ORIGINAL ARTICLE

Clinical course of chronic periodontitis: effect of lifelong light smoking (20 years) on loss of attachment and teeth

Marc Schätzle[1], Harald Löe[1,2], Christoph A. Ramseier[2], Walter Bürgin[2], Åge Ånerud[3], Hans Boysen[3] & Niklaus P. Lang[1,2]

1 Faculty of Dentistry, Prince Philip Dental Hospital, The University of Hong Kong, Hong Kong, China
2 School of Dental Medicine, University of Berne, Berne, Switzerland
3 Private Practice, Vejle, Denmark, and Kongsvinger, Norway

Abstract

Aim: To examine the lifelong effect of light smoking on periodontal health.

Methods: The data were derived from a 20-year longitudinal study of a group of Norwegian, middle-class males. The patients were subset according to their smoking history. A total of 119 non-smokers and 17 smokers were examined, 20 years apart.

Results: Current smokers had significantly higher plaque indices than non-smokers after the age of 35 years, while before 35 years, there was no difference. Before 20 years of age, the non-smokers exhibited greater gingival indices, but after the age of 35, the smokers had significantly more sites that bled upon probing. Smokers demonstrated higher mean calculus indices after 35 years and as they approached 50 years of age. At baseline, the two groups showed similar attachment loss (0.14 mm), but with increasing age and approaching 50 years, the attachment loss progressed significantly faster in smokers than in non-smokers (2.31 and 1.57 mm, respectively). Linear regression indicated that ageing and light smoking were independently and significantly related to attachment loss.

Conclusions: Lifelong light smoking could be confirmed as a risk factor for periodontal disease progression. However, in this population, smoking did not significantly increase the risk of tooth loss.

Introduction

The significance of tobacco smoking and the occurrence of periodontal disease have been the subject of a long-standing debate. One of the first reports on the subject revealed that, in Danish navy personnel, there was a significant correlation between the occurrence of ulcerative gingivitis and tobacco consumption.[1,2] Subsequently, data from Sweden[3] showed that the frequency of periodontal pathology was greater in smoking than non-smoking dental students. Moreover, Norwegian investigations[4] supported the view of a positive correlation between the loss of alveolar bone and tobacco consumption.

In a number of more recent studies, the relationship between smoking and periodontal health or disease was again explored, and seemed to confirm that smoking was a putative risk factor for the loss of periodontal attachment and alveolar bone.[5–10] Furthermore, the severity of periodontal lesions was directly related to the quantity of cigarettes consumed.[8,10–13] The prevalence of smoking also seemed to be very high in patients with recurrent (refractory) periodontitis,[14] and it was maintained that the response to periodontal therapy was found to be less favorable in cigarette smokers than in non-smokers.[15–19] Regenerative therapy in smokers resulted in treatment outcomes that were clearly less favorable than in non-smokers.[20]

It has been found that smoking has an adverse effect on the immune and inflammatory systems.[21] Decreased polymorphonuclear leucocyte (PMN) migration into the

oral cavity of smokers had already been suggested in 1969.[22] Subsequently, PMN harvested from the gingival sulci of smokers were shown to have reduced phagocytic capacity compared to PMN from non-smokers.[23] Smokers yielded increased numbers of leukocytes in circulation, while fewer PMN migrated into the gingival crevice/pocket. *In vitro* studies tended to show a direct inhibition of neutrophil- and monocyte-macrophage-defensive functions at high concentrations of nicotine.[24] Abnormal PMN phagocytosis was associated with a high level of cigarette smoking.[14] Using a Markov chain statistical model for the analysis of longitudinal data, it has also been suggested that smoking inhibits the healing process rather than promoting the disease progression of periodontitis.[25]

Most studies examining the effects of smoking on the periodontium have used a cross-sectional design. While cross-sectional studies can be valuable in identifying possible risk indicators associated with disease, prospective studies with longitudinal assessments are necessary to provide evidence that a condition or feature can represent a true risk factor.[26] To date, few such studies are available to explore the long-term influence of smoking on periodontal health or disease progression.

In a 10-year follow-up study,[27] the influence of smoking on periodontal health was evaluated prospectively. Based on evidence of an increase in periodontal probing depths concomitant with periodontal bone loss in chronic smokers, it was suggested that smoking compromised periodontal health. However, in non-smokers, the periodontal conditions remained relatively unchanged over the 10-year follow-up period. Similar results were found in another longitudinal study mentioned earlier.[25]

In contrast, no significant relationship between smoking and loss of attachment (LoA) was found in a 20-year longitudinal study of a Sri Lankan tea laborer population that had never practiced oral hygiene.[28] Given the high level of periodontal disease progression in the absence of oral hygiene practices, and no periodontal treatment rendered, the effect of local irritants might have overshadowed the effect of smoking on disease progression in that study.

The purpose of the present study was to explore the pattern of periodontal attachment loss in light smokers or non-smokers who, during their adult life, had regular dental care and practiced good to excellent oral hygiene.

Materials and methods

The present report represents an analysis of data obtained from a longitudinal study of the initiation and progression of chronic periodontitis and tooth loss over major portions of adult life in middle-class, Norwegian men.

Clinical parameters

The examinations were performed in well-equipped clinical facilities at the Faculty of Odontology, University of Oslo, and included assessments of the periodontal tissues and adjacent portions of the oral cavity and the dentition. At each appointment, the participants answered questions regarding their personal dental care and smoking habits. Throughout the study, the same indices were scored by the same two investigators who were both experienced periodontists and well-trained and calibrated examiners (HB and ÅÅ).

The following parameters were assessed:[32] (a) plaque index (PlI);[29] (b) calculus index (ClI);[30] (c) gingival index (GI);[30,31] and (d) LoA.[38]

In the 1981 survey, and in all subsequent examinations, the distal and lingual surfaces were also included in the examinations, while before that survey, the examinations were restricted to buccal and mesial sites.

Tooth loss was identified when a tooth was present in 1969 and missing at any of the subsequent examinations. Information on the exact date or the reason for tooth loss was not collected. Third molars were not included in the evaluation at any time.

Patients were stratified according to their smoking history into self-reported "smokers" and "non-smokers".

The non-smoking cohort was made up of individuals who, at each examination, reported that they had never smoked. The smoking group consisted of all patients, who at every survey in which they participated, reported smoking two or more cigarettes per day (Table 1).

Irregular smokers, who reported smoking at some examinations, but not at others, were eliminated from the analyses.

Data source

The study population has been described earlier.[32–37] The Norwegian group was established in Oslo in 1969 and

Table 1. Number of patients examined at each survey from 1969 to 1988

Age group (years)	Baseline		Follow-up	
	Non-smokers	Smokers	Non-smokers	Smokers
<20	25	3		
20–24	59	8		
25–30	35	6		
35–39			42	6
40–44			51	6
45–50			26	5
Patients per survey	119	17	119	17

consisted of 565 men between 17 and 30 years of age and who had a minimum of 13 years of education. The group was randomly selected by the Norwegian Bureau of Statistics. They were all born and raised in the city of Oslo and had received regular systematic dental care since childhood. This population practiced oral home care on a daily basis, and reported seeing their dentist on an annual basis.

With respect to smoking, the group was examined in 1969 and 20 later in 1988, although the patients had been examined longitudinally every 2–7 years. Thus, only patients present at baseline and in 1988 were considered in order to avoid overlapping the various cohorts. In 1969, the participants were divided into three age groups (<20, 20–24, and 25–30 years of age), which became the following age groups after 20 years: 35–39, 40–44, and 45–50 (Table 1). As a result of this division, 119 non-smokers and 17 lifelong smokers were compared after an observation period of 20 years.

Data analyses

As in most longitudinal studies of this size and length, a number of patients dropped out and could not be followed up. Other patients missed one or more examinations, but showed up at a later survey. Of the 565 patients who started in the investigation in 1969, 136 showed up for the last examination 20 years later and were the basis for the evaluation in the present analysis (Table 1).

SAS software (SAS Institute, Cary, NC, USA) was used to calculate frequencies, mean values, and the regression models. For comparing the significant differences in the mean values between the non-smoking and smoking cohorts as stratified groups (mean values) and at different age levels, the Wilcoxon rank sum test was used.

For odds ratio calculations, the logistic regression models (PROC LOGISTIC; SAS) were used to model the binary tooth loss variable as a function of smoking habits and age. The level of significance was set at $\alpha = 0.05$.

Results

The baseline population consisted of 565 men, among those, 94 (16.6%) were self-declared smokers. Twenty years later, 203 patients were re-examined in 1988. From those, 17 were self-declared smokers, representing a percentage of 8.4%. One hundred and nineteen could be identified as never having smoked, representing 58.6%. The remaining 67 (33%) belonged to a group of intermittent smokers, excluded from the analysis. Thus, the same non-smokers and smokers at survey 6 were used to compare their baseline data 20 years earlier.

Clinical parameters

Plaque index

The mean PlI and the frequency distributions of the PlI scores for both non-smokers and smokers are illustrated in Table 2 and Figure 1. Before the age of 30 years, the mean PlI scores for non-smokers and smokers were comparable (PlI = 1.15–1.18 and 1.17–1.37, respectively). After 35 years of age, and as the cohort approached 50 years, the smokers showed statistically significantly higher mean PlI values than non-smokers (PlI = 1.46 vs 1.75).

After 35 years of age, there were also fewer PlI scores of 2 or 3 at sites of non-smokers (47–55%), as compared to smokers (56–77%) at different age levels.

Gingival index

Before 30 years of age, the mean GI scores (Table 3; Figure 2) were comparable or slightly higher in non-smokers. In cohorts older than 35 years of age, however, the smokers had significantly greater mean GI scores (GI = 0.90–1.23) than the non-smokers (GI = 0.81–0.85).

The frequency distribution of various GI scores (Table 3) also indicated that there were fewer GI scores of 2 or 3 among the smokers (4–7%) than the non-smokers (8–14%) before 30 years of age. Approaching 50 years of age, the non-smokers yielded significantly lower

Table 2. Mean values and frequency distribution of plaque index (PlI) scores for non-smokers and smokers by age group

Age group (years)	Non-smokers				Smokers			
	PlI = 0 (%)	PlI = 1 (%)	PlI = 2, 3 (%)	Mean PlI	PlI = 0 (%)	PlI = 1 (%)	PlI = 2, 3 (%)	Mean PlI
<20	16.33	52.34	31.33	1.15	16.67	49.4	33.93	1.17
20–24	16.41	51.58	32.01	1.16	11.59	49.32	39.09	1.28
25–30	17.31	47.19	35.50	1.18	10.44	41.77	47.78	1.37
35–39	11.27	38.73	50.00	1.39	9.43	34.13	56.44	1.47
40–44	12.07	40.80	47.13	1.35	7.62	32.16	60.21	1.53
45–50	8.42	37.03	54.55	1.46*	1.74	21.90	76.36	1.75*

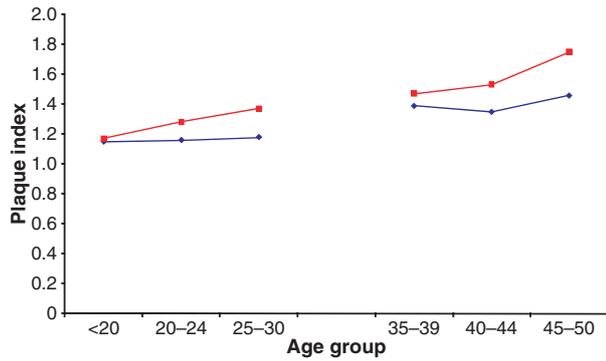*Significant differences ($P < 0.05$).

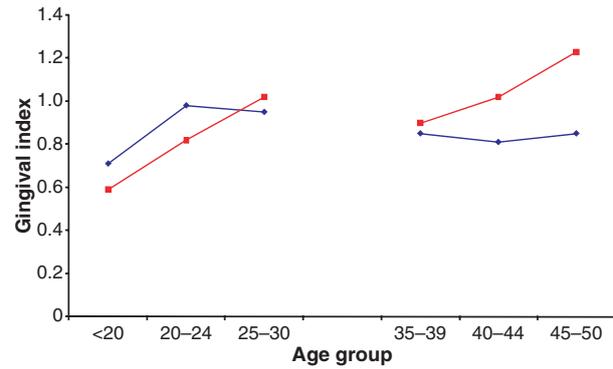**Figure 1.** Mean plaque index scores for non-smokers and smokers by age group. ◆, Non-smoker; ■, smoker.

Figure 2. Mean gingival index scores for non-smokers and smokers by age group. ◆, Non-smoker; ■, smoker.

proportions of GI scores of 2 or 3 (16%) when compared to the smokers (35%).

Calculus index

Table 4 and Figure 3 show the frequency distribution of the different ClI scores for both non-smokers and smokers over the various age ranges. Before the age of 30 years, non-smokers and smokers showed similar mean calculus scores. More than 80% of all the surfaces were calculus free. After the age of 35, and as the patients approached 50 years of age, the prevalence of subgingival calculus (ClI = 2, 3) increased substantially from 13% to 33% in smokers, whereas in the non-smokers, subgingival calculus showed very little increase over the age span (4–8%).

Loss of attachment

The cumulative LoA during the 20 years of observation is shown in Table 5 and Figure 4. At baseline, the mean LoA for non-smokers and smokers was 0.14 mm. In non-smokers, 87–97% of sites did not yield a LoA of more than 1 mm, while in smokers, the respective proportion was 87–96% (before the age of 30 years). Approaching 50 years of age, the cumulative mean LoA was 1.57 mm

in non-smokers and 2.31 mm in smokers, respectively. Moreover, there were more lesions with LoA ≥4 mm in smokers (7.5% *vs* 17.7%; Table 5).

Figure 5 provides a scatterplot of the mean attachment loss in smokers and non-smokers and their ages. Age was significantly related to the attachment level in both groups ($P < 0.001$). The slope of the regression line for smokers was approximately 1.5 times steeper than that of the non-smokers, indicating that smoking had an increasing effect with increasing age. The slopes were significantly different from each other ($P < 0.05$).

Tooth loss

The smokers did not lose significantly more teeth over the 20-year observation period than the non-smokers (Table 6). In smokers, of the initial 462 teeth present in 1969, 461 were retained after 20 years; that is, two teeth or 0.43% were lost during the observation period. Non-smokers had lost 15 (0.46%) of 3246 teeth present at baseline. The odds ratio for smokers to lose a tooth was 1.07 (confidence interval: 0.24–4.67) compared to non-smokers, and was not statistically significant.

Table 3. Mean values and frequency distribution of gingival index (GI) scores for non-smokers and smokers by age group

Age group (years)	Non-smokers				Smokers			
	GI = 0 (%)	GI = 1 (%)	GI = 2, 3 (%)	Mean GI	GI = 0 (%)	GI = 1 (%)	GI = 2, 3 (%)	Mean GI
<20	37.41	54.47	8.13	0.71	45.24	50.60	4.17	0.59
20–24	16.19	70.06	13.75	0.98	22.05	74.32	3.64	0.82
25–30	16.22	72.82	10.97	0.95	6.01	86.71	7.28	1.02
35–39	31.95	51.39	16.65	0.85	24.85	60.03	15.12	0.90
40–44	35.91	47.13	16.96	0.81*	22.56	54.27	23.17	1.02*
45–50	31.58	52.11	16.32	0.85*	12.60	52.71	34.69	1.23*

*Significant differences ($P < 0.05$).

Table 4. Mean values and frequency distribution of calculus index (CI) scores for non-smokers and smokers by age group

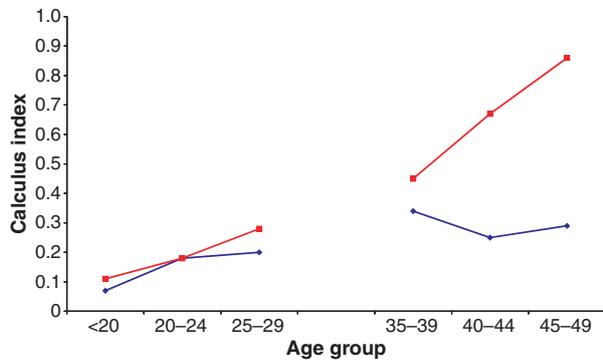| Age group (years)	Non-smokers				Smokers			
	CI = 0 (%)	CI = 1 (%)	CI = 2, 3 (%)	Mean CI	CI = 0 (%)	CI = 1 (%)	CI = 2, 3 (%)	Mean CI
<20	93.12	6.44	0.44	0.07	89.29	10.12	0.60	0.11
20–24	85.67	11.05	3.28	0.18	84.09	14.09	1.82	0.18
25–30	84.15	11.23	4.62	0.20	80.38	11.39	8.23	0.28
35–39	73.69	18.04	8.27	0.34	66.92	20.81	12.28	0.45
40–44	79.99	15.23	4.78	0.25*	57.47	19.36	23.17	0.67*
45–50	74.90	20.60	4.50	0.29*	47.87	19.77	32.36	0.86*

*Significant differences ($P < 0.05$).

Figure 3. Mean calculus index scores for non-smokers and smokers by age group. ◆, Non-smoker; ■, smoker.
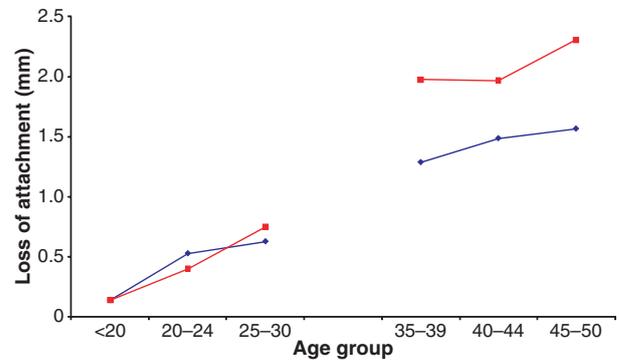

Figure 4. Mean loss of attachment for non-smokers and smokers by age group. ◆, Non-smoker; ■, smoker.

Discussion

The purpose of the present study was to evaluate the clinical parameters of health and disease in adult male, lifelong smokers and non-smokers of a middle-class population with good to excellent oral hygiene practices. On the basis of two clinical examinations 20 years apart, the data describe the accumulation of plaque and calculus and the attachment loss, as well as tooth mortality before 50 years of age, based on the participants' self-reported smoking history. While the baseline cohort presented with 16.6% smokers, the re-evaluation 20 years later revealed only a proportion of 8.4% self-declared lifelong smokers. This in turn means that the number of dropouts was increased twofold in smokers than non-smokers. The reason for this remains unknown. However, it can be speculated that lifelong smokers lack the interest to be re-examined. In the present study, lifelong smokers were defined as patients who were reported to have smoked two cigarettes or more a day for 20 years. This represents

Table 5. Mean values and frequency distribution of loss of attachment (LoA) scores for non-smokers and smokers by age group

Age group (years)	Non-smokers					Smokers				
	LoA = 0, 1 (%)	LoA = 2, 3 (%)	LoA = 4, 5 (%)	LoA ≥6 (%)	Mean LoA	LoA = 0, 1 (%)	LoA = 2, 3 (%)	LoA = 4, 5 (%)	LoA ≥6 (%)	Mean LoA
<20	97.57	2.36	0.07	0.00	0.14	96.43	3.57	0.00	0.00	0.14
20–24	90.85	8.69	0.40	0.06	0.53	91.03	8.51	0.46	0.00	0.40
25–30	86.71	11.30	1.72	0.26	0.63	87.25	11.44	1.31	0.00	0.75
35–39	64.03*	32.57	3.34*	0.06*	1.29*	44.48*	40.64	12.16*	2.72*	1.98*
40–44	56.60*	37.53	5.46*	0.41*	1.49*	42.56*	43.37	13.11*	0.98*	1.97*
45–50	52.56*	39.95	7.33*	0.16*	1.57*	34.07*	48.23	15.49*	2.21*	2.31*

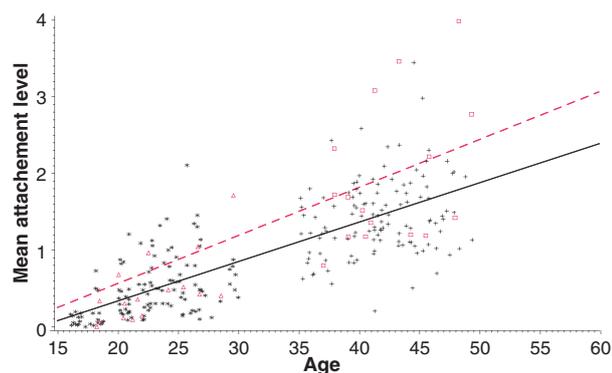*Significant differences ($P < 0.05$).

Figure 5. Scatterplot of mean attachment level and age in smokers and non-smokers. (*) Non-smokers 16–30 years of age; (+) non-smokers 36–60 years of age; (△) smokers 16–30 years of age; and (□) and smokers 36–60 years of age. Survey smoke all: ***, 10; △ △ △, 12; +++, 60; □ □ □, 62.

a definition that generally would classify them as light smokers. While heavy smokers smoking one pack of cigarettes or more have often been identified as at risk for periodontal disease progression,[6,8,10,15,18,39] the influence of light smoking on the progression of periodontitis has generally not been addressed. The middle-class, Norwegian males represent a well-educated group, motivated to perform oral hygiene and in maintaining a healthy dentition. In that respect, the small study population might not represent an average population, and generalizability of the results has to be questioned. Nevertheless, the effect of light, but lifelong, cigarette smoking on the progression of loss of periodontal attachment throughout life is indisputable, and supports that even lower exposure to cigarette smoking, when performed lifelong, can be detrimental to periodontal health.

Oral hygiene standards

In the smokers and the non-smokers younger than 30 years of age, there was little or no difference in the standard of oral hygiene, as revealed by plaque accumula-

tion. For the period of 35–50 years, however, the smokers consistently exhibited significantly greater PlI scores than the non-smokers. These findings tended to confirm the long-held view that smokers display worse standards of oral hygiene than non-smokers. They also stand in contrast to suggestions that tobacco use could act as an antiplaque agent.[40] In accordance with numerous studies over the years, increasing PlI scores were accompanied by increasing GI values for all age levels of smokers, as well as non-smokers.

Before the age of 30 years, there was very little subgingival calculus in either cohort, while in the later decades of life, the smokers exhibited consistently more subgingival calculus than the non-smokers.

While the mean PlI in smokers was only approximately 1.2 times greater than that of the non-smokers, the mean ClI for smokers was almost three times higher than that of the non-smokers as the patients approached 50 years of age. This combined impact of plaque and calculus accumulation corresponded particularly to the increasing mean GI scores, and significantly more sites with bleeding gingiva in smokers 35 years and older. Thus, it could be suggested that in smokers, this combined increase in plaque and calculus formation might have had significant detrimental effects both on the gingival health and the subsequent progression of the periodontal lesions.

Peridontal changes

Before 30 years of age, LoA occurred at equally low levels in smokers and non-smokers, but with increasing age, and especially at 35–40 years of age, periodontal lesions progressed at a higher rate in smokers than in non-smokers (Figure 5). This finding is in accordance with that of Gunsolley *et al.*[41] and Haffajee and Socransky,[42] who found that smokers with minimal periodontal destruction exhibited greater LoA than patients with minimal disease who did not smoke.

It is generally known that with increasing age, there is an increase in LoA. The amount of attachment loss

Table 6. Frequency distribution of tooth loss for non-smokers and smokers

	Non-smokers				Smokers				Total			
	Retained		Lost		Retained		Lost		Retained		Lost	
Incisors	947	99.73%	1	0.11%	136	100.00%	0	0.00%	1083	99.91%	1	0.09%
Canines	476	100.00%	0	0.00%	68	100.00%	0	0.00%	544	100.00%	0	0.00%
Premolar	893	99.33%	6	0.67%	126	99.21%	1	0.79%	1019	99.32%	7	0.68%
Molars	930	99.15%	8	0.85%	131	99.24%	1	0.76%	1061	99.16%	7	0.84%
Total	3246	99.54%	15	0.46%	461	99.57%	2	0.43%	3707	99.54	17	0.46%

At baseline: 84 missing teeth.

from the age of 16–50 years was 1.43 mm for the non-smokers (0.14–1.57 mm) and 2.17 mm for smokers, indicating that both smoking and ageing were independently associated with increased attachment loss. The relationship between smoking and attachment loss was significant at $P < 0.05$ (SAS General Linear Modeling; SAS), and the slope of the scatterplot that related age to mean attachment level was 1.5 times greater for smokers than for non-smokers. In contrast to the data of attachment loss, smokers did not have a significantly increased risk for tooth loss. This in turn can be explained on the basis that, in this dentally-minded, middle-class population, tooth loss was a relatively rare event.[37]

By and large, these results coincide with those of several cross-sectional,[8] long-term follow-up,[43,44] and longitudinal[28,45,46] studies, that smokers might be at higher risk for periodontal disease than non-smokers. However, knowledge of the mechanisms of this disease progression is skewed: how much is due to local factors, and how much is due to the direct or systemic effect of smoking itself and the chemicals involved?

This and other clinical studies have been unable to adequately answer these questions. In this context, two features which, according to the data of the present study, suggest that: (a) the difference between the periodontal changes in those who consistently smoked for 20 years compared to those who never smoked was relatively small (gingivitis level, LoA) or absent (tooth loss); and (b) the biggest difference in the two cohorts occurred in the accumulation of supragingival calculus and subgingival calculus, and that the combined impact of plaque and calculus in smokers might explain the modest increase in periodontal pathology.

These findings support a previous analysis of this data set.[47] In that analysis, age and smoking status were identified as two systemic variables influencing disease progression and regression. Increasing age lowered the rate of disease regression, while smoking increased the rate of disease progression.

Thus, it is concluded that this longitudinal study of middle-class, Scandinavian men with regular dental check-ups and daily oral hygiene practices, has shown that even light smokers lose slightly more periodontal attachment than non-smokers, and that the major factor in this attachment loss is due to the increased accumulation of plaque, as well as supragingival calculus and subgingival calculus, as compared to non-smokers. Furthermore, this study failed to document that light smoking had an influence on tooth loss before 50 years of age.

Acknowledgment

References

1 Pindborg JJ. Gingiviternes hyppighed og årsager belyst ved undersøgelse af 3600 soldater. *Tandlægebladet* 1946; **50**: 421–3.

2 Pindborg JJ. Correlation between consumption of tabacco, ulceromembranous gingivitis and calculus. *J Dent Res* 1949; **28**: 461–3.

3 Herluf G. Om det marginale alveolarbenet hos ungdom I studiealderen – en röntgenstudie. *Svensk Tandläken Tidning* 1950; **43**: 42–82.

4 Schei O, Wærhaug J, Løvdal A, Arno A. Alveolar bone loss as related to oral hygiene and age. *J Periodontol* 1959; **30**: 7–16.

5 Ismail AI, Burt BA, Eklund SA. Epidemiologic patterns of smoking and periodontal disease in the United States. *J Am Dent Assoc* 1983; **106**: 617–21.

6 Bergström J, Eliasson S, Preber H. Cigarette smoking and periodontal bone loss. *J Periodontol* 1991; **62**: 242–6.

7 Horning G, Hatch C, Cohen M. Risk indicators for periodontitis in a military treatment population. *J Periodontol* 1992; **63**: 297–302.

8 Haber J, Wattles J, Crowley M, Mandell R, Joshipura K, Kent RL. Evidence for cigarette smoking as a major risk factor for periodontitis. *J Periodontol* 1993; **61**: 364–7.

9 Bolin A, Eklund G, Frithiof L, Lavestedt S. The effect of changed smoking habits on marginal alveolar bone loss. *Swed Dent J* 1993; **17**: 211–6.

10 Grossi SG, Zambon JJ, Ho AW *et al.* Assessment of risk for periodontal disease I. Risk indicators for attachment loss. *J Periodontol* 1994; **65**: 260–7.

11 Goultschin J, Cohen HDS, Donchin M, Brayer L, Soskolne WA. Association of smoking with periodontal treatment needs. *J Periodontol* 1990; **61**: 364–7.

12 Grossi SG, Genco RJ, Machtei EE *et al.* Assessment of risk for periodontal disease II. Risk indicators for alveolar bone loss. *J Periodontol* 1995; **66**: 23–9.

13 Norderyd O, Hugoson A. Risk of severe periodontal disease in a Swedish adult population. *J Clin Periodontol* 1998; **28**: 1022–8.

14 MacFarlane G, Herzberg M, Wolff L, Hardie N. Refractory periodontitis associated with abnormal polymorphonuclear leukocyte. *J Periodontol* 1992; **63**: 908–13.

15 Preber H, Bergström J. The effect of non-surgical treatment on periodontal pockets in smokers and non-smokers. *J Clin Periodontol* 1986; **13**: 319–23.

16 Preber H, Bergström J. Effect of cigarette smoking on periodontal healing following surgical therapy. *J Clin Periodontol* 1990; **17**: 324–8.

17 Ah MKB, Johnson GK, Kaldahl WB, Patil KD, Kalkwarf KL. The effect of smoking on the response to periodontal therapy. *J Clin Periodontol* 1994; **21**: 91–7.

18 Grossi SG, Zambon J, Machtei EE *et al.* Effects of smoking and smoking cessation on healing after mechanical periodontal therapy. *J Am Dent Assoc* 1997; **128**: 599–607.

19 Kaldahl WB, Johnson GK, Patil KD, Kalkwarf KL. Levels of cigarette consumption and response to periodontal therapy. *J Periodontol* 1996; **67**: 675–81.

20 Tonetti MS, Pini- Prato G, Cortellini P. Effect of cigarette smoking on periodontal healing following GTR in infrabony defects. A preliminary retrospective study. *J Clin Periodontol* 1995; **22**: 229–34.

21 Barbour SE, Nakashima K, Zhang JB *et al.* Tobacco and smoking: environmental factors that modify the host response (immune system) and have an impact on periodontal health. *Crit Rev Oral Biol Med* 1997; **8**: 437–60.

22 Eichel B, Shahrik HA. Tobacco smoke toxicity: loss of human oral leukocyte function and fluid-cell metabolism. *Science* 1969; **166**: 1424–8.

23 Kenney EB, Kraal JH, Saxe SR, Jones J. The effect of cigarette smoke on human oral polymorphonuclear leukocytes. *J Periodontal Res* 1977; **12**: 227–34.

24 Pabst MJ, Pabst KM, Collier JA *et al.* Inhibition of neutrophil and monocyte defensive functions by nicotine. *J Periodontol* 1995; **66**: 1047–55.

25 Faddy MJ, Cullinan MP, Palmer JE, Westerman B, Seymour GJ. Ante-dependence modeling in a longitudinal study of periodontal disease: the effect of age, gender and smoking status. *J Periodontol* 2000; **71**: 454–9.

26 Genco RJ. Current view of risk factors for periodontal diseases. *J Periodontol* 1996; **67**: 1041–9.

27 Bergström J, Eliasson S, Dock J. A 10-year prospective study of tobacco smoking and periodontal health. *J Periodontol* 2000; **71**: 1338–47.

28 Neely AL, Holford TR, Löe H, Å nerud Å, Boysen H. The natural history of periodontal disease in man. Risk factors for progression of attachment loss in individuals receiving no oral health care. *J Periodontol* 2001; **72**: 1006–15.

29 Silness J, Löe H. Periodontal disease in pregnancy II. Correlation between oral hygiene and periodontal condition. *Acta Odontol Scand* 1964; **22**: 121–35.

30 Löe H. The gingival index, the plaque index and the retention index systems. *J Periodontol* 1967; **36**: 610–6.

31 Löe H, Silness J. Periodontal disease in pregnancy. Prevalence and severity. *Acta Odontol Scand* 1963; **21**: 533–51.

32 Löe H, Ånerud Å, Boysen H, Smith M. The natural history of periodontal disease in man. Study design and baseline data. *J Periodontal Res* 1978; **13**: 550–62.

33 Löe H, Ånerud Å, Boysen H, Smith M. The natural history of periodontal disease in man. Tooth mortality rates before 40 years of age. *J Periodontal Res* 1978; **13**: 563–72.

34 Löe H, Ånerud Å, Boysen H, Smith M. The natural history of periodontal disease in man: the rate of periodontal destruction before 40 years of age. *J Periodontol* 1978; **49**: 607–20.

35 Löe H, Ånerud Å, Boysen H, Morrison E. Natural history of periodontal disease in man. Rapid, moderate and no loss of attachment in Sri Lankan laborers 14 to 46 years of age. *J Clin Periodontol* 1986; **13**: 431–41.

36 Ånerud Å, Löe H, Boysen H. The natural history and clinical course of calculus formation in man. *J Clin Periodontol* 1991; **18**: 160–70.

37 Schätzle M, Löe H, Lang NP, Bürgin W, Ånerud Å, Boysen H. The Clinical Course of Chronic Periodontitis. IV. Gingival inflammation as a risk factor for tooth mortality. *J Clin Periodontol* 2004; **31**: 1122–7.

38 Glavind L, Löe H. Errors in the clinical assessment of periodontal destruction. *J Periodontal Res* 1967; **2**: 180–4.

39 Bergström J. Cigarette smoking as risk factor in chronic periodontal disease. *Commun Dent Oral Epidemiol* 1989; **17**: 245–7.

40 Danielsen B, Manji F, Nagelkerke N, Fejerskov O, Baelum V. Effect of cigarette smoking on the transition dynamics in experimental gingivitis. *J Clin Periodontol* 1990; **17**: 159–64.

41 Gunsolley JC, Quinn SM, Tew J, Gooss CM, Brooks CN, Schenkein HA. The effect of smoking on individuals with minimal periodontal destruction. *J Periodontol* 1998; **69**: 165–70.

42 Haffajee AD, Socransky SS. Relationship of cigarette smoking to attachment level profiles. *J Clin Periodontol* 2001; **28**: 283–95.

43 Burt BA, Ismail AI, Morrison EC, Beltran ED. Risk factors for tooth loss over a 28-year period. *J Dent Res* 1990; **69**: 1126–30.

44 Ismail AI, Morrison EC, Burt BA, Caffesse RG, Kavanagh MT. Findings from the Tecumseh periodontal disease study. *J Dent Res* 1990; **69**: 430–5.

45 Van der Velden U, Abbas F, Armand S *et al.* Java project on periodontal diseases. The natural development of periodontitis: risk factors, risk predictors and risk determinants. *J Clin Periodontol* 2006; **33**: 540–8.

46 Hugoson A, Sjödin B, Norderyd O. Trends over 30 years, 1973-2003, in the prevalence and severity of periodontal disease. *J Clin Periodontol* 2008; **35**: 405–14.

47 Schätzle M, Faddy MJ, Cullinan MP *et al.* The clinical course of chronic periodontitis: V. Predictive factors in periodontal disease. *J Clin Periodontol* 2009; **36**: 365–71.