# A comparative analysis of periapical health based on historic and current data

**J. C. Chazel, P. Tramini, J. Valcarcel & B. Pélissier**
UFR d'Odontologie de Montpellier, Montpellier, France

## Abstract

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**Aim** To compare periapical health using samples from prehistoric and historic periods until the present day, and to emphasize the major risk indicators for apical periodontitis (AP).

**Methodology** A comparative survey to assess periapical health was performed on five samples (525 individuals) drawn from different periods of history within the time frame 2000 BC to 2000 AD. Twenty-one binary risk indicators for AP were retained for a logistic regression model. The probability of a diseased tooth was defined from a two-level response variable based on the periapical index (PAI). An individual regression model was computed with partial least squares (PLS) regression model, based on the individual mean values of the nine retained risk indicators.

**Results** Condensing osteitis, tooth wear, caries, root fillings and the presence of inadequate root fillings were associated with the PAI levels. The maxillary molars and recent time periods (contemporaneous and seventeenth century) were also risk indicators for the pathological condition. The PLS regression for individuals demonstrated correlations between risk factors. This multidimensional analysis indicated that the mean PAI was correlated mainly with caries and condensing osteitis. Condensing osteitis was more frequent in the mandibular than in the maxillary bone ($P = 0.001$), and correlated with tooth wear in ancient periods.

**Conclusions** This comparative analysis demonstrated a significantly higher prevalence of AP in the contemporary period. The most important risk indicators for that period were the presence of inadequate root fillings, carious lesions and condensing osteitis.

**Keywords:** apical periodontitis, condensing osteitis, dental anthropology, logistic regression, partial least squares regression.

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## Introduction

Many reports have investigated the evolution of caries experience from prehistoric times (Hardwick 1960, Hillson 2001), however, most studies on periapical health have evaluated contemporaneous populations (De Moor *et al.* 2000, Kirkevang *et al.* 2000, Boucher *et al.* 2002, Eriksen *et al.* 2002, Friedman 2002). With the exception of a genetic component that is difficult to control, these changes in periapical status over time are mostly environmental: individuals lived in conditions different from today and with no conservative dental treatment. These conditions included nutrition habits and sociologic factors, superimposed upon a lack of disease prevention (Maytie 1973, Alt *et al.* 1998, Hillson 2001, Lodter *et al.* 2003).

Some of these parameters had an influence on the lives of individuals and are reflected inside the dental and periapical tissues (Hardwick 1960, Molnar 1971, Smith *et al.* 1986).

Recent epidemiological studies of contemporaneous populations have shown that socioeconomic factors, secondary carious lesions, and inadequate conservative treatments are risks factors for apical periodon-

Correspondence: Dr J.C. Chazel, 5 place du castellas, 30540 Milhaud, France (Tel.: +33 4 66 74 26 03; fax: +33 4 66 74 10 11; e-mail: j-c.chazel@wanadoo.fr).

titis (AP) (Eriksen & Bjertness 1991, Ray & Trope 1995, Kirkevang & Wenzel 2003). Sometimes they are simply indicators for the disease process, but evidence for causality may require more complex cohort studies.

The objective of this study was first, to identify major risk indicators for the dependent variable, AP, by testing a regression model; then, to assess all the relationships between these parameters, and analyse their evolution through prehistoric and historic periods. The choice of potential risk factors was limited by the data available from archaeological material, so only those common to all period groups were selected. Conservative treatments were included, as a characteristic of modern populations.

## Materials and methods

Five samples of individuals drawn from five different historic periods were examined:

- P1: Prehistoric sample (2000 BC)
- P2: Late antique sample (300–600 AD)
- P3: Medieval sample (1000–1200 AD)
- P4: Recent historic sample (1500–1600 AD)
- P5: Contemporaneous sample (2000 AD).

The archaeological site from which P1 was taken was located in Roaix, south-eastern France. It was discovered some time ago, and the remains of 50 skulls and 570 teeth were examined (Table 1).

P2–P3–P4 came from a necropolis located near the Church of Notre Dame du Bourg and comprised 36, 107 and 109 skeletons, respectively, and 797, 2241 and 2221 teeth. In the analysis, teeth lost before death were differentiated from teeth lost after death (Hillson 2001). All well conserved archaeological remains were included in the analysis.

P5 included 223 patients, randomly selected from a private dental practice in Nîmes (5678 examined teeth). The inclusion criteria was four minimum remaining teeth. So all samples came from the same geographic area, south-eastern France (approximately 100 km range).

**Table 1** Number of examined teeth

| | P1 | P2 | P3 | P4 | P5 | Total |
|---|---|---|---|---|---|---|
| Anteriors | 186 | 325 | 926 | 862 | 2487 | 4786 |
| Premolars | 149 | 174 | 503 | 500 | 1473 | 2799 |
| Molars | 235 | 298 | 812 | 859 | 1718 | 3922 |
| Total | 570 | 797 | 2241 | 2221 | 5678 | 11 507 |
| Age 1 | 178 | 178 | 445 | 523 | 538 | 1862 |
| Age 2 | 134 | 170 | 832 | 886 | 2187 | 4209 |
| Age 3 | 258 | 449 | 964 | 812 | 2953 | 5436 |

The method of age estimation according to Masset (1982) was used in the archaeological samples. For all samples, three age groups were determined: age 1, between 12 and 25 years old; age 2, between 26 and 36 years old; and age 3, after 36 years old (Table 1).

Gender determination was based on pelvic bone examination, when this bone was well conserved (Ferembach *et al.* 1979).

Periapical health was assessed by radiographic examination: panoramic radiographs (P.M. proline of 2002 cc; Planmeca, Helsinki, Finland) and periapical radiographs (Philips generator, Oralix 65 kV, with a digital sensor, coupled with acquisition and image processing software, Wixwin 2.3; Gendex, Des Plaines, IL, USA). To evaluate AP, the periapical index (PAI) was used, as proposed by Ørstavik *et al.* (1986). It has been used in many epidemiological studies (Eriksen & Bjertness 1991, Kirkevang & Wenzel 2003), usually with a threshold for disease set at a score greater than 2. Thus, a score equal to or greater than three was categorized as a diseased periapex.

The individuals from P1 to P5 were examined with dental mirrors and dental explorers, and diagnosis was made at the caries into dentine threshold. For P5, restored surfaces were categorized as carious. The caries and PAI registrations were performed by one examiner and prior to this study, intraexaminer agreement was determined using the kappa test on a randomly selected sample of 50 individuals ($\kappa = 0.82$ for caries and 0.80 for PAI).

A radiological manifestation of the apical area, condensing osteitis, was not frequently encountered, but constant through this 40-century range analysis. Studies on this structure have been few (Bhaskar 1966, Marmary & Kutiner 1986, Maixner *et al.* 1992, Caliskan *et al.* 1997), especially in archaeological remains. It often appears to be transitory and develops most often without subjective symptoms (Marmary & Kutiner 1986). It may be reversible, spontaneously change into disease, or be accompanied by AP. Condensing osteitis was clearly identified as a radiopaque region in the periapical area.

Tooth wear was evaluated using the method of Brabant (1962), with five levels of wear (from 0 to 4), following the nature of the tissue concerned with the loss of tissue.

The quality of coronal restorations and endodontic treatments for P5 was evaluated upon clinical and radiographic examinations (Fava & Dummer 1997). Coronal treatments included intra-coronal restorations and crowns. Coronal restorations were recorded as inadequate when radiographic signs of overhangs, open margins, or caries were found. Root fillings were inadequate when the radiographs showed voids along the walls of the canal, or when the root filling ended more than 2 mm from the radiographic apex (Kirkevang *et al.* 2000).

## Statistical analyses

The mathematic modelling was based on PAI as the response variable ($Y$), and the other variables as independent, explanatory variables ($X_i$).

### Regression model at the tooth level

Although this model could yield the probability of disease $p(Y = 1)$, for a given tooth, knowing the $X_i$ values measured on this tooth (prediction), the focus was on testing the association between $Y$ and all the $X_i$.

In this case, $Y$ is a binary response variable: $Y = 0$ for PAI $\leq 2$ and $Y = 1$ for PAI $> 2$.

The explanatory variables and their respective levels are shown in Table 2.

**Table 2** Variables and codes for the logistic regression

| Variable | Level 1 | Level 0 |
|---|---|---|
| $Y$ | PAI > 2 | PAI ≤ 2 |
| $X_1$ | Period 1 | – |
| $X_2$ | Period 2 | – |
| $X_3$ | Period 3 | – |
| $X_4$ | Period 4 | – |
| $X_5$ | Period 5 | – |
| $X_6$ | Age 1 | – |
| $X_7$ | Age 2 | – |
| $X_8$ | Age 3 | – |
| $X_9$ | Female | Male |
| $X_{10}$ | Maxilla | Mandible |
| $X_{11}$ | Anterior | – |
| $X_{12}$ | Premolar | – |
| $X_{13}$ | Molar | – |
| $X_{14}$ | Decayed | – |
| $X_{15}$ | Tooth wear 0 + 1 | – |
| $X_{16}$ | Tooth wear 2 | – |
| $X_{17}$ | Tooth wear 3 | – |
| $X_{18}$ | Tooth wear 4 | – |
| $X_{19}$ | Condensing osteitis | – |
| $X_{20}$ | Coronal restoration | – |
| $X_{21}$ | Root filling | – |
| $X_{22}$ | Inadequate coronal restoration | Adequate coronal restoration |
| $X_{23}$ | Inadequate root filling | Adequate root filling |

So a binary response variable and 21 dichotomous variables were defined as disjunctive variables. Some of them might be undisclosed confounders. In this model, a multidimensional analysis of correlations could be performed with a logistic regression model (Hosmer & Lemeshow 1989). With $p(Y)$ ranging from 0 to 1, the following general model could be established:

$$p(Y = 1/X_i) = \frac{1}{1 + \exp\left(-\sum_{i=0}^{i=21} \beta_i x_i\right)} \qquad \text{with } X_0 = 1$$

where $\beta_i$ represented the adjusted effect of each $X_i$. Then we could calculate an estimation of the odds ratio (OR) for each $X_i$: OR $= e^{\beta}$ was calculated.

Specifically for the contemporaneous period (P5), we added two supplementary variables, concerning the quality of conservative treatment: adequate coronal restorations ($X_{22}$) and adequate root filling ($X_{23}$).

The variables $X_1$ to $X_5$ (periods) and $X_9$ (sex) were no longer present, and the tooth wear variables were reduced to two levels: (0 + 1 + 2) and (3 + 4). So this model now included 15 independent variables.

### Regression model at the individual level

This model could both test the association of the explanatory variables with the response variable, and predict the mean PAI for a given individual, knowing the $X_i$ mean values measured on his/her teeth. As in the tooth level, the analysis was restricted to the statistical test of association between the variables.

In this case, the logistic regression model was no longer used, because it strongly depended on the cut-off values determined for the construction of the class variables of the individual.

The statistical units were now the individuals, with a number $q$ of remaining teeth ($4 \leq q \leq 32$). A partial least squares linear regression model (PLS) which best fitted the data was used. The aim was to best fit the $Y$ vector of the response variable by the $X_i$ matrix and observe their common structure. This statistical analysis used the outcome of a principal component analysis into a linear regression: at each iteration of the algorithm, it maximized the covariance between each component and the unexplained part of the $Y$ vector (Wold 1966). It was both a descriptive and predictive analysis and was appropriate for various types of data, because it did not have the limitation of a parametric model, and took into account the coliniarity between the $X_i$, although it may lead to a singular matrix

(Tenenhaus & Gauchi 1995). Contrary to the logistic regression, explanatory variables were no longer categorical, but quantitative: the individual mean values of $Y$ and $X_i$ were retained, which therefore were weighted by the number of remaining teeth. The eight independent variables involved in the regression were: age, period, caries, missing teeth, condensing osteitis, tooth wear, coronal restorations and root fillings. For the analysis of P5, variables 'adequate coronal restorations' and 'adequate root filling' were used instead of 'period'. The outcome of the regression was then represented on a graph which plotted the different positions of the $X_i$ towards $Y$, according to their respective correlations. This provided a global representation of the problem, which included the explanation of $Y$ by the $X_i$. The between-variable distances were proportional to their correlations: when a variable was located at the end of an axis (horizontal or vertical), while another variable at the other end of the same axis, the two variables were found highly negatively correlated. Thus, these analyses combined computation of factorial analysis with those of the partial least squares regression.

### Untreated teeth analysis

Another between-period analysis was carried out, in order to retain only non-treated teeth in the analysis. So the proportion of teeth with PAI > 2 in the historic group (P1 + P2 + P3 + P4) with a subset of P5 concerning solely non-treated teeth (65.2% of the remaining teeth) were compared.

All the statistical analyses were performed with SAS software package (SAS Institute Inc., Cary, NC, USA) and the coefficients of the PLS regression were optimized using the SAS interactive matrix language.

## Results

### General regression model at the tooth level (between periods study)

Condensing osteitis was the most influent risk indicator, with an OR = 20.6 (confidence interval: 12.2–34.7). This was followed by tooth wear (level 4): OR = 18 (11.8–27.5), caries OR = 10.5 (8.7–12.6), and root filling OR = 7.8 (5.8–10.5). It was noteworthy that tooth wear variables had an OR proportional to the attrition levels (Table 3). Moreover, the lowest level (no attrition) even became a protective factor: 0.4 < OR < 0.7.

**Table 3** Results of logistic regression for general model

| Independent variable | Odds ratio (CI) | P |
|---|---|---|
| Period 1 ($X_1$) | – | 0.38 (ns) |
| Period 2 ($X_2$) | – | 0.73 (ns) |
| Period 3 ($X_3$) | – | 0.31 (ns) |
| Period 4 ($X_4$) | 1.7 (1.3–2.2) | 0.0004 |
| Period 5 ($X_5$) | 2.8 (2.1–3.7) | 0.0001 |
| Age 1 ($X_6$) | – | 0.10 (ns) |
| Age 2 ($X_7$) | – | 0.73 (ns) |
| Age 3 ($X_8$) | – | 0.23 (ns) |
| Maxilla ($X_9$) | 1.3 (1.1–1.6) | 0.0005 |
| Anterior ($X_{10}$) | – | 0.25 (ns) |
| Premolar ($X_{12}$) | – | 0.25 (ns) |
| Molar ($X_{13}$) | 1.5 (1.3–1.8) | 0.0001 |
| Caries ($X_{14}$) | 10.5 (8.7–12.6) | 0.0001 |
| Condensing osteitis ($X_{15}$) | 20.6 (12.2–34.7) | 0.0001 |
| Abrasion 0 + 1 ($X_{16}$) | 0.5 (0.4–0.7) | 0.0001 |
| Abrasion 2 ($X_{17}$) | 1.9 (1.5–2.4) | 0.0001 |
| Abrasion 3 ($X_{18}$) | 4.5 (2.3–4.4) | 0.0001 |
| Abrasion 4 ($X_{19}$) | 18 (11.8–27.5) | 0.0001 |
| Coronal restoration ($X_{20}$) | 1.6 (1.2–2.2) | 0.0006 |
| Root filling ($X_{21}$) | 7.8 (5.8–10.5) | 0.0001 |

The P4 and P5 period variables had a significant effect on periapical health. The most ancient periods (P1, P2 and P3) had no effect, that is why less pathology was found for these periods. The coronal restorations variable was significant too: OR = 1.6 (1.2–2.2).

The molar and maxilla variables, although influent, had a non-significant OR. Periapical disease was more prevalent for maxillary teeth than for mandibular teeth.

The age variable did not seem to be influent.

The chi-square test of the likelihood of the model is significant ($P = 0.0001$). This means that the combined effect of all independent variables in the model is significant.

**Table 4** Results of logistic regression for the contemporary population

| Independent variable | Odds ratio (CI) | P |
|---|---|---|
| Age 1 | 0.3 (0.1–0.6) | 0.0009 |
| Age 2 | – | 0.97 (ns) |
| Age 3 | – | 0.97 (ns) |
| Maxilla | 1.3 (1.0–1.5) | 0.0147 |
| Anterior | – | 0.56 (ns) |
| Premolar | – | 0.56 (ns) |
| Molar | 1.6 (1.3–1.9) | 0.0001 |
| Caries | 7.9 (6.3–10.0) | 0.0001 |
| Condensing osteitis | 27.9 (9.8–79.9) | 0.0001 |
| Abrasion 0 + 1 + 2 | 0.4 (0.3–0.5) | 0.0001 |
| Abrasion 3 + 4 | 1.7 (1.2–2.4) | 0.0012 |
| Coronal restoration | 1.8 (1.3–2.4) | 0.0006 |
| Root filling | 9.6 (7.0–13.3) | 0.0001 |
| Adequate coronal restoration | – | 0.51 (ns) |
| Adequate root filling | 8.0 (5.5–11.7) | 0.0001 |

 

### Regression model at the tooth level in P5

Differences from the general model consisted of the significant influence for the inadequate root filling variable: OR = 8.0 (5.5–11.7) (see Table 4). The 'presence of root filling' variable still was significant: OR = 9.6 (7.0–13.3). Tooth wear variable had the same effect as in the general model. The OR for condensing osteitis is still very high: 27.9 (9.8–79.9). The presence of this bone structure for a given tooth could be deduced as a major risk indicator for the periapical status of this tooth. A tooth with a condensing osteitis stood a chance of having AP 28 times greater than a tooth without condensing osteitis. In addition, if it was a molar, with an inadequate root filling, the probability of disease approached 93%.

### General regression model at the individual level (between periods study)

The nine variables involved in this model were plotted in the graph of the correlation circle (Fig. 1). The geometrical distances were computed knowing the regression of $Y$ on the $X_i$, actually the variables were positioned around the explanation of the mean PAI. Three variables were correlated to the PAI: 'caries', 'age' and 'missing teeth'. Thus, a correlation between PAI and age group, which did not exist in the tooth model, was found. The difference came from the individual factor introduced in the partial least squares regression model. But 'coronal restorations' and 'root fillings' were very close to 'period'; they were indeed specific to the P5 period.

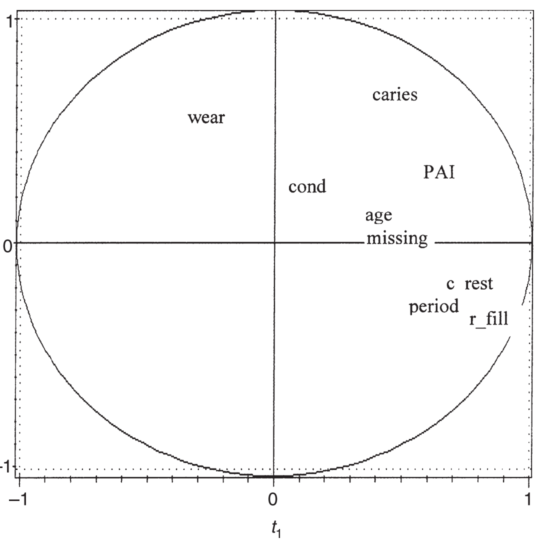


**Figure 1** Correlations between variables for the general model. PAI; caries; wear = tooth wear; cond = condensing osteitis; miss = missing teeth; age; period; c_rest = coronal restoration; r_fill = root filling.

The tooth wear variable was somewhat isolated from all the rest, and negatively correlated to the previous group (fillings and period). 'Condensing osteitis' was playing an interesting and specific role: it was the only independent variable to have a non-significant correlation with the first latent variable ($P = 0.21$). But it showed a significant correlation with the second latent variable ($P < 0.01$), as did 'tooth wear' and 'caries'. This led to consideration a bidimensional approach of the correlations between the $X_i$. 'Condensing osteitis' was in some way highly correlated to 'tooth wear' and 'caries', but some components of this variable were specific and not correlated to any variable.

### Regression model at the individual level in P5

The regression line of this model is represented in Fig. 2. The correlations between variables can be seen in Fig. 3. The difference with the previous analysis (between periods) was the peculiar role of 'tooth wear', now correlated with PAI and restorations. The 'adequate restorations' variables showed a strong negative correlation with PAI and caries. A close relation between 'adequate coronal restorations' and condensing osteitis was found, with an almost opposing situation with caries versus condensing osteitis. 'Age' and 'tooth wear' variables were now well correlated, because unlike ancient periods, a high level of abrasion was encountered mostly among older individuals. The relation between PAI, caries and condensing osteitis was remarkably similar to the one found in the previous model.

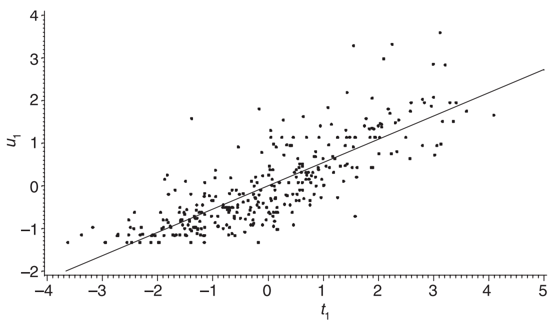


**Figure 2** Regression line computed from the teeth of P5, which indicates the correlation between PAI ($u_1$) and a linear combination of the $X_i$ ($t_1$).

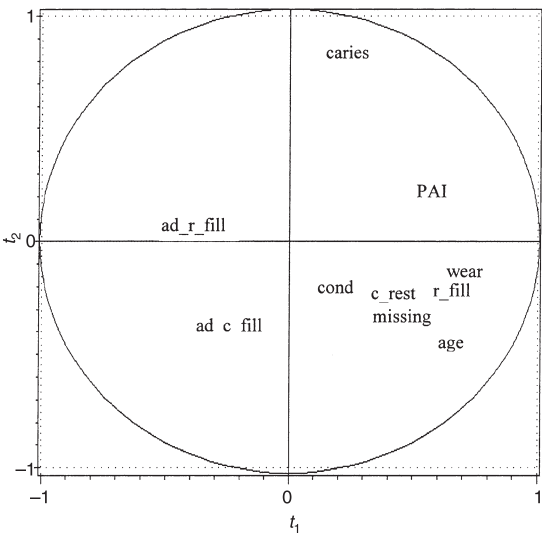


**Figure 3** Correlations between variables in P5. PAI; caries; wear = tooth wear; condens = condensing osteitis; miss = missing teeth; age; c_rest = coronal restoration; r_fill = root filling; ad_c_rest = adequate coronal restoration; ad_r_fill = adequate root filling.

### Untreated teeth analysis

The proportion of teeth with PAI > 2 was 7.5% for the historic group and 5.2% for P5 (significant chi-square, $P = 0.001$). When the treated teeth were included, the proportion changed to 11.4% for P5, now significantly greater than the proportion in the historic periods.

The logistic regression without treated teeth gave the same results as those when treated teeth were included, except for the 'molar' variable, which became non-significant. This was in accordance with the well-known phenomenon that the first molar is often diseased, and thus the tooth treated most often, and often associated with periapical disease (Linn *et al.* 1987, Hillson 2001).

The variable 'gender' was not significant for any analysis, with the exception of the distribution of 'condensing osteitis': this lesion was found more frequent among females ($P = 0.04$) and only within archaeological periods.

## Discussion

For archaeological material, clinical or radiological data, can be incomplete (Ferembach *et al.* 1979). For example, age or gender determinations were uncertain for some individuals. Those individuals were therefore eliminated from the analysis, when such variables were necessary.

The 'period' effect tested by logistic regression appeared only to be significant for the most recent periods, P4 and P5, where it was found that AP was more common than in the ancient periods. However, the odds ratios were low and only weakly significant. In other words, at a global level, periapical health had not changed through the ages. This conclusion should be restricted to the samples of this study, and is not necessarily generalizable.

The distribution of apical lesions per period, as a function of the presence of condensing osteitis, is shown in Fig. 4; the individual distribution of condensing periodontitis is detailed in Table 5. A relatively low proportion of teeth with condensing osteitis had a PAI ≤ 2, a sound periapex. This proportion became significant for periods P1 and P4. These periods appeared to have the most severe tooth wear, and most of the teeth involved in this condensing bone structure were not diseased, or had only minor damage. This fact was consistent with the competition process between abrasion and decay (Maat & Van der Velde 1987, Clarke & Hirsch 1991, Keiser *et al.* 2001). However, in this particular case of no caries, condensing osteitis no longer appeared to be involved in AP.

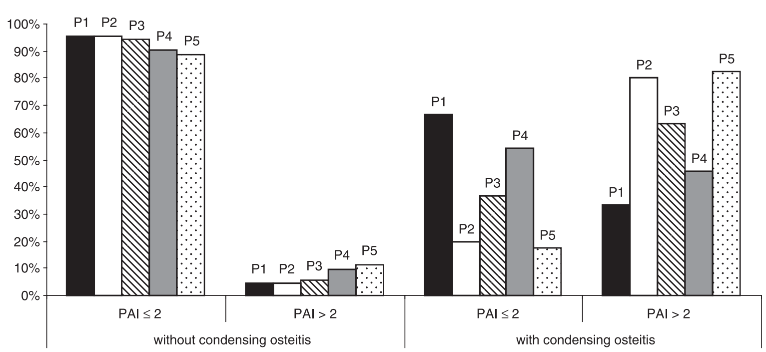


**Figure 4** Distribution of condensing osteitis per period.

**Table 5** Percentage of individuals with one (or more) condensing osteitis

| Period | With condensing osteitis |
|---|---|
| P1 | 10.0 |
| P2 | 13.9 |
| P3 | 22.4 |
| P4 | 19.3 |
| P5 | 12.6 |

Thus, condensing osteitis could be a non-specific response to irritation, whereas AP is specific to infection.

Some reservations remain over the findings on the effect of conservative treatments on periapical health. Indeed, it was impossible to assess the periapical status before the completion of restorative or endodontic treatment. Thus, it was impossible to identify it as a treatment effect (Eriksen & Bjertness 1991). For example, only in the modern sample, the percentage of teeth with a PAI > 2 was 24.5% for treated teeth, and 5.2% for non-treated teeth. The difference was significant, but the conclusion is still uncertain (Whitworth 2000).

Another factor involved in periapical disease needs further consideration, that is, was it healing and on the way to recovery, or unfavourable and associated with post treatment disease at the time of the PAI evaluation? All these disadvantages could be avoided by a follow-up study. But concerning the variable effects as risk indicators, a good estimation of their relative risk could be achieved through the odds ratio estimations.

When comparing logistic and PLS regressions results, the former mainly represented the risk of one tooth developing apical disease, and the latter expressed the probability at the individual level. There was a major difference especially for the 'condensing osteitis' variable, which was more influential in the model at the tooth level than in the model at the individual level. These radiopaque lesions appeared to be more frequently associated with the mandible than the maxilla (87%/13%, chi-square test, $P = 0.001$, significant), as found by Marmary & Kutiner (1986). But the proportion of teeth with PAI > 2 was higher for the maxilla (53%/47%, chi-square test, $P = 0.001$, significant). It could be assumed that a different bone response pattern occurs in the two jaws: and perhaps the propensity to develop condensing osteitis in the mandibular teeth could reflect an increased resistance evolving more spontaneously into the intermediate step of the condensing process. This could delay the transformation into fully developed apical lesions, but the evidence of that should require more histological observations. In a way, the occurrence of condensing osteitis is indeed a risk indicator for AP, but may be an opportunity for the practitioner to play a role in prevention. However, this type of reaction did not seem to be a constant evolution of the periapical pathology, and only occurred when the irritation was chronic or subacute, just as responsive dentine, generated by the pulpo-dentinal complex is a reaction against caries irritation.

## Conclusions

This study allows a better understanding of the major role of condensing lesions in AP, and more generally its possible role in recovery. The results of the PLS regression showed that the response variable was partly generated from caries and partly from condensing lesions, and that condensing lesions were sometimes independent from caries. Thus, some of these lesions occurred without any obvious cause, apart from an association with substantial attrition, when no carious lesions were present.

Moreover, the regression models could predict with minor risk of error the periapical health for a given tooth, and more globally, the mean PAI index for an individual. The logistic regression analysis provided 80% of concordant pairs in the prediction. The goodness-of-fit (between observed and predicted responses) was significant ($P = 0.0001$). However, 20% of the variance was not explained by the model. This remaining proportion was partly due to the between-subject variability. It could be improved by including other pertinent risk factors among the explanatory variables. But the study was limited by the partial information available from the archaeological material. Another way to improve the goodness-of-fit could be the use of more complex statistical modelling such as nonlinear partial least square regression (Wold 1992).

## References

Ørstavik D, Kerekes K, Eriksen HM (1986) The periapical index: a scoring system for radiographic assessment of apical periodontitis. *Endodontics and Dental Traumatology* **2**, 20–34.

Alt KW, Rosing FW, Teschler-Nicola M (1998) *Dental Anthropology. Fundamentals, Limits and Prospects*. New York: Springer, Wien.

Bhaskar SN (1966) Periapical lesions. Types, incidence and clinical features. *Oral Surgery, Oral Medicine and Oral Pathology* **21**, 657–71.

Boucher Y, Matossian L, Rilliard F, Machtou P (2002) Radiographic evaluation of the prevalence and technical quality of root canal treatment in a French subpopulation. *International Endodontic Journal* **35**, 229–38.

Brabant H (1962) Contribution à l'étude de la palèopathologie des dents et des maxillaries. La denture en Belgique à l'époque nèolithique. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique* **38**, 1–32.

Caliskan MK, Turkun M, Oztop F (1997) Histological evaluation of a tooth with hyperplastic pulpitis and periapical osteoslerosis. *International Endodontic Journal* **30**, 347–51.

Clarke NG, Hirsch RS (1991) Tooth dislocation: The relationship with tooth wear and dental abscesses. *American Journal of Physical Anthropology* **85**, 293–8.

De Moor RJG, Hommez GMG, De Boever JG, Delmé KIM, Martens GEI (2000) Periapical health related tot the quality of root canal treatment in a Belgian population. *International Endodontic Journal* **33**, 113–20.

Eriksen HM, Bjertness E (1991) Prevalence of periapical periodontitis and results of endodontic treatment in middle-age adults in Norway. *Endodontics and Dental Traumatology* **7**, 1–4.

Eriksen HM, Kirkevang L-L, Petersson K (2002) Endodontic epidemiology and treatment outcome: general considerations. *Endodontic Topics* **2**, 1–9.

Fava LRG, Dummer PMH (1997) Periapical radiographic techniques during endodontic diagnosis and treatment. *International Endodontic Journal* **30**, 250–61.

Ferembach D, Schwidetzky I, Stloukal M (1979) Recommandations pour déterminer l'âge et le sexe sur le squelette. *Bulletin et mémoires de la Société d'Anthropologie de Paris* **6**, 7–45.

Friedman S (2002) Prognosis of initial endodontic therapy. *Endodontic Topics* **2**, 59–88.

Hardwick JL (1960) The incidence and distribution of caries throughout the ages in relation to the English-man's diet. *British Dental Journal* **108**, 9–17.

Hillson S (2001) Recording dental caries in archaeological dental remains. *International Journal of Osteoarchaeology* **11**, 249–89.

Hosmer DW, Lemeshow S (1989) *Applied Logistic Regression, 2nd edn.* New York: John Wiley & Sons Inc.

Keiser JA, Kelsen A, Love R, Herbison PGP, Dennison KJ (2001) Periapical lesions and dental wear in the early Maori. *International Journal of Osteoarchaeology* **11**, 290–7.

Kirkevang L-L, Wenzel A (2003) Risk indicators for apical periodontitis. *Community Dentistry and Oral Epidemiology* **31**, 59–67.

Kirkevang L-L, Ørstavik D, Hörsted-Bindslev P, Wenzel A (2000) Periapical status and quality of root canal fillings and coronal restorations in a Danish population. *International Endodontic Journal* **33**, 509–15.

Linn JW, Clarke NG, Smith Srikandi T (1987) Radiographic and visual assessment of alveolar pathology of first molars in dry skulls. *American Journal of Physical Anthropology* **72**, 515–21.

Lodter JP, Grimoud AM, Gatignol JM, Zerbib A, Boulbet-Mauger M (2003) La dent en anthropologie. *Encyclopédie Médico-Chirurgicale* **22**, 1–11.

Maat GJR, Van der Velde EA (1987) The caries-attrition competition. *International Journal of Anthropology* **2**, 281–92.

Maixner D, Green TL, Walton RE, Leider A (1992) Histological examination of condensing osteitis. *Journal of Endodontics* **18**, 196.

Marmary Y, Kutiner G (1986) A radiographic survey of periapical jawbone lesions. *Oral surgery, Oral Medicine and Oral Pathology* **61**, 405–8.

Masset C (1982) Erreurs systématiques dans la détermination de l'âge par les sutures crâniennes. *Bulletin et mémoires de la Société d'Anthropologie de Paris* **7**, 85–105.

Maytie A (1973) Aspect évolutif de la carie dentaire de la Préhistoire à nos jours. *Actualités Odontostomatologiques* **104**, 767–80.

Molnar S (1971) Human tooth wear, tooth function, and cultural variability. *American Journal of Physical Anthropology* **34**, 175–90.

Ray HA, Trope M (1995) Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. *International Endodontic Journal* **28**, 12–8.

Smith P, Wax Y, Adler R, Silberman U, Heinic G (1986) Pleistocene changes in tooth, root and jaw relationships. *American Journal of Physical Anthropology* **70**, 339–48.

Tenenhaus M, Gauchi JP (1995) Régression PLS et applications. *Revue de Statistique Appliquée* **43**, 7–63.

Whitworth JM (2000) Apparent periapical repair without operative intervention: a case report and discussion. *International Endodontic Journal* **33**, 286–9.

Wold H (1966) Estimation of principal components and related models by iterative least squares. In: Krishnaiah PR, ed. *Multivariate Analysis*. New York: Academic Press, pp. 391–420.

Wold S (1992) Nonlinear partial least squares modelling. II. Spline inner relation. *Chemometrics and Intelligent Laboratory Systems* **14**, 71–84.