The Effect of Smoking on Osseointegrated Dental Implants. Part II: Peri-implant Bone Loss

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Purpose: The detrimental effect of cigarette smoking on implant survival has been previously demonstrated. The purpose of this study was to retrospectively investigate the effect of smoking on marginal bone loss around endosseous dental implants. ***Materials and Methods:*** The sample consisted of 767 Brånemark implants placed in 235 patients between 1979 and 1999. Bone level changes were determined using periapical radiographs taken at annual recall visits for 1 to 20 years following prosthesis insertion. Nonparametric tests and multiple linear regression were used to determine the influence of various factors on peri-implant bone loss during the first year of clinical loading and for all subsequent years. ***Results:*** The mean annual bone loss was 0.178 mm ± 0.401 during the first year of clinical loading and 0.066 mm ± 0.227 per year thereafter. A positive smoking history was associated with a higher rate of peri-implant bone loss, and the majority of implant failures were observed in this group of patients. Smoking at the time of stage 1 surgery did not appear to predispose implants to more marginal bone loss. ***Conclusion:*** Cigarette smoking should not be an absolute contraindication for implant therapy; rather, long-term heavy smokers must be informed that they are at a slightly higher risk of late implant failure and are susceptible to more marginal bone loss over the long-term, irrespective of their smoking status at the time of implant placement. *Int J Prosthodont 2006;19:560–566.*

Osseointegrated dental implants are routinely prescribed for a variety of prosthodontic situations, with impressive long-term success rates.[1–6] In an attempt to further improve treatment outcomes, various benchmarks for implant success have been defined, with research emphasis placed on numerous factors that may challenge the dependability of this therapeutic modality. Cigarette smoking is one factor implicated in unsuccessful treatment outcomes, and in Part I of this investigation it was found to have a negative effect on implant survival.[8] Individuals who were smokers at the time of stage 1 surgery were found to have an incidence of early implant failures 1.69 times higher than nonsmokers. Furthermore, a positive smoking history was found to be a significant factor for late implant failure. Multivariate survival analysis showed implant length and site of implant placement in the maxilla to be additional factors that independently contributed to the implant failures observed. Previous studies have also demonstrated that patients who smoke appear to be at a greater risk of implant loss.[9–13]

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While the detrimental effect of smoking on implant survival has been established, it must be acknowledged that proposed success criteria for dental implants have also evolved beyond a measure of mere implant survival, and encompass both clinical and radiographic prerequisites.[14–20] One such criterion is the quantitative long-term radiographic assessment of peri-implant bone loss. A mean vertical bone loss of less than 0.2 mm per year following the first year of clinical loading is considered acceptable.[21] Following successful osseointegration, marginal bone loss will occur if the amount of bone resorption exceeds the amount of bone formation.[22] Theoretically, local and systemic factors that cause an imbalance in the osteoblast-osteoclast activity can lead to an increase in peri-implant bone loss over time. If the bone loss becomes excessive, the support system of the implant may become compromised, and implant failure will ensue.[23] Therefore, an investigation of whether smoking increases marginal bone loss will not only provide insight into the predictability of implant therapy in smokers, as defined by currently accepted success criteria, but may also contribute to an understanding of the mechanism by which smoking imparts this deleterious effect on implant survival.

The literature suggests that there is an association between smoking and peri-implant bone loss; however, few long-term studies are available to substantiate this claim. Furthermore, the effect of smoking on bone loss in the presence of potentially confounding variables has not been thoroughly investigated, and few studies sought to accurately qualify and quantify the smoking habit.[24–28] The purpose of this study was to investigate the effect of smoking on marginal bone loss around Brånemark (Nobel Biocare) endosseous dental implants using a long-term retrospective approach. In addition, other factors that may influence peri-implant bone loss during the first year of clinical loading and during long-term function were assessed.

Materials and Methods

The original study that investigated the effect of smoking on implant survival was carried out in 464 consecutively treated patients at the Implant Prosthodontic Unit at the University of Toronto.[8] These patients, who were completely or partially edentulous, were accepted for treatment over a 20-year period beginning in 1979. The protocol for patient selection is described elsewhere.[29–32] Furthermore, the inclusion criteria for the selected implants to be studied were successful osseointegration and restoration of the implant, and the availability of at least 2 consecutive annual standard periapical radiographs.

Clinical Procedure

The treatment principles and follow-up procedures were previously outlined.[8,29–32] All patients underwent 2-stage implant surgery, performed according to the Brånemark surgical protocol,[1] and were assessed 1 week postoperatively after each surgical stage. Following prosthetic rehabilitation, which consisted of implant-supported single-tooth prostheses, multi-unit prostheses, complete fixed prostheses, or overdenture prostheses, annual recall visits were scheduled, but not always attended by all patients. Each recall visit included a complete clinical and radiographic examination. Standard periapical radiographs were taken to monitor bone height, with the first radiograph examination performed at the time of prosthesis insertion. Whenever possible, film type, alignment, exposure, and development were consistent over the 20-year follow-up period.

The osseointegration status of each implant was initially evaluated at stage 2 surgery and at each follow-up visit thereafter. An implant was considered a failure if it was removed because of clinical mobility, evidence of peri-implant radiolucency, and/or persistent pain, discomfort, or infection attributable to the implant.[21] The number of implant failures that occurred following stage 2 surgery (late failures) was recorded. Smoking habits were determined using a specific questionnaire as previously described.[8] A cigarette year (cy) was defined as the product of the amount of cigarettes smoked per day and the number of years smoked. Other information documented included the patient's age, gender, medical status, chronic medication use, implant surgeon, date of implant placement, implant length, implant diameter, site of implant placement, prosthesis design, and type of opposing dentition.

Bone Loss Registration

Bone level changes were determined using periapical radiographs taken at annual recall visits for 1 to 20 years following prosthesis insertion. The computer-assisted measurement technique described by Wyatt et al was used.[33] A slide scanner (Microtek Scanmaker 35T, Microtek Lab) set at a resolution of 300 dots per inch was used to digitize the radiographs and provide a magnification of approximately 4 times. SciImage computer software (Scion) was used to manipulate the digital images and measure the bone adjacent to the implant surface. The known interthread distance of 0.6 mm (± 0.005 mm) was used to calibrate images prior to bone measurements.

All measurements were performed by a calibrated investigator in a blind fashion. For each digitized image,

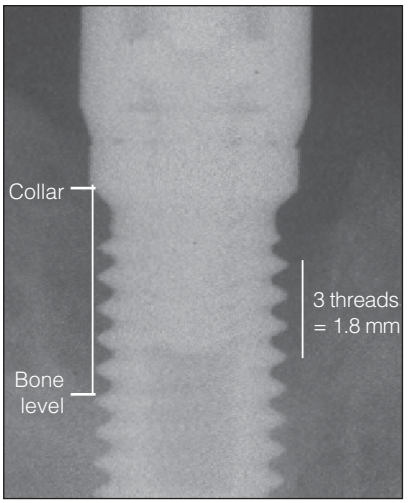

Fig 1 Bone loss registration. For each digitized image, mesial and distal measurements were made from the inferior edge of the implant collar to the lowest observed point of bone-to-implant contact. The known interthread distance of 0.6 mm (± 0.005 mm) was used to calibrate images prior to bone measurements.

mesial and distal measurements were made from the inferior edge of the implant collar to the lowest observed point of implant-to-bone contact (Fig 1). Measurements were not included for radiographs where the observer could not confidently identify these points because of improper radiographic placement or poor image definition. Bone loss was calculated by subtracting the bone level measurement of each year with the previous year. Bone loss was expressed as a positive value, whereas a gain in bone over time was expressed as a negative value. In total, 763 mesial and 748 distal sites were measured on the 767 implants included in this study. Mesial and distal sites were treated as distinct sites for all analyses. Mean bone loss was calculated separately for the first year of clinical loading and for the subsequent years based on the 1,511 implant sites measured.

Statistical Analysis

The SPSS statistical package (SPSS) was used for all statistical analyses. Nonparametric tests were carried out to determine the influence of the various factors on marginal bone loss. Specifically, the significance of difference between 2 groups was tested with the 2-tailed Mann-Whitney *U* test. The Kruskal-Wallis test was used when comparing more than 2 groups. In addition, multiple linear regression was used to test the joint effect of the independent variables on the bone loss measured. Separate models were constructed for bone loss during the first year of clinical loading (year 0 to 1) and for the subsequent years (years 1 to 20). Statistical significance was set at $P \leq .05$.

Results

Patient Demographics

In total, 767 implants placed in 235 patients (157 women and 78 men) from 1979 to 1999 were included in this study. Patient ages ranged from 15 to 77 years (mean: 52.12) at the time of implant placement. One hundred forty-eight patients reported a well-controlled chronic medical condition at the time of surgery, including cardiac conditions, endocrine disorders, arthritis, and osteoporosis. One hundred twelve patients were on long-term medication. At the time of stage 1 surgery, 146 patients were nonsmokers (NS1), whereas 54 were active smokers (S1). The smoking status at the time of implant placement could not be determined for 35 patients. Ninety-six patients reported a positive smoking history (S2), compared to 108 who had never smoked or smoked ≤ 25 cy until stage 2 surgery (NS2). The smoking history was unknown for 31 patients. The average amount of cigarette consumption in group S2 was found to be 381.25 cy. Over the 20-year follow-up period, 15 late implant failures were observed. The smoking status of 7 of the failed implants was unknown. Of the additional 8 implants that failed, 6 (75%) occurred in patients with a positive smoking history.

Peri-implant Bone Loss

The mean annual bone loss was 0.178 mm ± 0.401 during the first year of clinical loading and 0.066 mm ± 0.227 per year thereafter (Table 1). The annual rate of marginal bone loss decreased following the first year of prosthetic function, with a lower steady state structure developing over time (Fig 2). No statically significant difference in marginal bone loss were found between the mesial and distal implant sites measured. A significantly higher rate of marginal bone loss was observed following the first year of function for those implants that eventually failed (0.017).

Forty-six percent of the sites measured were of implants placed in patients with a positive smoking history, while 37.7% of the sites measured were of implants placed in patients who did not posses a positive smoking history. No statistically significant difference in peri-implant bone loss was observed between the 2 groups during the first year of clinical loading. A positive smoking history, however, was found to be a significant factor for bone loss in the subsequent years, with a mean bone loss of 0.073 mm ± 0.263 and 0.041 mm ± 0.124 recorded for groups S2 and NS2, respectively ($P = .048$) (Fig 3). Smoking at the time of stage 1 surgery did not predispose patients to a higher rate of marginal bone loss. Other nonsignificant variables investigated included age, gender, medical status,

Table 1 Peri-implant Bone Loss (mm/y)

Interval (y)	No. of sites	Mean	Minimum mean	Maximum mean	SD	SE
0–1	439	0.178	-1.320	3.070	0.401	0.020
1–5	814	0.090	-1.445	2.645	0.281	0.010
6–10	415	0.025	-1.210	0.615	0.141	0.007
11–20	120	0.045	-0.335	0.870	0.142	0.014
Overall	1,511	0.094	-1.445	3.070	0.290	0.007

Table 2 Linear Regression Model for Year 1 Bone Loss and Overall Bone Loss (mm/y)

	Year 1*			Overall (1-19 y)†		
Factor	β	SE	*P*	β	SE	*P*
Constant	-0.226	0.140	.107	-0.280	0.059	.630
Smoking status (S2 vs NS2)	-0.044	0.041	.275	0.039	0.015	.010
Surgeon (grouped)	0.098	0.060	.106	0.015	0.024	.530
Year of placement (≤ 1990 vs > 1990)	0.040	0.044	.369	0.029	0.017	.080
Opposing prosthesis	0.031	0.023	.190	0.020	0.010	.036
Zone	0.042	0.019	.033	-0.008	0.009	.399

*F = 1.955, $P = .085$, $R^2 = 0.031$.
†F = 5.025, $P < .001$, $R^2 = 0.031$.

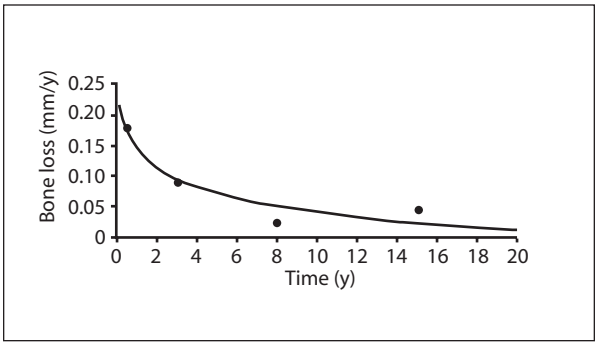

Fig 2 The rate of peri-implant bone loss 1 to 20 years after placement.

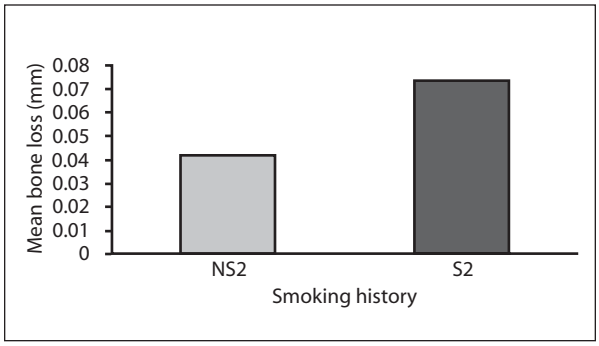

Fig 3 Mean bone loss following the first year of clinical loading.

chronic medication use, implant location in the maxilla or mandible, implant length and diameter, and prosthesis design.

Implants placed in the posterior region ($P = .048$) and those placed in the earlier time period (≤ 1990) ($P = .001$) experienced significantly more bone loss during the first year of clinical loading. Year of implant placement continued to show significance in the subsequent years ($P = .001$), with implants placed by less experienced surgeons also showing more bone loss during this time period ($P = .05$). The type of opposing dentition also proved to be an important factor following the first year of prosthetic function, with implants opposed by natural dentate arches experiencing more bone loss than those opposed by restored partially edentulous arches or completely edentulous arches (with or without complete dentures) ($P = .011$). In addition, there was a trend for implants placed in the maxilla to have more bone loss long term, although the small number of maxillary implants precluded a meaningful analysis.

The linear regression model for peri-implant bone loss following the first year of clinical loading (year 1 to 20) indicated that a positive smoking history and the type of opposing prosthesis were significant factors that independently contributed to the bone loss observed in this group of implants. The region of implant placement was the only significant variable in the model for marginal bone loss during the first year of function (year 0 to 1) (Table 2).

Discussion

Overall Bone Loss

The pattern of observed bone loss is similar to that originally described by Adell et al[1] in 1981, with more bone loss occurring during the first year of clinical loading and tapering off in the subsequent years. The initial high rate of bone loss is most likely a response to the inevitable surgical trauma involved with implant insertion. The lower steady state bone loss recorded following wound healing probably reflects the normal physiologic bone remodelling process, through coupled osteoblast and osteoclast activity.[1] The rates of bone loss obtained are consistent with the findings of previous investigators.[34–39] Moreover, while individual variation was observed, the mean bone loss for the first year of clinical loading and the subsequent years exceeded the recommendations stated in proposed criteria for implant success.[14–21] In addition, the results of this study suggest peri-implant bone loss to be a potentially important mechanism underlying late implant failures, as significantly more bone loss was observed following the first year of clinical loading for those implants that eventually failed.

The Effect of Smoking

The adverse effect of smoking on implant longevity[8–13] and marginal bone levels[24–28] has been reported. Moreover, implementation of a smoking cessation protocol prior to stage 1 surgery has been shown to reduce the incidence of early implant loss.[40] The results of this long-term investigation confirm these earlier claims, and suggest that grouping patients based on the nature of their smoking habit allows for a more comprehensive understanding of the way smoking may influence implant therapy. A positive smoking history was associated with a higher rate of peri-implant bone loss, and the majority of late implant failures were observed in this group of patients. Smoking at the time of stage 1 surgery did not appear to predispose implants to more marginal bone loss over time, but was associated with a greater incidence of early implant failures in Part I of this investigation.[8] This suggests that the mechanism by which smoking predisposes patients to late implant failures may be different from that causing early implant loss. The results of this study suggest that following successful osseointegration, smoking may raise the risk of late implant failures, at least in part, by predisposing implants to a higher rate of marginal bone loss over time. Cigarette smoking has been shown to systemically reduce bone density[41–45] and has been implicated as an independent risk factor for osteopenia[41–44] and periodontitis.[46–50] Therefore, the available literature suggests that smoking may cause an increase in marginal bone loss by increasing bone resorption,[43,51–53] reducing bone formation,[54–58] or through a combined effect.

Notably, the difference in mean peri-implant bone loss over the 20-year follow-up period between groups S2 and NS2 was relatively small and may not completely account for the higher rate of late implant failures observed in this group of patients. Additional research is required to understand the way in which smoking may predispose patients to an increase in implant failure following successful osseointegration. In vitro experiments and animal models appear to be a convenient research tool that would aid in this process. Moreover, clinical investigation is required to determine if the effect of smoking on marginal bone loss is reversible following smoking cessation. At the present time, clinical evidence suggests that patients who are smokers at the time of consultation should be encouraged to stop smoking, at least for the short-term, to improve their chances of osseointegration.[8,40] However, long-term heavy smokers must be informed that they are at a slightly higher risk of late implant failure and susceptible to more marginal bone loss over the long-term, irrespective of their smoking status at the time of implant placement. Additionally, this investigation suggests that smoking habits should be routinely included in future studies of implant failure and peri-implant bone loss.

Additional Factors

Part I of this investigation showed that late implant failure rates are significantly higher in the maxilla than in the mandible.[8,59–60] Although these findings failed to reach statistical significance—likely a result of the lack of power in the population sample—more marginal bone loss was indeed observed in the maxilla than in the mandible following the first year of clinical loading. While the region of implant placement was the only factor investigated that may explain the bone loss observed in the first year of function, it was not found to be important in the analysis of long-term bone loss, nor did it result in an increase in implant failure.[8] The relevance of implant length to implant survival and peri-implant bone loss are extensively documented.[20,59–61] Part I of this investigation suggested that late implant failure rates appears to be significantly higher for shorter implants.[8] When considering implant length, the net effect of the observed bone loss on the residual implant-bone interface cannot be ignored, and shorter implants have a clearly reduced implant-bone surface contact area. Consequently, it may be hypothesized that a similar amount of absolute bone loss may result in a higher failure rate over time.[62] The results of this study appear

to support such a notion. Occlusal load was found to be an independent factor that significantly affected peri-implant bone loss following the first year of prosthetic loading. However, previous investigations have inconsistently documented the effect of occlusal overload on implant survival and marginal bone loss.[38,63–64] Moreover, the type of opposing dentition was previously found to be insignificant in the model for late implant failures.[8] Therefore, while a higher rate of bone loss may be observed around those implants subject to repetitive higher loads, the net effect on implant survival appears to be negligible.

While this study benefits from a lengthy follow-up period, a greater emphasis on regular recall appointments by all patients following prosthesis insertion appears to be desirable. Experimental and clinical studies that allow for better control of confounding factors and provide the rigor of consecutive image analysis over the long-term are clearly needed. Without such data, a better understanding of possible causes and mechanisms of marginal bone loss and late implant failure remains elusive.

Conclusions

1. The mean annual bone loss was 0.178 mm ± 0.401 during the first year of clinical loading and 0.066 mm ± 0.227 per year thereafter. The mean bone loss observed exceeds the recommendations stated in proposed criteria for implant success, reaffirming the reliability of the Brånemark implant system.
2. A positive smoking history was associated with a higher rate of peri-implant bone loss, and the majority of implant failures where observed in this group of patients. Smoking at the time of stage 1 surgery did not appear to predispose implants to more marginal bone loss over time.
3. At the present time, clinical evidence suggests that patients who are smokers at the time of consultation should be encouraged to stop smoking, at least for the short-term, to aid the healing process of osseointegration. However, long-term heavy smokers should also be informed that they are at a slightly higher risk of late implant failure and are susceptible to more marginal bone loss over the long-term, irrespective of their smoking status at the time of implant placement.

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