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Risk factors for developing apical periodontitis in a general population

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Abstract

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Aim To identify and describe individual and tooth-specific factors associated with the incidence or the persistence of apical periodontitis (AP) in a general population.

Methodology In 1997, 616 randomly selected individuals had a full-mouth radiographic survey. In 2003, 77% of the participants returned for a new full-mouth radiographic examination. All teeth were assessed individually and data recorded for caries, marginal bone level, and tooth restorations. Multiple logistic regression analyses were performed to identify predictors of AP in the individual. Conditional logistic regression analyses were used to identify risk factors for development of AP in a tooth. Independent variables included a number of individual and tooth-specific variables.

Results Root fillings, coronal restorations, primary carious lesions, and reduced marginal bone level were associated with the incidence of AP in the individual. In teeth, the quality and presence of a coronal restoration was associated with the incidence of AP, and presence of a root filling also increased the risk of developing AP. Furthermore, an increased risk of developing AP was seen in relation to primary carious lesions, reduced marginal bone level, and molar teeth. The quality of the root filling was not associated with the incidence of AP, but the results suggest an association between the quality of the root filling and the healing of AP.

Conclusions Results from the present study demonstrate that it is important to provide high quality dental restorations to minimize the risk of pulpal infection. The clinical focus, in relation to the incidence of AP, should be on improving the quality of the coronal restoration. The quality of a root filling was not associated with the incidence of AP, but may be of importance in relation to healing of AP.

Key words: apical periodontitis, epidemiology, incidence, longitudinal, risk factors.

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Introduction

Apical periodontitis (AP) is an inflammatory process in the periapical tissues that may develop if bacteria are introduced into the dental pulp. The relation between AP and bacteria infecting the root canal system is well established in experimental studies (Kakehashi *et al.* 1965, Sundqvist 1976, Möller *et al.* 1981). An infection of the coronal pulp may spread apically, and cause necrosis of the pulpal tissues, and eventually reach the apical part of the root canal. If left untreated, bacterial elements invade the periapical area and cause local bone destruction. The infection cannot resolve spontaneously, since the immune defence system is ineffective due to the localization

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of the infection inside the root canal. Therefore, root canal treatment is necessary to eliminate the bacterial infection and permit the healing of AP.

Several cross-sectional studies have focused on prevalence and frequencies of AP and demonstrated that 30–50% of individuals exhibit AP. The presence and radiographic quality of a root filling and to some extent the radiographic quality of the coronal restoration were associated with AP in teeth (Eriksen *et al.* 2002). A few studies have tried to identify risk indicators for an individual having AP. A Lithuanian study found that the periapical status in an individual was closely related to general oral health (Aleksejuniene *et al.* 2000). Moreover, a Danish study found that the socio-economic status of the individual did not provide much additional information on the periapical status, when dental information was available (Kirkevang & Wenzel 2003).

A Danish cross-sectional study of tooth-specific risk indicators reported mutually adjusted risk estimates of dental parameters. The presence of AP was strongly associated with root fillings, particularly technically inadequate root fillings. Furthermore, coronal fillings or crowns were associated with AP, and the association was slightly stronger for radiographically inadequate coronal fillings or crowns than for adequate ones. Moreover, teeth with primary carious lesions had higher risk of AP (Kirkevang *et al.* 2004).

Cross-sectional studies provide little information on the dynamics of the disease since no information on the timing of the events is available. In particular, it is not possible to distinguish between factors that influence development of AP and factors related to the healing process. Longitudinal observational population studies, including healthy individuals and healthy teeth, are therefore needed to gain information on the incidence of AP and possible risk factors associated with the development of AP. The aim of the present study was to identify and describe individual and tooth-specific factors associated with the incidence or persistence of AP in a general population, and quantify the risk of these factors.

Materials and methods

The initial population consisted of 1199 randomly selected individuals from Aarhus County, Denmark in 1997. The year of birth ranged from 1935 to 1975. The individuals were contacted by letter and offered a full-mouth radiographic survey. Only individuals who had at least one tooth were included in the study. Written informed consent was given by 311 males and 305 females, who then attended the radiographic examination. Thus, the attendance rate in 1997 was 51%. An analysis of non-participation has been presented previously (Kirkevang *et al.* 2001).

In 2003, the 616 participants from the 1997 study were contacted again and offered a new full-mouth radiographic survey. Of these individuals, 473 gave written informed consent and attended the radiographic examination in 2003 (234 males and 239 females). Thus, the attendance rate in the 2003 study was 77% of the 1997 participants. Reasons for not attending the second investigation included lack of time or interest (22), pregnancy (3), general diseases (2), death (1), and unknown reason (115). Analysis of the non-participation was performed based on information from the 1997 study (Kirkevang *et al.* 2001). The analysis revealed no differences between participants and non-participants concerning sex, age distribution, smoking habits, visits to the dentist, root fillings and crowns. The group of non-participants included more individuals with very few coronal fillings and more individuals with very few teeth. The regional Committee of Ethics approved the study design in both 1997 and 2003.

Radiographic recording

In 1997 and in 2003, all participants underwent a full-mouth radiographic survey consisting of 14 periapicals and two bitewings, one in each side. Radiographs were taken using a 'GX 1000' X-ray unit (Gendex Corporation, Milwaukee, WI, USA), and the paralleling technique. The exposure details were 70 kV, 10 mA, a film-focus distance of 28 cm. Film processing was automated (Dürr 1330, AC 245L; Bietigheim-Bissingen, Germany).

The radiographic procedure used in 2003 did not differ from the 1997 study except for the radiographic film used. In 1997, Kodak Ektaspeed Plus film (Eastman Kodak, Rochester, NY, USA), and in 2003 Kodak Insight film (Eastman Kodak) were used. In both studies, the fastest well-documented film on the market was chosen to minimize the radiation dose to the participants. The change in film was not expected to have influenced the results since the performance of the two films has been shown not to be significantly different in relation to the diagnostic outcome (Ludlow *et al.* 2001).

Radiographic registration methods and diagnostic thresholds

One observer examined all radiographs (L-L K). Results on all teeth were recorded according to the FDI nomenclature using the full-mouth radiographic survey. Third molars were excluded. In all individuals, the variables listed in Table 1 were assessed. All recordings of treatment quality in the present study were based on radiographic assessments. Teeth with root fillings present at both examinations, for which obvious differences existed either in relation to radiographic density or length of the root filling, were defined as having had a revision of the root filling. The Periapical Index (PAI) was used to identify teeth with AP (Ørstavik *et al.* 1986). The PAI was based on a study by Brynolf (1967), who compared histological and radiographic appearances of periapical changes in human autopsy materials to disclose to what extent histological changes were reflected in radiographs. The PAI consists of five categories, each representing a step on an ordinal scale from sound periapical bone to severe AP. One or two radiographs from Brynolf's original material represent each of the five categories, and these radiographs were used as visual references (Fig. 1).

According to the Periapical Index, one of the five PAI-scores was assigned to the periapical tissues of each tooth in the study by comparing the radiographic appearance of the periapical bone to the visual references for the five categories. If in doubt which score to assign, the higher score should be chosen. A tooth was classified as periapically healthy if the assigned score was 1 or 2, and as having AP if score 3, 4 or 5 was given. The observer in the current study was calibrated to a 'golden standard atlas' of PAI before evaluating the material both in 1997 and in 2003.

Statistical methods

The cumulative incidence of AP in the period between the two examinations was analysed with both the

Table 1 Categories for the independent variables

Parameters	Categories[a]
Person-specific variables	
Gender	Female, male
Age	20–29, 30–39, 40–49, ≥50
Smoking	No, yes
Frequency of dental visits	≤6 month, >6 month
Pain	No, yes
Number of healthy teeth	0–24, 25–27, 28
Primary carious lesion	0, ≥1
Secondary carious lesion	0, ≥1
Number of crowns or coronal fillings	0–10, 11–15, 0, ≥16
Number of inadequate crowns or coronal fillings	0–2, ≥2
Number of root fillings	0, 1, ≥2
Pulpal post	0, ≥1
Marginal bone level (from cemento-enamel junction to marginal bone)	≤3 mm, 3–4 mm, >4 mm
Tooth-specific variables	
Primary carious lesion	No caries or caries in enamel, caries in dentine, caries reaching the pulp
Secondary carious lesion	No caries or caries in enamel, caries in dentine, caries reaching the pulp
Coronal filling	Radiographically sealed filling, radiographic signs of overhangs or open margins of filling
Crown	Radiographically sealed crown, radiographic signs of overhangs or open margins of crown
Pulpal post	No, yes
Root filling	No, yes
Length of root filling	≤3 mm from apex, >3 mm short of the apex, overfilling
Seal of root filling	No voids detectable, voids detectable
Tooth group	Incisors and canines, premolars, molars
Jaw	Maxilla, mandible
Marginal bone level	≤4 mm, >4 mm

Person-specific variables of tooth characteristics are formed by aggregating information from all healthy teeth.
[a]Categories separated by comma. First category was used as reference group in the conditional logistic regression analyses.

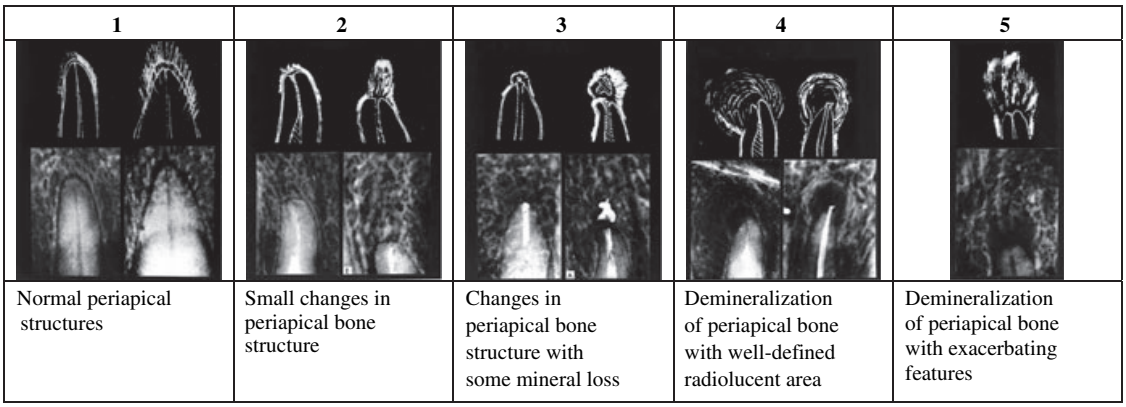

Figure 1 Visual references of the Periapical Index (PAI) (Ørstavik *et al.* 1986).

individual and the tooth as the unit of analysis. An individual was defined as having developed AP if at least one disease-free tooth at the first examination had AP at the second examination. Person-specific risk factors including gender, age, smoking, frequency of dental visits, and a number of tooth-specific variables were aggregated to form a summary of the healthy teeth of the individual. The person-specific variables were categorized as shown in Table 1. The associations between development of AP in an individual and each of the person-specific variables were first described by an unadjusted odds ratio (OR) with a 95% confidence interval (CI). Next, development of AP was used as the dependent variable in a series of multiple logistic regression analyses to identify a minimal set of independent predictors of disease. Finally, the effect of the independent predictors was described by a set of mutually adjusted ORs with 95% CIs.

Conditional logistic regression analysis was used to identify tooth-specific risk indicators for the development of AP in a tooth. In these analyses, healthy teeth that developed AP during the period between examinations were compared with teeth that remained healthy in the same person, and the effect of a predictor was described by an OR with a 95% CI. The matching on person ensured that the effect of the tooth-specific predictors was corrected for main effects of all person-specific factors. The tooth-specific risk factors and the categorization used in the analysis are shown in Table 1. Associations between development of AP and each of the tooth-specific risk factors were first assessed separately and then all tooth-specific variables were entered simultaneously to identify the independent risk factors. A series of supplementary analyses assessed if the effect of the tooth-specific risk factors depended on tooth group or jaw, by including interaction terms with these two factors.

The data did not allow a comprehensive analysis of healing of AP, but bivariate within-mouth analyses of coronal fillings, crowns, root fillings, and the quality of root fillings were performed. To further elucidate the role of the tooth-specific risk factors in the disease process, all teeth within a mouth were also analysed by conditional logistic regression. In these analyses, tooth-specific risk factors registered at the first examination were used to predict the presence of AP at the second examination. Factors associated with the persistence of AP were therefore also revealed. The tooth-specific risk factors were assessed simultaneously both with and without adjustment for disease status at the first examination.

SPSS version 11 was used for data management. The data was then transferred to Stata version 8, which was used for all statistical calculations.

Results

A total of 473 individuals with 12 443 teeth participated in both examinations. At the first examination 12 043 teeth had no AP, 379 had AP, and 21 could not be assessed. In the period between the two examinations 248 healthy teeth developed AP and 105 diseased teeth healed.

At the second examination revision of a root filling was detected in 42 teeth, and 128 teeth had received a new root filling in the period between the two examinations, 23 of these teeth had AP at the first examination, 104 teeth were periapically sound at the first examination, and one tooth could not be assessed. During the period between the two

examinations 114 teeth were extracted, 53 of these had AP at the first examination.

Individuals

Of the 473 individuals examined, 170 individuals developed AP in one or more teeth during the period between the two examinations. When the person-specific risk factors shown in Table 1 were assessed separately, all variables except gender, pain, and primary carious lesions had a statistically significant association with development of AP. The final multiple logistic regression analysis showed that root fillings, pulpal posts, inadequate crowns or coronal fillings, primary carious lesions, reduced marginal bone level, and age were independent predictors for developing AP in an individual. Table 2 presents unadjusted, as well as mutually adjusted ORs for these predictors. No additional factors had a statistically significant association with AP when adjusting for the effect of these variables. In particular, smoking was a statistically significant risk factor when assessed separately (OR 1.9, CI 1.3–2.8) but had a reduced, and non-significant, effect on the risk of developing AP when adjusting for age and reduced marginal bone level (OR 1.3, CI 0.9–2.1).

Table 2 Association between person-specific risk indicators and incidence of AP. Crude and adjusted odds ratio (OR) with 95% confidence interval (CI)

		Crude		Adjusted	
	Persons	OR	95% CI	OR	95% CI
Root filling					
0	294	1.0	Reference	1.0	Reference
1	107	2.5	1.5–3.9	3.2	1.8–5.6
≥2	72	6.4	3.7–11.3	11.6	4.8–27.8
Pulpal post					
0	378	1.0	Reference	1.0	Reference
≥1	95	2.4	1.5–3.8	0.3	0.2–0.7
Inadequate crown or coronal filling					
<2	381	1.0	Reference	1.0	Reference
≥2	92	3.9	2.4–6.2	2.3	1.4–4.0
Primary carious lesion					
0	379	1.0	Reference	1.0	Reference
≥1	94	1.5	0.9–2.4	2.3	1.3–3.9
Marginal bone level (mm)					
≤3	369	1.0	Reference	1.0	Reference
3–4	55	3.0	1.7–5.3	2.7	1.4–5.3
>4	49	5.6	2.9–10.8	4.4	2.0–9.4
Age (years)					
≤29	79	1.0	Reference	1.0	Reference
30–39	119	2.1	1.0–4.3	1.8	0.8–4.0
40–49	134	3.9	1.9–7.9	2.4	1.1–5.2
≥50	141	5.7	2.8–11.4	2.3	1.0–5.3

Adjusted analysis: all estimates are mutually adjusted.

Teeth

The conditional logistic regression analysis of tooth-specific risk factors was based on 4087 initially healthy teeth in 170 individuals. The remaining individuals did not develop AP and consequently did not provide any information on risks associated with tooth-specific factors.

The first analysis presented in Table 3 shows ORs and CIs from a simultaneous evaluation of the effect of the risk factors on the development of AP in teeth that were healthy at the first examination. Teeth with root fillings had a higher risk of developing AP than comparable teeth with no root fillings. Coronal fillings and crowns, especially inadequate ones, exhibited a high risk of developing AP. The risk of developing AP in relation to crowns was more than two times the risk of developing AP in relation to coronal fillings, and the risk of developing AP was 1.7 times higher for inadequate coronal fillings than for adequate ones. Primary carious lesions, secondary carious lesions and reduced marginal bone level were associated with development of AP. A statistically significant interaction was found between the effects of tooth group and jaw, and this interaction was therefore included in the model. Molars had a higher risk of developing AP than incisors and premolars, especially incisors and premolars in the mandible exhibited lower risk of developing AP.

Table 3 also presents results of conditional logistic regression analyses of all teeth with outcome defined as presence of AP at the second examination. These analyses were based on 5918 teeth in 239 individuals. When the same predictors were included in the regression analysis the OR associated with a root filling was increased. For the other risk factors, the inclusion of teeth with AP at first examination had little effect on the OR. When also adjusted for initial AP, the OR related to a root filling decreased considerably, but the ORs related to the other risk factors were essentially unchanged.

In Table 4, the relation between the quality of a root filling and AP was evaluated using conditional logistic regression analysis. The outcome, the number of individuals and teeth in the analyses were identical to those in the corresponding columns in Table 3. These estimates were adjusted for all variables in Table 3, but only the estimates related to the quality of the root

Table 3 Association between tooth-specific risk factors at first examination and incidence of AP (left) and frequency of AP at second examination (right). Adjusted odds ratio (OR) with 95% confidence interval (CI)

	New disease in healthy teeth			Disease at second examination: all teeth				
Predictor[a]	Healthy teeth	Adjusted[b] OR	95% CI	All teeth	Adjusted[c] OR	95% CI	Adjusted[c] OR	95% CI
Coronal filling								
Adequate	1.831	2.8	1.4–5.4	2.674	3.0	1.7–5.3	3.1	1.7–5.7
Inadequate	311	4.9	2.2–10.9	464	5.2	2.6–10.2	5.8	2.9–11.7
Crown								
Adequate	174	6.9	2.9–16.4	342	6.8	3.3–13.7	5.7	2.6–12.1
Inadequate	22	19.4	5.2–72.3	51	21.3	7.8–58.3	20.3	6.4–63.9
Root filling								
Yes	189	8.6	5.1–14.6	483	14.4	10.1–20.4	4.6	3.0–7.1
Pulpal post								
Yes	93	0.4	0.2–1.0	230	0.8	0.5–1.2	0.8	0.5–1.4
Primary carious lesion								
Yes	61	2.9	1.2–6.9	68	2.8	1.2–6.5	3.1	1.4–7.1
Secondary carious lesion								
Yes	113	1.6	0.8–2.9	170	1.5	0.9–2.6	1.4	0.8–2.5
Marginal bone level								
>4 mm	755	2.2	1.3–3.5	1000	1.6	1.1–2.4	1.7	1.1–2.5
Jaw, tooth group								
Maxillary premolars	550	1.7	1.0–2.9	795	1.7	1.1–2.5	1.7	1.1–2.6
Maxillary molars	511	3.7	2.3–6.0	788	4.2	2.9–6.2	3.5	2.3–5.2
Mandibular incisors & canines	987	0.4	0.1–1.0	1.374	0.5	0.2–1.0	0.5	0.2–1.1
Mandibular premolars	607	0.4	0.2–0.9	853	0.4	0.2–0.8	0.5	0.3–1.0
Mandibular molars	511	4.2	2.6–6.7	776	3.6	2.4–5.4	3.4	2.2–5.2
AP initially								
Yes	–	–		303	–	–	13.3	8.7–20.4

Adjusted analysis: All variables are fitted simultaneously.
[a]Reference category is 'no', except marginal bones level with reference ≤4 mm and jaw, tooth group with reference maxillary incisors and canines.
[b]Conditional logistic regression based on 4087 teeth in 170 persons.
[c]Conditional logistic regression based on 5918 teeth in 239 persons.

Table 4 Association between quality of root filling at first examination and incidence of AP (left) and frequency of AP at second examination (right). Adjusted odds ratio (OR) with 95% confidence interval (CI)

		New disease in healthy teeth			Disease at second examination All teeth				
Predictor	Category	Healthy teeth	Adjusted[a] OR	95% CI	All teeth	Adjusted[b] OR	95% CI	Adjusted[c] OR	95% CI
Root filling, sealing	Adequate	86	1.0	Reference	174	1.0	Reference	1.0	Reference
	Inadequate	103	1.4	0.7–2.9	309	1.3	0.8–2.1	0.9	0.5–1.5
Root filling, length	Adequate	131	1.0	Reference	276	1.0	Reference	1.0	Reference
	Too short	38	0.9	0.4–2.1	142	1.7	1.0–2.9	1.1	0.6–2.0
	Too long	20	0.7	0.2–2.1	65	1.8	0.9–3.4	1.0	0.5–2.1

[a]Conditional logistic regression based on 4087 healthy teeth in 170 persons. Estimates adjusted for all other variables.
[b]Conditional logistic regression based on 5918 teeth in 239 persons. Estimates adjusted for all other variables except initial AP.
[c]Conditional logistic regression based on 5918 teeth in 239 persons. Estimates adjusted for all other variables including initial AP.

filling are shown in Table 4, because the remaining estimates were essentially unchanged. The results related to the incidence of AP showed that root fillings with radiographic voids exhibited a slightly increased risk of developing AP. If the root filling was too long or to short, the risk of developing AP was slightly decreased. These findings were, however, not statistically significant.

Table 4 also shows results of analyses of all teeth when the outcome was presence of AP at the second examination. If initial AP was not included as an independent variable, the root fillings that were too

short or too long had a higher risk of having AP at the second examination relative to root fillings of adequate length. Including initial AP as an independent variable eliminated the risk associated with the quality of the root filling, and the results were similar to those found in the analysis of the incidence of AP.

Discussion

The aim of the present study was to describe individual and tooth-specific factors associated with the incidence and/or the persistence of AP in a general population, and quantify the risk of these factors to the outcome. The proportion of individuals who attended the second radiographic examination after a 5-year period was almost 80%. The high participation rate provides a solid basis for investigations of risk factors related to the dynamics of AP in a general Danish population.

In the main analysis, the outcome was the incidence of AP. A strict definition of disease was applied. Teeth with sound periapical bone (PAI score 1 or 2) at the first examination, and AP (PAI score 3, 4 or 5) at the second examination were defined as incident cases of AP. However, some teeth had a revision of a root filling or a new root filling probably as a consequence of an AP diagnosis in the period between the two examinations. If such a tooth healed before the second examination it was not counted as an incident case of AP in the analysis. Unfortunately, these teeth could not be identified in the present study, because specific information related to treatments performed during the period between the two examinations was not available. Consequently, some underestimation of the incidence of AP must be expected. Therefore, an investigation of the sensitivity of the results to the definition of the outcome was performed. Very similar results were seen if the outcome was expanded to also include initially healthy teeth that had a revision of a root filling or a new root filling (results available on request). Although some of the latter additional cases might represent pulpitis rather than AP, the sensitivity analysis suggests that the results are not a consequence of misclassification of the outcome. Moreover, it seems reasonable to assume that the risk factors related to pulpitis are similar to those related to AP.

Misclassification of the risk factors must also be expected, in particular with regard to the quality of coronal restorations and root fillings. However, the risk factors were assessed without knowledge of the outcome, so the misclassification is most likely non-differential. For dichotomous risk factors, this will lead to conservative estimates of the association. Misclassification of the quality of the coronal fillings and the crowns will mainly be inadequate restorations categorized as adequate restorations on radiographs. Assuming that inadequate restorations have the highest risk, this misclassification will increase the risk associated with adequate restorations and slightly reduce the risk for inadequate restorations. The misclassification must, however, be unrealistically high to fully explain the increased risk associated with adequate restorations. The classification of the quality of the root fillings must essentially be random if non-differential misclassification is the explanation of the findings. A classification at random has no predictive value for any outcome. However, a significant association between the quality of the root fillings and the prevalence of AP was identified in a cross-sectional study based on the same registrations from the first examination (Kirkevang *et al.* 2004). This certainly suggests that the classification is informative and that results related to the incidence of AP is not simply a consequence of non-differential misclassification.

Individuals

Few studies have presented results with the individual as the unit of analysis. The finding that the incidence of periapical lesions increased with the number of root fillings already present in the individual is in agreement with a Swedish study (Petersson 1993). In a recent, cross-sectional Danish study of risk indicators in the individual the presence of root fillings was by far the most indicative parameter for presence of AP (Kirkevang & Wenzel 2003).

The present study showed that individuals with reduced marginal bone level had an increased risk of developing AP. In epidemiological endodontic research, studies of the relation between marginal bone level and AP are scarce, and have not previously been investigated in a longitudinal study. In a cross-sectional study of 147, 35–44-year olds in Lithuania no association between presence of AP and marginal periodontitis was found (Aleksejuniene *et al.* 2000).

The risk of developing AP increased if the individual had carious lesions, coronal fillings and/or crowns. This agrees with findings from cross-sectional studies, where individuals with several carious lesions, coronal fillings and crowns exhibited an increased risk of having AP (Aleksejuniene *et al.* 2000, Kirkevang & Wenzel 2003).

When assessed separately smoking was a statistically significant risk factor for development of AP in the

individual, but not when adjusted for age and marginal bone level. The association between AP and smoking was previously investigated in cross-sectional studies, and the findings were conflicting (Kirkevang & Wenzel 2003, Bergström *et al.* 2004). The relation between marginal periodontitis and smoking has been described in several studies of periodontal health (Bolin *et al.* 1993, Bergström *et al.* 2000a,b, 2004). The strong correlation between smoking and marginal periodontitis found in these studies may, at least partly, explain why the association between smoking and AP was reduced when both smoking and marginal bone level were entered into the analysis in the present study.

Teeth

The present study focused on identification of risk factors for development of AP in initially healthy teeth, and to investigate their interrelation. The most important finding was a strong association between the presence and quality of the coronal restoration, especially crowns, and the development of AP. The presence of a root filling was also strongly associated with development of AP. When interpreting the results in Table 3, it should be kept in mind that usually root fillings are not present in teeth without restorations. The OR associated with root fillings therefore describes the additional risk associated with a root filling in a restored tooth. Relative to a healthy tooth the OR for a root filled tooth with, e.g. an adequate crown therefore becomes 57.2.

Unexpectedly, an inadequate quality of a root filling was not significantly associated with an increased risk of development of AP. However, the CIs were rather wide and a modest positive association was not inconsistent with the data. This result was the main motivation for further analyses of the disease process. A comprehensive within-mouth analysis of risk factors associated with healing of AP was not feasible. Bivariate analyses suggested that inadequate root fillings and coronal restorations were associated with an increased risk of no healing, but the numbers were small and the findings were not statistically significant (results not shown). In an attempt to also identify factors associated with the persistence of AP the conditional logistic regression was expanded to include all teeth, and not just initially healthy teeth. Overall, the results from this approach were very similar to those related to the incidence of AP, suggesting that the risk factors influencing development of AP are also associated with persistence of AP. Initial AP was a highly significant predictor of AP at the second examination. Moreover, the quality of the root filling was only statistically significant when not adjusted for initial AP. This suggests that the association between inadequate root fillings and AP at the second examination is mediated by the presence of AP at first examination, and that inadequate root fillings are primarily associated with a poorer prognosis of healing. This interpretation is supported by the excess risk associated with inadequate root fillings reported by Kirkevang *et al.* (2004), who studied the presence of AP in the same sample at first examination. Detailed data on the root canal treatment are needed to further elucidate this interpretation, but such data were not available in the present study.

Risk factors for success/failure related to treatment of AP have been investigated in controlled clinical studies. The results show that the technical quality of the root filling is related to treatment outcome, with lower success rates if the quality of the root filling is assessed as inadequate (Kirkevang & Hörsted-Bindslev 2002). These results do not contradict the findings of the present study since treatment success reflects the healing process rather than incidence of AP. Moreover, two longitudinal population studies provide indirect support to the findings from the present study. The studies show that even though the quality of root fillings improved in the time period between the examinations, the periapical status did not improve correspondingly (Eckerbom *et al.* 1989, Petersson *et al.* 1991). The role of bacteria in the development of AP is well established, and it has been argued that root fillings should avoid penetration of bacterial products, but may be the importance of strict aseptic procedures during the entire root canal treatment should be brought more into focus. It has been demonstrated that when no bacteria remain in the root canal after root canal treatment, healing occurs independently of the quality of the root filling, whereas if residual bacteria could be detected in the root canal after treatment, then the healing of inadequate root fillings was impaired (Fabricius *et al.* 2006). It is known that Danish dentists do not routinely use rubber dam when performing endodontic treatment, and this may have influenced the results (Bjørndal & Reit 2005).

A highly significant association between the quality of a coronal filling or a crown and the incidence of AP was demonstrated. In particular, teeth with low quality crowns exhibited a high risk of developing AP. Comparable risk estimates were demonstrated in a recent Danish cross-sectional study of risk indicators for presence of AP (Kirkevang *et al.* 2004). In a recent

German retrospective study, it was indicated that the preparation of crowns might induce pulpal damage and result in root canal treatment (Tekyatan *et al.* 2005). Longitudinal studies have found that 5–10% of crowned teeth without root fillings developed AP (Ericson *et al.* 1966, Karlsson & Hedegård 1984). However, it has also been demonstrated that crown therapy did not impair the periapical status (Eckerbom *et al.* 1991). Even though previous studies have somewhat conflicting findings, current evidence emphasizes the importance of performing high quality coronal restorations to minimize the risk of pulpal infection.

Teeth with carious lesions had an increased risk of developing AP. This is not surprising, since carious lesions are one of the main gateways for bacteria infecting the pulp. In a Danish cross-sectional study, primary carious lesions significantly increased the risk of having AP (Kirkevang *et al.* 2004). This was supported by a recent German study, in which the risk of receiving a root canal treatment increased if the tooth had a carious lesion (Tekyatan *et al.* 2005). This suggests that prevention of dental caries and gaining control of the disease progression, either by non-operative or operative treatment, may be a possible way of reducing the incidence of AP.

A reduced marginal bone level was associated with development of AP. Previous studies have shown that the presence of AP in a tooth increased the risk of having a reduced marginal bone level, as well as developing bone loss in the same tooth (Jansson *et al.* 1993, Jansson & Ehnevid 1998). Possible explanations of this relationship include suggestions that bacteria or metabolic substances originating from the infected pulp tissue may spread through dentinal tubules to the marginal periodontal tissue, or that marginal inflammation may progress to the apical area.

Conclusion

In the individual, smoking and reduced marginal bone level indicates an environment in the mouth that favours disease development. Furthermore, the presence of root fillings, coronal fillings, crowns and carious lesions indicate that the person is at higher risk for developing AP. In teeth, the most decisive risk factors for developing AP were crowns and coronal fillings, especially inadequate ones. Presence of a root filling increased the risk of developing AP, whereas the quality of a root filling was insignificant. However, the results support that the quality of a root filling was important in relation to the healing of AP. Other dental diseases such as carious lesions and reduced marginal bone level also increased the risk of developing AP. Thus, to lower the incidence of AP in the general population focus should be on improving the quality of restorative dental work, especially coronal restorations, and to diagnose and control the progression of carious lesions, either by operative or by non-operative treatment, before pulpal damage occurs. Furthermore, to facilitate healing of an AP lesion the procedure by which the root canal is cleaned, shaped, disinfected and filled should be optimal.

Hopefully, the present study will initiate further research on the incidence of AP in different populations, as little is known about risk factors associated with the incidence of AP.

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