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Risk factors for tooth loss in an adult population: a radiographic study

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Abstract

Aim: The aim of the present study was to estimate the incidence and identify risk factors for tooth loss during a 5-year period in a randomly selected Danish population.

Material and Methods: In 1997 and 2003, 473 randomly selected adults received a full-mouth radiographic examination. The total number of teeth was 12,444. For each tooth, the following information was recorded from the radiographs: marginal bone level, filling, crown, root canal post, root filling, apicectomy, periapical status and caries lesion. Unconditional and conditional logistic regression analyses were used to identify risk factors for tooth loss.

Results: During the study period, 107 teeth in 60 individuals were lost. On the individual level, reduced marginal bone level and apical periodontitis (AP) were highly associated with tooth loss. On the tooth level, a reduced marginal bone level, AP and apicectomy were strongly associated with tooth loss. Canines were not lost often, whereas tooth loss was more frequently observed in molars and premolars than in incisors.

Conclusions: A reduced marginal bone level and AP were associated with tooth loss over time. Furthermore, there was a higher risk of tooth loss in the posterior regions than in the anterior region.

Key words: apical periodontitis; longitudinal; marginal bone level; radiography; tooth loss

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Dental health has improved in Western countries, and people are more likely to keep their teeth. However, some teeth are still lost and several factors may influence the decision to extract a tooth.

Conflict of interest and source of funding statement

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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.

Apart from the disease processes in the tooth, pain, overall dental status and treatment plan may contribute to the decision. More generally, socio-economic aspects may also be important. Associations between tooth extraction and dental diseases have been extensively studied. Caries lesions and pulpal diseases have been shown to be associated with tooth loss. Some studies have shown that caries lesions, especially root and secondary caries lesions, were the primary reason for tooth extractions in elderly individuals (Fure & Zickert 1997, Fure 2003).

A Swedish study of patients referred to a department of radiology showed that root-filled teeth, teeth with root canal posts and teeth with apical periodontitis (AP) were at higher risk of being lost than teeth without endodontic treatment (Eckerbom et al. 1992). Similar findings have been reported by others (Caplan et al. 2005, Willershausen et al. 2005, Wegner et al. 2006).

Marginal periodontitis has also been identified as a risk factor for tooth loss, and several studies have shown that periodontal maintenance treatment is effective in postponing tooth loss (Tonetti et al. 2000, Konig et al. 2002, Fardal et al. 2004). A reduced marginal bone level has been shown to be associated with an increased risk of tooth loss (Dannewitz et al. 2006). Also, individuals with few remaining teeth had a higher risk of tooth loss than individuals with a full dentition (Dannewitz et al. 2006).

Risk factors for tooth loss have been shown to be gender (men had a higher

risk of tooth loss than women) (Fardal et al. 2004), age (Papapanou et al. 1989) and smoking (Axelsson et al. 1998, Albandar et al. 2000, Dietrich et al. 2007). Moreover, social factors (Burt et al. 1990) and income (Gilbert et al. 1999) have been shown to have an impact on loss of teeth.

The aim of the present study was to estimate the incidence of tooth loss and identify risk factors for tooth loss during a 5-year period in a randomly selected Danish adult population. The focus of the study was on risk factors related to dental diseases and their sequelae.

Material and Methods

Population

In 1997, a random sample of 1,199 individuals, 601 men and 598 women, was drawn from the 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 thereby included in the study in 1997 (Kirkevang et al. 2001, Bahrami et al. 2006a). In 2003, the 616 individuals were once more contacted 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 [standard deviation (SD) = 0.4 years)]. Of the 616 individuals, 481 (78%) accepted to participate in the study; however, only 473 eventually participated 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. 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 still examined in 2003. In 1997, all the 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; Dürr, Bietigheim-Bissingen, Germany). In 2003, the radiographic procedure was identical to 1997, except 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 radiographic survey, the patient completed a questionnaire, in which the smoking habits of the individuals were recorded.

Radiographic assessments

In all the teeth except third molars, the radiographs were used to assess all variables. Tooth loss was determined by comparing the recordings from the two examinations.

The marginal bone was measured 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). The remaining bone measurement was performed from the most coronal part of the bone, at which the lamina dura had a normal width, to the apex of the root in question, mesially (B_m) and distally (B_d). 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 radiographic registrations also included coronal restorations (fillings and crowns), root canal posts, root fillings, apicectomies, periapical status and caries lesions. The categories for these variables are shown in Table 1. The periapical status was assessed using the periapical index (PAI) (Ørstavik et al. 1986). Periapical status and caries lesion were assessed by one examiner (L.-L.K.). All the other variables were recorded by another examiner (G.B.). Table 2 displays the distribution of individuals according to the categoriza-

Table 1. The definitions for tooth-related variables other than marginal bone level

Filling	Crown	Root canal post	Root filling	Apicectomy	Periapical status (PAI)	Caries (primary and secondary)
Absent	Absent	Absent	Absent	Absent	Normal	Absent
Amalgam	Metal-ceramic	Parallel	Present	Apicectomy (+apical filling)	Small changes in bone structure	Caries in enamel
Composite	Metal	Conical		Apicectomy (− apical filling)	Changes in bone structure with some mineral loss	Caries in dentine
	Full ceramic	Stepwise			Demineralization of periapical bone with well-defined radiolucent area	Caries reaching the pulp
	Metal-ceramic (FDP)*				Demineralization of periapical bone with exacerbating features	
	Metal (FDP)*					
	Full ceramic (FDP)*					

*Fixed dental prosthesis.
PAI, periapical index.

tions considered in the individual-level analyses.

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 SD of the four repeated measurements was 0.46 mm (Bahrami et al. 2006a).

The radiographs from the second survey were merely used to identify missing teeth.

Data treatment

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: $A_{ind} = \Sigma A_{tooth}/N_{teeth}$. The thresholds for marginal bone level in mm (A_{ind}) were defined as $A_{ind} < 3$ mm, normal marginal bone level; $3 \leqslant A_{ind} < 4$ mm, borderline marginal bone level and $A_{ind} \geqslant 4$ mm, reduced marginal bone level. These thresholds were used because the average ''anatomic'' distance from the cemento-enamel junction to the marginal bone crest varies between individuals and has been reported to be between 0.4 and 3 mm (Tugnait et al. 2000). This distance and the observed measurement error were taken into account when defining the threshold for a reduced marginal bone level ($A \geqslant 4$ mm) and the borderline marginal bone level ($3 \text{ mm} \leqslant A < 4$ mm) in the present study (Bahrami et al. 2006a). The remaining bone for each tooth was calculated as $B_{tooth} = (B_m + B_d)/2$, and was analysed both in mm and as a percentage of the root length.

The periapical recordings were classified into healthy periapical bone defined as PAI scores 1 or 2 and AP defined as PAI scores 3, 4 or 5 (Table 1). The remaining variables (crowns, fillings, root fillings, root canal posts, apicectomies and caries lesions) were recorded as absent or present. Caries lesions were considered present if the lesion was reaching into the dentine.

Statistical analysis

A dropout analysis was performed to determine whether there were significant differences between the two groups (the participants and the non-participants of the second radiographic survey) with respect to their initial marginal bone level, number of teeth, gender and age. The comparison of the initial marginal bone level was performed using the Mann–Whitney *U*-test, both on the individual level, for each age group (20–39 years, 40–49 years, 50–59 years and 60+ years) as well as for all the ages combined. The same analysis was used for number of teeth. The analysis of gender was performed using χ^2-test, while an independent sample *t*-test was used for the analysis of age. Tooth loss between the two examinations was analysed with both the individual and the tooth as the statistical unit. Individual-based potential risk factors included gender, age, smoking, average marginal bone level and number of teeth at the first examination. Also the association between tooth loss and the number of teeth with AP, fillings, crowns, root canal posts and root fillings was studied on individual level. In the analyses, these variables were categorized as shown in Table 2. In particular, the cut points used for the number of teeth reflected that approximately 75% of the individuals had at least 26 teeth and more than 50% of the individuals had all 28 teeth. In the crude analyses, the association between tooth loss and each of the individual-based factors was analysed separately by logistic regression analysis with tooth loss as the outcome (0 = no loss, 1 = at least one lost tooth). In the final model, each independent variable was adjusted for average marginal bone level, the presence of AP and apicectomy. The results were described by odds ratios (OR) and 95% confidence intervals (95% CI).

Conditional logistic regression analysis was used to identify tooth-specific factors associated with tooth loss. In these analyses, teeth that were lost during the 5-year study period were compared with the same individual's teeth that were not lost, and results were described by an OR with a 95% CI. This ensured that the influence of the variables on tooth level was corrected for the individual-level variables, e.g. socio-economic factors and smoking. The tooth-specific factors and the categorization used in the analysis are shown in Table 4. Marginal bone level was here represented as a continuous variable, because preliminary analyses of different categorizations revealed that the risk increased well beyond 4 mm and that the increase was approximately linear in the measured value when modelled by a logistic regression. Associations between tooth loss and each of the potential risk factors on tooth level were first assessed separately. In the final model, the variables were adjusted for marginal bone level, AP, apicectomy and tooth group.

SPSS version 13 (SPSS Inc. Chicago, Ill. USA) was used for data manage-

Table 2. The distribution of individuals according to the categorizations considered in the individual-level analyses

	n	⩾1 lost teeth	%	*p*-value*
Marginal bone level				
<3 mm	366	19	5.2	
3–4 mm	56	11	19.6	
⩾4 mm	51	30	58.8	<0.001
AP				
0	278	6	2.2	
1	101	15	14.9	
⩾2	94	39	41.5	<0.001
Apicectomies				
0	451	52	11.5	
⩾1	22	8	36.4	0.001
Fillings				
<7	61	4	6.6	
7–16	304	43	14.1	
⩾17	108	13	12.0	0.26
Crowns				
0	289	23	8.0	
1–3	135	25	18.5	
⩾4	49	12	24.5	<0.001
Caries lesions				
0	178	14	7.9	
1	136	20	14.7	
⩾2	159	26	16.4	0.05
Root canal posts				
0	320	18	5.6	
1	76	18	23.7	
⩾2	77	24	31.2	<0.001
Root fillings				
0	224	12	5.4	
1–2	162	21	13.0	
⩾3	87	27	31.0	<0.001
Gender				
Women	239	24	10.0	
Men	234	36	15.4	0.08
Smoking				
No	277	21	7.6	
Yes	188	35	18.6	<0.001
Age				
<30	80	1	1.3	
30–39	119	5	4.2	
40–49	133	14	10.5	
⩾50	141	40	28.4	<0.001
Number of teeth				
0–23	47	20	42.6	
24–25	67	14	20.9	
26–27	109	13	11.9	
28	250	13	5.2	<0.001

*χ^2-test of the hypothesis of independence between risk factor and tooth loss.

Table 3. Risk factors for tooth loss on the individual level

Variables	Initial				Final			
	OR	95%	CI	*p*-value	OR	95%	CI	*p*-value
Marginal bone level (ref: < 3 mm)								
3–4 mm	4.46	2.00	9.98	0.00	2.85	1.18	6.85	0.02
⩾4 mm	26.09	12.65	53.82	0.00	12.82	5.66	29.01	0.00
AP (ref: 0*)								
1	7.91	2.98	21.01	0.00	5.52	1.98	15.36	0.00
⩾2	32.15	12.98	79.62	0.00	11.20	4.14	30.25	0.00
Apicectomies (ref: 0*)								
⩾1	4.38	1.76	10.95	0.00	3.56	1.24	10.25	0.19
Fillings (ref: < 7*)								
7–16	2.35	0.81	6.80	0.12	1.94	0.51	7.35	0.33
⩾17	1.95	0.61	6.27	0.26	1.40	0.33	5.98	0.65
Crowns (ref: 0*)								
1–3	2.63	1.43	4.83	0.00	0.95	0.44	2.06	0.89
⩾4	3.75	1.72	8.17	0.00	0.76	0.27	2.14	0.61
Caries lesions (ref: 0*)								
1	2.02	0.98	4.16	0.06	2.37	0.98	5.76	0.06
⩾2	2.29	1.15	4.56	0.02	2.20	0.96	5.07	0.06
Root canal posts (ref: 0*)								
1	5.21	2.56	10.60	0.00	2.19	0.89	5.38	0.09
⩾2	7.60	3.86	14.96	0.00	1.51	0.61	3.70	0.37
Root fillings (ref: 0*)								
1–2	2.63	1.25	5.52	0.00	0.66	0.23	1.96	0.46
⩾3	7.95	3.80	16.63	0.00	0.69	0.21	2.24	0.54
Gender (ref: women)								
Men	1.63	0.94	2.83	0.08	1.98	0.98	3.97	0.06
Smoking (ref: no)								
Yes	2.79	1.57	4.97	0.00	1.24	0.58	2.64	0.58
Age (ref: < 30)								
30–39	3.46	0.40	30.23	0.26	2.10	0.22	19.74	0.52
40–49	9.29	1.20	72.09	0.03	3.12	0.37	26.11	0.29
⩾50	31.29	4.21	232.6	0.00	4.07	0.48	34.51	0.20
Number of teeth (ref: 28)								
0–23	13.50	4.75	21.70	0.00	1.79	0.60	5.33	0.30
24–25	4.82	1.68	7.80	0.00	1.57	0.56	4.41	0.39
26–27	2.47	0.96	4.26	0.03	0.77	0.28	2.11	0.61

Final analysis is adjusted for marginal bone level, apicectomies and apical periodontitis (AP).
*Number per individual.
OR, odds ratio; CI, confidence interval.

ment. The data was then transferred to Stata version 9 (StataCorp LP, College Station, TX, USA), which was used for all the statistical calculations.

Results

The total number of teeth lost during the study period was 107 in 60 individuals. The marginal bone level for the lost teeth varied between 1.25 and 15.9 mm with no obvious clustering. The mean and SD were 6.4 and 3.1 mm. The corresponding figures for the teeth that remained were 2.5 and 1.2 mm. AP (PAI score at least 3) was seen in 52 of the lost teeth and in 327 of the remaining teeth.

The number of individuals with lost teeth was 60. The majority of these individuals had lost only one tooth during the study period (65%), 12 individuals (20%) had lost two teeth and the remaining individuals with lost teeth had lost ⩾3 teeth. The highest number of lost teeth per individual during the study period was eight.

The 473 participants in the longitudinal study did not differ significantly from the 143 non-participants with respect to age and gender ($p = 0.2$). The difference in number of teeth was not significant, neither for all ages nor within the age groups, except for the 50–59 years age group, in which the participants had a higher number of teeth (mean 24.6) than the non-participants (mean 20.9) ($p = 0.01$). There was no significant difference in initial marginal bone level between the participants and non-participants on the individual level ($p = 0.3$) for all the age groups. Within the age groups, a significant difference was found only for the 50–59 years age group, the non-participants displaying a more reduced marginal bone level than the participants ($p = 0.04$).

Individuals

In the crude analyses on the individual level, all the variables were statistically significantly associated with tooth loss, with the exception of gender and fillings (Table 3). When mutually adjusted, marginal bone level and AP remained strongly associated with tooth loss. Individuals with a borderline marginal bone level (3–4 mm) and individuals with a reduced marginal bone level (⩾4 mm) had, respectively, a three times higher risk and a more than 12 times higher risk of losing teeth during the study period. Moreover, individuals with one tooth with AP had approximately five times higher risk of losing a tooth, and the risk of tooth loss more than doubled (OR = 11.20) when two or more teeth had AP. Individuals with apicectomies were three times more likely to have tooth loss, but this estimate was not statistically significant. When corrected for marginal bone level, AP and apicectomies, the remaining variables had little or no association with tooth loss. A tendency towards a higher risk of tooth loss was observed in men ($p = 0.06$), and for individuals with caries lesions ($p = 0.06$).

Teeth

The 60 individuals, who had lost at least one tooth during the study period, had a total of 1,421 teeth at the first radiographic survey. In the crude analyses, all the variables were statistically significant, except primary caries lesions and composite fillings (Table 4). Marginal bone level was represented as a continuous variable in the tooth-level analysis. Marginal bone level, AP, apicectomies and tooth groups were statistically significant when mutually adjusted. The risk of tooth loss doubled for each millimetre reduction in marginal bone level (OR = 2.04). Teeth with AP had a six times higher risk of being lost than periapically healthy teeth.

Teeth with apicectomy had a more than 90 times higher risk of being lost than teeth without apicectomy, but the 95% CI was extremely wide. The number of teeth with apicectomies was 27 in the whole population. The total number of teeth included in the lost teeth analysis

Table 4. Risk factors for tooth loss at the tooth level

Variables	Initial				Final			
	OR	95%	CI	*p*-value	OR	95%	CI	*p*-value
Marginal bone level								
Cont./per mm	2.01	1.72	2.36	0.00	2.04	1.68	2.47	0.00
AP (ref: no)								
Yes	16.68	10.08	27.60	0.00	5.90	3.20	10.88	0.00
Apicectomies (ref: no)								
Yes	145.2	17.60	1197	0.00	92.83	8.30	1038	0.00
Tooth groups (ref: incisors)								
Molars	7.58	4.04	14.24	0.00	8.39	3.58	19.64	0.00
Premolars	2.53	1.30	4.94	0.01	5.19	2.11	12.77	0.00
Canines	0.22	0.05	0.99	0.05	0.20	0.03	2.13	0.20
Fillings (ref: no)								
Amalgam	2.64	1.63	4.27	0.00	1.19	0.61	2.34	0.61
Composite	1.12	0.6	2.09	0.73				
Crowns (ref: no)								
Metal-ceramic	3.26	1.62	6.58	0.00	1.09	0.47	2.54	0.84
Metal	3.92	1.64	9.35	0.00				
Root canal posts (ref: no)								
Yes	6.00	3.37	10.71	0.00	1.58	0.68	3.67	0.29
Primary caries lesions (ref: no)								
Yes	1.64	0.45	5.95	0.45	2.32	0.47	11.41	0.30
Secondary caries lesions (ref: no caries)								
Yes	3.03	1.50	6.14	0.00	1.12	0.46	2.76	0.80
Root fillings (ref: no)								
Yes	8.54	5.10	14.31	0.00	1.20	0.51	2.82	0.68
Jaw (ref: lower)								
Upper	1.64	1.08	2.50	0.02	0.93	0.54	1.61	0.81

Final analysis is adjusted for marginal bone level, apical periodontitis (AP), apicectomies and tooth groups.
OR, odds ratio; CI, confidence interval.

was 1,421, of which nine had an apicectomy. Seven of these nine teeth were lost during the study period. Molars and premolars had a higher risk of being lost compared with incisors (OR = 8.39 and 5.19, respectively). Canines had, however, a lower risk than incisors (OR = 0.20).

The influence of the amount of remaining bone on tooth loss was also analysed on the tooth level using an identical method as the marginal bone-level analysis. It was found that the OR for each millimetre reduction of remaining bone level was 1.59 (95% CI: 1.44–1.76, $p < 0.05$). The association between other variables and tooth loss was very similar to the analysis of marginal bone level and is therefore not presented here.

All the analyses were repeated with the bone level measured as a percentage of root length with similar results when bone level was measured in mm. Therefore, only the latter results are presented.

Discussion

The study showed that marginal bone level and AP were major risk factors for tooth loss. In the present study, the term risk factor is used merely to designate a variable, which is associated with an increased risk of tooth loss, but no cause–effect is claimed. While the presence of dental problems is the reason for considering extracting a tooth, the actual decision of tooth extraction is in many cases based on several factors. Some teeth are in a condition where even the most advanced approaches cannot save the tooth or the tooth will not function properly after treatment. Other teeth may need advanced (technical, biological or economical) procedures to be saved. When considering the overall treatment plan for a patient, it may be appropriate to extract a tooth with an advanced treatment instead of using resources in trying to save it. Ideally, this decision should be made by the patient with the consultation of the dentist. Socio-economic factors, acute symptoms, the position of the tooth (posterior-positioned teeth are more likely to be extracted because they do not always need to be replaced) and the attitude of the patient may all influence this decision (Gilbert et al. 1999, Müller et al. 2007). As societies become more and more health oriented and the wealth of the populations grows, more people choose to keep their teeth instead of extracting them (Hugoson et al. 1995). Both on the individual level as well as on the tooth level, a reduced marginal bone level compared with a normal bone level at the first radiographic examination was associated with an increased risk of tooth loss during the 5-year study period. This association should not be interpreted as the sole explanation for tooth extraction. More likely, the reduced marginal bone level is just one of the several factors that lead to the decision of extracting the tooth. However, the results of this study indicated that the presence of a reduced marginal bone level and AP are important factors, when a tooth extraction is considered.

The participants in the present study are randomly selected from a general population and, therefore, not merely periodontal patients. Consequently, only 1% of the total number of teeth was lost during the study period, which is comparable with the findings from other Nordic countries (Hujoel et al. 1998). The participants of the present study form a subset of a random sample of individuals living in a Danish County. Of the 1,199 persons invited in the first survey, 616 attended the first examination. These individuals were re-invited 5 years later and 473 participated in the second examination. A comparison of non-participants and participants in the first examination using data from Statistics Denmark showed no major differences, except for use of dental services (Kirkevang et al. 2001). A higher proportion of the non-participants had not visited a dentist in the previous year. Also, retired people and housewives were more frequent among the non-participants. In the present study, we compared non-participants and participants in the second examination and found no difference in age and gender distribution. Overall, the number of teeth and the marginal bone level did not differ, but differences were seen in the age group of 50–59 years, the non-participants having fewer teeth and more reduced bone level. Taken together, these comparisons suggest that the dental health of the participants in the present study may be slightly better than that of a random sample of individuals.

The study relied on information obtained from the radiographs. The

risk of misclassification and measurement errors was reduced by adopting a full-mouth radiographic survey, but errors of registrations cannot be ruled out completely. However, the baseline measurements were registered without the knowledge of the future outcome, so the effect of misclassification and measurement error was most likely non-differential. The effect of measurement error of marginal bone level would, therefore, be to attenuate the effect of this parameter on the risk of tooth loss.

In the present study, marginal bone level and AP were strongly associated with tooth loss on both the individual and tooth level, while apicectomies were primarily associated with tooth loss on the tooth level. The association between marginal bone level and tooth loss has been demonstrated in several other studies, all describing the positive effect of therapy and maintenance on periodontal disease (Tonetti et al. 2000, Konig et al. 2002, Fardal et al. 2004, Pretzl et al. 2008). Because of the radiographic nature of the present study, no clinical information was available. In particular, we have no information on whether or not the participants had received periodontal therapy at some point during the study period. Furthermore, a reduced baseline bone level has been shown to be associated with more rapid bone loss (Bahrami et al. 2006b), and a reduced bone level may also be seen as an indirect risk factor for tooth loss.

The other variable that was associated with tooth loss both on the individual level and on tooth level was AP. Individuals with at lease one tooth with AP had a more than five times higher risk of tooth loss, and teeth with AP had an almost six times higher risk of being lost. The association between AP and tooth loss is in accordance with the other studies (Eckerbom et al. 1992, Müller et al. 2007). The risk of tooth loss for teeth with apicectomies was particularly high (OR = 92). However, the high OR in combination with an extremely wide CI probably reflects the low number of teeth with apicectomies in the study. The extremely wide CI indicates that the risk estimate is so imprecise that quantification perhaps should be avoided. Apicectomy is normally performed when orthograde endodontic treatment has failed; hence, this procedure may be seen as the last resort for saving a tooth and avoiding extraction. The success rate of this treatment has been reported to be as high as 80–90% (Ørstavik & Pitt Ford 1998). However, several factors may affect the outcome of this treatment, such as a reduced marginal bone level, the experience of the operator and whether the surgery is a first-time operation or a re-operation (Wang et al. 2004). It was not possible to study the reason for the failed apicectomy procedures, because no detailed information on treatment procedure was available.

Besides marginal bone level, AP and apicectomies, specific tooth groups were also associated with tooth loss. Posterior teeth had a higher risk of being lost than anterior teeth (Anagnou-Varelzides et al. 1986, Papapanou et al. 1989, Paulander et al. 2004, Sayegh et al. 2004). This may be due to aesthetic considerations, the prognosis of endodontic treatment and the ability to maintain good oral hygiene in the anterior parts of the oral cavity, rather than the posterior parts. Possible periodontal involvement of the furcation area in molars could also play a role.

In the present study, an increased risk of tooth loss was shown in individuals with one or more caries lesions, but this tendency was not statistically significant. Caries lesions have been identified as a cause of tooth loss in several studies (Eckerbom et al. 1992, Fure & Zickert 1997, Gilbert et al. 1999, Sayegh et al. 2004).

Tooth loss has been associated with smoking in the previous studies (Albandar et al. 2000, Fardal et al. 2004, Dannewitz et al. 2006, Eickholz et al. 2008). The information on smoking habits was crude. Heavy smokers could not be differentiated from light smokers and information on the duration of smoking was not available. However, smoking was statistically significant until adjusted for marginal bone level, which suggests that the association between smoking and tooth loss is partly mediated by reduced marginal bone level (Bergström 2004, Preshaw et al. 2005, Nitzan et al. 2005, Bahrami et al. 2006b).

Both the presence of endodontic treatment (Caplan et al. 2005) and root canal post (Willershausen et al. 2005, Wegner et al. 2006) as well as older age (Papapanou et al. 1989) and a low number of remaining teeth (Dannewitz et al. 2006) have previously been shown to increase the risk of tooth loss. In the present study, the above-mentioned factors were also associated with tooth loss in the crude analyses, but not after adjusting for average marginal bone level and the presence of teeth with AP. This observation indicates that it is not endodontic treatment, a root canal post, old age or low number of teeth *per se* that is of importance in relation to tooth loss, but rather that these parameters are associated with a reduced marginal bone level and/or AP and, thereby indirectly with tooth loss. The study focused on risk factors related to dental diseases and their sequelae as observed in the radiographs. Neither clinical data nor socio-economic information about the participants, or information on pain, was available. Regression models were used to identify risk factors both on the tooth level and on the individual level. Except for age, gender and smoking habits, the individual-level analysis included only predictors derived from the radiographs and this is certainly a limitation of the study. However, the tooth-level analysis was based completely on within person comparisons, and these results were therefore fully adjusted for both observed and unobserved individual-level variables (e.g. socio-economic status). The impact of unmeasured tooth-level variables (e.g. pain) is not taken into account and future studies should include additional data sources to expand the lists of risk factors to be assessed and confounding factors to be controlled. Further studies are therefore needed to confirm the findings of this study and to provide further insights into the events that increase the risk of tooth loss.

In conclusion, it was shown in the present study that marginal bone level, AP and apicectomies are associated with tooth loss over time, and posterior teeth have a higher risk of being lost compared with anterior teeth.

References

Albandar, J. M., Streckfus, C. F., Adesanya, M. R. & Winn, D. M. (2000) Cigar, pipe, and cigarette smoking as risk factors for periodontal disease and tooth loss. *Journal of Periodontology* **71**, 1874–1881.

Anagnou-Varelzides, A., Komboli, M., Tsami, A. & Mitsis, F. (1986) Pattern of tooth loss in a selected population in Greece. *Community Dentistry and Oral Epidemiology* **14**, 349–352.

Axelsson, P., Paulartder, J. & Lindhe, J. (1998) Relationship between smoking and dental status in 35-, 50-, 65-, and 75-year-old indi-

viduals. *Journal of Clinical Periodontology* **25**, 297–305.

Bahrami, G., Isidor, F., Kirkevang, L. L., Vaeth, M. & Wenzel, A. (2006a) Marginal bone level in an adult Danish population. *Oral Health and Preventive Dentistry* **4**, 119–127.

Bahrami, G., Wenzel, A., Kirkevang, L. L., Isidor, F. & Vaeth, M. (2006b) Risk indicators for a reduced marginal bone level in the individual. *Oral Health and Preventive Dentistry* **4**, 215–222.

Bergström, J. (2004) Influence of tobacco smoking on periodontal bone height. Long-term observations and a hypothesis. *Journal of Clinical Periodontology* **31**, 260–266.

Björn, H., Halling, A. & Thyberg, H. (1969) Radiographic assessment of marginal bone loss. *Odontologisk Revy* **20**, 165–179.

Burt, B. A., Ismail, A. I., Morrison, E. C. & Beltran, E. D. (1990) Risk factors for tooth loss over a 28-year period. *Journal of Dental Research* **69**, 1126–1130.

Caplan, D. J., Cai, J., Yin, G. & White, B. A. (2005) Root canal filled versus non-root canal filled teeth: a retrospective comparison of survival times. *Journal of Public Health Dentistry* **65**, 90–96.

Dannewitz, B., Krieger, J. K., Husing, J. & Eickholz, P. (2006) Loss of molars in periodontally treated patients: a retrospective analysis five years or more after active periodontal treatment. *Journal of Clinical Periodontology* **33**, 53–61.

Dietrich, T., Maserejian, N. N., Joshipura, K. J., Krall, E. A. & Garcia, R. I. (2007) Tobacco use and incidence of tooth loss among US male health professionals. *Journal of Dental Research* **86**, 373–377.

Eckerbom, M., Magnusson, T. & Martinsson, T. (1992) Reasons for and incidence of tooth mortality in a Swedish population. *Dental Traumatology* **8**, 230–234.

Eickholz, P., Kaltschmitt, J., Berbig, J., Reitmeir, P. & Pretzl, B. (2008) Tooth loss after active periodontal therapy. 1: patient-related factors for risk, prognosis, and quality of outcome. *Journal of Clinical Periodontology* **35**, 165–174.

Fardal, Ø., Johannessen, A. C. & Linden, G. J. (2004) Tooth loss during maintenance following periodontal treatment in a periodontal practice in Norway. *Journal of Clinical Periodontology* **31**, 550–555.

Fure, S. (2003) Ten-year incidence of tooth loss and dental caries in elderly Swedish individuals. *Caries Research* **37**, 462–469.

Fure, S. & Zickert, I. (1997) Incidence of tooth loss and dental caries in 60-, 70- and 80-year-old Swedish individuals. *Community Dentistry and Oral Epidemiology* **25**, 137–142.

Gilbert, G. H., Miller, M. K., Duncan, R. P., Ringelberg, M. L., Dolan, T. A. & Foerster, U. (1999) Tooth-specific and person-level predictors of 24-month tooth loss among older adults. *Community Dentistry and Oral Epidemiology* **27**, 372–385.

Hugoson, A., Koch, G., Bergendal, T., Hallonsten, A. L., Slotte, C., Thorstensson, B. & Thorstensson, H. (1995) Oral health of individuals aged 3–80 years in Jonkoping, Sweden in 1973, 1983, and 1993. II. Review of clinical and radiographic findings. *Swedish Dental Journal* **19**, 243–260.

Hujoel, P. P., Loe, H., Anerud, A., Boysen, H. & Leroux, B. G. (1998) Forty-five-year tooth survival probabilities among men in Oslo, Norway. *Journal of Dental Research* **77**, 2020–2027.

Kirkevang, L. L., Hørsted-Bindslev, P., Ørstavik, D. & Wenzel, A. (2001) Frequency and distribution of endodontically treated teeth and apical periodontitis in an urban Danish population. *International Endodontic Journal* **34**, 198–205.

Konig, J., Plagmann, H. C., Ruhling, A. & Kocher, T. (2002) Tooth loss and pocket probing depths in compliant periodontally treated patients: a retrospective analysis. *Journal of Clinical Periodontology* **29**, 1092–1100.

Ludlow, J. B., Abreu, M. Jr. & Mol, A. (2001) Performance of a new F-speed film for caries detection. *Dentomaxillofacial Radiology* **30**, 110–113.

Müller, F., Naharro, M. & Carlsson, G. E. (2007) What are the prevalence and incidence of tooth loss in the adult and elderly population in Europe? *Clinical Oral Implants Research* **18**, 2–14.

Nitzan, D., Mamlider, A., Levin, L. & Schwartz-Arad, D. (2005) Impact of smoking on marginal bone loss. *The International Journal of Oral & Maxillofacial Implants* **20**, 605–609.

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

Ørstavik, D. & Pitt Ford, T. R. (1998) *Essential Endodontology*, pp. 367–401. Blackwell Science Ltd, Oxford, UK.

Papapanou, P. N., Wennström, J. L. & Gröndahl, K. (1989) A 10-year retrospective study of periodontal disease progression. *Journal of Clinical Periodontology* **16**, 403–411.

Paulander, J., Axelsson, P., Lindhe, J. & Wennström, J. (2004) Intra-oral pattern of tooth and periodontal bone loss between the age of 50 and 60 years. A longitudinal prospective study. *Acta Odontologica Scandinavica* **62**, 214–222.

Preshaw, P. M., Heasman, L., Stacey, F., Steen, N., McCracken, G. I. & Heasman, P. A. (2005) The effect of quitting smoking on chronic periodontitis. *Journal of Clinical Periodontology* **32**, 869–879.

Pretzl, B., Kaltschmitt, J., Kim, T.-S., Reitmeir, P. & Eickholz, P. (2008) Tooth loss after active periodontal therapy. 2: tooth-related factors. *Journal of Clinical Periodontology* **35**, 175–182.

Sayegh, A., Hilow, H. & Bedi, R. (2004) Pattern of tooth loss in recipients of free dental treatment at the University Hospital of Amman, Jordan. *Journal of Oral Rehabilitation* **31**, 124–130.

Tonetti, M. S., Steffen, P., Muller-Campanile, V., Suvan, J. & Lang, N. P. (2000) Initial extractions and tooth loss during supportive care in a periodontal population seeking comprehensive care. *Journal of Clinical Periodontology* **27**, 824–831.

Tugnait, A., Clerehugh, V. & Hirschmann, P. N. (2000) The usefulness of radiographs in diagnosis and management of periodontal diseases: a review. *Journal of Dentistry* **28**, 219–226.

Wang, Q., Cheung, G. S. P. & Ng, R. P. Y. (2004) Survival of surgical endodontic treatment performed in a dental teaching hospital: a cohort study. *International Endodontic Journal* **37**, 764–775.

Wegner, P. K., Freitag, S. & Kern, M. (2006) Survival rate of endodontically treated teeth with posts after prosthetic restoration. *Journal of Endodontics* **32**, 928–931.

Willershausen, B., Tekyatan, H., Krummenauer, F. & Briseno, M. B. (2005) Survival rate of endodontically treated teeth in relation to conservative vs post insertion techniques – a retrospective study. *European Journal of Medical Research* **10**, 204–208.

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Clinical Relevance

Scientific rationale for the study: Knowledge of risk factors for tooth loss is an important pre-requisite for proper treatment planning. To identify these risk factors, a longitudinal study is required.

Principal findings: A reduced marginal bone level, apicectomy and AP were identified as risk factors for tooth loss. Coronal restorations, root canal fillings and posts were not identified as risk factors for tooth loss.

Practical implications: This study found that marginal bone loss and AP were associated with tooth loss. The possible role of these factors in causing tooth loss and in patient's or practitioner's decisions for tooth extraction needs further investigation.