EFFECTS OF SMOKING AND SMOKING CESSATION ON HEALING AFTER MECHANICAL PERIODONTAL THERAPY

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Smoking has been unequivocally established as a risk factor for periodontal disease. The 1973 National Health and Nutrition Examination Survey I and subsequent follow-up studies noted that after controlling for confounding variables such as age, race, income, education and oral hygiene practices, smoking emerged as significantly associated with severe periodontal disease index scores.[1] In the Erie County study—a survey of risk factors for periodontal disease—researchers found that after controlling for age, race, gender, systemic diseases, plaque and calculus, smoking was the strongest predictor of attachment loss[2] and alveolar bone loss.[3] The risk of more severe attachment loss and alveolar bone loss in smokers depended on the amount of smoking.[2,3] Heavy smokers had greater risk of attachment loss (odds ratio, 4.27) and bone loss (odds ratio, 7.28) than moderate smokers (odds ratio, 3.21 and 5.23, respectively) and light smokers (odds ratio, 2.05 and 3.25, respectively).[2,3]

ABSTRACT

This study investigated the effect of cigarette smoking on 143 patients' clinical and microbiological responses to mechanical therapy. Treatment included four to six sessions of subgingival scaling and root planing and instruction in oral hygiene. Results indicate that current smokers have less healing and reduction in subgingival *Bacteroides forsythus* and *Porphyromonas gingivalis* after treatment compared to former and nonsmokers, suggesting that smoking impairs periodontal healing. As the healing and microbial response of former smokers is comparable to that of nonsmokers, smoking cessation may restore the normal periodontal healing response.

Smoking was also more prevalent in patients seen in a periodontal practice compared to patients seen in a general dentist practice.[4] Among the patients in the periodontal practice, the severity of periodontal disease increased with the frequency of current smoking.[5] Smokers with periodontal disease also harbor greater numbers of subgingival *Porphyromonas gingivalis* and *Bacteroides forsythus* than nonsmokers with comparable levels of periodontal disease.[6]

Several studies have evaluated the effect of periodontal therapy in smokers and nonsmokers.[7-9] Collectively, these studies report a less favorable response to therapy in smokers as compared with nonsmokers. However, methodological design deficiencies cloud the significance of these findings. In two of these studies, for example,[7,8] attachment level was not used to measure treatment outcome. No assessments of the microbial flora were included in determining the response to periodontal therapy,[7-9] and the nonsmoker group included people who had smoked in the past.[8,9]

From current available data, no definite conclusions can be drawn as to whether the re-

TABLE

DESCRIPTION OF POPULATION.

GROUP	NO. OF SUBJECTS	MEAN ± SD* AGE (YEARS)†	MEAN ± SD PACK-YEARS‡	MEAN ± SD QUIT-YEARS§
Nonsmokers	28	46.5 ± 6.5	0	0
Former smokers	55	49.4 ± 8.2	21.9 ± 21.6	10.8 ± 8.4
Current smokers	60	43.1 ± 6.4	19.9 ± 13.0	0

* SD: Standard deviation.
† $P < .0001$ (P-value indicates that current smokers were significantly younger than non- and former smokers).
‡ Pack-years: no. of packs of cigarettes smoked per day (one pack = 20 cigarettes) × no. of years smoked.
§ Quit-years: no. of years since subject stopped smoking.

duced clinical response observed in smokers is also associated with a change in the microbial response to therapy. In addition, no information is available about the effect of cessation of smoking on the clinical and microbiological response to periodontal therapy.

The aim of this study was to determine the effect of smoking on the clinical and microbiological response to mechanical periodontal therapy. In addition, we wanted to determine how cessation of smoking affected the response to mechanical periodontal therapy.

MATERIALS AND METHODS

Study population. The study population included 143 patients, 77 males and 66 females, between 35 and 65 years of age. To qualify for the study, patients had to have "established periodontitis" according to the 1992 criteria of Machtei and others.[10] These criteria are as follows:

- two interproximal sites with attachment loss ≥ 6 millimeters;
- one additional interproximal site with pocket depth ≥ 5 mm.

In addition, patients were not eligible if they had received periodontal therapy in the past 12 months or had taken antibiotics or antimicrobials during the 3 months before the study. Patients requiring antibiotic prophylaxis to prevent subacute bacterial endocarditis or taking continuous nonsteroidal anti-inflammatory drugs were excluded. The study was approved by the human subject review board of the dental school at the State University of New York at Buffalo. All patients signed an informed consent.

Smoking status was assessed by means of a self-reported questionnaire, which included information on number of cigarettes smoked per day, number of years patients had smoked and, if no longer smoking, number of years since quitting. Study patients were defined, based on smoking status, as current smokers if they were currently smoking regardless of the number of cigarettes smoked and frequency. Patients were classified as former smokers if they smoked in the past but had quit 1 year ago or longer. Nonsmokers were defined as people who had never smoked. The overall lifelong exposure to tobacco was quantified in "pack-years," or the number of packs of cigarettes (one pack equals 20 cigarettes) smoked per day times the number of years the patient smoked. The period free of tobacco was quantified in "quit-years," or the number of years since smoking was stopped.

Periodontal therapy. Periodontal therapy was administered by dental hygienists and monitored by periodontists. Patients received one session of supragingival scaling and oral hygiene instruction. The patients then received four to six sessions of subgingival scaling and root planing. These treatments were administered by quadrant with the patients under local anesthesia. Subgingival scaling included use of ultrasonic devices and hand instrumentation. The end point of the mechanical treatment included removal of all subgingival calcified deposits to achieve a smooth, hard surface. After the first four sessions of subgingival scaling, patients received one or two additional sessions as needed to remove all clinically detectable calcified subgingival deposits from all teeth.

Clinical assessment. At baseline and 3 months after mechanical therapy, all patients received a clinical assessment including the following periodontal variables: plaque index, or PI,[11] bleeding index, or BI,[12] pocket depth, or PD,[10] and clinical attachment level, or CAL.[10] CAL was defined as the distance from the cementoenamel junction, or CEJ, to the base of the clinical pocket. The measurement was performed as the distance from the CEJ to the free gingival mar-

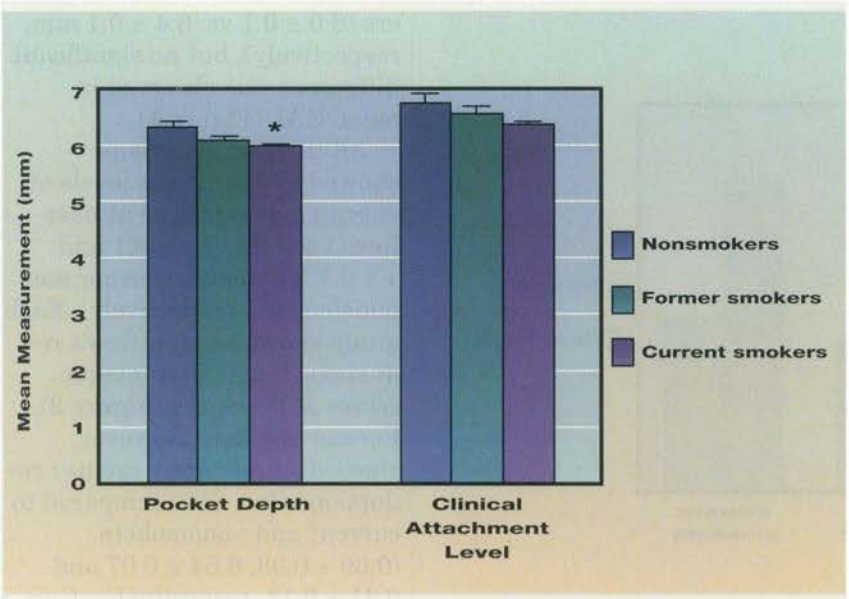

Figure 1. Baseline mean (± SE) pocket depth, or PD, and clinical attachment level, or CAL, for pockets ≥ 5 mm. Mean PD was significantly less in current smokers than in nonsmokers, while all three study groups showed comparable mean CAL. *$P < .004$.

gin (negative values for recession) and then subtracted from the PD measurement at the same site. The plaque and bleeding indexes were scored on three surfaces per tooth (B-MB-L). The probing measurements were performed on six sites per tooth (DB-B-MB-DL-L-ML) with the Florida probe.[13] All teeth present in the mouth except third molars were measured.

Measurements of PD and CAL were performed by three periodontists who were trained and calibrated in the study protocol. One examiner participated as the gold standard. Inter-examiner variance from the gold standard for the other two examiners was 0.32 and 0.50 mm for PD measurements and 0.56 and 0.52 mm for CAL measurements.

Microbial assessment. Microbial assessment was performed on about half of the patients enrolled in the study. The first 74 patients enrolled in the study, who met all inclusion and exclusion criteria, were eligible for the microbial assessment. Plaque samples were obtained from a total of six sites per patient (one site in each sextant), each selected as having ≥ 5 mm PD. The presence of *B. forsythus* and *P. gingivalis* was determined in subgingival plaque samples using immunofluorescence techniques.[14,15] A sample was considered positive if the target microorganism constituted ≥ 1 percent of the total subgingival flora. A patient was considered to have tested positive if any of the sampled sites was positive. Level of bacteria was the average of all sites sampled within each patient.

Statistical analysis. The study population was grouped on the basis of smoking status as nonsmoker, former and current smoker. Mean values for plaque, gingival bleeding, PD, CAL and percentage of sites meeting the inclusion criteria for PD (that is, ≥ 5 mm) were calculated for all three study groups. Comparisons for these variables were made between study groups at baseline using analysis of variance, or ANOVA, and at 3 months using analysis of covariance, or ANCOVA. In addition, changes in mean PD, mean CAL and microbial levels in deep pockets (PD ≥ 5 mm) were calculated and analyzed, adjusting for baseline levels, using ANCOVA. The Fisher's Protected Least Significant Difference multiple comparison procedure was used for pairwise comparisons; this test is valid even when, as in this study, the group sample sizes are unequal. A χ^2 analysis was used to compare the percent of positive subjects for the given periodontal pathogens 3 months after treatment. Differences were considered significant at $P < .05$.

RESULTS

In a preliminary analysis, we examined the baseline periodontal characteristics (mean whole-mouth PD and CAL, percentage of sites with PD ≥ 5 mm, mean plaque score and percentage of bleeding sites) among patients with and without microbial assessment. No significant differences were observed in baseline periodontal status or in clinical response to therapy between these two groups of patients. Therefore, reporting the data on all 143 patients for all clinical outcomes of therapy was justified.

The entire study population for whom clinical data were obtained included 28 nonsmokers, 55 former smokers and 60 current smokers. The mean number of pack-years for former and current smokers was 21.9 and 19.9, respectively. Former smokers had stopped smoking

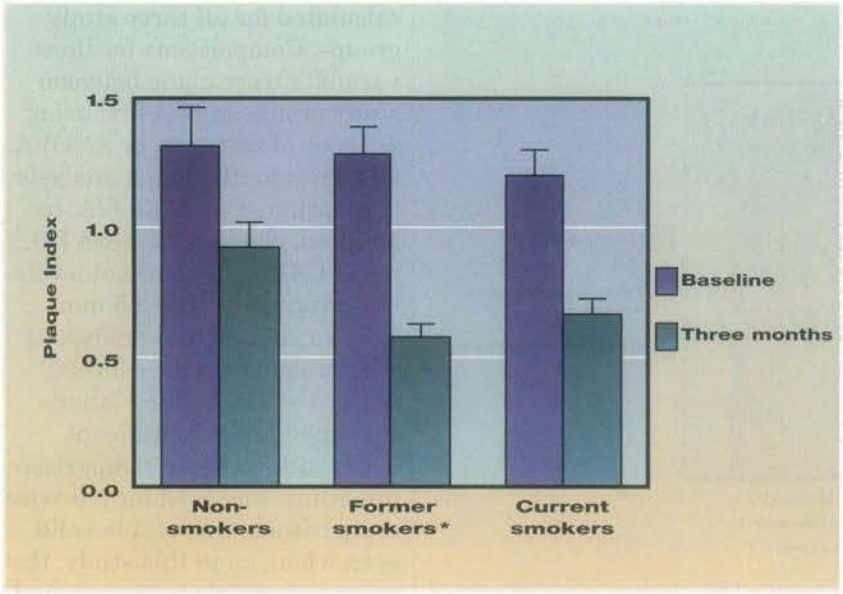

Figure 2. Plaque assessment at baseline and 3 months (mean ± SE). All three study groups showed a reduction in plaque accumulation. However, former smokers showed a significantly greater reduction after adjustment for baseline values. *$P < .002$.

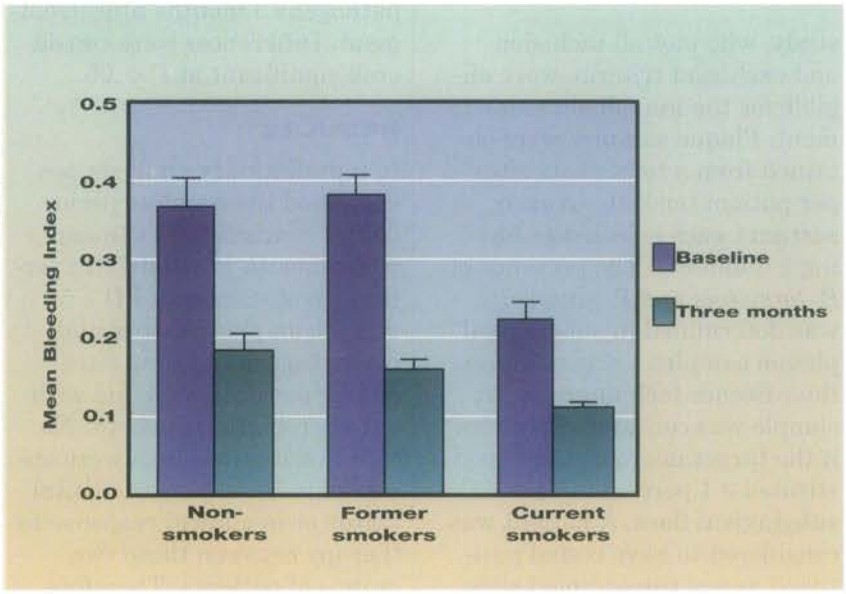

Figure 3. Gingival bleeding at baseline and 3 months (mean ± SE). All three study groups showed a reduction in gingival bleeding; however, there was no significant difference after adjustment for baseline values.

an average of 11 years before (range, 1 to 35 years) (Table). Baseline mean ± standard error whole-mouth pocket depth was 3.0 ± 0.1, 3.0 ± 0.1 and 3.1 ± 0.1 mm for nonsmoker, former smoker and current smoker groups. The mean whole-mouth CAL was 3.2 ± 0.2, 3.4 ± 0.1 and 3.4 ± 0.1 mm for these three groups, respectively. However, when only deep pockets were considered (initial pocket depth ≥ 5 mm), mean PD was significantly less ($P < .004$) in current smokers compared to nonsmokers (6.0 ± 0.1 vs. 6.4 ± 0.1 mm, respectively), but no significant difference was observed in mean CAL (Figure 1).

All three study groups showed similar mean levels of supragingival plaque at baseline (1.3 ± 0.1, 1.3 ± 0.1 and 1 ± 0.1 for current, former and nonsmokers, respectively). Each group showed a significant reduction ($P < .003$) in plaque scores at 3 months (Figure 2). Former smokers, however, showed significantly greater reductions ($P < .002$) compared to current and nonsmokers, (0.69 ± 0.08, 0.54 ± 0.07 and 0.41 ± 0.12, respectively). Current smokers showed significantly less gingival bleeding ($P < .0001$) at baseline compared to former and nonsmokers (0.23 ± 0.02, 0.38 ± 0.03 and 0.37 ± 0.04, respectively) (Figure 3). All three groups showed a reduction in gingival bleeding at 3 months, with the greatest reduction occurring in former smokers. There were, however, no significant differences when adjusting for baseline values.

Changes in mean PD and mean CAL after treatment were examined using the level of supragingival plaque at baseline as an additional covariate. Reduction in whole-mouth mean PD was significantly less ($P < .04$) in current smokers compared to former and nonsmokers (0.33 ± 0.04, 0.49 ± 0.06 and 0.49 ± 0.08, respectively). Although not significant, the gain in mean whole-mouth CAL was also less in current smokers compared to former and nonsmokers (0.32 ± 0.04, 0.43 ± 0.05 and 0.43 ± 0.08, respectively) (data not shown). Figure 4 illustrates the changes in mean PD and mean CAL for deep

sites (initial PD ≥ 5 mm). Current smokers had significantly less reduction in PD ($P < .005$) and significantly less gain in CAL ($P < .03$) in deep pockets than did former and nonsmokers. The individual group reductions in mean PD were 1.8 ± 0.1, 1.7 ± 0.1 and 1.3 ± 0.1 mm for nonsmokers, former and current smokers, respectively. The corresponding mean gains in CAL were 1.7 ± 0.2, 1.6 ± 0.1 and 1.3 ± 0.1 mm (Figure 4). The gain in CAL in deep pockets in the patients having microbial assessment was 1.5, 1.3 and 1.1 mm for the three groups, and 1.9, 2.0 and 1.4 for those who did not have microbial assessment (data not shown).

Although the gain in CAL in the group without microbial assessment was significantly greater, the same pattern of periodontal healing was seen in both groups of patients. The current smokers responded less favorably to mechanical therapy, almost 0.5 mm less when compared to former and nonsmokers. All three study groups showed modest changes in recession after treatment (Figure 4). Although no significant differences were observed among the three study groups, current smokers had the least change in recession. But in the three groups, nearly all the reduction in pocket depth was the result of gain in clinical attachment, rather than gingival recession. After treatment, current smokers showed significantly less reduction in the percentage of sites measuring 5 mm or greater compared to former and nonsmokers (4.8 ± 0.7, 7.1 ± 1.2 and 7.2 ± 1.4 percent, respectively) ($P < .09$) (Figure 5).

At baseline for all patients, only current smokers showed higher proportions of *B. forsythus* ($P < .04$) and *P. gingivalis* (not significant) compared to former and nonsmokers. The baseline proportions of *B. forsythus* and *P. gingivalis* were 1.4 ± 0.2, 0.7 ± 0.1 and 0.9 ± 0.2 percent and 0.8 ± 0.3, 0.5 ± 0.2 and 0.3 ± 0.1 percent for current, former and nonsmokers, respectively (data not shown).

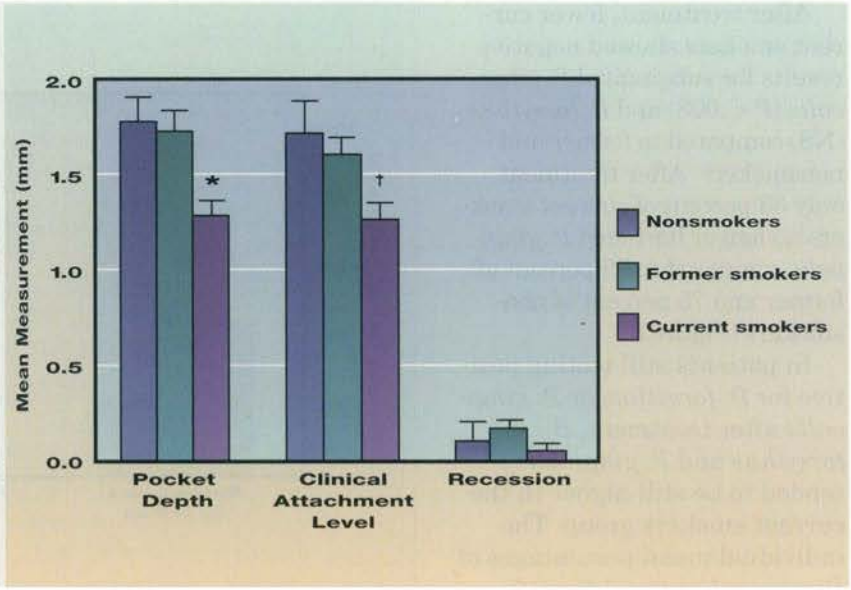

Figure 4. Changes in mean PD, CAL and recession in deep pockets. Current smokers showed significantly less reduction in mean PD and mean CAL than did former and nonsmokers. For all three study groups, essentially all the reduction in mean PD was the result of gain in CAL and not of recession. *$P < .005$. †$P < .03$.

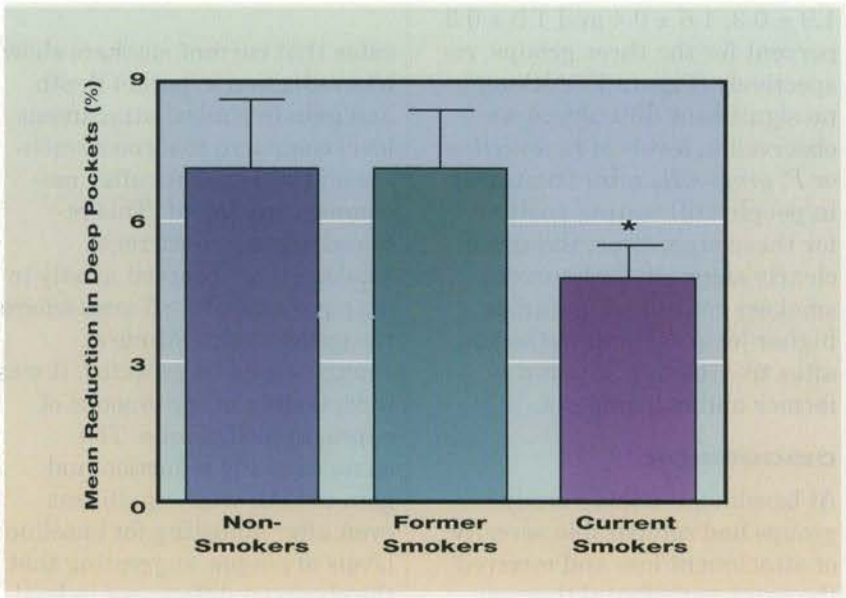

Figure 5. Percentage reduction in deep pockets. Current smokers showed significantly less reduction *($P < .009$) in deep pockets (PD ≥ 5 mm) at 3 months than did former and nonsmokers. The percentage reduction in deep pockets in former smokers was identical to that of nonsmokers. *$P < .009$.

After treatment, fewer current smokers showed negative results for subgingival *P. gingivalis* ($P < .008$) and *B. forsythus* (NS) compared to former and nonsmokers. After treatment, only 33 percent of current smokers no longer harbored *P. gingivalis* compared to 92 percent of former and 75 percent of nonsmokers (Figure 6).

In patients still testing positive for *B. forsythus* or *P. gingivalis* after treatment, *B. forsythus* and *P. gingivalis* tended to be still higher in the current smokers group. The individual mean percentages of *P. gingivalis* were 1.8 ± 0.7, 0.7 ± 0.7 and 0.7 ± 0.7 percent for current, former and nonsmokers, respectively. The corresponding percentages of *B. forsythus* were 1.9 ± 0.3, 1.6 ± 0.4 and 1.0 ± 0.3 percent for the three groups, respectively (Figure 7). Although no significant differences were observed in levels of *B. forsythus* or *P. gingivalis* after treatment in people still testing positive for these organisms, the trend clearly suggests that current smokers continued to harbor higher levels of both pathogens after treatment compared to former and nonsmokers.

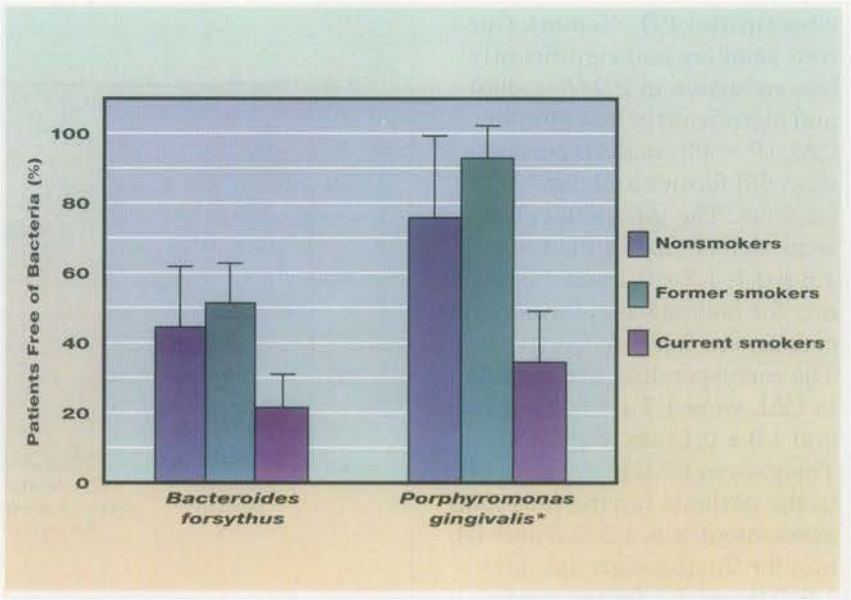

Figure 6. Percentage of patients who became negative for *P. gingivalis* and *B. forsythus* after treatment. Significantly fewer (*$P < .008$) current smokers than former and nonsmokers became negative for *P. gingivalis* after treatment. Fewer current smokers than former and nonsmokers became negative for *B. forsythus*.

DISCUSSION

At baseline, the three study groups had comparable severity of attachment loss and received the same periodontal therapy, but differed in smoking status. Therefore, the changes observed in response to therapy could be attributed essentially to the effect of smoking. Studies designed to compare or examine the effects of smoking on clinical or microbiological variables have to include study populations clearly defined in terms of their smoking status. Our study indicates that current smokers show less reduction in pocket depth and gain in clinical attachment level compared to former smokers and nonsmokers after mechanical treatment. This reduced healing in current smokers was observed mostly in deep pockets (PD ≥ 5 mm) where the greatest magnitude of change would be expected; it was independent of the amount of supragingival plaque. The changes in PD reduction and gain in CAL were significant even after adjusting for baseline levels of plaque, suggesting that the observed differences in healing response between current, former and nonsmokers were indeed related to smoking.

Pearson's correlation coefficient was used to relate the overall exposure to tobacco, measured as pack-years, with baseline whole-mouth mean PD ($r = .231$, $P < .02$) and mean CAL ($r = .358$, $P < .001$). This finding is consistent with previous observations that the relationship between the severity of periodontal destruction and the amount of smoking shows a dose-response effect.[2,3] However, the smoking frequency of current smokers, measured as pack-years or cigarettes per day, was not related to change in PD or CAL after treatment.

Similarly, there was no association between number of years since cessation of smoking and changes in mean PD or CAL in former smokers. This suggests that there is an early benefit of smoking cessation in terms of periodontal treatment outcome. This finding is especially relevant in clinical practice, where we may infer that smokers do not need to have stopped smoking for a long time to increase their chances of improved response to therapy. Rather, we may recommend that merely ceasing to smoke before periodontal therapy increases the likelihood of better treatment outcome.

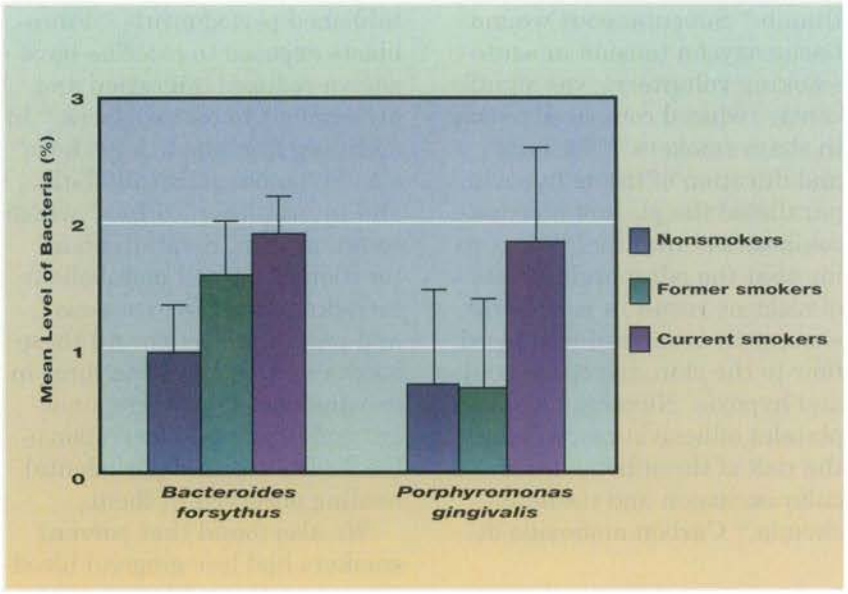

Figure 7. Levels of *P. gingivalis* and *B. forsythus* in patients still testing positive after treatment. Higher levels of *P. gingivalis* and *B. forsythus* were detected in current smokers who were still positive for these organisms after treatment than in former and nonsmokers.

The reduced healing in current smokers was associated with the persistence of subgingival *P. gingivalis* and *B. forsythus* after mechanical debridement. Previous studies failed to show a difference in subgingival flora between smokers and nonsmokers.[16,17] Differences in microbiological methodologies and sample size could partly explain the differences between our results and those previously reported.[16,17] Recently, Preber and colleagues[18] reported a less favorable clinical outcome for nonsurgical therapy in smokers compared to nonsmokers, which is consistent with our results. But they found no difference in reduction of *P. gingivalis* between the groups. It should be noted that their study population was one-third the size of ours and only one subgingival site per patient was sampled for microbial analysis. This may explain the discrepancy in reduction of *P. gingivalis* between their study and ours.

Our study clearly indicates a difference in the subgingival flora of current smokers, former smokers and nonsmokers in spite of comparable levels of periodontal attachment loss, suggesting that cigarette smoking has a modulating effect on subgingival flora. Furthermore, the reduced clinical response observed in current smokers may be associated with the patients' continuing to harbor a pathogenic subgingival flora. In 1994, Zambon and co-workers[6] found that smokers are more likely than nonsmokers to be infected with *B. forsythus* and *P. gingivalis* and that there are decided quantitative and qualitative differences in the subgingival microflora of current smokers compared to former and nonsmokers. The risk of infection with *B. forsythus* depended on the dose of cigarette smoking; thus, they concluded that smoking increases the likelihood of infection with *B. forsythus* and *P. gingivalis*.

The negative effect of smoking on the subgingival environment and flora appears to be reversible. This is evidenced by the fact that a comparable proportion of former and nonsmokers became negative for *P. gingivalis* and *B. forsythus* after mechanical treatment. Fewer current smokers, on the other hand, became negative for these two pathogens compared to former and nonsmokers. In a similar manner, the negative effect of smoking on the healing response also appeared to be reversible. Again, this is based on the fact that former smokers showed a reduction in pocket depth and gain in attachment that were comparable to those of nonsmokers and significantly different from those of current smokers.

We propose that the reduced healing observed in current smokers is likely the result of the combined persistence of subgingival pathogens and impaired smoking-mediated wound healing. In a 1994 study by Ah and others,[9] smokers who received periodontal surgery had significantly less reduction in PD and gain in probing attachment levels during 6 years of maintenance therapy compared to nonsmokers who received either modified Widman flap surgery or mucoperiosteal flap.

Smoking has been associated with refractory periodontitis and the corresponding lack of response to periodontal therapy.[19] Cigarette smoking has also been associated with a reduced healing response after guided tissue regeneration therapy in deep intrabony defects[20] and with an 80 percent failure rate in treatment of furcation defects.[21] In addition, smoking has decreased the percentage of root coverage that takes place

after tissue grafting.[22] Eighty percent of current smokers undergoing intraoral bone grafting and simultaneous implant placement showed impaired wound healing, defined as loss of bone or implant, compared to only 10 percent of nonsmokers.[23]

Slower healing has been observed clinically in smokers with wounds resulting from trauma, disease or surgical procedures.[24] In addition, several reports document the adverse effects of smoking in wound healing for a variety of surgical procedures. Significantly less skin healing and cosmetic results of surgical incisions after laparotomy procedures,[25] and significantly reduced outcomes of plastic surgical procedures[26] were reported in smokers vs. nonsmokers. Current smoking was a significant independent predictor of sternal-mediastinal-wound infection after elective cardiac surgery[27] and is associated with a significantly higher rate of complications after muscle transposition procedures compared to that for former and nonsmoking patients.[28]

Smokers are also at risk of developing complications after elective microsurgery, mostly at the flap interface with the wound or overlying skin graft.[29] The unanswered question is how smoking exerts these adverse effects on wound healing. One possible mechanism is that the toxic constituents of cigarette smoke—particularly nicotine, cotinine, carbon monoxide and hydrogen cyanide—are cytotoxic to a number of cells and inhibit wound repair. Acute smoking (inhaling two cigarettes) resulted in an almost 30 percent reduction in laser Doppler blood flow in the microcirculation of the skin of the thumb.[30] Subcutaneous wound-tissue oxygen tension in acute smoking volunteers was significantly reduced compared to that in sham smokers.[31] The onset and duration of tissue hypoxia paralleled the plasma pharmacokinetics of nicotine,[31] suggesting that the adrenergic effects of nicotine result in peripheral vasoconstriction, reduced blood flow to the skin, tissue ischemia and hypoxia. Nicotine increases platelet adhesiveness, raising the risk of thrombotic microvascular occlusion and tissue ischemia.[24] Carbon monoxide diminishes oxygen transport, and hydrogen cyanide inhibits the enzyme systems operative in oxidative metabolism and oxygen transport at the cellular level.[24] These vascular changes could, in turn, impair healing of injured tissue.

We found that current smokers had less gingival bleeding at baseline, although their oral health status was similar to that of former and nonsmokers.

Nicotine inhibits proliferation of fibroblasts and macrophages.[24] Several studies have demonstrated the absorption of nicotine in periodontal tissues. Nicotine has been detected on root surfaces of periodontally diseased teeth in smokers.[32] Cotinine—the major metabolite of nicotine—is found in serum, saliva and gingival crevicular fluid of smokers.[33] Serum levels of cotinine have been correlated with severity of attachment loss in a group of patients with established periodontitis.[34] Fibroblasts exposed to nicotine have shown reduced migration and attachment to root surfaces.[35] In addition, fibroblasts have been shown to nonspecifically bind and internalize nicotine,[36] which could, in turn, result in an alteration of the cell metabolism including collagen synthesis and protein secretion. All these mechanisms could be in force in causing periodontitis in smokers and ultimately be responsible for the reduced periodontal healing observed in them.

We also found that current smokers had less gingival bleeding at baseline, although their oral health status was similar to that of former and nonsmokers. These results are consistent with the proposal of Danielsen and colleagues[37] that smokers "have a reduced capacity to mount and maintain an effective defense reaction to a given plaque challenge." This was assessed in an experimental gingivitis model. Present results suggest that smoking cessation reverses this effect as well.

CONCLUSION

Our study clearly shows that current smokers exhibit less healing and less microbial response to mechanical therapy than do former and nonsmokers. The study also found that former smokers responded to periodontal therapy no differently than did nonsmokers. We provide the first evidence that the negative effects of smoking on periodontal healing and subgingival microflora are reversible after cessation of smoking. Based on the results of our study and the evidence supporting the toxic effects of active smoking on wound healing, we conclude that smokers should

be advised to stop smoking before and immediately after receiving periodontal therapy (nonsurgical or surgical). Ultimately, smoking cessation is the ideal alternative for adequate management of periodontal disease in smokers. ■

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This study was supported in part by USPHS grant No. DE 04898 and Unilever Research, Port Sunlight Laboratory, England.

The authors thank Mr. Robert Dunford for statistical analysis and Mr. Homer Reynolds and Ms. Carol Parker for expert technical assistance.

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