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Prediction of future marginal bone level: a radiographic study

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Abstract

Aim: The aim of the study was to predict the marginal bone level at a 5-year follow-up based on the information available from an initial radiographic examination and to evaluate the precision of the prediction by comparing the predicted bone levels with those actually observed at the follow-up.

Materials and Methods: In 1997, 616 randomly selected dentate individuals underwent a full-mouth radiographic survey. In 2003, 473 of those individuals (77%) participated in a second radiographic examination. Marginal bone level, caries lesions, fillings, crowns, root fillings and periapical status were recorded on all teeth. On the basis of data available from the first examination, a linear mixed model regression analysis with the tooth as the unit of analysis was used to predict the marginal bone level 5 years later.

Results: Number of teeth, smoking, and also presence of apical periodontitis and crowns were associated with bone loss and could be used as predictors of future marginal bone level.

Conclusion: The analysis of all teeth showed that the number of tooth- and person-specific factors at the first examination influenced the prediction of the marginal bone level at the 5-year follow-up examination. However, the performance of the combined prediction model was less satisfactory.

Key words: longitudinal; marginal bone level; prediction; radiography

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In epidemiological studies of marginal periodontitis one of the major problems is definition and threshold for disease. This problem is further complicated by the use of different sources of information. Most epidemiological studies of marginal periodontitis are based on information gathered from clinical examinations, fewer studies rely on information from radiographic examinations and rarely both types of data are available (Leroy et al. 2010). The type of data available influences the definition of the endpoint used in previous investigations of factors associated with disease. These problems may impede the comparison of different studies, and risk factors identified in one study will not necessarily be those found in others. Comparisons are further complicated by lack of a clear distinction between prevalence, incidence and progression of the disease.

Several person-related risk factors for marginal periodontitis have been identified including smoking, insufficient oral hygiene, genetics, diabetes mellitus and age (Genco 1996, Khader et al. 2003, Paulander et al. 2004, Torrungruang et al. 2005, Van Dyke & Sheilesh 2005). On the tooth level, pocket depth, radiographic marginal bone level, bleeding on probing, dental plaque, vertical bony defects and others have been associated with marginal periodontitis (Haffajee et al. 1991, Papapanou & Wennström 1991, Schätzle et al. 2004, Airila-Månsson et al. 2005). The presence of these risk factors may aggravate existing disease, but does not necessarily cause the disease (Leininger et al. 2010). It is well known that disease progression varies among individuals, and that individual risk factors influence the progression rate (Heitz-Mayfield 2005). The rate of disease progression is important for the practitioner as it influences the treatment plan for the patient. If the practitioner could predict the future course of the disease, it would improve the individual treatment plan, and eventually the chance of a successful treatment outcome.

In recent years focus has been on identifying person-related risk factors

Conflict of interest and source of funding statement

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Ethical statement: The study was conducted with the understanding and after receiving written informed consent from each participant. The regional Committee of Ethics had approved the study design.

for disease progression, and several diagnostic models have been developed in an attempt to assist the clinician in making risk assessments for further progression of marginal periodontitis. These diagnostic models have all addressed the disease on the individual level and include clinical, radiographic and person-specific variables. One of the most well-known approaches is the hexagonal risk diagram for periodontal risk assessment (Lang & Tonetti 2003), but comparable models have been developed by others (Page et al. 2002, Persson et al. 2003).

The aim of the present study was to predict the marginal bone level at a 5-year follow-up radiographic examination based on the information available from an initial radiographic examination and basic demographic factors. The precision of the prediction was determined by comparing the predicted bone levels to those actually observed at the follow-up examination.

Materials and Methods

Population

In 1997 a random sample of 1199 individuals, 601 men and 598 women, was drawn from the population of approximately 380,000 individuals born between 1935 and 1975 and living in Aarhus County, Denmark. Six hundred and sixteen (51.4%) dentate individuals (304 women and 312 men), signed and returned the consent form and were included in the study in 1997 (Kirkevang et al. 2001, Bahrami et al. 2006). In 2003, the 616 individuals were contacted once more by letter and offered to participate in a longitudinal study, where they would undergo a new full-mouth radiographic survey. The time period between the first (1997/1998) and the second (2003/2004) radiographic survey was on average 5.5 years (SD = 0.4 years). Of the 616 individuals, 481 (78%) accepted the invitation, and 473 individuals eventually participated in the study because eight did not show up even after two reminders. Thus, the attendance rate for the longitudinal study in 2003 was 77%. The 473 individuals had 12,444 teeth at the first registration; 107 teeth were lost during the study period. The regional Committee of Ethics had approved the study design both in 1997 and 2003.

Radiographic recording

At both examinations the participants underwent a full-mouth radiographic survey consisting of 14 periapicals and two bitewings, one in each side. Regions, where tooth loss had occurred during the study period, were also examined in 2003. In 1997, all radiographs were taken with a ''GX 1,000'' X-ray unit (Gendex Corporation, Milwaukee, WI, USA), using the paralleling technique, 70 kV, 10 mA, a film-focus distance of 28 cm, and Kodak Ektaspeed Plus film (Eastman Kodak, Rochester, NY, USA). Film processing was automated in the same developing machine (Dürr 1330, AC 245L, Bietigheim-Bissingen, Germany). In 2003, the radiographic procedure was similar to the one in 1997 except for the choice of film as Kodak Insight film (Eastman Kodak) was used. By choosing the fastest well-documented film on the market, the radiation dose to the participants was minimized (Ludlow et al. 2001).

At the time of the first radiographic survey the patients completed a short questionnaire, which included a question about smoking habits with two response categories: ''non-smoker'' and ''smoker''. The intensity and frequency of smoking were not assessed. No data from clinical examinations were obtained from the participants or their dentists.

Radiographic assessments

The radiographs from both surveys were used to assess all teeth except third molars. The marginal bone level was measured, under a magnifying glass (× 1.3) with a digital calliper from the cemento-enamel junction to the most coronal part of the marginal bone (A), at the mesial (A_m) and distal (A_d) part of the tooth, at which the lamina dura had a normal width (Björn et al. 1969). In the case of a coronal restoration extending beyond the cemento-enamel junction, the border of the restoration was used as the reference point. The teeth were grouped in molars, premolars, canines and incisors. The average marginal bone level for each tooth was calculated: $A_{tooth} = (A_m + A_d)/2$. Average marginal bone level for each individual was calculated as follows: $A_{ind} = \sum A_{tooth} / N_{teeth}$.

The radiographic registrations also included: caries lesions, fillings, crowns, root fillings and periapical status. Caries lesions were considered present if the lesion had reached the dentine. The periapical status was assessed using the periapical index (PAI) (Ørstavik et al. 1986). The periapical recordings (PAI) were classified into healthy periapical bone defined as PAI scores 1 or 2 and apical periodontitis (AP) defined as PAI scores 3, 4 or 5. Fillings, crowns and root fillings were recorded as absent or present on each tooth. Periapical status and caries lesions were assessed by one examiner (L.-L. K.). All other variables were recorded by another examiner (G. B.). The number of remaining teeth for each individual was categorized as $\leqslant 20$ teeth or > 20 teeth.

Reproducibility of bone level measurements was assessed in radiographs from 20 individuals with a total of 514 teeth. Bone level measurements on these radiographs were assessed four times within a 16-month period. The average change between successive measurements was 0.05 mm, and the pooled standard deviation of the four repeated measurements was 0.46 mm (Bahrami et al. 2006).The examiner (L.-L. K.) of the periapical status was calibrated to the ''golden standard atlas'' of PAI before evaluating the material (Ørstavik et al. 1986). The Cohen's κ was 0.813.

Statistical analysis

Linear mixed model regression analysis with the tooth as the unit of analysis was used to predict the marginal bone level in 2003. The dependent variable was marginal bone level in 2003 measured in millimetres, and the independent variables used in the prediction were based on information available at the 1997 registrations. The validity of the prediction was determined by comparing the predicted values of the marginal bone level to the actual bone level value observed in 2003. The analysis was based on all teeth present at both examinations. The regression model included two random components, person and tooth, to distinguish the between- and within-person variations. Potential predictors included both person-specific variables (age, smoking, number of remaining teeth) and tooth-specific variables (tooth number, jaw, side, caries lesion, crown, filling, root filling, periapical status and marginal bone level).

The analysis assessed the predictive information in each variable, and a predicted value of the marginal bone level of a tooth in 2003 was derived from the

informative variables. The prediction error had both a between-person and a within-person component. The formula of the predicted value was: $b_0+b_1z_1+b_2z_2+b_3z_3+\ldots+b_kz_k$, where $z_1+z_2+\ldots+z_k$, refer to the person- and tooth-specific factors that were included in the prediction. The average marginal bone level of the tooth and the average marginal bone level of the individual were included as the first two predictors, i.e. $z_1 = A_{\text{tooth}}^{1997}$ and $z_2 = A_{\text{ind}}^{1997}$. The regression coefficients $b_0+b_1+\ldots+b_k$ described the relative importance of each predictor, and in the analysis these parameters were estimated from the data.

Supplementary analyses included a separate analysis of teeth with a reduced marginal bone level (>4 mm) in 1997–98. The linear mixed model approach was also used for the supplementary analyses.

SPSS version 13 was used for data management. The data were then transferred to Stata version 9, which was used for all statistical calculations. The level of statistical significance was $p<0.05$.

Table 1. Tooth- and person-specific factors contributing to the prediction of the marginal bone level

	All teeth*		
Information from 1997 to 1998 registrations	regression coefficient†	standard error	*p*-value
Marginal bone level			
Tooth	0.618	0.027	< 0.001
Person average	0.375	0.040	< 0.001
Gender‡			
Male	0.076	0.041	0.062
Number of teeth‡			
$\leqslant 20$	0.268	0.135	0.047
Smoking‡			
Yes	0.238	0.045	< 0.001
Crown‡			
Present	0.218	0.055	< 0.001
Apical periodontitis‡			
PAI >2	0.201	0.074	0.006
Random effects	Variance		
Person	0.174		
Tooth	0.446		
Intraclass correlation	0.280		

*Analysis based on 465 persons with 11,671 teeth.
†Estimates are mutually adjusted and also adjusted for tooth number in each jaw (tooth number estimates shown in Fig. 1).
‡Reference category for gender: female; for number of teeth: <20; for smoking: no; for crown: absent; for apical periodontitis: PAI <2.

Results

The analysis was based on 11,671 teeth with complete information from both registrations. Several factors influenced and impaired the measuring of the marginal bone level. Overlapping of anatomical structures, overlapping approximal surfaces, angulation errors and others resulted in 666 immeasurable teeth. At the baseline registration 1204 teeth had a reduced marginal bone level. During the study period 107 teeth were lost, and were hence excluded from the study. At the first registration the average marginal bone level of all teeth was 2.51 mm, and at the second registration the corresponding average was 3.21 mm.

In the analysis of all teeth the prediction model had a constant term (b_0) equal to 0.40 mm with a standard error (SE) of 0.07 mm, i.e., b_0 is the marginal bone loss for a tooth with all the applied risk factors absent. The regression coefficient (SE) for marginal bone level in 1997 was 0.62 (0.03), and the regression coefficient associated with the person's average marginal bone level was 0.38 (0.40) (Table 1). The prediction further depended on the tooth number in each jaw. Figure 1 shows the contribution of each tooth relative to the mandibular canines, which were used as reference teeth. The prediction shows that the largest values of marginal bone loss were expected for maxillary molars and for mandibular first incisors.

The analysis of all teeth furthermore showed that a number of tooth- and person-specific factors influenced the prediction of the marginal bone level in 2003 (Table 1). A tooth with a crown was expected to have 0.22 mm additional marginal bone loss compared with a similar tooth without a crown, and the predicted marginal bone loss for a tooth with AP was 0.20 mm larger than that of a similar tooth without AP. If the person smoked the predicted marginal bone loss of a tooth was increased by 0.24 mm compared with a similar tooth of a non-smoker, and if the person had 20 teeth or fewer in 1997 the predicted marginal bone loss of one of the remaining teeth was 0.27 mm more than for a similar tooth of a person with more than 20 teeth. Finally, the analysis indicated that the marginal bone loss was slightly larger for a tooth in men compared with a similar tooth in women. This difference was however not statistically significant ($p = 0.06$). Wald's test was used to provide an overall assessment of the predictive value of the variables included in the model. The test statistics was highly significant ($\chi^2(20) = 2738$, $p<0.001$). Inclusion of additional variables did not lead to a statistically significant improvement of the prediction.

To elaborate on the use of the prediction formula, consider a male smoker with 27 teeth in 1997 with an average marginal bone level (A_{ind}) of 2.7 mm, and assume that his tooth number 36 has no crown, nor AP, and that the marginal bone level for the tooth (A_{tooth}) is 2.4 mm. The predicted marginal bone level 5 years later was computed as follows:

$$\begin{aligned}\text{Prediction} = {} & 0.40 + 0.62 \cdot 2.4 + 0.37 \cdot 2.7 \\ & + 0.08 \cdot 1(\text{tooth } 36) \\ & + 0.22 \cdot 0(\text{no crown}) \\ & + 0.20 \cdot 0(\text{no AP}) \\ & + 0.24 \cdot 1(\text{smoker}) \\ & + 0.27 \cdot 0(>20 \text{ teeth}) \\ & + 0.08 \cdot 1(\text{male}) = 3.29,\end{aligned}$$

Thus, the prediction postulates that the marginal bone level of this tooth would be 3.29 mm in 2003.

The regression model explained 37% of the variation between teeth from the same person and 87% of the between-person variation giving an overall R^2 of 68%. However, the unexplained variation was still considerable. The between-person variation had a standard

deviation of 0.42 mm, and the within-person standard deviation was 0.67 mm. The standard deviation of the total prediction error was 0.79 mm, so the width of a 95% prediction interval was approximately 3 mm.

In the analysis restricted to the subset of teeth with a reduced baseline marginal bone level (≥4 mm), gender, number of teeth and AP were not statistically significant predictors for further bone loss (Fig. 2). The predictive value of the model was also here highly significant (Wald's test: $\chi^2(20) = 600$, $p < 0.001$). Compared with the analysis of all teeth the impact of smoking almost doubled. The between-person variation had a standard deviation of 0.49 mm and the within-person standard deviation was 1.12 mm, so the uncertainty of the prediction was larger in this analysis, which can be due to lower number of teeth included in the analysis.

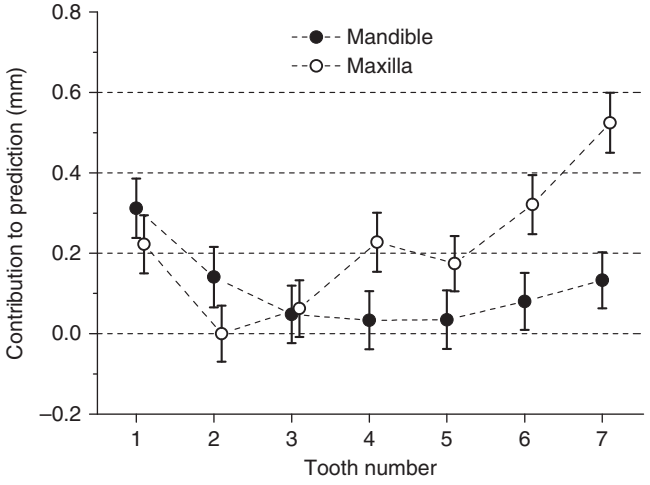

Fig. 1. Contribution to the predicted value for each tooth relative to the mandibular canines.

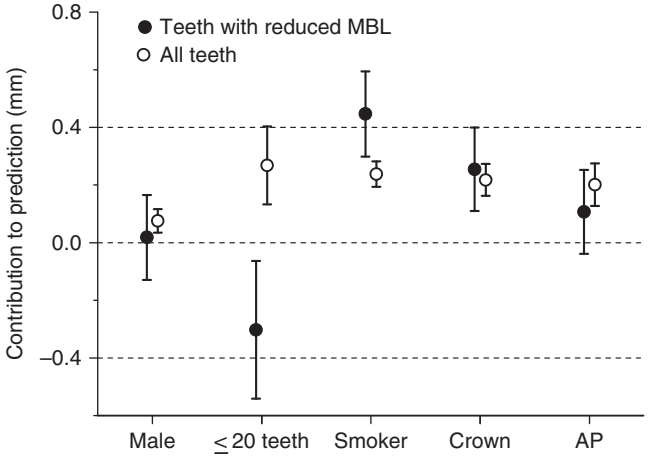

Fig. 2. Tooth- and person-specific factors contributing to the prediction of the marginal bone level in teeth with a reduced baseline marginal bone level (≥4 mm), and all teeth (scale bars showing ± 1 SE).

Discussion

Several reviews regarding marginal periodontitis have stressed the need for identification and quantification of risk factors related to disease progression (Page & Beck 1997, Borrell & Papapanou 2005, Leroy et al. 2010). These reviews have mainly focused on marginal periodontitis as a disease of the individual, and the discussion of risk factors has therefore concentrated on person-specific factors. Moreover, the risk assessment tools presented in the literature have typically been based on expert opinions rather than on evidence derived from appropriate statistical analyses of actual data.

In the present study, the data were derived from radiographs and a short questionnaire. In particular, no data from clinical examinations were available. Therefore, the endpoint was the marginal bone level. The tooth, rather than the surface, was chosen as the unit of analysis. This decision reflected that some of the tooth-specific variables are not related to surfaces of a tooth. This is in particular the case for root fillings and periapical status. The use of a rigorous statistical approach allowed evaluation of risk factors related both to tooth- and person-level. Moreover, a prediction of the future bone level was estimated from the risk profile of the tooth, and the error of prediction could be determined by comparing the predicted value with the measured value in 2003. Ideally, the assessment of the predictions should be based on independent data to avoid a too optimistic evaluation caused by the use of the same data to first drive the prediction model and next to assess its predictive value. This may be a problem, in particular in small studies with considerable variable selection.

Studies using a similar approach as the present are rare (Albandar et al. 1995), and this complicates a direct comparison of the results with those found in the literature. Nevertheless, an overall comparison of the risk factors identified here and those previously described may still be possible. Moreover, an advantage of the regression method is the ability to quantify the precision of the prediction by giving an estimate of the SE of the prediction. This knowledge may improve the dentist's ability to evaluate the implication of the risk profile for the tooth or for the patient.

The statistically significant prediction factors were: individuals with less than 20 teeth, smokers, teeth with AP, and teeth with crowns. Males had a slightly higher risk of marginal bone loss than females, however, this was not statistically significant. The number of teeth had the largest influence on the prediction of further marginal bone loss in our study. This may be explained by the fact that teeth often are lost due to marginal periodontitis (Anagnou-Varelzides et al. 1986, Jansson & Lavstedt 2002, Jansson et al. 2002, Bahrami et al. 2008) and that individuals with few teeth, therefore, often display marginal periodontitis

and a reduced bone level. This association could also explain the reason why the risk factor was not more pronounced since the teeth with severe marginal bone loss were lost during the study period, thus skewing the results. Smoking was another contributor to marginal bone loss. The influence of smoking on further marginal bone loss has been shown in several studies (Norderyd & Hugoson 1998, Kinane & Chestnutt 2000, Bergström 2004). AP was moreover a statistically significant risk factor for marginal bone loss. The association between marginal and AP and the influence of apical lesions on progression and healing of marginal disease has been shown in several studies (Ehnevid et al. 1993, Jansson et al. 1993a, 1995a, b). The presence of a crown at baseline also had an effect on the marginal bone loss observed after 5 years. This may be explained by an increased gingival inflammation due to sublingually placed crown margins with a possibly poor fit (Sorensen et al. 1986, Goldberg et al. 2001). However, this study was limited in recognizing the implications of crown treatment since only the presence or absence of full crowns was registered. The marginal fit or possible caries lesion under the crown was not assessed.

Besides analysing all teeth in the study, a separate analysis of teeth with baseline marginal bone level $\geqslant 4$ mm was performed. In a previous study, it was shown that these teeth lost more marginal bone in a 5-year period (Bahrami et al. 2007). Furthermore, teeth with a reduced marginal bone level were more likely to be lost during a 5-year period (Bahrami et al. 2008).

The purpose of the present study was to predict the future marginal bone level by applying a regression model, based mainly on radiographic variables from a randomly selected sample of individuals. The analysis identified a number of risk factors that had a statistically significant association with future bone level. These risk factors were similar to those previously reported in other studies (Burt et al. 1990, Jansson et al. 1993b, 2002, Norderyd et al. 1999, Torrungruang et al. 2005, Van Dyke & Sheilesh 2005). A prediction model derived from these risk factors was also investigated. The analysis showed that the prediction model could explain a large part of the variation of the dependent variable. However, the unexplained variation was still considerable so the SE of the predictions was relatively large, both for the prediction of the bone level for a tooth and for the prediction of the average bone level for a person. Consequently, the prediction intervals were rather wide. The low precision of the results reflected the large variation between and within individuals. It is not likely that other endpoints are easier to predict, but previous prediction models have not quantified the uncertainty. The precision of the prediction would possibly be improved if important clinical variables were included in the prediction model, but this information was not available in the present study.

In conclusion, it was shown that number of teeth, smoking, AP and crowns are risk factors for bone loss and may be used as predictors of future marginal bone level. However, the performance of the combined prediction model was less satisfactory.

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Clinical Relevance

Scientific rationale for the study: Investigating the possibility of predicting further marginal bone loss, by identifying possible risk factors in individuals.

Principal findings: Number of teeth, smoking and also presence of AP and crowns were associated with bone loss and may be used as predictors of future marginal bone level.

Practical implications: Marginal periodontitis is a multi-factorial disease that causes loss of marginal bone and eventually tooth loss. Tooth and individual factors influence a further marginal bone loss. The possibility of predicting further marginal bone loss, based on baseline observations would assist the practitioners in making an optimal treatment plan and thus increase the chance of success of a treatment.