The Effect of Smoking on Osseointegrated Dental Implants. Part I: Implant Survival

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Purpose: Recent studies implicate smoking as a significant factor in the failure of dental implants. The purpose of this long-term retrospective study was to evaluate the survival of Brånemark endosseous dental implants in relation to cigarette smoking. ***Materials and Methods:*** The sample consisted of 464 consecutively treated completely and partially edentulous patients who had a total of 1852 implants placed between 1979 and 1999, and who were part of a surgical/prosthodontic prospective treatment outcomes study. The effect of cigarette smoking on implant survival in relation to the time of implant failure, gender, age, surgeon, date and site of implant placement, implant length and diameter, prosthesis design, and occlusal loading considerations was assessed in bivariate and multivariate survival analyses. ***Results:*** The overall implant failure rate was 7.72%. Patients who were smokers at the time of implant surgery had a significantly higher implant failure rate (23.08%) than nonsmokers (13.33%). Multivariate survival analysis showed early implant failure to be significantly associated with smoking at the time of stage 1 surgery and late implant failure to be significantly associated with a positive smoking history. Short implants and implant placement in the maxilla were additional independent risk factors for implant failure. ***Conclusion:*** Cigarette smoking should not be an absolute contraindication for implant therapy; however, patients should be informed that they are at a slightly greater risk of implant failure if they smoke during the initial healing phase following implant insertion or if they have a significant smoking history.
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The predictability of oral implant therapy has been increasingly well documented in the scientific literature. Numerous studies on patients treated with various Brånemark (Nobel Biocare) implant-supported prostheses have demonstrated impressive long-term success rates.[1–6] The improvements in masticatory function and patient satisfaction attributed to implant-supported prostheses have eclipsed the reported improvements gained by other preprosthetic surgical techniques. As a result, implant prosthodontics has become an integral and indispensable part of the dental clinician's therapeutic repertoire.[7] Nonetheless, failures can occur, and when they do, they represent a significant burden to both the patient and the dental team. Recent reports have analyzed possible reasons for implant failures.[8–11] Cigarette smoking has emerged as one such factor and was the focus of this investigation.

Implant failure can be classified as either early or late. Early implant failures occur at or before abutment connection surgery (preloading), while late implant failures occur after stage 2 surgery (postloading). Most implant failures are identified at or before stage 2 surgery or during the first 2 years of prosthetic service.[12] This suggests that interference with the wound healing process following implant placement may be an important reason for implant failure. Cigarette smoking has been shown to adversely affect wound healing, and, therefore, may contribute to early implant loss.[13–15] Further, cigarette smoking has been implicated in the reduction of bone density and increased peri-implant

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bone loss, both of which have been associated with late implant failures.[16–20] Consequently, smoking may lower implant survival outcomes even after successful osseointegration has occurred.[17,21]

While recent studies implicate smoking as a significant factor in the failure of dental implants, confounding variables that could potentially contribute to implant failure have not been thoroughly investigated. In addition, the follow-up time in most cases was limited, and few studies accurately qualified and quantified the smoking habit.[22–26] Therefore, long-term research that accounts for potentially confounding variables and specifically analyzes the smoking history would be useful in determining the true effects of smoking on the survival of osseointegrated dental implants.

The purpose of this study was to evaluate retrospectively the survival of Brånemark endosseous dental implants in relation to cigarette smoking. Specifically, it was investigated whether there is a greater incidence of early implant failure in patients who smoke at the time of implant surgery compared to nonsmokers, and whether a positive smoking history decreases the survival of endosseous dental implants over the long-term.

Materials and Methods

The study population comprised 464 consecutively treated patients at the Implant Prosthodontic Unit at the University of Toronto. These patients, who were completely or partially edentulous, were part of the study populations from previous prospective studies, with the inclusion and exclusion criteria described elsewhere.[27–30]

Clinical Procedures

During initial consultation, baseline demographic information and medical and dental histories were recorded along with clinical and radiographic examinations. All patients were treated with a 2-stage surgical procedure, performed according to the Brånemark surgical protocol.[1] A total of 14 surgeons placed the implants over a 20-year period, with the majority of implants placed by 3 surgeons. At stage 2 surgery, the implants were exposed to the oral environment and subsequently restored. Completely edentulous patients received either fixed or overdenture prostheses, whereas partially edentulous patients were prescribed single or multiunit fixed prostheses. Patients were assessed 1 week postoperatively after each surgical stage and followed up at regular recall appointments following prosthesis insertion. Prosthodontic management was mainly carried out by residents under staff supervision. Each recall visit included a thorough clinical exam and standard periapical radiographic examination. In order to discriminate early failures from late failures, all implants removed prior to insertion of the prosthesis were classified as early failures, while those occurring after prosthetic rehabilitation were classified as late failures. An implant was considered a failure if it was removed as a result of clinical mobility, or if it showed evidence of a peri-implant radiolucency and/or persistent pain, discomfort, or infection that was attributable to the implant.[31]

Information sought for the prospective studies included a simple dichotomous identification of smoker or nonsmoker at the time of each first clinical interview.[27–30] However, the nature of this study demanded a more rigorous approach to stratify smoking habits via the employed specific questionnaire. Past or current use of smoking tobacco was determined via the specific questionnaire approved for the purpose of this study by the University of Toronto Ethics Review Board. The number of cigarettes consumed per day and the number of years smoked were also recorded. A cigarette year (cy) was defined as the product of the amount of cigarettes smoked per day and the number of years smoked. Each patient's smoking habit was classified as follows:

- *Group A.* To assess the effect of smoking at the time of implant placement surgery, patients were split into 2 groups:
  1. *NS1:* Individuals who had never smoked or were previous smokers but quit smoking at least 1 week prior to stage 1 surgery
  2. *S1:* Individuals who were smokers at the time of implant surgery and continued to smoke at least until after prosthesis insertion
- *Group B.* To assess the effect of a positive smoking history, patients were split into 2 groups:
  1. *NS2:* Individuals who had never smoked or smoked ≤ 25 cy until stage 2 surgery
  2. *S2:* Individuals who had a > 25 cy smoking history

Statistical Analysis

Patients' demographic information and smoking history, implant surgeon, date of implant placement, length of implant, implant diameter, site of implant placement, prosthesis design, opposing dentition, and time of implant failure were compiled retrospectively and input for analysis in the SAS statistical package (SAS). The individual effects of the preceding variables on implant survival and relative risk of implant failure were derived in a univariate analysis with the Proportional Hazard Regression (PH Reg) procedure of the SAS program package. The odds ratio (OR) was also calculated to describe the effect of smoking sta-

tus on both early and late implant failures. The relative risk (RR) expresses the incidence of implant failure in the exposed group, relative to the incidence of failure in the nonexposed group. The higher risk group was always expressed in the numerator for the calculation of RR. An RR value of 1.0 indicates that there is no difference in implant failure between the exposed and nonexposed groups. The PH Reg procedure is based on the Kaplan-Meier life table method of survival curve development.[32] The entry point to the study was the date of stage 1 surgery, and the exit point was the date of implant failure or the last follow-up. To control for the potential confounding effects of the preceding variables on the effect of smoking on implant survival, all variables used in the univariate analysis were entered individually with smoking status in a bivariate survival analysis using the PH Reg method. Furthermore, all variables found to be significantly associated with implant failure in the bivariate analyses were combined in a multivariate analysis. Once again, the RR values were derived using the PH Reg procedure. The *t* test was used to compare continuous types of data, such as age, number of implants placed per patient, and years of follow-up.

The effect of smoking on implant failure was also analyzed on a patient basis using the chi-square method. The PH Reg method, which is based on a survival analysis, could not be used to analyze the data on a patient basis since it was impossible to assign a failure time to a patient, because one particular patient could have several dates of implant failure. Statistical significance for all analyses was set at $P \leq .05$.

Results

A total of 1852 Brånemark implants were placed in 464 patients (283 female, 181 male), between 1979 and 1999. Their ages ranged from 15 to 84 years, with a mean age of 49.3 years (mean age 49.7 years for females, 48.9 years for males). The average number of implants placed per patient was 4.0 (3.91 for females and 4.12 for males). Of the 1852 implants, 1106 were placed in female patients and 746 were placed in male patients. In each of the 4 groups (NS1, S1, NS2, S2), no significant difference between the mean ages of males and females or between the number of implants placed per patient was found. The average period of time between implant placement and stage 2 surgery was 6.8 months, while the average period between stage 2 surgery and prosthesis insertion was 4.6 months. The postinsertion follow-up time ranged from 1 month to 230 months, with a mean follow-up of 59.8 months. In total, 584 various implant-supported prostheses were delivered.

The questionnaire response rate was 84%. Of the 16% (75 patients) who did not respond, 4% (17 patients) were deceased. The remaining 12% (58 patients) were impossible to contact. A statistically significantly higher rate of failure was observed among the nonrespondents ($P = .001$). In total, the smoking habit of 389 patients (1539 implants) was recorded. At the time of implant placement, 285 patients were nonsmokers and 104 were active smokers. A total of 1045 and 494 implants were inserted in groups NS1 and S1, respectively. Eight hundred sixty implants were placed in 192 patients with a significant smoking history (S2), compared to 679 implants placed in 197 individuals who reported a $\leq$ 25 cy smoking history (NS2).

Overall, 143 (7.72%) of the 1852 inserted implants failed. This results in a crude rate for implant survival of 92.28% for the duration of the study. Seventy-eight (4.21%) of the implants failed prior to prosthesis insertion (early failures), while 65 (3.51%) failed after prosthesis insertion (late failures). Therefore, 54.5% were early failures and 45.5% were late failures (Table 1).

Early Implant Failures

Smoking at the time of implant placement was a significant factor for early implant failure. Of the 1045 implants placed in group NS1, 32 (3.06%) were early failures, whereas 26 (5.26%) of the 494 implants placed in group S1 failed early ($P = .034$, OR = 1.76). Further, a direct relationship was observed between the quantity of cigarettes consumed and early implant failure. Failure rates of 3.51%, 4.82%, and 5.65% were found for individuals who smoked $\leq$ 5 cigarettes per day, 6 to 14 cigarettes per day, and $\geq$ 15 cigarettes per day, respectively.

The analysis of early implant survival in relation to a positive smoking history was not significant. Other nonsignificant variables investigated included gender, age, and implant diameter. When implant length was considered, it was found that a significantly greater number of early implant failures occurred in shorter implants ($\leq$ 10 mm) compared to longer implants ($>$ 10 mm), ($P = .001$). Surgical skill also proved important. When surgeons were grouped according to early implant failure rates, surgeons in the high failure rate group ($>$ 8%; surgeons 11 to 14) had a 2.71 times greater early implant failure rate than the surgeons in the low failure rate group ($\leq$ 8%; surgeons 1 to 10) ($P = .0001$). The year of implant placement was also significant, with a higher percentage ($P = .001$) of early implant failures occurring in implants placed in the earliest year group (7.11%) compared to the later groups (4.78% and 2.54%, respectively). The site of implant placement also helped to explain the cause of early implant failures. A significantly higher early implant failure rate was found in the anterior regions (zone 1 of

Table 1 Distribution of Early and Late Implant Failures (%)

Total implants placed	Early failures	Late failures	Total failures
1852	78 (4.21)	65 (3.51)	143 (7.72)

Table 2 Bivariate Survival Analysis for Early Implant Failure

Variable	*P* (smoking)	RR (smoking)	*P* (variable)	RR (variable)
Smoking at the time of stage 1 surgery (S1)				
Gender	.04*	1.76	.6400	1.14
Age	.04*	1.73	.7800	1.00
Implant length	.03*	1.79	.0001*	1.31
Implant diameter	.04*	1.72	.8500	1.00
Surgeon	.04*	1.73	.0020*	2.57
Year placed	.03*	1.75	.0010*	1.08
Arch (maxilla vs mandible)	.05*	1.68	.0300*	1.78
Positive smoking history (S2)				
Gender	.14	1.51	.7200	1.10
Age	.15	1.49	.9100	1.00
Implant length	.13	1.52	.0001*	1.31
Implant diameter	.15	1.48	.8200	1.00
Surgeon	.12	1.53	.0010*	2.61
Year placed	.09	1.60	.0010*	1.08
Arch (maxilla vs mandible)	.17	1.46	.0200*	1.78

*$P \leq .05$.

the maxilla and mandible) compared to the posterior regions (zone 2 of the maxilla and mandible) ($P = .0082$). A greater implant failure rate was also found in the maxilla (5.11%) compared to the mandible (3.75%), although this analysis failed to reach significance, possibly because of the relatively small number of maxillary implants. Overall, the early implant failure rate was found to be highest in the anterior maxilla.

When the above factors were combined in a bivariate survival analysis, smoking at the time of stage 1 surgery was significantly associated with early implant loss, whereas a positive smoking history was not associated with early implant failure (Table 2). Furthermore, multivariate survival analysis showed that smoking at the time of stage 1 surgery, implant length, and site of implant placement in the maxilla were all significant factors that independently contributed to early implant failures (Table 3).

Late Implant Failures

Of the 1852 implants placed, 78 (4.2%) failed prior to prosthesis insertion (early failures). The late implant failure rates are based on the 1774 surviving implants. Smoking at the time of stage 1 surgery was not found to be a significant factor for late implant failure. A positive smoking history, however, was found to be a significant factor for late implant failure, with 3.90% of the remaining implants in group S2 failing, compared to only 1.98% in group NS2 ($P = .035$, OR = 2.01).

As with the early failures, more late implant failures were observed for short implants (< 10 mm) ($P = .004$) and for implants placed in the maxilla ($P = .007$). The trend of more implant failures in the anterior region was maintained following prosthesis insertion; however, this difference was no longer significant. A higher percentage of late implant failures was also observed in male patients ($P = .01$). Prosthesis design was also a significant factor influencing late implant loss, with implants supporting overdentures found to have the greatest failure rate, followed by those supporting partial, complete, and single-tooth prostheses ($P = .001$). The effect of occlusal load was considered according to the type of prosthesis opposing the implant. Implants opposed by restored partially edentulous arches had the greatest failure rate, followed by those opposed by edentulous arches (with or without complete dentures), and then those opposed by the natural dentition ($P = .01$). Age, surgeon, year of implant placement, and implant diameter were all nonsignificant.

In the bivariate survival analysis, a positive smoking history was significantly associated with late implant failure when combined with all variables except for gender and opposing dentition (Table 4). Further, multivariate survival analysis showed that late implant failure was significantly associated with a positive smoking history, implant length, and site of implant placement in the maxilla (Table 5).

Table 3 Multivariate Survival Analysis for Early Implant Failure

Variable	*P*	RR
First analysis		
Smoking at stage 1 surgery (S1)	.040*	1.70
Implant length	.001*	0.75
Surgeon	.800	1.12
Year placed	.160	1.05
Arch (maxilla vs mandible)	.003*	0.42
Second analysis		
Smoking at stage 1 surgery (S1)	.050*	1.69
Implant length	.001*	0.76
Arch (maxilla vs mandible)	.030*	0.56

*$P \leq .05$.

Table 4 Bivariate Survival Analysis for Late Implant Failure

Variable	*P* (smoking)	RR (smoking)	*P* (variable)	RR (variable)
Smoking at the time of stage 1 surgery (S1)				
Gender	.10	1.82	.070	1.72
Age	.16	1.65	.940	1.02
Implant length	.18	1.61	.060	1.14
Implant diameter	1.67	1.61	.600	1.00
Surgeon	.17	1.63	.040*	1.26
Year placed	.15	1.68	.030*	1.08
Arch (maxilla vs mandible)	.13	1.72	.004*	2.39
Opposing dentition	.13	1.73	.001*	3.32
Prosthesis design	.42	1.34	.080	2.74
Smoking history (S2)				
Gender	.06	1.88	.24	1.43
Age	.03*	2.03	.71	1.12
Implant length	.03*	2.01	.05*	1.15
Implant diameter	.03*	2.00	.54	1.00
Surgeon	.04*	1.95	.04*	1.26
Year placed	.05*	1.88	.04*	1.07
Arch (maxilla vs mandible)	.04*	1.94	.01*	2.23
Opposing dentition	.06	1.84	.64	3.01
Prosthesis design	.03*	2.06	.61	0.29

*$P \leq .05$.

Table 5 Multivariate Survival Analysis for Late Implant Failure

Variable	*P*	RR
First analysis		
Positive smoking history (S2)	.050*	1.87
Implant length	.008*	1.20
Surgeon	.080	1.26
Year placed	.540	1.02
Arch (maxilla vs mandible)	.030*	1.92
Second analysis		
Positive smoking history (S2)	.050*	1.91
Implant length	.030*	1.16
Arch (maxilla vs mandible)	.004*	2.38

*$P \leq .05$.

Implant Failure on a Patient Basis

When the data were analyzed on a patient basis, patients who were smokers at the time of implant placement surgery had a significantly higher overall implant failure rate (23.08%) compared to nonsmokers (13.33%) ($P = .02$, RR = 1.73). Similarly, patients with a significant smoking history experienced twice as many failures as individuals who did not have a positive smoking history ($P = .004$). Smoking at the time of stage 1 surgery and a positive smoking history were both significantly associated with early implant failures ($P = .012$, RR = 2.05 and $P = .04$, RR = 1.85, respectively), while neither was significantly associated with the late implant failures (Table 6).

Table 6 Implant Failures on a Patient Basis

		Overall failures		Early failures		Late failures	
Smoking status	No. of patients	No. (%)	*P*	No. (%)	*P*	No. (%)	*P*
S1	104	24 (23.08)	.02*	18 (17.31)	.01*	8 (7.77)	.895
NS1	285	38 (13.33)		24 (8.42)		21 (7.37)	
S2	192	41 (21.35)	.004*	27 (14.06)	.04*	19 (9.95)	.068
NS2	197	21 (10.66)		15 (7.61)		10 (5.08)	

*$P \leq .05$.

Discussion

Overall Survival

The overall implant survival rate of 92.28% over a 20-year period is consistent with previous studies that have demonstrated the long-term success of Brånemark implants in a variety of clinical situations.[1–6] Moreover, the proportion of early and late implant failures is comparable with the findings of Esposito et al,[33] who found that roughly half of all implant failures occur prior to occlusal loading.

While an acceptable response rate was obtained, a higher implant failure rate was observed in the nonrespondents. Although the smoking status of these individuals was consequently unknown, all other patient- and implant-related factors were recorded and did not appear to explain the high rate of implant failures observed in this group of patients. It is tempting to speculate that a high percentage of the nonrespondents were smokers, and that this nonresponse bias could contribute to the relatively small difference in failure rates observed between the smoking and nonsmoking groups.

The Effect of Smoking

The results of this study confirm the findings of previous investigations, which suggest smoking has a detrimental effect on implant survival.[17,21–26] Patients who were smokers at the time of implant placement had a significantly higher overall implant failure rate (23.08%) compared to nonsmokers (13.33%). Moreover, grouping patients based on aspects of their smoking behavior, although not mutually exclusive, provided additional insight into this outcome. To achieve successful osseointegration, a highly organized series of events must follow the surgical placement of the implant. Components of cigarette smoke have been shown to impede various steps in this process.[34–39] Although clinical evidence suggests a clear tendency of slower wound repair in smokers,[40–43] the effect is believed to be reversible within a 1- to 2-week period prior to surgery.[44] In line with this rationale, implementation of a smoking cessation protocol has been previously shown to improve the chances of successful osseointegration.[45] In this study, individuals who were smokers at the time of stage 1 surgery were found to have a 1.69 times higher incidence of early implant failures compared to patients who had never smoked or stopped smoking at least 1 week prior to implant surgery. Therefore, it can be deduced that smoking decreases the possibility of successful ossseointegration, with the suboptimal healing response that occurs in smokers leading to a higher incidence of early implant failure.

Following prosthetic rehabilitation, a positive smoking history, with no smoking habit at the time of stage 1 surgery, was associated with an increased risk of implant failure. Individuals with a positive smoking history were found to have a 1.91 times greater late implant failure rate compared to patients who had never smoked or had a $\leq$ 25 cy smoking history. Since a positive smoking history was not found to increase the incidence of early implant failures, it can be assumed that a history of smoking does not interfere with the wound healing process involved in establishing osseointegration. Rather, a positive smoking history was associated with the failure to *maintain* an established osseointegration. Smoking has been associated with a reduction in bone density[16,46–48] and increased peri-implant bone loss,[17–20] and thus may lead to an increase in late implant failures.[21,49]

It has also been suggested that implant failures tend to be concentrated in a few individuals,[50] and smoking is one factor that may contribute to such an event.[23,24] However, in this study, nonclustering of failures was observed in both the smoking and nonsmoking groups when the data were assessed on a patient basis. Of the 285 patients in group NS1, 246 had more than 1 implant placed. Of those patients, 19 (7.7%) had only 1 early implant failure, and 5 (2.0%) had more than 1 early implant failure. Similarly, of the 104 patients in group S1, 95 had more than 1 implant placed, 12 (12.6%) of which had only 1 early implant failure, and 6 (6.3%) of which had more than 1 early implant failure. The same trend, with the majority of failures being single implant failures, existed for groups S2 and NS2, for both early and late implant failures.

Therefore, in this study, the cluster phenomenon was not observed.

Additional Factors

In accordance with previous studies, the failure rate was significantly higher for short implants[49,51–54] and for implants placed in the maxilla.[33,52,55] Surgical skill, year of implant placement, site of implant placement in the anterior zone, and prosthetic design were all positively associated with implant failure in the univariate and bivariate analyses; however, none were found to be important factors in the overall models for implant failure. In fact, implant length appears to be the underlying confounding factor. It was found that the surgeons with the highest failure rate (> 8.0%) placed the majority (85%) of the dental implants in the earliest time period (1979 to 1985), and that the majority (88.0%) of those implants were short (≤ 10 mm). Similarly, the majority of short dental implants were placed in the anterior zone of severely resorbed mandibles and were primarily used to support overdentures. Occlusal overload has also been implicated in the reduction of implant survival outcomes[56,57]; however, in this study, the type of opposing dentition was not found to be an independent risk factor for implant failure.

While the present study offers insight into the potentially confounding variables that may affect early and late implant failures, more detailed long-term prospective clinical studies are required to draw definitive conclusions regarding all factors that may affect implant survival.

Although a statistically significantly higher rate of implant failures were observed in smokers, the clinical significance must be addressed. First, the absolute difference in implant failure rates between the groups was relatively small. Second, despite the 143 implant failures that occurred in this study, over 98% of the patients received an implant-supported prosthesis and were, for the most part, extremely satisfied with the prosthodontic outcome.[2,3,5] These results suggest that the major determinant of success—patient satisfaction—arguably may depend on the versatility of prosthodontic judgement and design, rather than exclusively on the risk of implant failure. Nonetheless, it is important to inform patients of the potential factors associated with implant failure. This study suggests that clinicians can confidently inform patients that they have a greater risk of implant failure if they have a positive smoking history or actively smoke during the initial healing phase following implant insertion. Smoking should not be considered a contraindication to implant placement; rather, patients should be encouraged to stop smoking if they wish to maximize the potential for implant success. Additional studies are required to ascertain the effect of smoking on additional implant success criteria and to determine the mechanism by which smoking imparts this deleterious effect on implant survival pre- and postloading.

Conclusions

1. This study's overall survival rate (92.28%) over a 20-year period reaffirms the successful outcomes of Brånemark implants.
2. Cigarette smoking appears to have a negative effect on implant survival even after accounting for potential confounding variables.
3. Early implant failure was significantly associated with smoking at the time of stage 1 surgery, implant length, and site of implant placement in the maxilla; while late implant failure was significantly associated with a positive smoking history of more than 25 cy, implant length, and site of implant placement in the maxilla.
4. These results suggest that cigarette smoking should not be an absolute contraindication for implant therapy; rather, patients should be informed that they are at a slightly greater risk of implant failure if they smoke during the initial healing phase following implant insertion or if they have a significant smoking history.

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