available for South African population used the caries correction factor, these results were not used in further comparative analyses.

The caries intensity was also calculated per tooth type. In general, carious lesions affected anterior teeth (incisors and canines) significantly less than posterior teeth (premolars and molars) ($\chi^2 = 57.295$, p-value < 0.01), as was expected. This is due to the difference in morphology of these teeth with posterior teeth having fissures and crevices to which cariogenic substances can much easier adhere than on the smooth surfaces of the anterior teeth (Hillson, 1996).

The second molars were significantly more affected by carious lesions than any of the other teeth (χ^2 varies between 7.2 and 52.6, p-value < 0.01 for all), followed by the third molar, first molar and second premolar, although intensity differences between these teeth were not significant (Table 2). The canine was the least affected. No significant difference in the distribution pattern of carious teeth was observed between males and females (Table 2).

Periapical granulomata, -cysts and chronic periapical abscesses

Periapical granulomata and -cysts (Figure 1) were observed in 17.7% ($N = 14$) of males and 15.4% ($N = 2$) of females, with no significant difference existing between the sexes ($\chi^2 = 0.042$, p-value > 0.75). A total of 19 periapical

Table 1. Summary of the prevalence of dental caries as observed in the Gladstone skeletal sample

Variables	Caries frequency[a]			Lesions per mouth[b]			Caries intensity[c]		
	n	nia	%	nia	nta	c/m	nt	nta	%
Male	79	45	57.0	45	122	2.7	2291	122	5.3
Female	13	6	46.2	6	23	3.8	405	23	5.7
Total	92	51	55.4	51	145	2.8	2696	145	5.4

[a] total number of individuals affected by dental caries/total number of individuals present.
[b] total number of carious teeth/total number of individuals affected by dental caries.
[c] total number of carious teeth/total number of teeth present.
n, total number of individuals investigated; nia, total number of individuals affected with dental caries; nta, total number of teeth affected by dental caries; c/m, average number of carious lesions per mouth; nt, total number of teeth present.

Table 2. Caries intensity sorted by sex and tooth type

Tooth	Male			Female			Total			χ^2
	n	na	%	*n*	na	%	*n*	na	%	
I1	275	2	0.7	51	2	3.9	326	4	1.2	3.622
I2	279	4	1.4	51	2	3.9	330	6	1.8	1.495
C	293	1	0.3	52	0	0.0	345	1	0.3	0.178
PM1	298	10	3.4	52	3	5.8	350	13	3.7	0.721
PM2	294	16	5.4	52	2	3.8	346	18	5.2	0.228
M1	280	19	6.8	52	6	11.5	332	25	7.5	1.423
M2	291	44	15.1	50	7	14.0	341	51	15.0	0.042
M3	281	26	9.3	45	1	2.2	326	27	8.3	2.523
Total	2291	122	5.3	405	23	5.7	2696	145	5.4	0.085

n, number of teeth investigated; na, number of teeth affected by carious lesions; I, incisor; C, canine; PM, premolar; M, molar. No significant differences were observed between males and females.

granulomata, eight periapical cysts and two chronic periapical abscesses were observed in 16 individuals, with the majority presenting with two or more lesions. In general, posterior teeth (26 of the 29 cases) were significantly more affected than anterior teeth ($\chi^2 = 36.483$, p-value < 0.001). The first molar was significantly more affected by granuloma formation than the incisors, canines and second premolars, with ten of the 29 lesions observed (χ^2 between 9.08 and 6.7, p-value < 0.05 for all), followed by the second molar and first premolar with five lesions each. Only one periapical granuloma was found associated with the canines and incisors respectively and four third molars were affected.

Bony evidence of periodontal disease

Bony evidence of periodontal disease was noted in 39.5% ($N = 30$) of males and 53.8% ($N = 7$) of females. No significant differences were observed in the prevalence between males and females ($\chi^2 = 0.94$, p-value > 0.2). In previous research, it was found that 16 individuals possibly suffered from scurvy. Of these, seven showed signs of periodontal disease (43.8%) (Van der Merwe *et al.*, 2009c).

It should be kept in mind that scurvy, which was well documented to have been present in the sample population by the end of the 19th century, often results in chronic gingivitis, which in turn will result in periodontal disease (Dias & Tayles, 1997; Hirschmann & Raugi, 1999; Pimental, 2003). However no significant difference existed in the prevalence of periodontal disease between individuals suffering from scurvy and those who did not. It should be considered that periodontal disease also develops due to neglected oral hygiene, which would have had a big influence on the prevalence of this condition in all individuals.

Antemortem tooth loss

Antemortem loss of one or more teeth (Figure 2) was observed in 30.4% and 23.1% of males and females,

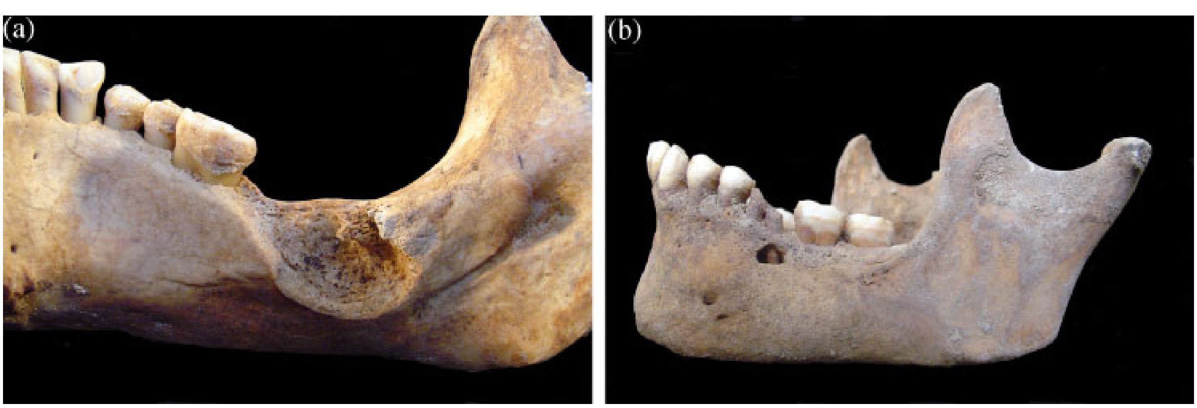

Figure 1. Possible periapical cysts/abscesses affecting the (a) right mandibular second and third molars in a female (33–43 years old) and (b) left mandibular first molar in a 25–30 year old male. This figure is available in colour online at www.interscience.wiley.com/journal/oa.

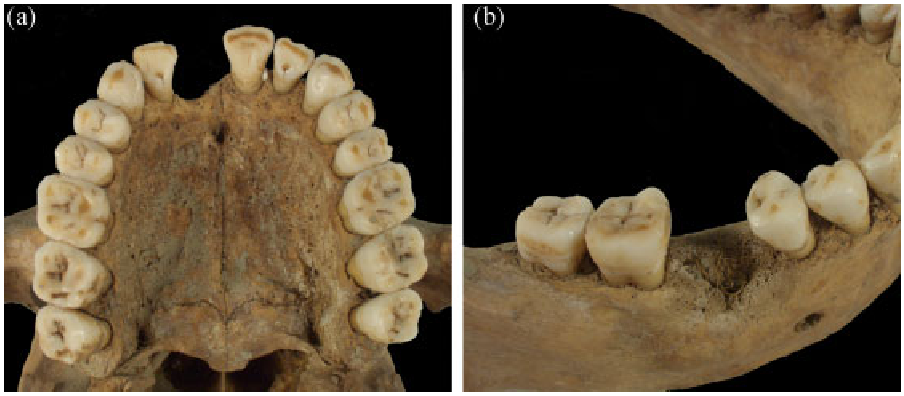

Figure 2. Antemortem tooth loss of the right maxillary first incisor (a) with complete resorption of the alveolar bone and (b) antemortem tooth loss of the right mandibular first molar shortly before death in a male, 30–40 years of age at the time of death. It can be seen here that the alveolar is only partially re-modelled. This figure is available in colour online at www.interscience.wiley.com/journal/oa.

Table 3. Summary of the prevalence of antemortem tooth loss (AMTL)

Sex	AMTL frequency[a]			AMTL Per mouth[b]			AMTL intensity[c]		
	n	nia	%	nia	nta	AMTL/m	nt	nta	%
Male	79	24	30.4	24	90	3.8	2381	90	3.8
Female	13	3	23.1	3	5	1.7	410	5	1.2
Total	92	27	29.3	27	95	3.5	2791	95	3.4

[a] Total number of individuals with one or more teeth lost antemortem/ total number of individuals present.
[b] Total number of teeth lost antemortem/ total number of individuals present.
[c] Total number of teeth lost antemortem/ total number of teeth present.
n, number of individuals investigated; nia, total number of individuals with one or more teeth lost antemortem; nta, number of teeth lost antemortem; AMTL/m, average number of teeth lost antemortem per mouth; nt, number of teeth present before AMTL.

respectively (Table 3). This yielded an AMTL intensity of 3.8% for males and 1.7% for females. Individuals who suffered from AMTL had an average of 3.5 teeth lost per mouth. No significant difference existed in the prevalence of individuals affected by AMTL between males and females ($\chi^2 = 0.287$, p-value > 0.5). A significant difference was, however, present in the AMTL intensity between males and females, with males being significantly more affected ($\chi^2 = 6.974$, p-value < 0.01).

As can be seen in Table 4, AMTL of the first molar (6.2% in total) was in general significantly more prevalent (χ^2 values between 5.74 and 9.38, p-value < 0.02 for all when testing the frequency of ATML of M1 against all the other specific types of teeth) than the ATML of any other tooth type. In

Table 4. Antemortem tooth loss per tooth type

Tooth	Male			Female			Total		
	n	na	%	*n*	na	%	*n*	na	%
I1	287	12	4.2	52	1	1.9	339	13	3.8
I2	290	11	3.8	52	1	1.9	342	12	3.5
C	299	6	2.0	52	0	0.0	351	6	1.7
PM1	303	5	1.7	52	0	0.0	355	5	1.4
PM2	303	9	3.0	52	0	0.0	355	9	2.5
M1	302	22	7.3	52	0	0.0	354	22	6.2
M2	304	13	4.3	52	2	3.8	356	15	4.2
M3	293	12	4.1	46	1	2.2	339	13	3.8
Total	2381	90	3.8	410	5	1.2	2791	95	3.4

n, total number of teeth present before AMTL; na, total number of teeth lost antemortem; I, incisor; C, canine; PM, premolar; M, molar.

females, however, the second molar was most often affected by AMTL, whereas males showed most frequent loss of the first molar. It should be kept in mind, though, that only three females were affected by AMTL, making any conclusions regarding the distribution of AMTL among females impossible. The rest of the molars and incisors followed the first molar, all being almost equally affected. Canines (1.7% in total) as well as premolars (1.4% and 2.5% respectively) were the least affected.

Enamel hypoplasia

EH was noted in 15.2% ($N = 14$) of individuals (Table 5). Of the 14 individuals with lesions, two showed evidence of pitting EH (Figure 3a) and 12 were cases of linear EH (Figure 3b). No significant difference exists between the prevalence of this defect in males and females ($\chi^2 = 0.664$, p-value > 0.25).

Due to the skewed demographic composition of the skeletal sample as well as the fact that they were historically documented to have most probably been migrant workers and thus did not develop the EH in Kimberley but at various different geographical locations, it was decided not to analyse these results any further.

Table 5. Summary of the prevalence of enamel hypoplasia

Sex	*n*	na	%
Male	79	13	16.5
Female	13	1	7.7
Total	92	14	15.2

n, total number of individuals; na, total number of individuals affected by enamel hypoplasia.

Discussion

By 1898 diamond mining in Kimberley progressed from a single diamond found on a hill by an opportunistic private prospector, into a huge industry. Colesberg Kopje became Kimberley and the mine became the property of the De Beers Consolidated mines (Kretschmet, 1998).

When mining activities commenced in Kimberley, all black labourers were given accommodation and food by their employers and were free to walk around town at own will. However, in 1885 a decision was made that all these labourers should be confined to closed camps (compounds) for the duration of their contracts at the mine. Several reasons were put forward for this confinement: it would prevent unlawful diamond trade, and this in turn would reduce the amount of diamonds stolen from the mine; labourers would have no access to alcohol, making them fit for work each day, and they would be given proper food, which according to the authorities, was sure to benefit their health (Roberts, 1976). Unfortunately, living conditions and diets in these camps were nothing as expected with historical governmental and hospital documents indicating that death and disease were regular occurrences in the overcrowded compound sheds (Stoney, 1900; Jochelson, 2001).

Historical documents indicated that the diets of mine workers housed in the compounds mainly consisted of maize meal and occasional coarse meat. There were also times when no food was being supplied to workers and they were responsible for buying and preparing their own meals. These meals, however, also did consist of not much more than maize meal and sauce since they were not earning much and only certain foods could be purchased at the compound shop (Harries, 1994). The diet of these individuals is

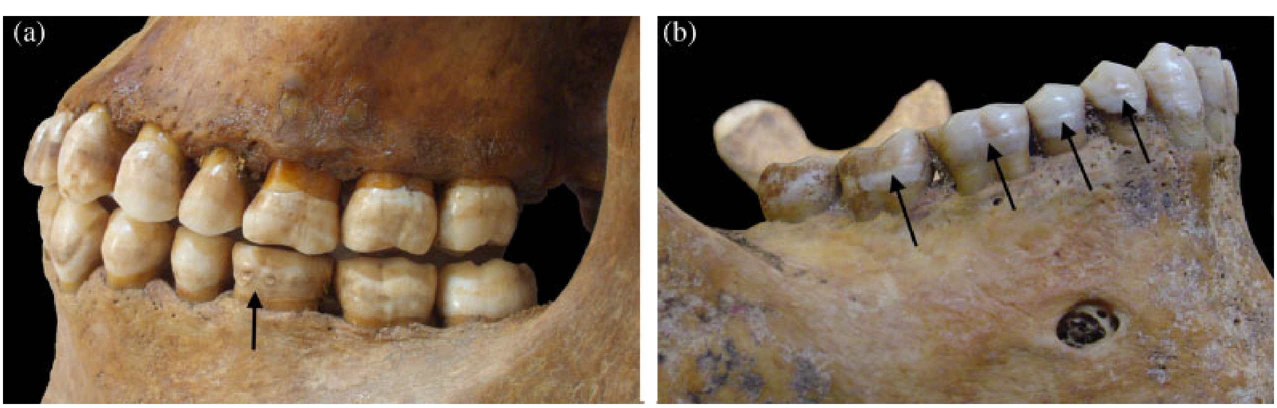

Figure 3. (a) The teeth of a 22–28 year old male with pitted enamel hypoplasia indicated by the arrow. (b) Linear enamel hypoplasie (arrows) as seen in a 50–60 year old male. This figure is available in colour online at www.interscience.wiley.com/journal/oa.

thus historically recorded to have been high in machine ground carbohydrates, low in animal proteins and low in fresh fruit and vegetables (Grusin & Samuel, 1957; Seftel *et al.*, 1966).

According to historical documents migrant labourers came from all over South Africa and its neighbouring countries to labour in the mines. Although differences in the diets between these traditional groups can be expected based on their geographical location and its associated agricultural advantages and disadvantages, all most likely followed a traditional agriculturalist diet since their rural villages were located several days travel by foot from the nearest urban settlement from which supplies could be obtained (Oranje *et al.*, 1935, Jochelson, 2001). Such a diet was most likely high in self-produced and ground carbohydrates and vegetables, occasional meat and naturally occurring fruit with limited access to varied amounts of machine ground carbohydrates and sugars based on the socio-economic status of the rural group (Oranje *et al.*, 1935).

As can be seen in Table 6, the Gladstone population had a much higher caries frequency (57%) when compared to a group who followed a traditional agricultural diet, such as the 'Primitive Xhosa' (36%), which was mainly composed of whole cooked maize with no to occasional access to sugar ($\chi^2 = 12.6$, p-value < 0.05).

In contrast, the caries intensity of the Gladstone skeletal population (5.3%) was significantly lower than those of populations with agricultural-urban diets such as the Venda (11.5%) and 'Urban Negro' (14.3%) ($\chi^2 = 17.9$ and 134.8 respectively, p-value < 0.05 for both). These diets were most likely characterised by high quantities of refined carbohydrates and sugars causing a dramatic increase in the number of individuals affected by dental decay.

The caries frequency, as was observed in the Gladstone skeletal sample, was statistically comparable to what was also recorded for the 'Mine Xhosa' (56%) ($\chi^2 = = 0.03$, p-value > 0.05), a contemporary living mining population of similar age distribution, as well as caries frequency of the skeletal sample from Maroelabult (56.6%) ($\chi^2 = 0.001$, p-value > 0.05). Interestingly, there were also no statistical difference in the caries frequencies between the Gladstone skeletal sample and the 'Primitive Xhosa' following a diet mainly consisting of ground maize ($\chi^2 = 1.8$, p-value > 0.05) and the regular consumption of sugar ($\chi^2 = 1.5$, p-value > 0.05) (Table 7).

It is of interest that the prevalence of dental caries is lower in the Gladstone sample when compared to the Koffiefontein population (86%), since both of these groups are late 19th century diamond mine workers. This difference may be due to the small sample size of the Koffiefontein skeletal sample with only 36 skeletons being recovered and the teeth of only 24 individuals being available for investigation, or it could be that sugar and maize were easier accessible to workers in the compounds where they were being housed.

The results and comparisons made for the prevalence of dental caries in the Gladstone sample do suggest a diet similar to what has been described in historical documents, and probably reflects a group of people who were experiencing changes in their eating patterns. The frequencies fit a diet high in ground carbohydrates with easier access to sugar than those following a strict agricultural-traditional diet such as the 'Primitive Xhosa', but definitely more restricted access than those samples that were not limited to products available in the mining compounds such as the Venda and the 'Urban Negro' (Oranje *et al.*, 1935; Staz, 1938; L'Abbé, 2005).

Table 6. The prevalence of dental caries among various other South African young male skeletal populations

	n	nia	nt	nta	Caries Frequency %	Caries intensity %	Carious teeth per mouth	χ^2	Source
Gladstone	79	45	2291	122	57.0	5.3	2.7		This study
Agricultural-traditional									
Primitive Xhosa	465	167	—	385	35.9	—	2.3	12.6*	Oranje *et al.*, 1935
Maroelabult	23	13	582	26	56.5	4.5	2.0	0.001	Steyn *et al.*, 2002
Mine labourers									
Mine Xhosa	90	50	—	217	55.6	—	4.3	0.03	Oranje *et al.*, 1935
Koffiefontein	24	21	1016	76	87.5	7.5	3.6	7.6*	L'Abbé *et al.*, 2003
Agricultural-urban									
Urban Negro	331	298	9178	1312	90.0	14.3	4.4	134.8*	Staz, 1938
Venda	—	—	305	35	—	11.5	—	17.92*	L'Abbé, 2005

* p-value < 0.0001, significant difference between previous study and results from Gladstone.
n, number of individuals investigated; nia, total number of individuals with one or more teeth lost antemortem; nt, number of teeth present before AMTL; nta, number of teeth lost antemortem.

Table 7. The prevalence of dental caries as observed in groups following an agricultural-traditional diet with varying amounts of sugar and refined carbohydrates

	n	nia	nt	nta	Caries frequency %	Caries intensity %	Carious teeth per mouth	χ^2	Source
Gladstone	79	45	2291	122	57.0	5.3	2.7		This study
Diet variation in primitive Xhosa									
No/occasional sugar	60	17	—	67	28	—	3,9	11.3*	Oranje *et al.*, 1935
Regular sugar	61	42	—	129	69	—	3,1	1.5	Oranje *et al.*, 1935
Unground maize	190	51	—	108	27	—	2,1	22.1*	Oranje *et al.*, 1935
Machine ground maize	157	75	—	166	48	—	2,2	1.8	Oranje *et al.*, 1935

* *p*-value < 0.05, significant difference between previous study and results from Gladstone.
n, number of individuals investigated; nia, total number of individuals with one or more teeth lost antemortem; nt, number of teeth present before AMTL; nta, number of teeth lost antemortem.

As was mentioned earlier, the prevalence of dental caries also varies between groups following an agricultural-traditional diet in relation to their socio-economic status and geographical location, since these two factor will have an influence as to whether they firstly can afford refined carbohydrates and sugars and secondly have access to a larger town from which to obtain these products from on a regular basis (Oranje *et al.*, 1935). This is most likely the reason why the prevalence of dental caries in the Gladstone sample was comparable to that observed in Maroelabult. Skeletal remains in the Maroelabult sample are believed to have been those of farm workers, and it is obvious that this will result in access to the products in question (Steyn *et al.*, 2002). It should be kept in mind though that there is still a significant difference between groups following agricultural-traditional and agricultural-urban diets and thus, although the prevalence of dental caries increases in the agricultural-traditional diet groups when their socioeconomic status changes, it does not reach the high levels observed in those groups residing in urban areas (Oranje *et al.*, 1935; Staz, 1938). It can accordingly be suggested that, as was mentioned in historical documents, the majority of individuals investigated in the Gladstone study did not permanently reside in Kimberley. The migrant labourers were in a way caught halfway between a traditional agricultural diet, which was followed in their rural homes, and the agricultural urban diet associated with the social and economic growth in Kimberley.

It may be suggested that the prevalence of carious lesions observed in this study was rather low for a carbohydrate rich diet as described in historical documents. This can possibly be explained by the young age of most individuals within this sample, a traditional less cariogenic diet when away from the mines, limited access to cariogenic food when working on the mines as well as the fluoride levels in the drinking water (Sealy *et al.*, 1992). Investigations showed that the fluoride concentrations of naturally occurring water in and around Kimberley are between 0.1 and 0.9 mg/L. These are within the optimal concentration levels to aid in the prevention of carious lesions (Silverstone *et al.*, 1981). It should, however, be considered that most individuals within this sample did most likely not originate from Kimberley and therefore they may not have been exposed to optimal levels of fluoride in their drinking water during the period of tooth development. It has been suggested that, apart from the antibacterial function of fluoride in drinking water, the absorption of fluoride into the enamel of adult teeth may also aid in the prevention of dental caries. The absorption of fluoride into adult tooth enamel is however dependant of the length of exposure of the teeth to the fluoride, the concentration of fluoride it is exposed to, the age of the individuals being studied as well as the different tooth surfaces under investigation (Tanaka *et al.*, 1993; Li *et al.*, 1994; Hirose *et al.*, 1996). It has thus been shown that the difference in absorbed enamel fluoride when comparing groups exposed to water from a naturally fluoridated area and those from a non-fluoridated area is not significant and therefore its influence in the prevention of dental caries is negligible (Li *et al.*, 1994).

The young age of the sample in conjunction with a low cariogenic diet, even though they were working in an economically expanding environment with easier access to refined carbohydrates and sugars, is therefore a plausible explanation for the low caries rate.

The first permanent molar is known to be the tooth mostly affected by the formation of carious lesions in populations with a diet mainly consisting of refined carbohydrates and sugars (Henneberg, 1991). Generally, it can be said that molars are the most affected, followed by premolars, incisors and lastly canines (Hillson, 1998; Henneberg, 1991). The same distribution of carious lesions was observed in this study. In general, posterior teeth (molars and premolars) were significantly more affected by carious lesions than anterior teeth (incisors and canines). However, the highest prevalence of carious lesions was found on the second molar, and not on the first molar as described by Henneberg (1991). This can most likely be explained by the pattern of AMTL in the Gladstone skeletal sample in which the first molars were mostly affected, accordingly skewing the distribution of dental caries.

In order to compensate for teeth lost antemortem a 'corrected caries intensity' was also calculated. This method functions on the assumption that all teeth lost antemortem were due to the effects of either dental caries or dental wear (Lukacs, 1995). As was seen in the study done by Lukacs (1995) on the Harappa population, an increase of the caries intensity was observed with the calculation of the 'corrected caries intensity'. It made the caries intensity double in the Harappa sample (from 6.8 to 12.1%), but only a small increase in intensity was observed in this study (from 5.4 to 8.1%). The reason for only this slight increase can be associated with the relatively low intensity of teeth lost antemortem (3.4%). It is obvious that with a low intensity of AMTL, the teeth present will be well representative of the prevalence of carious lesions within the skeletal population sample.

Large carious lesions, severe periodontal disease, advanced dental attrition and trauma are usually responsible for the antemortem loss of teeth (Bonfigliolo *et al.*, 2003). In this population, in which very little attrition was observed, the antemortem loss of teeth can most probably be ascribed to carious activity.

Although a high prevalence of periodontal disease (in some cases probably as a result of scurvy) was observed within this population, it could in general not be associated with the AMTL observed in the sample. The Gladstone skeletal sample presented with an average of only 3.5 teeth lost antemortem per individual affected by AMTL. It should be mentioned here that 63% of those affected by AMTL lost only a single or two teeth and that the average number of teeth lost antemortem was skewed by a single individual who was edentulous. By excluding this individual the average number of teeth becomes even lower with an average of 2.5 teeth lost antemortem by those affected by the condition. Furthermore, the loss of consecutive teeth, which would be expected in cases where periodontal disease is responsible for the AMTL, was only observed in nine individuals (33%). Thus, although periodontal disease cannot be excluded as a possible cause of the AMTL observed in this population, the pattern of AMTL does suggest that tooth loss was, in the majority of cases, the result of dental caries.

A study by Lukacs (1992) showed that the antemortem loss due to dental caries mostly affects molars, with anterior teeth such as incisors and canines seldom being affected. An opposite pattern of tooth loss, on the other hand, is observed in cases where teeth are willingly extracted for decorative or ritualistic purposes. When extractions are done for cosmetic purposes, the antemortem loss of anterior teeth is most often seen, since these teeth are the ones that are visible (Morris, 1998). It has also been shown that carious lesions most often affect the first molar. This is probably because this is the first permanent molar to erupt and it is thus longer exposed to cariogenic factors than the other molars (Henneberg, 1991; Steyn, 1994). Therefore, results indicating most frequent loss of M1 in this study are possibly indicative of tooth extraction, following dental caries to alleviate pain, or natural avulsion due to severe carious activity. It is suggested that teeth were most likely not willingly extracted for decorative purposes, since the prevalence of AMTL of anterior teeth would then have been much higher (Morris, 1989).

Dental trauma cannot be excluded as a reason for AMTL within this population. It can be suggested, however, that it did not have a significant influence since anterior teeth loss was not commonly observed.

The high prevalence of bony evidence of periodontal disease and periapical granulomata and -cysts also supports the hypothesis that this population had a diet consisting mainly of refined carbohydrates with access to sugar as the prevalence of these conditions can be expected to increase as dental health (carious lesions) and dental hygiene decrease. Very little dental wear was observed in this population, and the majority of periapical granulomata and -cysts formed as a result of periodontal disease and advanced stages of dental caries.

Conclusion

In conclusion, the prevalence of dental caries observed in the Gladstone skeletal sample suggests a diet relatively high in machine ground carbohydrates, although most probably not often highly refined carbohydrates, and concurs well with the historical accounts of a diet dominated by agricultural products such as maize meal. It probably also reflects the changing circumstances of the people in question, as they were caught somewhere in between their traditional eating habits and the more refined foods commonly associated with urban living. The young age of individuals within this population, the limited amount of time they spent in Kimberley as migrant labourers before returning to their traditional low cariogenic diets as well as the restricted access labourers housed in the compounds had to products sold outside of the compound walls all influenced the caries intensity observed in this sample population.

The antemortem loss of teeth observed in the Gladstone skeletal population is most likely the result of carious dental activity and periodontal disease associated with poor oral hygiene, although AMTL due to scurvy and dental trauma cannot be excluded. No pattern suggesting dental mutilation was observed in this population.

In general, the high prevalence of bony evidence of periapical granulomata and cysts and periodontal disease observed in this study supports the hypothesis of a carbohydrate rich diet and poor oral hygiene. Very little dental wear was observed, and the majority of periapical granulomata formed as a result of periodontal disease and advanced stages of dental caries.

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