Factors Associated with Failure of Surface-Modified Implants up to Four Years of Function

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ABSTRACT

Objectives: The relative impact of innovative treatment concepts on the failure of surface-modified implants is not well understood. This retrospective study aimed to explore this using data obtained in a university postgraduate training center.

Material and Methods: Patients treated with implants for a variety of indications over a 3-year period were included. All implants had been at least 1 year in function. Clinical records were evaluated for implant failure and in reference to implant length/diameter/location, time from tooth loss to implant placement, bone condition (native/grafted), surgical protocol (two-/one-stage), loading protocol (delayed/early/immediate), type of prosthesis (removable/fixed), surgeon's experience level (resident/trainee) and specialty (periodontist/oral surgeon). The impact of each covariate on failure was tested using the Fisher's exact test. Kaplan-Meier survival functions were constructed and Mantel-Cox log–rank tests were used to compare survival functions. To correct for possible interaction, Cox proportional Hazards regression was adopted.

Results: Forty-one of 1,180 (3.5%) implants were lost in 34/461 (7.4%) patients (245 ♀, 216 ♂; mean age 51, range 18–90). Factors showing significant impact on failure on the basis of univariate analyses were implant location ($p = .015$), surgical protocol ($p = .002$), loading protocol ($p = .002$), surgeon's experience level ($p = .035$) and specialty ($p = .001$). When controlling for other covariates, only the loading protocol had a significant influence ($p = .049$) with early loading more prone to failure ($p = .014$) when compared with delayed loading. Immediate loading and delayed loading showed comparable implant survival ($p = .311$).

Conclusions: Implant therapy may be highly successful in a training center where inexperienced clinicians are strictly monitored and personally guided. Implant specific variables do not affect implant survival but early loading is a risk indicator for implant failure, whereas immediate loading is not.

KEY WORDS: implant characteristics, implant failure, loading protocol, postgraduate training, risk indicators, surgical experience

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INTRODUCTION

Originally, dental implants were predominantly used to restore function in fully edentulous patients. The traditional Brånemark protocol including submerged healing and delayed loading proved to be a reliable concept for these patients with a limited failure rate and stable conditions in the long term especially in the mandible.[1] During the last decades, however, implant dentistry has evolved to seemingly unlimited indications to restore function and esthetics in the shortest possible time span. Non-submerged healing of two-piece implants, early or immediate implant placement after tooth loss, early or immediate loading and implant surface modifications could be considered as the most prominent innovations to meet these demands. Following careful case selection, all of them have been found to result in a favorable clinical outcome.[2–5] However, these modifications may possibly increase the incidence of implant failure as more occlusal forces are allowed during the early stages of healing possibly hampering the osseointegration process. Furthermore, implant placement in non-healed sites or fresh extraction sockets is technique-sensitive because primary implant stability is critical, and simultaneous bone regeneration may be required. Finally, the use of surface-modified implants, those with microtextured collars in particular, could increase the risk for peri-implantitis,[3,6,7] which is one of the main reasons for late implant failure.

Hitherto, it is unclear to what extent innovative treatment concepts influence implant failure. The objective of this retrospective study was to evaluate 1–4-year implant survival on the basis of data from a postgraduate training center using different surgical techniques and loading protocols in a variety of indications by clinicians with different experience levels.

MATERIALS AND METHODS

Study Sample

In this cross-sectional study, all dental implants that were included had been placed between September 2004 and August 2007 at the University Hospital in Ghent. Data on all implants placed by resident specialists in periodontology and maxillofacial surgery as specialists in training in both aforementioned disciplines were included. Patients were either referred by general dentists, by other departments of the dental school, or by the hospital. They comprised straightforward and complex cases in healthy or medically compromised patients. There were no restrictions in terms of patient selection, extent of surgical, and/or prosthetic treatment.

Proper radiologic and presurgical planning was performed for all patients. Endodontic and/or periodontal pathology were treated beforehand. The diagnostic, surgical, postoperative and restorative protocol was left to the discretion of the surgeon and restorative dentist following the guidelines provided by the implants' manufacturers.

Dependent Variable and Covariates

All hospital files were evaluated by two clinicians (VE, BH). Implant failure was considered the dependent variable in the analyses. The following factors were included as covariates or predictors, and information on these parameters was also collected from the files: implant length, implant diameter, implant location, time from tooth loss to implant placement, bone condition, surgical protocol, loading protocol, suprastructure, surgeon's experience level, surgeon's specialty. The study protocol was approved by the ethics committee of the University Hospital in Ghent.

Statistical Analysis

Contingency tables were constructed cross-classifying each predictor and the dependent variable. The impact of each predictor on implant failure was evaluated by means of the Fisher's exact test. All continuous covariates were categorized for this purpose. Kaplan–Meier survival functions were also constructed for each predictor. Mantel–Cox log rank tests were used to compare survival functions. Because interaction between multiple predictors was conceivable, we considered these univariate analytic methods as exploratory. Multivariate analysis was performed to correct for clustering. Cox proportional Hazards regression was adopted for this purpose. A model was fitted including as much covariates as possible. The validity of this model was evaluated using logistic regression analysis. The level of significance was set at 0.05.

RESULTS

Overall Clinical Outcome

Four hundred sixty-one patients (245 ♀, 216 ♂; mean age 51, range 18–90) were treated in the 3-year interval with 1,180 surface-modified implants. The sample consisted of a mixture of at least 23 implant types and 7 surfaces from the following manufacturers: 442 from Nobel Biocare (Zürich, Switzerland), 266 from Straumann (Basel, Switzerland), 183 from Dentsply Friadent (Mannheim, Germany), 174 from Astra Tech (Mölndal, Sweden), and 125 from Biomet 3i (Palm Beach, FL, USA). Figure 1 shows all implant types included.

All indications were included in the survival analyses: 14% were single-tooth implants, 70% of the implants supported a fixed partial denture or full-arch bridge and 16% retained a removable partial or complete denture.

The average time between implant placement and moment of evaluation was 30 months (range 12–48). Forty-one of the 1,180 implants were lost, corresponding to a 3.5% failure rate. Twenty-two of the 639

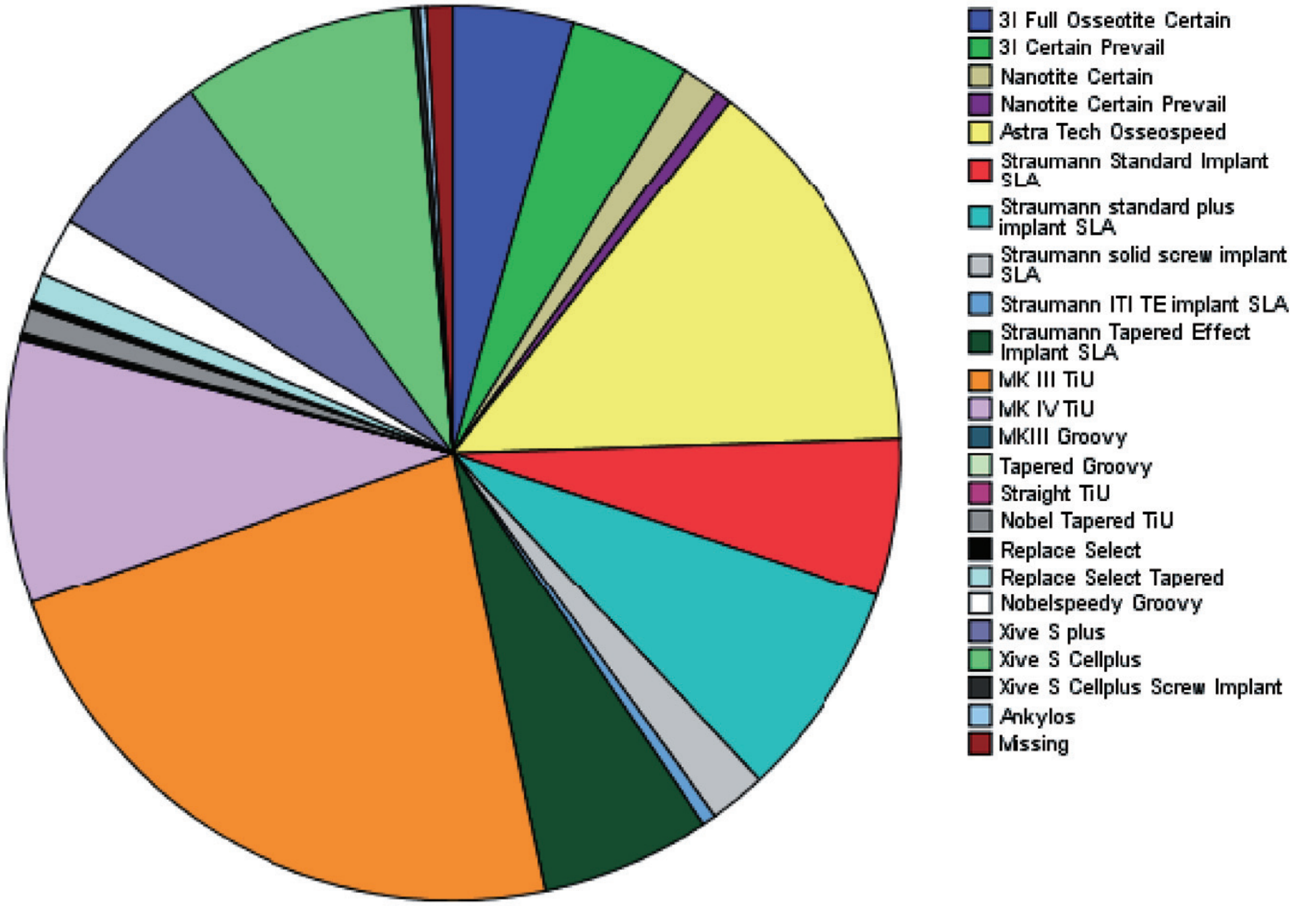

Figure 1 Pie diagram showing the proportion of the different implant types ($n = 24$) placed in the study group.

implants (3.4%) were lost in 19 female patients (mean age 54, range 24–76). Nineteen of the 541 implants (3.5%) were lost in 15 male patients (mean age 53, range 33–81). Twenty-seven patients lost one implant and seven lost two implants. Thirty-one were lost during the first year of function among which 16 within 3 months following implant installation. None of these failures occurred in diabetic patients, even though diabetics had occasionally been treated by means of dental implants. Thirty-four of 461 (7.4%) patients had at least one implant failure.

Implant Dimensions and Locations

Implant length and diameter were cross-classified and shown in Table 1. Implants were grouped for length (short <10 mm, standard 10–13 mm and long >13 mm) and diameter (small <3.75 mm, standard 3.75–4.5 mm and wide >4.5 mm). Neither implant length (p-values: Fisher: .458; log–rank: .463) nor implant diameter (p-values: Fisher: .253; log–rank: .257) had a significant impact on implant failure (Table 2). Multivariate analysis also failed to show a significant influence of these parameters ($p = .247$, respectively, $p = .932$) (Table 8).

Implants were allocated according to jaw and location, whereby anterior was defined as locations from canine to canine and posterior included the premolars and molars. Univariate analyses showed a significant influence of the implant location on implant failure (p-values: Fisher and log–rank: .015) (Table 3) mainly because of increased failure rate in the posterior mandible (6.6%). However, multivariate analysis failed to show a significant impact of the implant location ($p = .487$) (Table 8).

Time from Tooth Loss to Implant Placement

Six percent were immediate implant placements, 7% of the implants were installed within 6 weeks following tooth removal (early placement) and 87% were inserted in completely healed sites (delayed placement).

TABLE 1 Frequency Distribution of Implant Length and Diameter (n = 1,169; 11 Missing Values). The Failed Implants Are Given between Brackets.

	Implant Diameter														
Implant Length	3.00	3.30	3.40	3.50	3.75	3.80	4.00	4.10	4.30	4.50	4.80	5.00	5.50	6.00	Total
6.0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	3
7.0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2
8.0	0	0	0	0	0 (1)	2	0 (1)	5	0	0	4	0 (1)	0	0	11
8.5	0	0	0	0	6	0	9	0	0	0	0	5	0	0	20 (3)
9.0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	4
9.5	0	0	0	0	0	2	0	0	0	2	0	0	0	0	4
10.0	1	2	0	0	21 (2)	0	26 (4)	76 (1)	0	0	18 (1)	4	0	0	148 (8)
11.0	2	0	10	9	0	7	14	0	7 (1)	15 (1)	0	0	0	0	64 (2)
11.5	0	0	0	0	17 (1)	0	30 (2)	0	1	0	0	7 (1)	0	0	55 (4)
12.0	0	6	0	0	0	0	0	87 (1)	0	0	19	0	0	0	112 (1)
13.0	3	3	25	18	72 (5)	15 (1)	131 (3)	1	11	21	0	4	1	1	306 (9)
14.0	0	6	0	0	0	0	0	24	0	0	6	0	0	0	36
15.0	0	2 (1)	14	12	120 (2)	41	157 (9)	0	0	20	1	8	1	0	376 (12)
16.0	0	0	0	0	0	0	0	2	5	0	0	0	0	0	7
17.0	0	0	0	3	0	0	12 (1)	0	0	1	0	4	0	0	20 (1)
18.0	0	0	0	0	0	0	1 (1)	0	0	0	0	0	0	0	1 (1)
Total	6	19 (1)	49	44	236 (11)	67 (1)	384 (21)	197 (2)	24 (1)	59 (1)	49 (1)	32 (2)	2	1	1,169 (41)

TABLE 2 Frequency Distribution of the *Implant Dimensions* for Successful and Failed Implants

	Implant Length (%)			Implant Diameter (%)		
	Short	Standard	Long	Small	Standard	Wide
Successful	41 (93.2)	661 (96.5)	426 (96.8)	117 (99.2)	932 (96.2)	81 (96.4)
Failed	3 (6.8)	24 (3.5)	14 (3.2)	1 (0.9)	37 (3.8)	3 (3.6)

The time from tooth loss to implant surgery had no significant impact on implant failure (*p*-values: Fisher: .469; log–rank: .470) (Table 4). Multivariate analysis also failed to show a significant influence of this parameter ($p = .942$) (Table 8).

Surgical and Loading Protocols

Eighty-two percent of the implants were installed in native bone and 18% in augmented bone. The latter comprised onlay and inlay bone grafts with or without the use of biomaterials and regenerative techniques according to the protocols clinically used by experienced surgeons. These additional procedures had no significant impact on implant failure (*p*-values: Fisher: .836; log–rank: .807) (Table 5).

Forty-three percent of the implants were installed with a one-stage surgical approach and 57% with a two-stage approach. Univariate analyses showed a significant influence of the surgical protocol on implant failure (*p*-values: Fisher and log–rank: .002) (Table 5). Of the non-submerged implants, 4.9% were lost; whereas, only 1.6% of the submerged implants failed. Multivariate analysis failed to show significant differences for bone condition and surgical protocol ($p = .564$ and .914) (Table 8).

Twenty-five percent of the implants were loaded within 72 h of insertion (immediate loading), 3% within 12 weeks (early loading), and 72% thereafter (delayed loading). Univariate analyses showed a significant influence of the loading protocol on implant failure (*p*-values: Fisher: .003; log–rank: .002) (Table 5). Early loading resulted in significantly higher failure rates in comparison to delayed loading (6.9% vs 0.8%; *p*-values: Fisher: .033; log–rank: .001). Similarly, immediate loading showed higher implant failure when compared with delayed loading (3.0% vs 0.8%; *p*-values: Fisher: .013; log–rank: .006). There was no significant difference between early and immediate loading (*p*-values: Fisher: .259; log–rank: .298). Multivariate analysis confirmed the impact of the loading protocol on implant failure ($p = .049$) (Table 8). However, only early loading induced significantly more implant loss when compared with delayed loading ($p = .014$) with a hazard ratio of 9.7 (95% confidence interval 1.6–59.3).

Type of Prosthesis

A distinction was made between implant-supported overdentures on splinted or single-standing implants (removable) and fixed partial or full-arch restorations (fixed). Because of the variety of restorative materials used, no further distinctions were made. The type of prosthesis had no significant impact on implant failure (*p*-values: Fisher: .228; log–rank: .175) (Table 6). No multivariate model could be fitted which included this parameter.

Surgeon's Related Factors

The clinicians involved in the surgical part of implant therapy included two experienced maxillofacial surgeons and two surgeons-in-training. In the periodontal department, three experienced periodontists and three postgraduates installed implants. Clinicians with more than 5 years of surgical expertise were considered experienced. Both surgeon's experience and specialty

TABLE 3 Frequency Distribution of the *Implant Location* for Successful and Failed Implants

	Mandible Anterior (%)	Mandible Posterior (%)	Maxilla Anterior (%)	Maxilla Posterior (%)
Successful	266 (98.5)	228 (93.4)	269 (97.1)	376 (96.7)
Failed	4 (1.5)	16 (6.6)	8 (2.9)	13 (3.3)

TABLE 4 Frequency Distribution of the *Time from Tooth Loss to Implant Placement* for Successful and Failed Implants

	Immediate Placement (%)	Early Placement (%)	Delayed Placement (%)
Successful	76 (98.7)	79 (97.5)	983 (96.3)
Failed	1 (1.3)	2 (2.5)	38 (3.7)

(Table 7) showed a significant influence on implant failure in favor of inexperienced clinicians (p-values: Fisher and log–rank: $< .001$) and oral surgeons (p-values: Fisher: .040; log–rank: .035). However, multivariate analysis failed to show a significant impact of these surgeon's related parameters ($p = .875$, respectively, $p = .418$) (Table 8).

DISCUSSION

The current study evaluated implant outcome in an academic specialist training center and reported all patients treated over a 3-year period without exclusion. This implies that all patients regardless of their medical and/or oral risk profile were included in the analyses. Additionally, given the specific profile of the academic postgraduate center, treatments were performed by clinicians with various experience levels and skills. As such, straightforward cases as well as complex cases were treated using evidence-based as well as experimental treatment strategies involving various implant systems. Taking this into consideration, the overall implant failure rate of 3.5% yields substantial success compared with other studies using different systems in all kinds of indications in the short term.[5,8–12]

This retrospective study involved at least 23 implant types and 7 different surfaces from several implant branches. In this respect, it is noteworthy that some implant systems were predominantly used in research

TABLE 6 Frequency Distribution of the *Type of Prosthesis* for Successful and Failed Implants

	Removable (%)	Fixed (%)
Successful	187 (99.5)	914 (98.1)
Failed	1 (0.5)	18 (1.9)

projects under challenging conditions (eg, immediate loading in grafted maxillary bone), while others were solely used to support an overdenture on two implants in the symphysis with a conservative approach (two-stage delayed loading procedure). Hence, it was deemed inappropriate to include implant type and surface as covariates. Despite these various indications, the overall success of any individual implant system was above 90%.

Implant failures have been subdivided into early and late failures.[13] In the context of conventional implant surgery, early failures refer to implant loss up to abutment connection and result from "the inability to establish an intimate bone-to-implant contact."[14] In this case, the physiological processes of bone healing do not occur and the implant becomes surrounded by fibrous scar tissue leading to mobility and eventually implant loss.[15] Recently, natural teeth neighboring the implant site, smoking habits, Crohn's disease, osteoporosis, and hormone replacement have been associated with these early failures.[16,17] Late failures occur following normal osseointegration and may be explained by peri-implantitis and/or occlusal overload.[6] Implant location and radiotherapy have been identified as significant predictors of such late failures.[18] In the present study, 18 implants were lost within the first 3 months of function. Albeit these failures occurred during the early stages of healing, they do not necessarily correspond to the above-cited early failures as classified by Albrektsson et al.[13] Indeed, it is impossible to identify the etiology of implant failure when treatment concepts such as

TABLE 5 Frequency Distribution of Variables Related to the *Surgical and Loading Protocol* for Successful and Failed Implants

	Bone Condition (%)		Surgery (%)		Loading (%)		
	Native	Grafted	One-Stage	Two-Stage	Immediate	Early	Delayed
Successful	935 (96.6)	204 (96.2)	636 (95.1)	500 (98.4)	256 (97.0)	27 (93.1)	735 (99.2)
Failed	33 (3.4)	8 (3.8)	33 (4.9)	8 (1.6)	8 (3.0)	2 (6.9)	6 (0.8)

TABLE 7 Frequency Distribution of *Surgeon's Related Factors* for Successful and Failed Implants

	Surgeon's Experience (%)		Surgeon's Specialty (%)	
	Inexperienced	Experienced	Periodontist	Oral Surgeon
Successful	373 (98.2)	766 (95.8)	636 (94.6)	500 (99.0)
Failed	7 (1.8)	34 (4.3)	36 (5.4)	5 (1.0)

non-submerged healing and immediate loading are included. Because implants are already under loading conditions during osseointegration, any inadequate bone-to-implant contact resulting in failure could be inflicted during surgery or thereafter by overload. Given the relatively short time frame of function, being 30 months on average, it is unlikely that peri-implantitis was involved.

An interesting observation was that a number of factors showed a significant association with implant failure on the basis of univariate analyses (implant location, surgical protocol, loading protocol, surgeon's experience, surgeon's specialty). Controlling for covariates ruled out the significant impact of all but one (loading protocol). Obviously, univariate methods should be considered strictly exploratory in this context because they do not account for possible interactions.

The survival rate of standard length and diameter implants was comparable with what has been reported in the literature.[17,19–21] In our study, neither *implant length* nor *implant diameter* were significantly related to implant failure. This is in contrast to Renouard and Nissand[22,23] and Alsaadi et al.[16] mainly reporting on machined-surface implants, but in agreement with others.[24,25] In the latter reports, as in the present study, surface-modified implants were used, which may explain the disparity with the literature.

TABLE 8 Multivariate Analysis on Implant Failure

Predictor	*p*-Value
Implant length	0.247
Implant diameter	0.932
Implant location	0.487
Time from tooth loss to implant placement	0.942
Bone condition	0.564
Surgical protocol	0.914
Loading protocol*	0.049
Early loading versus delayed loading*	0.014
Immediate loading versus delayed loading	0.311
Early loading versus immediate loading	0.073
Clinician's experience	0.875
Clinician's specialty	0.418

*Significant predictor of implant failure.

Predictable treatment outcomes have been reported for implant therapy in various jaw locations.[1,26–33] With respect to *implant location*, most failures in our study occurred in the posterior mandible (6.6% vs 3.3%). Similar findings have been earlier described.[8,16,17] In our study, however, implant location was not significantly related to implant failure when controlling for other covariates.

The *time from tooth loss to implant placement* showed no significant association with failure in our study. This is in line with recent reports showing low failure rates for early and immediate implant placement following extraction.[2,9,29,33–38]

We observed no significant difference in the incidence of failures between implants placed in *native and grafted bone*. This is in accordance with other studies.[39–45] It still remains to be elucidated, however, whether implants placed in augmented areas enjoy the high long-term survival rates of implants inserted in pristine sites, as highlighted in a recent consensus report.[46]

Survival rates were comparable following conventional *two-stage surgery* and *one-stage surgery*, at least based on multivariate analyses. This is in agreement with the existing knowledge on submerged versus non-submerged healing.[3,8,47–54]

Clinical studies have shown good implant survival of early loaded turned[55–57] and surface-modified surface implants.[58–62] Under certain conditions this also holds true for immediate loading.[33,63–68] In some cases, immediate loading even yields superior outcome in standard bone conditions[67–69] or even in soft bone.[10] As well on the basis of univariate analyses as on the basis of Cox proportional Hazards regression the loading protocol was a significant predictor of implant failure. Controlling for covariates showed comparable implant loss for immediate and delayed loading. However, early loading induced significantly more implant loss in comparison with a conventional loading period ($p = .014$) with a hazard ratio or risk estimate for failure of 9.7. We examined the validity of our results obtained from the Cox proportional hazards regression by logistic regression analysis. The latter may be considered a simplification in this context as it does not take into account the time to event (failure). However, because the average time span to failure was only 5 months, this could be considered of minor importance. Logistic regression analysis also identified the loading protocol as the only explanatory variable for implant failure ($p = .050$). Again, early loading resulted in significantly more implant loss when compared with delayed loading ($p = .014$). This finding is in agreement with the results of a recent retrospective study on 490 implants with up to 5 years of follow-up showing cumulative survival rates of 94.4% for early loading and 97.9% for delayed loading.[70] A trend toward superior results following conventional loading has also been reported in recent systematic reviews.[4,5] We believe our results are important as the impact of the loading protocol was consolidated by statistical analyses controlling for other covariates. Consequently, the clinician should take into account that early loading may significantly increase implant failure because of uncontrolled loading during the initial healing period. Early loading follows most often a one-stage surgical approach whereby a healing abutment is piercing throughout the mucosal tissue, risks to be prematurely loaded during biting, clenching, and tongue or cheek pressure. Furthermore, manipulating implant components during the initial healing can coincide with the first 3–6 weeks reduction of implant stability following implant placement as described with resonance frequency analysis.[71] Whether this increased risk is clinically relevant today with the use of modified-surface implants remains a matter of debate. It is generally accepted, however, that immediate provisionalization of multiple splinted implants with a ridgid prosthesis is a safer approach to minimize implant jiggling that may hamper osseointegration. This could be a possible explanation for the better outcome of immediately loaded implants in the current study and was discussed in previous papers.[68,72]

The type of *prosthesis* (removable vs fixed) was not related to implant loss in this study. This confirms the general finding of high survival rates for implants supporting fixed as well as removable prostheses.[1,5,32,54,64,73–79]

A detailed analysis of patient-related factors such as smoking and systemic diseases was not the primary objective of the current retrospective study. At the time the patients were treated, these factors were not registered in a standardized manner. Possibly missing information on self-reported smoking habits was updated for all failed implants by detailed searching the complete patient file or questioning the surgeons and/or patients. Nineteen of the 41 failed implants occurred in smoking patients. These are absolute figures and should be interpreted with caution because the distribution of smokers in the total sample is unclear. A significant influence has, however, been highlighted in recent systematic reviews.[80,81] Especially during the early stages of healing, smoking seems to compromise osseointegration.[16,17] Smoking-related failures also seem to cluster in the maxilla.[80,82] One should, however, keep in mind that current systematic reviews are based predominantly on the outcome of turned implants. With the overwhelming usage of surface-modified implants today, this may not be longer valid today.[83] Factors such as osteoporosis and hormone replacement were also not registered in a systematic way. Their possible impact on implant failure is still controversial.[16,17,84,85]

A number of studies showed a relevant impact of the clinician's experience on implant survival indicating less failures for experienced surgeons.[86–89] These findings seem in contrast with our observations because *clinical experience* had no significant impact on implant survival, at least not on the basis of multivariate analyses which has recently been confirmed by others.[90,91] A significant difference in favor of inexperienced surgeons based on univariate methods could be explained by the fact that the more challenging cases with poor bone quality and/or quantity had been treated by the academic staff; whereas, standard cases had been usually treated by clinicians-in-training. Note that bone quality and quantity were not included as predictors in the present study. Similarly, the fewer failures by oral surgeons on the basis of univariate analyses could be explained by a disparity in treated cases and treatment strategies. Oral surgeons installed 38% of the implants in the anterior mandible for overdenture treatment using a two-stage surgical approach. This indication and strategy may be considered very predictable,[5,54,75,76,79] which is also supported by our data indicating only 0.5% failures in mandibular overdenture cases versus 1.0% and 2.4% failures for single-tooth replacements, respectively, multiple-unit bridges. The cases treated by periodontists, however, were much less homogeneous as well in terms of implant location as treatment approach frequently adopting innovative concepts often in conjunction with research protocols under scrutiny. For instance, periodontists placed 84% of the implants using a one-stage surgical approach. The corresponding value for oral surgeons was only 21%. Immediate loading was performed on 40% of the implants installed by periodontists. The corresponding value for oral surgeons was 8%. These findings indicate a more conventional treatment approach applied by the oral surgeons and may explain the obtained difference.

CONCLUSION

In conclusion, the loading protocol was the only factor that was significantly associated with implant failure in a large sample of implants placed in daily clinical practice and in function for up to 4 years. On the basis of these results, immediate loading may be considered a viable alternative for delayed loading; whereas, early loading may not. It must be stressed that these conclusions only relate to the presence of implants irrespective of their clinical success. The latter is clearly influenced by a number of factors including hard and soft tissue parameters, which have not been included in this study. In addition, our conclusions should not be considered definitive but rather exploratory for a number of reasons. First, the cross-sectional nature of this retrospective study should be emphasized. Second, the overall failure rate was very low (3.5%) but could have been underrated because patients were not actually examined. Instead, information on the parameter of interest, implant failure, was retrieved on the basis of hospital files. Finally, we only included a limited number of covariates. Clearly, large-scale prospective studies are needed to confirm our observations in the long term in conjunction with implant success based on bone loss data.

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