A Multifactorial Analysis to Identify Predictors of Implant Failure and Peri-Implant Bone Loss

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ABSTRACT

Objective: To identify risk factors for failure and bone loss of implants in a large study sample on the basis of multivariate analyses.

Materials and Methods: Patient files of all patients referred for implant treatment from November 2004 to December 2007 were scrutinized, and information on implant- and patient-related factors was collected. The study sample in this retrospective cohort study consisted of both partially dentate and fully edentulous patients referred for various indications. The only inclusion criterion was a follow-up of at least 2 years. Implant survival and bone loss were assessed by an external investigator (SV) comparing digital periapical radiographs taken during recall visits with the postoperative ones. Univariate and multivariate tests were adopted to identify possible risk indicators for implant failure and peri-implant bone loss.

Results: Twenty-one of 1,320 (1.6%) implants were lost in 19 of 376 (5.1%) patients (210 female, 166 male; mean age 56, range 17–82) after a mean follow-up of 32 months (range 24–62). Based on multivariate analysis, only smoking ($p = .001$) and recall compliance ($p = .010$) had a significant influence on implant failure, with smokers more prone to failure. The overall mean bone loss was 0.36 mm (SD 0.68, range 0.00–7.10). Smoking ($p = .001$) and jaw of treatment ($p = .001$) affected peri-implant bone loss. More peri-implant bone loss was observed in smokers and in the maxilla. A clear discrepancy was found between univariate and multivariate analysis with regard to identification of risk factors.

Conclusion: Multivariate analysis demonstrated that implant-related factors did not affect the clinical outcome, but smoking was identified as a predictor for implant failure. Predictors for peri-implant bone loss were smoking and jaw of treatment.

KEY WORDS: dental implant, implant survival, multifactorial, peri-implant bone loss, predictor

INTRODUCTION

A systematic review and meta-analysis based on multiple randomized controlled trials obtains the highest level of scientific evidence. In implant dentistry, such a level of evidence is available on the outcome of different implant treatment protocols[1,2] and different risk factors.[3–5] A risk factor for treatment failure can be identified in a randomized controlled trial; however, the relative importance of one factor in relation to others cannot be assessed in such a study. A thorough risk assessment requires multivariate analyses correcting for confounding factors. In this context, large prospective or even retrospective case series may become particularly important.

A recent retrospective study evaluated the influence of different factors on long-term bone stability around immediately placed implants in a large retrospective cohort.[6] Based on a univariate analysis, different factors such as age at time of implant placement, gender, implant surface, implant width, and implant location affected crestal bone loss. The authors described these factors as statistically significant but clinically irrelevant. Indeed,

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small differences can show statistical significance given the large number of implants but may not be clinically relevant. Another possible explanation is the adopted statistical analysis. Univariate tests do not correct for confounding factors. Given the large number of implants and explanatory variables, interaction between different variables may be conceivable. For this purpose a multivariate analysis was already suggested by Cosyn.[7] They evaluated the influence of different factors on implant failure and found a clear discrepancy between results of univariate and multivariate statistical analyses.

The primary aim of the study was to evaluate implant survival and peri-implant bone loss of surface-modified implants with a minimum follow-up of 2 years.

The secondary aim was to identify predictors affecting implant treatment outcome using multivariate tests that correct for confounding.

MATERIALS AND METHODS

Study Sample

All consecutively treated patients between November 2004 and December 2007 and with a minimum follow-up of 2 years were included in this retrospective cohort study. Patients were referred by their restorative dentist to a private periodontal practice for implant placement. No patients were excluded based on medical risk factors, history of periodontitis, or smoking habits. They comprised partially dentate and fully edentulous patients with various indications for implant rehabilitations. All patients were treated by the same surgeon using the same implant system (Osseospeed™, Astra Tech, Molndahl, Sweden). All implants were installed according to the manufacturer's guidelines based on proper presurgical radiographic planning. Patients with periodontitis or endodontic pathology were treated prior to implant placement to minimize the risk for biological complications. Implants were placed using different surgical techniques (one-stage and two-stage surgery) and different loading protocols (immediate loading and delayed loading). Hence, three different treatment protocols were analyzed, being immediate loading, one-stage delayed loading, and two-stage delayed loading. In the case of immediate loading, an impression was made directly after implant installation and a provisional acrylic, metal-reinforced, screw-retained restoration was placed the day after surgery. Immediate full-occlusal loading with balanced occlusion and articulation was applied for all cases, except for single tooth replacement, where nonocclusal loading was applied. The final restorations were made by the restorative dentists after a healing time of at least 3 months. The restorative dentists were both general practitioners and prosthodontists with different levels of experience. After implant treatment, all patients were invited for recall. Recall visits were adapted to individual patient needs and consisted of both clinical and radiological evaluation of the implants, including occlusion/articulation.

Dependent Variables and Covariates

Patient files were scrutinized by an external investigator from Ghent University. Implant failure and interproximal peri-implant bone loss were considered the dependent variables. Information on different predictors was collected from the patient files, including surgical protocol, loading protocol, smoking habit, jaw location, patient's recall status, implant length, implant width, implant design, prosthetic reconstruction, and the antagonistic jaw. Peri-implant bone loss was assessed by an external examiner comparing digital radiographs taken during recall visits with the postoperative ones taken by the surgeon immediately after implant installation (baseline). Digital software with an accuracy of 0.1 mm (Visi-quick®, Amsterdam, the Netherlands) was used for radiological evaluation. Marginal bone level was determined at both the mesial and distal sites of each implant by measuring the distance between a reference point (lower border of the smooth implant collar or the uppermost point of the microthreaded part) and the marginal bone-to-implant contact point. Values were averaged to obtain a single value per implant. The study protocol was approved by the ethical committee of the Ghent University Hospital.

Statistical Analysis

Inter- and intraexaminer reliability were assessed using the intraclass correlation coefficient (ICC) based on a two-way random model with absolute agreement. The possible predictors and dependent variables were cross-classified using contingency tables. The impact of the explanatory variables on implant survival was analyzed using the Mantel-Cox log-rank test. For this reason, the continuous predictors or so-called covariates were categorized. Because of possible interaction between the explanatory variables, the univariate analysis can be considered exploratory. For this purpose, a multivariate

analysis was adopted. This analysis consisted of the Cox proportional hazards regression. A model was fitted including as many variables as possible. The level of significance was set at .05.

The impact of the different explanatory variables on peri-implant bone loss was analyzed using both univariate and multivariate tests for the aforementioned reason. The Mann-Whitney *U*-test was adopted to explore the impact of each variable. Multivariate analysis consisted of the linear mixed-effect model analysis after a logarithmic transformation of the data. This transformation was mandatory after validation of the statistical model in terms of linearity and homoskedasticity. The level of significance was set at .05. The statistical analyses were performed using IBM® SPSS® 19.0 for Windows.

RESULTS

Overall Clinical Outcome

Three hundred seventy-six patients (166 men, 210 women; mean age 56, range 18–82) with 1,320 implants met the inclusion criterion of 2 years of follow-up. The average time between implant installation (baseline) and evaluation in this cross-sectional study was 32 months. Twenty-one implants failed in 19 patients, resulting in an absolute survival rate of 98.4%. Implant failure was experienced by 5.1% of the patients (Table 1). Seventeen patients lost 1 implant and 2 patients lost 2 implants. Eleven failures occurred during the first 6 months and 10 implants failed during follow-up, 24 to 59 months after implant placement. Table 2 shows cumulative survival rates (CSRs). After 24 to 29 months, the CSR was 98.7% and 96.8% with the implant and the patient as statistical unit, respectively.

Out of 1,299 surviving implants, 1,288 had readable radiographs. Intraexaminer repeatability on bone loss was high (ICC 0.969, 95% confidence interval (CI) 0.924–0.988), as was the interexaminer repeatability (ICC 0.964, 95% CI 0.910–0.985). A mean bone loss of 0.36 mm (SD 0.68, range 0.00–7.10) was observed after a mean follow-up of 32 months (Table 1). Individual peri-implant bone loss in relation to the follow-up time is given in Figure 1.

Identification of Predictors of Implant Failure and Peri-Implant Bone Loss

Treatment Protocol (Surgical and Loading Protocols). Implants were grouped according to surgical (one-stage vs two-stage surgery) and loading protocol (immediate vs delayed loading). Three different treatment protocols were defined: immediate loading (IL), one-stage delayed loading (1-DL), and two-stage delayed loading (2-DL). Six hundred forty-nine implants were loaded immediately and 671 implants were placed in a delayed loading protocol. Of the latter group, 211 implants were placed in a two-stage surgical protocol, allowing submerged healing. Primary reasons for a two-stage procedure were lack of primary stability or prosthesis wear, possibly interfering with implant integration. In the IL group, 0.5% of the implants failed, whereas 3.9% failed in the 1-DL group and no failures occurred in the 2-DL group. The corresponding bone loss values were 0.33 mm (SD 0.63, range 0.00–5.05), 0.33 mm (SD 0.70, range 0.00–7.10), and 0.51 mm (SD 0.72, range 0.00–4.60) (Table 1). Univariate analysis showed a significant influence of the treatment protocol on implant survival ($p < .001$) and peri-implant bone loss ($p < .001$), with more failures in the 1-DL group and more peri-implant bone loss for the 2-DL group. However multivariate analysis failed to show significant differences between the defined groups ($p = .497$, $p = .346$) (Table 3).

Smoking Habit. One thousand seventeen implants were installed in 297 nonsmokers and 290 in 74 smokers. Twelve failures occurred in 11 nonsmokers and 9 in 8 smokers. This corresponds with absolute survival rates of 98.8% and 96.9% with the implant as statistical unit. 10.8% of the smokers experienced implant failure compared with 3.7% of the nonsmokers. Cumulative survival rates are given in Table 4. After 24 to 29 months, the CSRs were 99.4% and 98.0% for nonsmokers at implant and patient level, respectively. The corresponding figures for smokers were 97.9% and 91.9%.

Mean bone loss for implants installed in smokers was 0.57 mm (SD 0.93, range 0.00–5.90) compared with 0.30 mm (SD 0.58, range 0.00–7.10) for implants installed in nonsmokers (Table 1). Smoking was identified as a significant factor affecting implant treatment outcome ($p = .009$, $p < .001$) based on univariate analysis. Multivariate analysis confirmed the impact of smoking on implant survival with a hazard ratio of 0.228 (95% CI 0.089–0.559; $p = .001$) and peri-implant bone loss ($p < .001$) (Table 3).

Jaw of Treatment. Five out of 757 implants failed in the maxilla and 16 of 563 in the mandible. This corresponds with absolute survival rates of 99.3% and 97.2%

TABLE 1 Implant Failure Rates and Peri-Implant Bone Loss with Respect to the Explanatory Variables

	Survival		Bone Loss			
Factor	Implants, *n*	Failures, *n* (%)	Implants, *n*	Mean	SD	Range
Overall	1,320	21 (1.6)	1,288	0.36	0.68	0.00–7.10
Treatment protocol						
Immediate loading	649	3 (0.5)	642	0.33	0.63	0.00–5.05
One-stage delayed loading	460	18 (3.9)	437	0.33	0.70	0.00–7.10
Two-stage delayed loading	211	0 (0.0)	209	0.51	0.72	0.00–4.60
Smoking status						
Smokers	290	9 (3.1)	279	0.57	0.93	0.00–5.90
Nonsmokers	1,017	12 (1.2)	996	0.30	0.58	0.00–7.10
Jaw						
Maxilla	757	5 (0.7)	745	0.42	0.70	0.00–7.10
Mandible	563	16 (2.8)	543	0.28	0.63	0.00–4.95
Implant length						
<10 mm	255	10 (3.9)	243	0.32	0.60	0.00–4.95
>10 mm	1,065	11 (1.0)	1,045	0.37	0.70	0.00–7.10
Implant width						
Narrow (≤3.5 mm)	348	7 (2.0)	339	0.35	0.60	0.00–5.05
Regular (4.0 mm)	576	9 (1.6)	562	0.35	0.65	0.00–4.95
Wide (≥4.5 mm)	396	5 (1.2)	387	0.38	0.77	0.00–7.10
Implant design						
Cylindrical	866	16 (1.8)	843	0.36	0.64	0.00–5.05
Conical	454	5 (1.1)	445	0.36	0.73	0.00–7.10
Recall status						
Responder	1,084	18 (1.7)	1,055	0.34	0.63	0.00–7.10
Nonresponder	236	3 (1.3)	233	0.46	0.83	0.00–4.95
Prosthetics						
Fixed full-arch	686	2 (0.3)	679	0.38	0.70	0.00–5.90
Fixed partial	419	11 (2.6)	404	0.36	0.67	0.00–7.10
Single tooth	165	8 (4.8)	155	0.32	0.58	0.00–4.55
Overdenture	50	0 (0.0)	50	0.21	0.55	0.00–2.75
Antagonist						
Natural teeth	920	18 (2.0)	894	0.40	0.72	0.00–7.10
Removable denture	172	1 (0.6)	169	0.28	0.73	0.00–4.95
Implants	228	2 (0.9)	225	0.24	0.35	0.00–2.40

(Table 1). After 24 to 29 months, the CSR was 99.3% for implants in the maxilla compared with 98.8% for implants installed in the mandible. The mean bone loss for maxillary implants was 0.42 mm (SD 0.70, range 0.00–7.10) compared with 0.28 mm for implants installed in the mandible (SD 0.63, range 0.00–4.95) (Table 1). Univariate analysis identified the jaw as a significant factor affecting implant survival ($p = .003$) and peri-implant bone loss ($p < .001$). However, multivariate analysis only confirmed the impact of this factor on peri-implant bone loss ($p < .001$) (Table 3).

Implant Features (Length, Width, Design). Implants were cross-classified in Table 5 for implant length and implant width with the corresponding failures for each group. Implants were grouped according to implant length (< 10 mm = short, > 10 mm = long), width (≤ 3.5 mm = small, 4.0 mm = regular, ≥ 4.5 mm = wide), and design (conical and cylindrical). Survival rates and peri-implant bone loss values are given in Table 1. Implant length was the only factor with a significant influence on implant survival based on univariate analysis ($p = .003$). However, neither implant length ($p = .133$)

TABLE 2 Overview of Overall Cumulative Survival Rates and Failures

	Implants			Patients		
Follow-Up (months)	*n* At Start of Period	Failures	Cumulative Survival (%)	*n* At Start of Period	Failures	Cumulative Survival (%)
0–5	1,320	11	99.2	376	11	97.1
6–11	1,309	0	99.1	365	0	97.1
12–17	1,309	0	99.1	365	0	97.1
18–23	1,309	0	99.1	365	0	97.1
24–29	1,309	1	98.7	365	1	96.8
30–35	708	7	97.9	216	5	94.3
36–41	389	0	97.9	135	0	94.3
42–47	234	1	97.5	86	1	93.2
48–53	120	0	97.5	45	0	93.2
54–59	48	1	78	16	1	62.1
60–65	2	0	78	1	0	62.1

TABLE 3 Results of the Univariate and Multivariate Analyses on Implant Survival and Peri-Implant Bone Loss

	Survival (*p*)		Bone Loss (*p*)	
	Univariate	Multivariate	Univariate	Multivariate
Treatment protocol	<.001	.497	<.001	.346
IL vs 1-DL	<.001		.280	
IL vs 2-DL	.212		<.001	
1-DL vs 2-DL	.004		<.001	
Smoking status	.009	.001*	<.001	<.001*
Jaw	.003	.465	<.001	<.001*
Implant length	.003	.133	.209	.212
Implant width	.556	.797	.568	.716
Implant design	.248	.633	.026	.263
Recall status	.019	.010*	.036	.387
Prosthetics	.002	.233	.011	.388
Single tooth vs full-arch	<.001		.514	
Single tooth vs partial	.289		.312	
Single tooth vs overdenture	.178		.014	
Partial vs overdenture	.275		.001	
Partial vs full-arch	.004		.553	
Full-arch vs overdenture	.632		.002	
Antagonist	.531	.830	<.001	.421
Natural teeth vs implants			.007	
Natural teeth vs removable denture			<.001	
Implants vs removable denture			.104	

The univariate analysis can be considered exploratory. Level of significance was set at .05.
*Significant predictor.
IL, immediate loading; 1-DL, one-stage delayed loading; 2-DL, two-stage delayed loading.

TABLE 4 Overview of Cumulative Survival Rates and Failures in Smokers and Nonsmokers

	Implants						Patients					
	Nonsmokers			Smokers			Nonsmokers			Smokers		
Follow-Up (months)	*n* At Start of Period	Failures	CSR (%)	*n* At Start of Period	Failures	CSR (%)	*n* At Start of Period	Failures	CSR (%)	*n* At Start of Period	Failures	CSR (%)
0–5	1,017	5	99.5	290	6	97.9	297	5	98.3	74	6	91.9
6–11	1,012	0	99.5	284	0	97.9	292	0	98.3	68	0	91.9
12–17	1,012	0	99.5	284	0	97.9	292	0	98.3	68	0	91.9
18–23	1,012	0	99.5	284	0	97.9	292	0	98.3	68	0	91.9
24–29	1,012	1	99.4	284	0	97.9	292	1	98	68	0	91.9
30–35	528	5	98.2	169	2	96.8	169	4	95.3	43	1	89.8
36–41	298	0	98.2	85	0	96.8	108	0	95.3	25	0	89.8
42–47	193	0	98.2	37	1	94.2	71	0	95.3	14	1	83.3
48–53	109	0	98.2	11	0	94.2	39	0	63.5	6	0	83.3
54–59	40	1	78.6	8	0	94.2	13	1	63.5	3	0	83.3
60–66	2	0	78.6	0	0	94.2	1	0	63.5	0	0	83.3

CSR, cumulative survival rate.

nor implant diameter ($p = .797$) nor implant design ($p = .633$) had a significant impact on implant survival based on a multifactorial analysis. Multifactorial analysis also failed to show a significant impact of the aforementioned parameters on peri-implant bone loss ($p = .212$, $p = .716$, $p = .263$).

Prosthetic Reconstruction. Implants were grouped according to the type of prosthetic reconstruction. A distinction was made between implants supporting removable dentures, single crowns, fixed partial restorations, and fixed full-arch restorations. Results regarding implant survival and peri-implant bone loss are given in Table 1. Although a significant difference was found based on univariate tests, multivariate analysis failed to show a significant difference regarding either implant survival ($p = .233$) or peri-implant bone loss ($p = .388$) (Table 2).

Antagonistic Structure in the Opposing Jaw. Implants were grouped according to the antagonistic structure in the opposing jaw. Nine hundred twenty implants were placed opposing natural teeth, 172 opposing removable dentures, and 228 opposing dental implants. Results are given in Tables 1 and 2. No significant differences were found regarding implant survival with either univariate ($p = .531$) or multivariate tests ($p = .830$). Univariate analysis showed a significant influence of the

TABLE 5 Implant Distribution according to Implant Length and Diameter

Length (mm)	Diameter (mm)				Total
	3.5	4.0	4.5	5	
8	49 (3)	47 (2)			96 (5)
9	26 (2)	39 (1)	41 (2)	54	160 (5)
11	52 (2)	87 (2)	28	50 (2)	217 (6)
13	114	154 (1)	81	44 (1)	393 (2)
15	107	240 (2)	57	42	446 (2)
17		8 (1)			8 (1)
Total	348 (7)	576 (9)	206 (2)	190 (3)	1,320 (21)

Number of failed implants is given in brackets.

antagonistic structure on peri-implant bone loss ($p < .001$), mainly because of increased bone loss around implants opposing natural teeth. However, multivariate analysis failed to confirm this impact ($p = .421$).

Recall Compliance. Two hundred ninety-three patients with 1,084 implants responded to the recall invitation after implant placement. All nonresponding patients were contacted by phone and invited for a free examination. Eighty-three patients with 236 implants were willing to attend this examination. Both groups were compared for implant survival and peri-implant bone loss. Results are given in Tables 1 and 2. Responding patients experienced more implant failures based on univariate ($p = .019$) and multivariate tests ($p = .010$). However, as most failures occurred before prosthetic loading, one can conclude that patients who experience implant failure are more compliant compared with patients with successfully integrated implants. After a mean follow-up of 32 months, a mean bone loss of 0.34 mm (SD 0.63, range 0.00–7.10) was observed for the responding group compared with 0.46 (SD 0.83, range 0.00–4.95) for the nonresponding group. The patient's compliance had a significant impact on peri-implant bone loss based on univariate analysis ($p = .036$), but this result was not confirmed based on multivariate analysis ($p = .387$).

DISCUSSION

The present study reports the outcome of all patients treated with fluoride-modified implants over a 3-year period in a private periodontal practice and with at least 2 years of follow-up. All patients were consecutively treated and included in the analysis regardless of their risk profile based on medical anamnesis, history of periodontitis, and smoking habits. Prospective studies are often based on small samples of selected patients to evaluate a novel technique or material. However, care has to be taken in extrapolating the results to daily practice, where less than ideal patients are treated. Hence, a survival rate of 98.4% after a mean follow-up of 32 months can be considered very successful, given the fact that this study represents "real-life" daily practice. The survival rate is in accordance with other studies using the same implant system and dealing with different indications and treatment protocols.[8–12] Out of 21 failures, 11 were categorized as early failures and occurred before prosthetic loading. Different factors such as excessive surgical trauma, smoking, and bone quality have been associated with biological complications due to impaired bone healing after implant placement, possibly leading to fibrous encapsulation and nonintegration.[13] Peri-implantitis and/or occlusal overload are described as the main reasons for late failures occurring after integration of the implant.[14–19] In the present study, all late failures occurred after at least 2 years of functional loading. The final restorations were made by the referring dentists. They comprised both general practitioners and prosthodontists with different levels of experience. This may be an important factor concerning the late failures. However, the referring dentists and their dental technicians attended multiple training sessions in implant rehabilitation, including individual peer-reviewed sessions organized by the surgeon to enhance the quality of the team approach. Moreover, the recall by the surgeon always consisted of a clinical and radiological examination, including occlusion and articulation. The small number of late failures is a clear proof of a successful team approach.

Recent studies evaluating peri-implant bone level changes around surface-modified implants reported mean bone level changes of 0.25 to 0.50 mm.[20–23] The current study reported a mean bone loss of 0.36 mm from the time of implant placement. Most studies reported bone loss from the time of prosthetic loading or second-stage surgery, often many months after implant placement.[22] One has to take into account that an important amount of bone loss can already occur during the first months of healing. This bone remodeling occurs after implant placement in order to reestablish enough biological space to sustain the bacterial load in the oral cavity, especially in patients or at sites with thin soft tissues at the time of implant placement.[24–26] In a recent study, the initial soft tissue thickness was associated with early bone remodeling. However, thereafter, stable bone conditions were described even for implants with early bone loss up to 2 years of function.[26] In the present study most late failures occurred after 2 years and were associated with ongoing bone loss from the day of implant placement. Hence, it is suggested to monitor patients with initial peri-implant bone loss more strictly to prevent future biological complications.

In the current study, implant survival and peri-implant bone loss were comparable for immediate loading, one-stage delayed loading, and two-stage delayed loading. This is in accordance with the

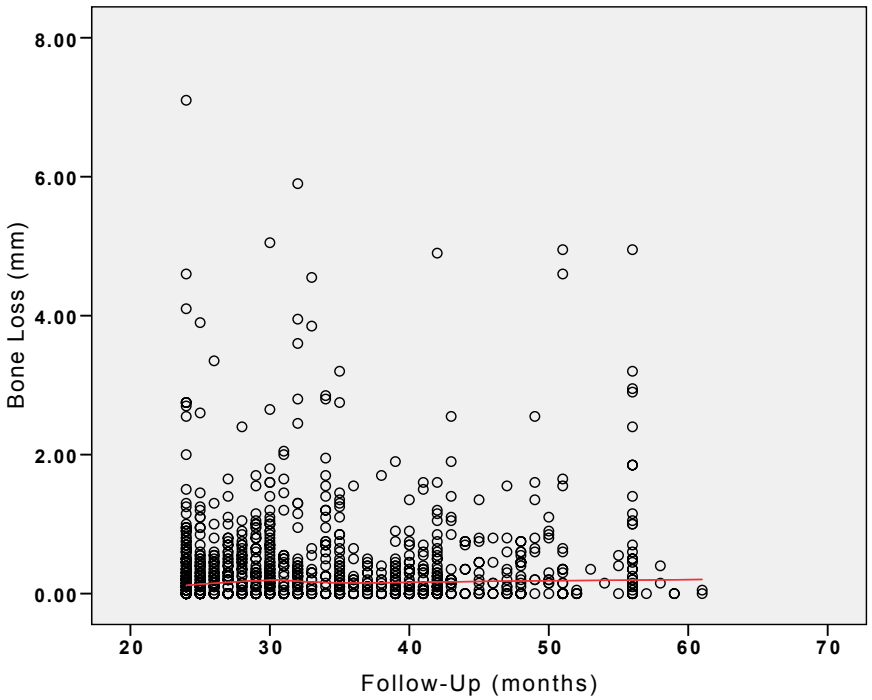

Figure 1 Scatter plot presenting individual peri-implant bone loss in relation to the follow-up time. Trendline (Loess curve fitted at 50%) is given in red.

existing literature on submerged versus nonsubmerged healing[27–31] and immediate loading versus delayed loading.[1,32–34] In a retrospective analysis of 1,180 surface-modified implants placed in a university postgraduate training center, Cosyn and colleagues described early loading as the only factor with significant impact on implant failure, whereas immediate loading was found to be a viable alternative for delayed loading.[7]

In the present study, the effect of smoking on implant survival and peri-implant bone loss was analyzed at both implant and patient level, as smoking is a systemic factor. Significantly more failures were observed in smokers, and one smoker out of 10 experienced implant failure. Moreover, implants installed in smokers showed significantly more peri-implant bone loss compared with nonsmokers. These results are in accordance with systematic reviews highlighting the effect of smoking on implant survival and peri-implant bone loss.[4,5] This might explain both the early failures related to impaired wound healing and late implant failures due to ongoing bone loss in the present study.

Both univariate and multivariate analyses revealed significantly more peri-implant bone loss around implants in the maxilla compared with the mandible. This finding is in agreement with previous clinical studies.[35–40]

The present study showed more failures in the group with patients responding to the recall invitation after implant placement. As most failures were early failures, this could be interpreted as meaning that patients who experienced implant failure were more compliant compared with patients with successfully integrated implants.

The present study showed a clear discrepancy between univariate and multivariate tests. Univariate analysis consisted of the log-rank test to evaluate implant survival and the Mann-Whitney *U*-test to evaluate peri-implant bone loss. The Cox proportional hazards regression and the mixed-effect model analysis were the respective multivariate tests. Treatment protocol ($p = .001$), smoking ($p = .001$), jaw of treatment ($p = .003$), patient's compliance ($p = .019$), implant length ($p = .003$), and prosthetic reconstruction ($p = .002$) were factors showing significant impact on implant survival on the basis of univariate analysis. However, when controlling for confounding factors, only smoking had a significant influence ($p = .001$), with smokers more prone to failure. Univariate analysis identified treatment protocol ($p = .001$), jaw of treatment ($p = .001$), smoking ($p = .001$), patient's compliance ($p = .036$), and prosthetic reconstruction ($p = .011$) as risk indicators for peri-implant bone loss. Only smoking ($p = .001$) and jaw

of treatment ($p = .001$) affected peri-implant bone loss when a multivariate analysis was adopted. The present study is a retrospective cohort study, which is a noncontrolled study design. Hence, controlling for confounding factors is necessary to identify true risk factors. This multivariate statistical approach was already suggested by Cosyn and colleagues.[7] They evaluated different factors associated with failure of surface-modified implants and considered the univariate analysis as exploratory because interaction between different predictors was conceivable.

CONCLUSION

The present study evaluated the clinical outcome of fluoride-modified implants in a well-organized surgical/prosthodontic team approach. Fluoride-modified implants are a reliable and highly successful treatment option with high survival rates and limited peri-implant bone loss after at least 2 years of function. Multivariate analysis demonstrated that implant-related factors did not affect the clinical outcome, but smoking was identified as a predictor for implant failure. Predictors for peri-implant bone loss were smoking and jaw of treatment.

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