Evaluation of Patient and Implant Characteristics as Potential Prognostic Factors for Oral Implant Failures

Irene Herrmann, LDS, Odont Lic[1]/Ulf Lekholm, LDS, Odont Dr[2]/Sture Holm, PhD[3]/Christina Kultje, MSc[4]

Purpose: *The purpose of this study was to evaluate patient, implant, and treatment characteristics to identify possible prognostic factors for implant failure.* ***Materials and Methods:*** *Out of a database with different dental implant treatment protocols, a research database of 1 randomly selected implant per patient was created. The database consisted of 487 implants. Of these, 80 were withdrawn, 36 failed, and 371 remained successful during a 5-year follow-up period. Potential risk factors were evaluated by chi-square tests and post hoc analyses.* ***Results:*** *Significant or strongly significant differences were found regarding implant failures as a result of jawbone quality, jaw shape, implant length, treatment protocol, and combinations of jawbone-related characteristics. Responsible clinics and number of implants supporting the restoration were factors that could not be associated with implant failure.* ***Discussion:*** *Implant failures in this study were more often seen when negative patient-related factors were present. Approximately 65% of the patients with a combination of the 2 most negative bone-related factors (jawbone quality 4 and jaw shape D or E) experienced implant failure. However, only 3% of the patients had this combination. Implant length, the only implant-related factor evaluated, was also significantly correlated with the success rate, but implant length could also be regarded as a result of the jawbone volume available. Another negative patient-related factor was the treatment protocol; however, in most cases this was also indirectly or partly related to the status of the jawbone available for implant placement.* ***Conclusion:*** *Patient selection appears to be of importance for increasing implant success rates.* INT J ORAL MAXILLOFAC IMPLANTS 2005;20:220–230

Key words: *dental implants, jaw shape, jawbone quality, multilevel analysis, risk factors, treatment protocols*

Different dental implant systems have long been used to treat edentulous and partially edentulous jaws, and cumulative implant success rates around 90% ± 10% after 5 years of follow-up have been presented.[1–6] Many studies have focused too much on the results of 1 specific implant system, scrutinizing implant features such as length and width, design (eg, self-tapping), abutment type (1- or 2-stage systems), and/or surface texture (roughness, coating).[7–11] The purpose of many studies has been to evaluate new or refined implant products for possible later use in the promotion of that specific system. However, few prospective studies have been performed specifically to calculate or analyze the likelihood for individual implant failures. Few studies have focused on the patient's oral status and anatomy, conditions that might have a great impact on the treatment outcome.

Esposito and colleagues[12] reviewed the literature regarding differential diagnosis and biologic complications as reasons for implant failures. They found that infection, impaired healing, and overload were considered the major etiologic factors for loss of oral implants. Scurria and associates[13] focused on survival and proportional hazard modeling techniques in their search for prognostic variables associated with implant losses. They reported that patient-related factors such as maxilla and posterior location could

[1]PhD Student, Oral Implant Surgery, Faculty of Odontology, University of Göteborg, Göteborg, Sweden.
[2]Professor, Oral Implant Surgery, Faculty of Odontology, University of Göteborg, Göteborg, Sweden.
[3]Professor, Biostatistic Branch, Department of Mathematical Statistics, University of Göteborg, Göteborg, Sweden.
[4]Clinical Quality Assurance Auditor, Astra Zeneca Research and Development, Mölndal, Sweden.

Correspondence to: Dr Irene Herrmann, Södra Småskolevägen 41, SE-429 44 Särö, Sweden. Fax +46 31 93 68 45. E-mail: irene.herrmann@lifecore.com

be regarded as prognostic risk factors. Eckert and coworkers,[7] on the other hand, used a clustered survival statistical technique to identify factors associated with implant failures. They demonstrated that a history of root canal treatment in the implant site could be an important risk factor for an implant failure. The method of Eckert and coworkers[7] was further developed by Chuang and associates[14] into a clustered failure-time multivariate model by which it was also possible to identify risk factors associated with lost implants. This research group found that tobacco use, immediate implant placement, and staging (1-stage instead of 2-stage procedures) were associated with negative implant outcomes.

Independent of the technique used, statistical methods have tended to become more sophisticated and complex. Nonetheless, findings from various studies may diverge. Furthermore, studies that have attempted to identify possible risk factors for implant failure have often been based on a few patients affected by complications.[15] Consequently, there seems to be a need for new ways of analyzing the data to find and evaluate challenging patients. One way could be to increase the number of patients by pooling data together from several prospective studies and to look for possible risk factors. Using a multilevel method, it would be possible to understand how different patient characteristics may influence each other. Knowing that a dependency exists between implants within the same jaw,[16] there must also be a cause or causes for such a dependency. Several authors have also mentioned surgical procedures, implant design, treatment protocols, jawbone qualities, and jaw shapes as possible influencing factors.[2,12,14,17–19] The patient's general health and tobacco habits have been referred to as other potential prognostic risks.[20,21] However, to date no study on prospectively collected patient data has assessed the influence of individual patient characteristics, or combinations of these, as potential prognostic factors for implant failures.

The aims of this study were *(1)* to individually evaluate some patient and implant characteristics and *(2)* to assess combinations of these characteristics with regard to their influence on the success rate of dental implants so as to identify possible prognostic factors for implant survival and failure.

MATERIALS AND METHODS

Baseline Data

Four multicenter studies reporting on 1 specific implant design (Brånemark System; Nobel Biocare, Göteborg, Sweden),[8,9,22,23] constituted the basis for the present research material. All studies followed similar protocols. Each study included a different category of patients: patients with single tooth loss,[23] patients with partial edentulism,[8] edentulous patients restored with overdentures,[22] and edentulous patients restored with fixed prostheses.[9] The patients were treated in either the maxilla or mandible. In total, 487 patients (55.6% women) with a mean age of 51.3 years were included in the 4 studies, representing 1,738 implants and 531 restorations. In general all patients were reported to be healthy, but smoking or alcohol habits were not specifically registered. The 4 studies followed similar prospective research protocols, including consecutive patient inclusion. In each study, the condition of each implant was evaluated after 5 years in clinical function in regard to implant and prosthesis success rates, marginal bone loss, and possible complications. The 5-year time period was calculated from the time of prosthetic loading. However, the results included all events from implant placement to the final 5-year check-up. One-, 3-, and 5-year results of the studies have previously been published.[8,9,22–31]

As previously reported,[32] the treatment failed in 25 patients. Of these, it failed completely in 20 individuals, who were forced to return to conventional prosthetic solutions. In 383 patients, the treatment was successful in the sense that these individuals could still utilize an implant-supported prosthetic restoration 5 years after implantation. However, a total of 79 patients had for various reasons not been re-examined at the final check-up. At the implant level, 1,305 implants were considered successful and 110 as failures, while 323 were not evaluated at the final check-up.[33]

Research Material

Of the total material, a database consisting of 1 randomized implant per patient was created to avoid the influence of dependency among the implants. Previously, the same approach has been used when evaluating the effect of random versus selected withdrawal of patients.[33] The randomization gave 487 placed implants; 80 withdrawn, 371 successful, and 36 failed implants (Table 1). The distribution of withdrawn and failed implants and the cumulative success rates are shown in a life table analysis in Table 2. According to the study design, specifically regarding single tooth loss and partial edentulism, involved patients may have received more than 2 crowns or prostheses. However, in cases where the patient had 2 prostheses, only the restoration supported by the randomly selected implant was evaluated.

In the implant/restoration evaluation, 12 patients were withdrawn because of implant failure prior to

Table 1 Distribution of Placed, Withdrawn, Successful, and Failed Implants in the Individual Treatment Protocols

Study	Treatment protocol	No. placed	No. withdrawn	No. successful	No. failed
Lekholm et al[8]	Fixed prosthesis for partial edentulism	159	18	130	11
Friberg et al[9]	Full fixed prosthesis for complete edentulism	103	16	82	5
Jemt et al[22]	Overdenture for complete edentulism	133	32	84	17
Henry et al[23]	Single crown for single tooth loss	92	14	75	3

Pearson chi-square test ($P < .05$), ie, at least 1 of the 4 groups' success rates differed significantly.

Table 2 Life Table for the Implants Included in the Study

Time	No. of implants at start of period	No. of failures	No. of implants lost to follow-up	Cumulative success rate (%)
Placement to loading	487	18	14	96.3
Loading to 1 y	455	10	21	94.2
1 to 2 y	424	3	11	93.5
2 to 3 y	410	1	16	93.3
3 to 4 y	393	1	18	93.1
4 to 5 y	374	3	0	92.4
5 y	371			

the start of the prosthetic treatment. Another 9 patients did not return for the second stage of treatment. Consequently, 466 patients contributed to the implant/restoration outcome in the current research material.

Parameters Evaluated and Tests Performed

Throughout the follow-up period, regular clinical and radiographic examinations were performed.[16] Applied success criteria included absence of implant mobility and marginal bone resorption not exceeding the limits set by Albrektsson and associates.[34] For the purpose of this article, the following information was collected from each patient's chart (Table 3):

- **Gender**
- **Age group:** Three age groups were evaluated: patients under 50 years, patients between 51 and 59 years, and patients over 60 years of age. (In a previous article by the authors,[33] the middle group was ignored.)
- **Jaw treated (maxilla or mandible):** The outcomes regarding the influence of age, gender, and treated jaw on implant survival were previously analyzed in a separate article by the authors.[33]
- **Responsible clinic:** Each clinic was looked upon as 1 unit. To evaluate whether any of the teams (surgeons and prosthodontists from the different clinics) had better or less favorable results, the influence of individual clinics within the same treatment protocol (study) were tested for statistical differences.
- **Jawbone quality:** Chi-square tests were used to evaluate whether any difference in failure rates could be detected between bone qualities 1, 2, 3, or 4 (Lekholm and Zarb[35]). Then, to identify a borderline between the failure rates of the various bone qualities, significance tests were made by comparing 2 groups at a time. First, the failure rate of jawbone quality 1 (mainly cortical bone) was compared with the failure rates of the 3 other bone qualities (2, 3, and 4), which stepwise represented less cortical bone and more marrow bone, respectively. Thereafter, the evaluation continued by comparing the failure rates of bone qualities 1 and 2 with those of bone qualities 3 and 4. Significantly different failure rates of placed implants were found for these 2 groups. Finally, the failure rate of implants placed in bone quality 4 (ie, the most porous bone) was compared with the failure rates for implants placed in the 3 other bone qualities. The borderline used was the first time a significant difference in failure rate could be detected.
- **Jaw shape:** The same calculations and procedures used to evaluate the impact of jawbone quality were also made regarding jaw shape. However, implants from the single-tooth study were disre-

garded, since jaw shape values were not measured in that study. The jaw shape index included 5 groups: Jaw shape A represented no or minimal resorption of the jawbone, while jaw shape E represented an extremely resorbed jaw.

- **Implant length:** First, chi-square tests were used to evaluate whether any differences in failure rates could be detected within the various lengths. Only implants 3.75 mm in diameter were included in this study. Implants 7 mm long were tested against all longer implants; then 7- and 10-mm-long implants were tested as a subgroup against longer implants regarding possible differences in failure rates. The final level of evaluation was done between the 2 shortest groups of implants (the 7- and 10-mm-long implants) to determine whether there was a significantly higher failure rate for the 7-mm-long implants compared to the 10-mm ones. As a subtest, the percentages of 7- and 10-mm-long implants placed in various jaw shapes were calculated to determine whether more bone was present when 10-mm implants were placed than when 7-mm implants were placed.
- **Treatment protocol:** Type of prosthetic treatment within each of the 4 studies. Significance analyses regarding implant failure rates were performed based on the various treatment protocols. Treated jaws were either completely or partially edentulous and had been treated with either overdentures, fixed prostheses, or single crowns (Table 1).

Effects of Combined Parameters

Combinations of subgroups, determined in the previous calculations, were created to perform the following analyses:

- **Combinations of bone qualities and jaw shapes:** Evaluation of the risk of implant failure was related to various combinations of bone volume and quality. The subgroups determined in the aforementioned analyses regarding jaw shape (A-B-C and D-E) and jawbone quality (1-2-3 and 4) were combined, giving 4 different combinations (A-B-C/1-2-3, A-B-C/4, D-E/1-2-3, and D-E/4). These 4 combinations were analyzed to determine whether any of them had a significantly higher failure rate than the others.
- **Implant length (short or long) within the combinations (bone qualities/jaw shapes):** Evaluation of the frequency of implant failure after dividing the 4 combinations of jawbone quality/jaw shape into new subgroups was the next phase of the multilevel analysis. Each of the 4 combinations was divided into 2 subgroups, "long" implants (13 to 20 mm) and "short" implants (7 or 10 mm), for the multilevel analysis.
- **Number of implants supporting the restoration:** The number of implants used to support a restoration ranged from 1 to 7 implants. The number of implants originally placed and supporting the patient's prosthetic restoration determined which group the prosthesis would be referred to. A Pearson chi-square test was performed to determine whether the number of implants supporting the prosthesis had any significance on the outcome.

Table 3 Evaluated Parameters Regarding Risks for Implant Failures as a Result of Variations Within Each Parameter, Studied by Chi-Square Tests

Parameter evaluated	χ^2
Gender	No significant difference*
Age groups	No significant difference*
Maxillary versus mandibular	Significant difference*
Responsible clinics	No significant difference
Jawbone qualities	Strong significant difference
Jaw shapes	Strong significant difference
Implant lengths	Strong significant difference
Treatment protocols**	Significant difference
Combination of jawbone quality and jaw shape	Strong significant difference
Number of implants supporting the restoration	No significant difference

*These parameters were evaluated and reported on in a previous paper by the authors.[33]
**Fixed prosthesis for partial edentulism,[8] full fixed prosthesis for complete edentulism,[9] overdenture for complete edentulism,[22] single crown for single tooth loss.[23]

Statistical Methods

SPSS (SPSS, Chicago, IL) and Mathematica (Wolfram Research, Champaign, IL) were used for the statistical evaluations. Life table analyses were used to evaluate the cumulative success rate.

The Fisher exact test was used when only 2 categories were compared to identify possible differences. The Pearson chi-square test was used to identify whether one or several categories in a group significantly differed from the others. The results were further analyzed with post hoc analyses to identify which value or values differed.[36]

Implants not being followed the entire study period were included in the evaluations for as long as they were followed. Information on withdrawn subjects has been included in earlier publications.[16,33] A significant difference was acknowledged when $P < .05$, and strong significant difference was acknowledged when $P < .001$.[37]

Table 4 Distribution of Lowest (Failed/Total) Versus Highest Failure Rates Observed in the Individual Responsible Clinics Within Each Treatment Protocol (Study), as well as the Results of Performed Chi-Square Tests between Failure Rates from all Clinics Within Each Study

Treatment protocol (study)	Lowest failure rate	Highest failure rate	Pearson chi-square test (*P*)
Lekholm et al[8]	0/38	4/21	.05
Friberg et al[9]	0/23	3/30	.05
Jemt et al[22]	0/13	6/20	.05
Henry et al[23]	0/20	3/26	.05

Pearson chi-square test ($P < .05$), ie, at least 1 of the 4 groups' success rates differed significantly.

Post Hoc Analyses

To determine whether there was an individual difference within a group, post hoc analyses[36] were used in separate evaluations of treatment protocol, jawbone quality, jaw shape, implant length, bone-quality/jaw shape combinations, and implant length/bone condition. Overall multiple interferences, including separate evaluations, were not formally taken into consideration. Within each of the evaluations for which the post hoc analyses were performed, a multiple significance level of .05 was used for the analyses of detailed questions.

When evaluating the parameter "treatment protocol," multiple analyses, by the use of conditional binomial tests,[32] were used for comparing each case with the mean of the others. The combined multiple tests were based on the *P* values for the parts. To get a correct multiple level of significance, a simulation for data at hand (bootstrap simulation) of size 499 was performed.

Regarding jawbone quality, jaw shape, implant length, combinations of bone qualities and jaw shapes, and implant length/bone condition, similar analyses were performed. However, the cases were ordered for all 4 parameters so the detailed parts of the multiple tests were binomial comparisons of the risk for cases up to (and including) a level and above this level, respectively, until a borderline of significantly different values was reached. Separate simulations were made for each test.

RESULTS

The cumulative success rate after 5 years was 92.4% (Table 2). An overview of the results from the chi-square tests can be seen in Table 3. Parameters not showing significant differences regarding failure rates were responsible clinic and number of implants supporting the restoration, as well as gender and age, which were reported on previously.[33] Including 3 age groups rather than ignoring the middle age group did not affect the statistical outcome. However, significant or strongly significant differences were shown regarding failure rates related to jawbone quality, jaw shape, implant length, treatment protocol, and the bone-related combinations, as well as jaw treated, as noted in the earlier study.[33]

Responsible Clinic

No statistically significant differences regarding the responsible clinics could be detected. However, some clinics experienced no failures, while others had failure rates of 10% to 30%. The failure rates in the overdenture study varied the most (range, 0% to 30%; see Table 4).

Jawbone Quality and Jaw Shape

Strong significant differences could be demonstrated both for all groups of bone qualities and jaw shapes, as well as for their 2 subgroups (Tables 5 and 6). Post hoc analyses confirmed, based on a simulated individual *P* value limit for bone qualities of .0226 (multiple *P* level of .05), that jawbone quality 4 was the jawbone quality with the highest failure rate (24.5%), giving an individual *P* limit of .00013. Corresponding post hoc analyses figures for jaw shapes with simulated individual *P* value limit of .017 confirmed that the jaw shapes D and E differed significantly from the others ($P = .00009$). A total of 21.0% of the placed implants in these 2 groups failed.

Implant Length Versus Jaw Shape

Strong significant differences could be demonstrated for the entire group (Table 7). The post hoc analyses with a simulated individual limit *P* of .018 showed that the 7-mm-long implants had a *P* of .0004. These implants were responsible for the high-

Table 5 Distribution of Failed Versus Placed Implants and Percentage of Failures in Relation to Identified Jawbone Quality*

Jawbone quality	No. of failed implants	No. of placed implants	Failures (%)	Pearson chi-square test (*P*)	Fisher exact test (*P*)
1	2	18	11.1		
2	7	155	4.5	*P* < .001	
3	15	265	5.7		< .001
4	12	49	24.5		
Total	36	487	7.4		

*Lekholm and Zarb[36] index.

Table 6 Distribution of Failed Versus Placed Implants and Percentage of Failures in Relation to Identified Jaw Shape*

Jaw shape	No. of failed implants	No. of placed implants	Failures (%)	Pearson chi-square test (*P*)	Fisher exact test (*P*)
A	0	39	0		
B	14	184	7.6		
C	6	110	5.5	< .001	< .001
D	5	44	11.4		
E	8	18	44.4		
Total**	33	395	8.4		

*Lekholm and Zarb[35] index.
**The single-tooth study[23] was excluded because jaw shape was not measured in that study.

Table 7 Distribution of Failed Versus Placed Implants and Percentage of Failures in Relation to Implant Length

Implant length (mm)	No. of failed implants	No. of placed implants	Failures (%)	Pearson chi-square test (*P*)	Fisher exact test (*P*)
7	12	55	21.8		.05
10	16	159	10.1		
13	5	116	4.3	< .001	< .001
15	1	93	1.1		
18	1	37	2.7		
20	0	13	0		
Total*	35	473	7.4		

*Only implants 3.75 mm wide were evaluated; wider implants were excluded.

est failure rate (21.8%; $P = .001$). When the implants were divided into groups of short implants and long implants in the post hoc analyses, a significant correlation was found between shorter implants and failure rate ($P = .00003$); the failure rate for shorter implants was 13.1%. Comparing the 2 groups of short implants, a significant difference ($P < .05$) was demonstrated between the 7- and the 10-mm implants, respectively.

Additionally, when the relationship between implant length and jawbone available was examined, it was found that 29.4% of the 7-mm implants were placed in jaws with jaw shape E, and 25.5% were placed in jaws with jaw shape D. The corresponding figures for the 10-mm implants were 1.4% and 17.4%. Of the remaining 7- and 10-mm-long implants, 13.7%, 29.4%, and 2.0% of the 7-mm implants and 35.4%, 42.3%, and 3.5% of the 10-mm implants

Table 8 Distribution of Failed Versus Placed Implants in Relation to Combinations of Jawbone Qualities and Jaw Shapes*

	Jaw shapes A, B, and C	Jaw shapes D and E	Pearson chi-square test (*P*)
Jawbone qualities 1, 2, and 3	Combination I 15/296	Combination II 6/51	< .001
Jawbone quality 4	Combination III 5/37	Combination IV 7/11	
Total**	33/395		

*Lekholm and Zarb[35] index.
**Single-tooth study[23] not included in test.

were placed in jaw shapes C, B, and A (ie, jaws with less resorption), respectively.

Treatment Protocol

In regard to failure rate, significant differences in outcome could be seen between the various treatment protocols (Table 1). In the post hoc analyses, the simulated limit of individual *P* was .0146. The overdenture study[22] was the only treatment that significantly differed from the other 3 studies ($P = .0029$). Of the 133 implants placed in that study, 17 failed (12.8%), while the study of partially edentulous patients,[8] the full fixed prosthesis study,[9] and the single-tooth study[23] had failure rates of 6.9%, 3.3%, and 4.9%, respectively.

Combinations of Jawbone Quality and Jaw Shape

Combination I consisted of implants placed in jaw shapes A, B, and C, and bone qualities 1, 2, and 3, ie, good jawbone quality and adequate jawbone volume. Seventy-five percent of the patients ($n = 296$) belonged to the combination in which the failure rates were low (ie, combination I). Combination II, which accounted for 13% of the patients, consisted of implants placed in jaw shapes with lower success rates (D and E), but in bone qualities with higher success rates (1, 2, and 3). Combination III, which accounted for 9% of the patients, consisted of implants placed in areas where an adequate amount of jawbone was available (jaw shapes A, B, or C), but the jawbone available was of quality 4 (the softest jawbone quality). Finally, combination IV, which accounted for 3% of the patients, consisted of implants placed in jawbone of shapes D and E and quality 4 (Table 8). Post hoc analyses confirmed that that combination (D or E and 4) differed significantly from all other combinations ($P = .0006$ compared to a simulated limit of individual *P* of .0083).

Implant Length in Regard to Bone Quality/ Jaw Shape

Implant length was added as the next level of a multivariate factor in this multilevel analysis. Short implants placed in combination I bone had a failure rate of 7.3% in comparison to 3.0% for long implants. For combinations II and III, the corresponding figures were 13.0% and 0%, and 25% and 5.9%, respectively. Only 11 implants were placed in combination IV bone, where the failure rates were 78.0% and 0%, respectively (Table 9). However, the post hoc analyses did not show significant difference for any group at this level, the results for long implants did not significantly differ from the results for short implants ($P >$ .05 for all combinations; individual *P* value of .0125).

Number of Implants Supporting the Restoration

Finally, the number of implants supporting the restoration did not give any statistically significant differences when tested (Table 10). Instead the highest failure rate (13.0%) was seen for the prostheses supported by 4 implants, whereas the failure rate decreased either when more implants or fewer implants per restoration were used. The post hoc analyses did not show any significant differences (the lowest *P* value was .290) between any of the groups (restorations supported by 1 implant, by 2, etc). The simulated limit of individual *P* value level was .015. The results of the tests performed are summarized in Table 11.

DISCUSSION

In the present study, potential risk factors were analyzed with respect to possible implant failures. Chi-square tests and post hoc evaluations were used as

Table 9 Distribution of Failed Versus Placed Implants in Relation to Implant Lengths (Short or Long) in the Various Combinations of Jawbone Qualities and Jaw Shapes*

	Jaw shapes A, B, and C	Jaw shapes D and E
Jawbone qualities 1, 2, and 3	Combination I 9 of 124 short 5 of 164 long	Combination II 6 of 46 short 0 of 5 long
Jawbone quality 4	Combination III 4 of 16 short 1 of 17 long	Combination IV 7 of 9 short 0 of 2 long
Total**	32/383	

*Lekholm and Zarb[35] index.
**Implants from the single-tooth study and wide implants were excluded from the test.
P >.05 in regard to all combinations (post hoc analyses).

Table 10 Distribution of Supporting Implants per Prosthetic Restoration, No. of Restorations, and Failed Implants and Percentage of Failures in Relation to the No. of Implants Supporting the Restorations

No. of supporting implants	No. of restorations*	No. of failed implants	Failures (%)	Pearson chi-square test (*P*)
1	92	3	3.2	
2	151	8	5.3	
3	77	5	6.5	
4	41	5	12.2	> .05
5	56	2	3.6	
6	46	1	2.2	
7	3	0	0.0	
Total**	487	36	7.4	

*Only one prosthesis or crown per patient was included.
**Total includes 21 patients (including 12 implant failures) who were withdrawn from the study before loading.

statistical methods with a multilevel approach to determine the patient-, implant-, or treatment-related factors that were dominant. The most important correlations were observed regarding patient-related factors (Table 3), such as jawbone quality and jaw shape (Tables 5 and 6). There was a highly significant correlation between these factors and implant failure. When performing the statistical analyses, a borderline of statistical differences between the 2 parameters mentioned was first conducted. A second level in the multilevel analyses was then tested regarding the 4 combinations (I, II, III, and IV) to identify whether 1 or several combinations would show any statistical differences. Patients with combination IV, ie, those patients with the most resorbed and porous jawbone situations, were only seen in 3% of the total patient material. The failure rate in combination IV patients was statistically higher compared to all other combinations. Consequently, 1 clear potential prognostic factor could be determined, ie, poor jawbone quality in combination with low jawbone volume.

The opposite was shown to be present for combination I, to which almost 75% of all patients belonged, and where the bone-related factors were good. In this group, only 1 in 20 patients experienced an implant failure. Furthermore, it was shown that when only 1 of the bone-related factors was good (ie, combinations II and III), then the good factor seemed to partly compensate for the less-good one, which of course is of interest in regard to patient selection and treatment planning. The negative effects of poor jawbone quality and severe jawbone resorption on implant survival have been demonstrated by many authors.[8,9,12,19,22,38] However, this is the first time that combinations of the 2 bone factors have been tested together, using a large and unique sample having a prospective design.

Table 11 Summary of Studied Prognostic Factors for Possible Implant Failures

Prognostic factors	Positive influence	Negative influence
Jaw	Mandible	Maxilla
Jawbone quality	1–3	4
Jaw shape	A, B, and C	D and E
Bone combination	I, II, and III	IV
Implant length	> 13 mm	7 and 10 mm

It was demonstrated that short implants had a higher failure rate than long ones (Table 7). Certainly, an increased implant failure rate in relation to shorter implants has been documented before,[8,14,15,23,24] but the new information in the current report was that more failures were also reported with the 10-mm implant (10%) than with implants 13 mm long or longer. When only the short implants were examined, however, the 7-mm implants had the highest failure rate (22%). The 78% survival rate seen with 7-mm implants after 5 years is comparable though to the results shown by other authors.[8,18,39]

When adding implant length as a level for the multilevel analyses, no statistical significance regarding any of the new combinations could be demonstrated (Table 9), despite the fact that 7 of 9 short implants failed in bone combination IV. This could be a result of too few implants in the subgroups. However, it is also important to remember that long implants ought not be placed if there is not bone enough for them. For example, mainly 7-mm-long implants were placed in jaw shape E. Therefore, implant length could indirectly be regarded as a patient-related factor, since it is related to the bone volume present.

The Cox regression method could have been used as an alternative method for multivariate analysis of the data. However, to clearly demonstrate the decreasing numbers in the final subgroups, post hoc analysis was selected as the method of choice. Dental implant studies with high success rates, ie, few failures, were also a limiting factor for the power of the statistical evaluation, especially in the subgroups (Table 9).

Some patient characteristics collected from the current prospective database turned out to be potential negative prognostic factors. Some of these (treated jaw, jawbone quality, jawbone shape [quantity]) were demonstrated to be such in earlier studies.[8–19,38–40] Other patient-related factors, such as smoking and alcohol habits, would have been of interest to study but were not documented in the studies used as the basis for this study. Two aspects not examined in the present study were the presence of general or local diseases and previous implant site infection. The present study did not include information on possible surgical trauma, prosthetic malfunction, or stomatognathic dysfunctions. These factors could, of course, also have an influence on implant treatment results.

Implant-related parameters, such as implant surface texture, implant diameters, and implant design, were not included in the present study, since the current data only related to the original Brånemark System. At the time of implant placement, the turned (machined) implant surface of a single diameter was the dominant implant in the field. However, studies comparing different implant types and systems are needed, as most published reports focus on only 1 implant design, surgical procedure, or prosthetic protocol at a time.[1–9,11–15,18–31] To analyze the effect of implant design, a completely different research database from the one used in the current study would be needed. For example, studies that used implants with rougher surfaces and alternative macro designs would be needed.

When looking at treatment-related factors such as treatment protocol (Table 1), responsible clinic (Table 4), and number of implants per restoration (Table 10), it was found that only the different treatment protocols differed significantly in regard to implant failure. However, treatment protocol could be regarded as another parameter indirectly or partially related to the individual patient, since it is most likely that the used therapy was in each situation related to the amount of jawbone present, at least in the edentulous jaws. Maxillary overdentures were the main option used in situations where jawbone quality was poor and the degree of resorption was extensive. When risks for implant failure are obvious at the treatment planning stage, less expensive prosthetic solutions may be chosen, thereby influencing the treatment protocol.

It was not possible to demonstrate the influence of the responsible clinic statistically. However, when looking at the descriptive data, large differences could be seen regarding this parameter. For example, of the clinics participating in the overdenture study, the success rates ranged from 70% to 100%. If the groups had been fewer and/or more patients had been included in each group, significant differences might have been detected. The present research material was originally not designed specifically for analyzing this parameter; thus, the treatment teams worked on varying numbers of patients, in various combinations. However, the currently observed difference in outcome between 2 clinics regarding the same treatment protocol is of interest and should be further evaluated. Such difference could of course be the result of variations in clinical experience, as it has been shown that a learning curve exists.[1,15,40] It could also have been the result of true variations in the clinical skill of the participating clinicians. However, if that were the case, greater patient materials from multicenter studies would then have been needed.

When the numbers of implants supporting the prosthetic restoration were tested, no significant differences could be detected. One reason for this could be that the number of implants supporting the restoration was not alone responsible for detecting possible differences. Other parameters, such as the number of implants in relation to the restoration, may also have influenced the outcome. For instance, when several implants support a prosthetic restoration, the risk for misfit has been reported to increase.[41] Furthermore, it is known that failures may result from overloading implants, as when an extended prosthesis is supported by too few implants.[42,43] Consequently, more detailed studies are needed before this aspect can be fully understood.

CONCLUSION

Within the limits of the research database used in the present study, patient-related factors (Table 11) dominated the increased risk of implant failure. Approximately 2 of 3 patients with the combination of poor jawbone quality and low bone volume experienced implant failure. However, only a small percentage of the treated patients presented with this challenging bone combination.

Patient selection appears to be of importance for increasing implant success rates. It is therefore suggested that if general practitioners were to identify and refer current patients for specialist treatment, complications could be avoided, and the patient could be saved time and expense.

REFERENCES

1. Adell R, Eriksson B, Lekholm U, Brånemark P-I, Jemt T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. Int J Oral Maxillofac Implants 1990;5:347–359.
2. Buser D, Mericske-Stern R, Bernard JP, et al. Long-term evaluation of non-submerged ITI implants. Part 1: 8-year life table analysis of a prospective multi-center study with 2359 implants. Clin Oral Implants Res 1997;8:161–172.
3. Ferrigno N, Laureti M, Fanali S, Grippaudo G. A long-term follow-up study of non-submerged ITI implants in the treatment of totally edentulous jaws. Part I: Ten-year life table analysis of a prospective multicenter study with 1286 implants. Clin Oral Implants Res 2002;13:260–273.
4. Arvidson K, Bystedt H, Frykholm A, von Konow L, Lothigius E. A 3-year clinical study of Astra dental implants in the treatment of edentulous mandibles. Int J Oral Maxillofac Implants 1992; 7:321–329.
5. Lekholm U, Gunne J, Henry P, et al. Survival of the Brånemark implant in partially edentulous jaws: A 10-year prospective multicenter study. Int J Oral Maxillofac Implants 1999;14: 639–645.
6. Levine RA, Clem D, Beagle J, et al. Multicenter retrospective analysis of the solid-screw ITI implant for posterior single-tooth replacements. Int J Oral Maxillofac Implants 2002;17: 550–556.
7. Eckert SE, Meraw SJ, Weaver AL, Lohse CM. Early experience with Wide-Platform Mk II implants. Part I: Implant survival. Part II: Evaluation of risk factors involving implant survival. Int J Oral Maxillofac Implants 2001;16:208–216.
8. Lekholm U, van Steenberghe D, Herrmann I, et al. Osseointegrated implants in the treatment of partially edentulous jaws: A prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1994;9:627–635.
9. Friberg B, Nilson H, Olsson M, Palmquist C. Mk II: The self-tapping Brånemark implant: 5-year results of a prospective 3-center study. Clin Oral Implants Res 1997;8:279–285.
10. Åstrand P, Engquist B, Anzen B, et al. Nonsubmerged and submerged implants in the treatment of the partially edentulous maxilla. Clin Implant Dent Relat Res 2002;4:115–127.
11. Testori T, Wiseman L, Woolfe S, Porter SS. A prospective multicenter clinical study of the Osseotite implant: Four-year interim report. Int J Oral Maxillofac Implants 2001;16:193–200.
12. Esposito M, Hirsch J, Lekholm U, Thomsen P. Differential diagnosis and treatment strategies for biologic complications and failing oral implants: A review of the literature. Int J Oral Maxillofac Implants 1999;14:473–490.
13. Scurria MS, Morgan ZV IV, Guckes AD, Li S, Koch G. Prognostic variables associated with implant failure: A retrospective effectiveness study. Int J Oral Maxillofac Implants 1998;13: 400–406.
14. Chuang SK, Wei LJ, Douglass CW, Dodson TB. Risk factors for dental implant failure: A strategy for the analysis of clustered failure-time observations. J Dent Res 2002;81:572–577.
15. Chuang SK, Tian L, Wei LJ, Dodson TB. Kaplan-Meier analysis of dental implant survival: A strategy for the estimating survival with clustered observations. J Dent Res 2001;80:2016–2020.
16. Herrmann I, Lekholm U, Holm S, Karlsson S. Impact of implant interdependency when evaluating success rates: A statistical analysis of multicenter results. Int J Prosthodont 1999;12: 160–166.
17. Engquist B, Åstrand P, Dahlgren S, Engquist E, Feldmann H, Gröndahl K. Marginal bone reaction to oral implants: A prospective comparative study of Astra Tech and Brånemark System implants. Clin Oral Implants Res 2002;13:30–37.
18. Hutton JE, Heath MR, Chai JY, et al. Factors related to success and failure rates at 3-year follow-up in a multicenter study of overdentures supported by Brånemark implants. Int J Oral Maxillofac Implants 1995;10:33–42.
19. Jemt T. Implant treatment in resorbed edentulous upper jaws. Clin Oral Implants Res 1993;4:187–194.
20. Bain C, Moy P. The association between the failure of dental implants and cigarette smoking. Int J Oral Maxillofac Implants 1993;8:609–615.

21. De Bruyn B, Collaert H. The effect of smoking on early implant failure. Clin Oral Implants Res 1994;5:260–264.
22. Jemt T, Chai J, Harnett J, et al. A 5-year prospective multicenter follow-up report on overdentures supported by osseointegrated implants. Int J Oral Maxillofac Implants 1996;11:291–298.
23. Henry PJ, Laney WR, Jemt T, et al. Osseointegrated implants for single-tooth replacement: A prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1996;11:450–455.
24. van Steenberghe D, Lekholm U, Bolender C, et al. Applicability of osseointegrated oral implants in the rehabilitation of partial edentulism: A prospective multicenter study on 558 fixtures. Int J Oral Maxillofac Implants 1990;5:272–281.
25. Johns RB, Jemt T, Heath MR, et al. A multicenter study of overdentures supported by Brånemark implants. Int J Oral Maxillofac Implants 1992;7:513–522.
26. Jemt T, Laney WR, Harris D, et al. Osseointegrated implants for single tooth replacement: A 1-year report from a multicenter prospective study. Int J Oral Maxillofac Implants 1991;6:29–36.
27. Laney WR, Jemt T, Harris D, et al. Osseointegrated implants for single-tooth replacement: Progress report from a multicenter prospective study after 3 years. Int J Oral Maxillofac Implants 1994;9:49–54.
28. van Steenberghe D, Klinge B, Linden U, Quirynen M, Herrmann I, Garpland C. Periodontal indices around natural and titanium abutments: A longitudinal multicenter study. J Periodontol 1993;64:538–541.
29. Olsson M, Friberg B, Nilson H, Kultje C. MkII – A modified selftapping Brånemark implant: 3-year results of a controlled prospective pilot study. Int J Oral Maxillofac Implants 1995; 10:15–21 [erratum 1995;10:243].
30. Gunne J, Jemt T, Linden B. Implant treatment in partially edentulous patients: A report on prostheses after 3 years. Int J Prosthodont 1994;7:143–148.
31. Henry PJ, Tolman DE, Bolender C. The applicability of osseointegrated implants in the treatment of partially edentulous patients: Three-year results of a prospective multicenter study. Quintessence Int 1993;24:123–129.
32. Herrmann I. Influences of Study Designs and Statistical Variations on the Outcome of Dental Implant Evaluation [thesis]. Göteborg, Sweden: Göteborg University, 2003.
33. Herrmann I, Lekholm U, Holm S. Statistical outcome of random versus selected withdrawal of dental implants. Int J Prosthodont 2003;16:25–30.
34. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.
35. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark P-I, Zarb GA, Albrektsson T (eds). Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:199–209.
36. Hochberg Y, Tamhane AC. Multiple Comparison Procedures. New York: John Wiley and Sons, 1987.
37. Altman DG. Practical Statistics for Medical Research. London: Chapland & Hall, 1991.
38. Lazzara R, Siddiqui AA, Binon P, et al. Retrospective multicenter analysis of 3i endosseous dental implants placed over a five-year period. Clin Oral Implants Res 1996;7:73–83.
39. Friberg B. On Bone Quality and Implant Stability Measurements [thesis]. Göteborg, Sweden: Göteborg University, 1999.
40. Haas R, Mensdorff-Pouilly N, Mailath G, Watzek G. Survival of 1,920 IMZ implants followed for up to 100 months. Int J Oral Maxillofac Implants 1996;11:581–588.
41. Jemt T, Lekholm U, Johansson CB. Bone response to implant-supported frameworks with differing degrees of misfit preload: In vivo study in rabbits. Clin Implant Dent Relat Res 2000; 3:129–137.
42. Hecker DM, Eckert SE. Cyclic loading of implant-supported prostheses: Changes in component fit over time. J Prosthet Dent 2003;89:346–351.
43. Brunski JB. In vivo bone response to biomechanical loading at the bone/dental-implant interface. Adv Dent Res 1999;13: 99–119.