Lead has no metabolic role in the human body and its presence is associated with various toxic effects. The deposition of lead in calcified tooth structure is indelible evidence of exposure to and absorption of lead. Under normal circumstances there is no turnover of calcified tooth structure once its matrix is complete and mineralised. In man, this absence of tissue turnover is unique to the calcified tooth layers. Therefore, tooth biopsies in vivo or after the removal of teeth from the body provide an absolutely reliable source of information about the deposition therein of substances such as lead, fluoride and tetracycline. Furthermore, the age at which the deposition took place can also be determined with a high degree of accuracy.

The deposition of lead in tooth structure is mainly the result of circulating blood lead, which is acquired largely via the inhalation of lead aerosol and, to a lesser extent, gastrointestinal absorption. Blood lead levels may fluctuate, dependent upon exposure to external sources and limited remobilisation of lead in bone and soft tissue during turnover. The presence of lead in different tissues of various South African populations has been studied since the early 1980s. However, the exhumation of human remains necessitated by urban redevelopment in the Cape Town area afforded a unique opportunity to determine lead concentrations in calcified tooth structures of people who lived in the Cape Town area during the period 1810 - 1922. Prior to 1921, minimal combustion of petrol took place in South Africa. Furthermore, leaded fuel was not utilised during that time. However, prior to 1922 the population was exposed to lead contamination in water reticulation systems, ceramic utensils, pewterware and minimal amounts of industrial and occupational waste. From 1922, an ever-increasing number of vehicles dependent upon leaded petrol for their fuel combustion came into use in South Africa.

The object of this study was to determine the lead concentrations in the circumpulpal dentine of the teeth of a population group who lived in the Cape Town area in the period before the combustion of leaded petrol.

Materials and methods

The teeth of 28 people, buried between 1863 and 1922 and exhumed recently, were analysed. The circumpulpal dentine was separated mechanically from the rest of each tooth with the help of a diamond disc cutter. The collected pieces of dentine of each tooth were etched with 1.0M hydrochloric acid to remove contamination, washed with lead-free water, dried, weighed and ashed in nitric acid as described by Keating et al. The lead in the final solution, which contained 5% nitric acid, was determined by means of graphite-furnace atomic absorption spectrometry, basically according to the method of Keating et al.

Results

The average age of the subjects was 43.6 years (SD = 29.3; median = 53.5; range 0.5 - 89 years). Table I shows the circumpulpal lead concentration (µg/g) in the exhumed teeth. The influence of age at the date of death on the lead levels is summarised in Table II. In general the lead concentration
increased significantly with the age of the donor ($P < 0.05$). The regression line for $y = ax^2$ was 0.73. Fig. 1 summarises the results of various workers and compares them with the result of this study.

Table I. Lead values in the circumpulpal dentine of teeth

<table>
<thead>
<tr>
<th>Age range (yrs)</th>
<th>Mean (SD)</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 - 10</td>
<td>106 (42)</td>
<td>65 - 122</td>
<td>5</td>
</tr>
<tr>
<td>11 - 20</td>
<td>262 (209)</td>
<td>124 - 503</td>
<td>2</td>
</tr>
<tr>
<td>21 - 30</td>
<td>219</td>
<td>110 - 237</td>
<td>1</td>
</tr>
<tr>
<td>31 - 40</td>
<td>173 (89)</td>
<td>116 - 310</td>
<td>3</td>
</tr>
<tr>
<td>41 - 50</td>
<td>254 (95)</td>
<td>217 - 583</td>
<td>6</td>
</tr>
<tr>
<td>51 - 60</td>
<td>354 (108)</td>
<td>200 - 454</td>
<td>4</td>
</tr>
<tr>
<td>61 - 70</td>
<td>482 (190)</td>
<td>259 - 697</td>
<td>4</td>
</tr>
<tr>
<td>71 - 80</td>
<td>646 (167)</td>
<td>528 - 764</td>
<td>1</td>
</tr>
</tbody>
</table>

Table II. Lead accumulation in circumpulpal dentine of excavated teeth in correlation with age at the date of death

<table>
<thead>
<tr>
<th>Age range (yrs)</th>
<th>Lead levels (µg/g dry weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
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</tbody>
</table>

Table Mountain served as the main catchment area for the water supply of Cape Town and surrounding areas for many years. Because of the presence of organic material, the water has a high acid content and is also soft (T. W. Timoney, Water Engineers Division, Cape Town City Council (retired) - personal communication). Therefore, a higher than normal dissolution of lead from the lead piping could have been expected. During 1812, the first reticulation system, linking the reservoirs on Table Mountain with Cape Town households was installed; the main pipes were constructed of cast iron while lead pipes linked each household to these. Many homes were equipped with wooden storage tanks, which were lead-lined and had lead-soldered joints in order to render them watertight. Such domestic water supply systems remained in use for over a century, until the Cape Town municipality appointed a special committee to investigate the problem of plumbago solvency in 1931.

SHAPIRO et al. (1973)$^{13}$
THIS STUDY
NEEDLEMAN et al. (1974)$^{24}$
MARESKY and GROBLER (1987)$^{25}$
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SHAPIRO et al. (1973)$^{13}$
DERISE et al. (1974)$^{26}$
NEEDLEMAN et al. (1974)$^{24}$
AL-NAIMI et al. (1980)$^{28}$
AL-NAIMI et al. (1980)$^{28}$
GROBLER et al. (1985)$^{25}$
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MARESKY and GROBLER (1987)$^{29}$
SHAPIRO et al. (1973)$^{13}$
GROBLER et al. (1985)$^{25}$
SHAPIRO et al. (1975)$^{27}$
RABINOWITZ et al. (1989)$^{28}$
KUHNLEIN and CALLOWAY (1977)$^{23}$
SHAPIRO (1980)$^{29}$
FOSSE and BERG-JUSTESEN (1978)$^{15}$

Discussion

No difference in the lead content was reported in various studies of deciduous teeth. Bercovitz and Laufer$^{28}$ also reported no significant difference in the lead level of different tooth types. However, Rabinowitz et al.$^{28}$ reported that differences in lead levels among tooth types are unlikely to reflect physiological factors such as blood supply to teeth or mineralisation rates. These differences are much more likely to depend on age-related, and consequently tooth-related, differences in exposure patterns. Thus, the general level of lead uptake could vary considerably during the various stages of tooth formation and at different time periods. In this study it was not possible to select the type of tooth from the excavated remains because of a lack of availability, while from the above results this also did not seem to be necessary.

Table Mountain served as the main catchment area for the water supply of Cape Town and surrounding areas for many years. Because of the presence of organic material, the water has a high acid content and is also soft (T. W. Timoney, Water Engineers Division, Cape Town City Council (retired) - personal communication). Therefore, a higher than normal dissolution of lead from the lead piping could have been expected. During 1812, the first reticulation system, linking the reservoirs on Table Mountain with Cape Town households was installed; the main pipes were constructed of cast iron while lead pipes linked each household to these. Many homes were equipped with wooden storage tanks, which were lead-lined and had lead-soldered joints in order to render them watertight. Such domestic water supply systems remained in use for over a century, until the Cape Town municipality appointed a special committee to investigate the problem of plumbago solvency in 1931.

Fig. 1. Comparison of various results.
In 1914 a report by the medical advisor, Dr J. Anderson, showed that domestic water supplies in Cape Town contained lead in concentrations ranging from 0.05 to 0.4 ppm. Furthermore, raw bulk supplies, allowed to stand overnight in new lead pipes, reached levels of 2.3 ppm. In 1917, samples of domestic water from Cape Town households tested by the State Health Laboratories showed levels ranging between 0.5 and 7.63 ppm. In 1926 three cases of lead-poisoning were reported. In Rosebank, a suburb of Cape Town, lead levels of 5.75 ppm were found. In New Church Street in the city, the level was found to be 0.5 ppm and in nearby Holf Street a level of 4 ppm was recorded. In all three cases, lead poisoning was found. In December 1928, a shop in Sir Lowry Road, equipped for soda water production, showed lead levels of 25.2 ppm. The soda water was prepared in copper tanks with leadsoldered joints. From there it was distributed to other outlets in the city.

Strong representations by Dr J. A. Mitchell (Assistant Medical Officer, Department of Home Affairs and later Secretary of the Department of Health) led to the Cape Town municipality's instituting a thorough investigation in early 1931 by a special committee (Cape Town Archives, 3/CT; 3A/10). In 1932, a decision was made to establish the first full-scale water treatment works at Constantia. This chemical treatment resulted in a 90% reduction in the leaching of lead into domestic water supplies. By 1938 several other treatment plants had been constructed and all Table Mountain's water was treated before it entered the domestic supplies of Cape Town (T. W. Timoney — personal communication). From about that time, lead pipes were gradually replaced by copper in all plumbing systems. However, many old houses in the Cape Town area had lead pipes for much longer, as was found in the District Six area during the 1970s.

In general we found an increase in tooth lead content with age (Table II). This has been reported by various authors. It must be remembered that lead was analysed in circumpulpal dentine, which is laid down continuously throughout life. A higher correlation between age and lead levels was therefore to be expected. The above reasons could also explain the high standard deviation (Table I). Furthermore, during the collection of circumpulpal dentine, the amount of other dentine which could not be physically separated would vary. Therefore, the lead levels in the circumpulpal dentine could be masked to a greater or lesser extent in different cases.

In this study we analysed the lead levels in the teeth of 6 children under the age of 15 years. The mean lead level was 109 µg/g. This is markedly higher than the 74 µg/g reported for children living in an industrialised urban area in Cape Town25 before the reduction of lead in petroleum (Fig. 1). The 74 µg/g level was attributed mainly to the degree of industrialisation and the petrol lead level of 0.8 g/l at that stage. The average lead level in the teeth of the adults over 15 years is 315 µg/g (N = 22). This is much higher than the 126 µg/g reported2 in a person who had been employed continuously as a motor technician in South Africa for 32 years, and had exhibited signs and symptoms typically manifested by people suffering from lead intoxication. However, an average level of 850 µg/g in the circumpulpal dentine of unequivocally lead-poisoned children from Philadelphia and Boston in the USA was reported.26 The lead level in this study (Table I) contrasts strongly with the low level of 2.5 µg/g reported for children in ancient Nubia where there was minimal lead detention in dentine showed. In dentine decreased with age up to an age of about 33 years, after which it stabilised. The Nubian children27 also showed a decrease in lead retention with increased age.

REFERENCES

30. Accepted 28 Dec 1993.