Reconstruction of the Atrophic Edentulous Maxilla with Free Iliac Crest Grafts and Implants: A 3-Year Report of a Prospective Clinical Study

Mats Sjöström, DDS, PhD;* Lars Sennerby, DDS, PhD;*† Hans Nilson, DDS;‡ Stefan Lundgren, DDS, PhD*

ABSTRACT

Purpose: The purpose of this study was to perform a longitudinal follow-up study of implant stability in grafted maxillae with the aid of clinical, radiological, and resonance frequency analysis (RFA) parameters.

Materials and Methods: The atrophic edentulous maxillae in 29 patients were reconstructed with free iliac crest grafts using onlay/inlay or interpositional grafting techniques. The endpoint of the resorption pattern in the maxilla determined the grafting technique used. Endosteal implants were placed after 6 months of bone-graft healing. Implant stability was measured four times using RFA: when the implants were placed, after 6 to 8 months of healing, after 6 months and 3 years of bridge loading. Individual checkups were performed at the two later RFA registrations after removal of the supraconstructions (Procera® Implant Bridge, Nobel Biocare AB, Göteborg, Sweden). Radiological follow up of marginal bone level was performed annually.

Results: Twenty-five patients remained for the follow-up period. A total of 192 implants were placed and with a survival rate of 90% at the 3-year follow up. Women and an implant position with a class 6 resorption prior to reconstruction were factors with significant increased risk for implant failure (multivariate logistic regression). Twelve of the 20 failed implants were lost before loading (early failures). The change in the marginal bone level was 0.3 ± 0.3 mm between baseline (bridge delivery) and the 3-year follow up. The implant stability quotient (ISQ) value for all implants differed significantly between abutment connection (60.2 ± 7.3) and after 6 months of bridge loading (62.5 ± 5.5) (Wilcoxon signed ranks test for paired data, $p = .05$) but were nonsignificant between 6 months of bridge loading and 3 years of bridge loading (61.8 ± 5.5). There was a significant difference between successful and failed implants when the ISQ values were compared for individual implants at placement (Mann-Whitney *U* test, $p = .004$). All 25 patients were provided with fixed implant bridges at the time of the 3-year follow up.

Conclusion: This clinical follow up using radiological examinations and RFA measurements indicates a predictable and stable long-term result for patients with atrophic edentulous maxillae reconstructed with autogenous bone and with delayed placement of endosteal implants. The ISQ value at the time of placement can probably serve as an indicator of level of risk for implant failure.

KEY WORDS: autogenous bone graft, edentulous atrophic maxilla, endosteal implants, implant survival, marginal bone level, resonance frequency analysis

The secondary effects of tooth loss are alveolar bone resorption. The loss of alveolar bone compromises soft tissue support and the lower anterior facial height.[1,2] The resorption of the alveolar process may preclude implant placement in the atrophic edentulous maxilla. Reconstruction of the alveolar process with bone augmentation prior to implant placement will facilitate the latter, but the result is influenced by the quality and quantity of the bone grafts. Several bone-grafting

*Department of Oral & Maxillofacial Surgery, Umeå University, Umeå, Sweden; †Department of Biomaterials, University of Göteborg, Sweden; ‡Department of Prosthetic Dentistry, Umeå University, Umeå, Sweden

Reprint requests: Mats Sjöström, Department of Oral & Maxillofacial Surgery, Umeå University, SE 901 87 Umeå, Sweden; e-mail: mats.sjostrom@odont.umu.se

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procedures with free autogenous bone are described in the literature: onlay bone grafting,[3] grafting to maxillary sinuses and the floor of the nose,[4] and interpositional bone grafting after a Le Fort I osteotomy.[5] The literature also reports a variety of donor sites, that is, iliac crest,[4] calvarial bone,[6] rib,[7] and different intraoral sites,[8,9] bone grafts in blocks or particulated,[8] different implant design,[10] varying healing times for the bone graft and simultaneous[3] or delayed placement of the implants.[11] Varying inclusion criteria in studies with small numbers of patients make it difficult to find relationships between different interventions and their outcomes. Palmer and Sendi[12] wrote that a meta-analysis would summarize the results of multiple studies and describe the true clinical effects of interventions more accurately than do small individual studies.

Implant stability is essential for the long-term success of oral implant treatment. The resonance frequency analysis (RFA) technique has proved sensitive in monitoring changes in implant stability during the healing time.[13,14] Glauser and colleagues[15] found that failing implants showed a continuous decrease in stability until failure and the RFA technique could be a clinical tool for identifying implants at risk of failure before failure occurs. Sjöström and colleagues[11] showed that implants placed in grafted maxillae were as stable as implants placed in normal maxillary bone when measured using the RFA technique from placement to 6 months of loading. At present, there are no long-term follow-up studies of implant stability in grafted maxillae measured by RFA.

The aim of this clinical study was to conduct a 3-year follow up with respect to clinical, radiological, and RFA parameters of implant stability in 29 consecutively admitted patients with atrophic edentulous maxillae reconstructed with free autogenous iliac bone graft and titanium implants. The aim was also to make a survey of the literature with respect to clinically relevant factors. The factors evaluated were: (1) which donor sites are used, (2) how implant survival is affected by different bone grafting techniques, and (3) the staging of the surgical procedures.

MATERIALS AND METHODS

Clinical Study

Ethical Approval. Ethical approval of the clinical study was granted by the Local Research Ethics committee.

Patients. This 3-year report includes 25 (17 females and 8 males; mean age: 55 years; range: 48–65 years) of 29 consecutively admitted patients (21 females and 8 males; mean age: 58 years; range: 48–73 years) with totally edentulous maxillae who were treated with reconstruction with free autogenous iliac bone grafts and delayed placement of titanium implants with a turned surface (Standard® and Mark II® Brånemark System, Nobel Biocare AB, Göteborg, Sweden).[11] Four patients dropped out during the study because of death ($n = 1$), refusal to participate ($n = 1$), or they moved out of the area ($n = 2$).

All patients were in good general health except one who had a chronic endocrine disorder (hypothyroidism). Eight patients (32%) were smokers and continued to be so during the treatment. The time the maxilla had been edentulous varied from 1 to 46 years (median: 34 years). Seven patients were edentulous in the mandible; 17 patients were partially dentate and one patient had retained all the teeth in the mandible. The seven edentulous patients were rehabilitated either with fixed implant bridges (4 patients) or removable dentures (3 patients). One of the patients with partial dentition had a unilateral occlusal support.

Preoperative Radiographic Examinations. The patients were examined radiographically using orthopantomograms, lateral cephalograms, intraoral radiographs, and lateral tomography.

The amount of bone at each planned implant site before reconstruction was assessed on the conventional tomograms. Table 1 presents the resorption at the planned implant sites for all 29 patients. Two out of 222 implant sites (1%) had no preoperative radiographic

TABLE 1 The Preoperative Status of Resorption in the Alveolar Process for 222 Planned Implant Sites, Classification According to Cawood and Howell

Cawood and Howell 1988	Number	Percent (%)
III	17	8
IV	67	30
V	111	50
VI	25	11
?	2	1
Total	222	100

The question mark indicates no preoperative radiological examination.

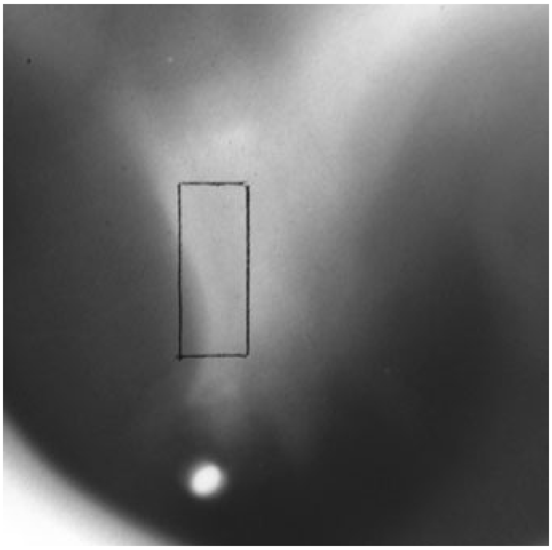

Figure 1 The bone dimension in the planned implant site was evaluated with a guide corresponding to an implant placed over the radiograph.

examination and were impossible to classify. These two sites were posterior in the alveolar process.

The resorption pattern was classified according to Cawood and Howell,[1] in the vertical and buccopalatal dimensions using a transparent template corresponding to a 10-mm-long implant with a regular platform (Figure 1). Bone grafting was considered if the dimensions of the available residual crest were less than 4 mm in width and 10 mm in height in the majority of the planned implant sites for the individual patient.

Surgical Procedures. Bone Grafting: Depending on the resorption pattern in the maxilla, two different bone-grafting techniques[11] were used. For five patients with a reversed intermaxillary relation, with or without increased vertical distance, a Le Fort I osteotomy and interpositional bone graft was used (Figure 2). In 24 patients with a thin alveolar crest or loss of vertical bone height in the anterior maxilla, the reconstruction was carried out using an onlay bone graft together with nasal floor inlay graft (Figure 3). A maxillary sinuses antral graft was performed in six of the onlay/inlay patients, while the remaining 18 patients had posterior onlay grafts. The bone graft surgery was performed under general anesthesia and cortico cancellus bone blocks were harvested from the anterior superior iliac crest. Either benzyl-penicillin (3 g × 3) or, in the case of allergy to penicillin, clindamycin (600 mg × 3) was given parenterally immediately preoperatively and for the following 24 hours. All patients were hospitalized 2 to 3 days postoperatively, and given phenoxymethyl penicillin (1 g × 3) or clindamycin (300 mg × 3) for the 7 days following the operation. Vacuum drainage at the donor site was used until the patient was mobilized. Analgesics (paracetamol or nonsteroid anti-inflammatory drugs) were prescribed 7 to 10 days postoperatively. New removable dentures were fabricated and could be worn from the 8th postoperative week.

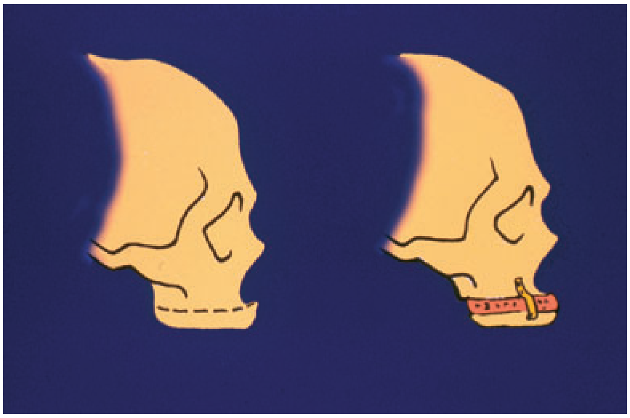

Figure 2 Diagram of the interpositional bone-grafting technique. Printed with permission from Quintessence Publishing Co, Inc.

Implant and Abutment Placement: For the 25 patients in the 3-year follow up, a total of 192 implants (171 standard implants and 21 self-tapping Mk II, machined surface Brånemark Nobel Biocare AB), 10 to 18 mm in length and 3.75 mm in diameter, were placed according to a two-stage surgical protocol after 6 months of bone-graft healing. The placement was performed under local anesthesia (2% lidocain/

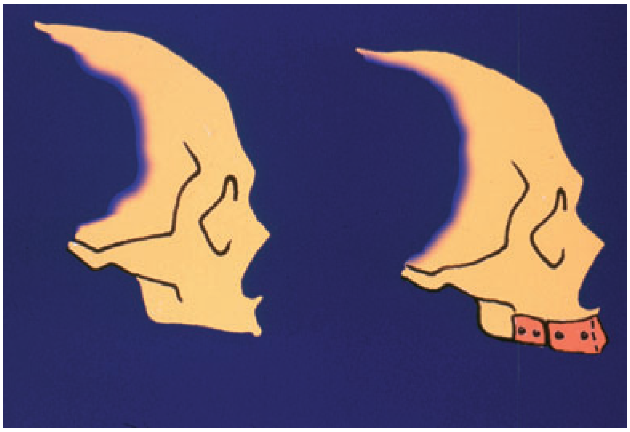

Figure 3 Diagram of the onlay bone-grafting technique. Printed with permission from Quintessence Publishing Co, Inc.

epinephrine 1/80000, ASTRA AB Södertälje, Sweden), with antibiotic prophylactics used for 7 days (phenoxymethyl penicillin or, in case of penicillin allergy, clindamycin) and conscious sedation. All implants were placed after preparation with a final drill diameter of 2.85 mm. The number of implants placed in each patient varied from six to eight. During placement of the cover screw on the implant, the surgeon evaluated the initial stability and decided how much healing time to allow. If one or more implants could be rotated together with the cover screw using a manual screwdriver, a prolonged healing time of 8 months was selected.

Eighteen implants (9%) in 13 patients showed such mobility. Other reasons for prolonged healing time were earlier bone grafting failures or extensive bruxism. For stable, nonrotating implants, the healing time was 6 months. Sixteen patients (64%) had a prolonged healing time of 8 months. To reduce interoperator variability, the same surgeon performed the implant placement and abutment connection in all patients.

Prosthetic Procedures. After the grafting procedure, the patients were instructed not to wear their dentures for 6 to 8 weeks. Thereafter, in most cases, the patients were supplied with a new denture; two patients chose to be without a denture during the healing period. During the healing period after the grafting procedure, the patients were recalled for individual checkups and the dentures were relined with a soft tissue relining material or with a permanent relining. After the implants were installed, the dentures were again adjusted and relined in a soft tissue material. After abutment connection, the bridges were fabricated using a metal framework in Titanium (Procera Implant Bridge®, Nobel Biocare AB). In patients where use of a metal-ceramic bridge was planned, a temporary all-acrylic bridge was fabricated and delivered immediately after abutment connection. The temporary bridge was used for 4 to 8 weeks. The temporary bridge was fabricated with short cantilevers or without cantilevers and with flat cusps in order to achieve a gentle occlusion. The permanent metal-ceramic bridges (Procera Implant Bridge) were produced according to normal procedures described in the manual. No temporary bridges were made if the final bridges were to be made of Titanium acrylic. During the time between abutment connection and bridge delivery, the patients were told to wear their removable denture as little as possible. Directly after abutment surgery, patients who had lost one or more implants were evaluated by the surgeon together with the restorative dentist regarding the need for supplementary implants.

The position of the remaining implants; the dentition in the opposing jaw; individual factors such as loading, functional habits, cantilever length, for example, played an important role in determining whether additional implants should be installed. If so, a temporary bridge was fabricated that was reinforced with Kevlar threads, and ordinary gold cylinders were used in the acrylic material. The temporary bridge was then used for the additional healing period of approximately 6 months.

After delivery of the final bridge, the patients were instructed in oral hygiene and an individual recall program was set up.

Follow Up. After delivery of the bridge, follow-up checkups were performed after 6 months, and 1, 2, and 3 years of function. The bridges were removed for stability tests of the individual implants after 6 months and 3 years.

Implant Survival: Implant survival was calculated based on registered failures. Stability tests of individual implants were performed at abutment surgery and after 6 months and 3 years of loading.

Marginal Bone Level: The implants were inserted with the cover screw above the bone level with the reference point (top of the implant) at the same level as the surrounding bone. Intraoral radiographs at bridge delivery (baseline) and after 1, 2, and 3 years of loading were used to evaluate the marginal bone level. The parallel technique was used to optimize the anatomy around each implant. The distance from the implant/abutment junction (reference point) to the most coronal point (marginal bone level), where the marginal bone meets the implant, was measured on both sides of each implant. Mean values were calculated for each patient and time. The registrations were made with a loupe with a magnification factor of 7 and a scale in tenths of millimeters. The distance over five threads was measured and divided by the real distance of 3.0 mm, thus revealing the variation in magnification in the radiographs. The resulting magnification factor for each implant and examination was used to transform the measured radiographic changes of bone level into real bone loss.

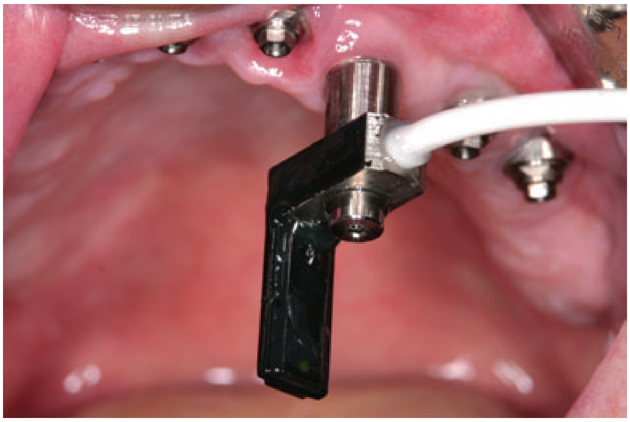

Figure 4 Resonance frequency registration at the time of the 3-year follow up.

RFA: RFA was performed to measure implant stability using an Osstell instrument (Integration Diagnostics AB, Göteborg, Sweden). Implant stability was measured in implant stability quotient (ISQ) units and was registered four times during the treatment: (1) at implant placement, (2) abutment connection, (3) after 6 months, and (4) after 3 years of loading. The bridge was removed on the two latter occasions to permit measurements of the individual implants (Figure 4). The mean ISQ values were calculated for each patient and time point. Mean values were also calculated for anterior and posterior implants for each patient and time point. Anterior implants were defined as implants placed in positions 12, 11, 21, or 22 (FDI nomenclature). Posterior implants were defined as implants placed posterior to positions 12 or 22. Mean ISQ values were also calculated for the different implant lengths at implant placement. Additionally placed implants and implants with angulated abutments were not included in the analysis.

Survey of the Literature

A survey of the literature without limitation regarding year of publication was conducted using the National Library of Medicine computerized bibliographic databases MEDLINE and PubMed, with links to related articles. The search words used were edentulous maxilla, bone graft, reconstruction, titanium implants, and their combinations. The reference lists in the collected articles were used to further expand the survey. The following inclusion criteria were applied:

1. The study had to have been published in English, or have an English abstract, in a refereed journal.
2. The study must include patients with edentulous maxillae, or in studies with mixed total/partial edentulism it should be possible to discern which.
3. The reconstructions in the patients should be with free autogenous bone grafts.
4. The reconstruction technique should be identifiable.
5. The number of placed and failed implants in grafted bone should be defined.
6. The minimum follow-up period should be 12 months, calculated after implant placement for all patients in the study.
7. In cases with multiple reports on the same patient/implant material, the most recent study with the longest follow up should be analyzed.

Statistics. The statistical analysis was performed using the SPSS software package (version 10.0, SPSS Inc., Chicago, IL, USA). The cumulative survival rate was evaluated using life table analysis based on all implants placed. The association between gender, smoking, length and position of implant, resorption of the planned implant position, the reconstruction technique, and implant failures was evaluated by unconditional logistic regression to estimate odds ratios (ORs) and corresponding 95% confidence intervals (CIs). The effect of each factor was assessed both in univariate (crude) analysis and after adjustment for the other factors considered. For analysis of RF values, all statistical tests were based on the patient as a unit except in cases of comparison between successful and failed implant. The Wilcoxon signed rank test for paired data was used for comparison of changes in ISQ between implant placement, abutment connection, and the situations with loaded implants, and also for comparison of anterior and posterior implants. For comparison of ISQ between successful and failed implants registered at the time of placement, the Mann-Whitney *U* test was performed both on a patient level as well as for the individual implant. For comparison between the different bone-grafting techniques in the literature survey, the chi-square test was performed. For analysis of the correlation between ISQ value at implant placement and implant length, a Spearman rank test was performed.

All significance tests were two-tailed and a value of $p \leq .05$ was considered significant.

TABLE 2 Distribution of Implant Failures with Regard to Patients

Number of Failures	Number of Patients	Number of Implants	Early Failures	Late Failures
1	5	5	3	2
2	2	4	3	1
3	2	6	6	
5	1	5		5
Total	10	20	12	8

RESULTS

Clinical Study

Clinical Observations. The grafting procedure and the healing period were uneventful in all patients. At the time of implant placement, 6 months after the grafting procedure, one patient exhibited extensive resorption of the bone graft. The graft was then supplemented with an additional graft taken from the mandibular ramus.

Implant Survival. A total of 20 of the 192 implants placed failed during the follow-up period, giving a survival rate of 90% after a minimum follow up of 3 years. Twelve of the failures happened prior to loading and were classified as early failures. Six out of 18 (30%) implants classified as having low primary stability at placement were lost during the treatment time.

The distributions of the failures among the patients are presented in Table 2. The locations for placed and failed implants with regard to tooth position are presented in Table 3. The distribution of implants with regard to length and failure is presented in Table 4. Sixty-one implants were placed in men and one implant (2%) failed. For women, 19 out of (14%) of 131 implants failed. One out of 29 implants (3%) failed in a patient where interpositional bone grafts were used for reconstruction. Nineteen out of 163 (12%) implants placed in onlay/inlay bone grafts failed. Two of eight smokers (25%) lost an implant during the follow-up period compared to eight out of 17 nonsmokers (47%). Table 5 presents OR with 95% CI for gender, smoking, implant length and position, resorption in planned implant position, and reconstruction technique. In univariate analysis, significant differences were found for gender implant length, implant position, and resorption in planned implant position. However, only gender and resorption remained significant after adjustment for the other factors. All patients received and maintained a fixed bridge throughout the 3-year follow up. However, at the 3-year follow-up visit 4 of 6 implants were unstable in one patient and suggested to be removed. The patient refused removal of the implants at that time so the bridge was inserted again without removal of the unstable implants. A life table including all the originally placed implants ($n = 222$) in 29 patients is presented in Table 6.

Marginal Bone Level. Figure 5 presents the change in marginal bone level during the study. At baseline registration (bridge delivery), the mean value for the marginal bone level was 1.9 ± 0.4 mm apical to the reference level. The marginal bone level was 2.0 ± 0.3 mm at the

TABLE 3 Distribution of Placed and Failed Implants with Regard to Tooth Position

Position (FDI)	Number of Placed Implants	Number of Failed Implants	Percent Failed
15/25	43	4	9
13/23	49	3	6
12/22	50	4	8
11/21	50	9	18
Total	192	20	10

TABLE 4 Distribution of Implants with Regard to Length and Failure

	Implant Length			
	10 mm	13 mm	15 mm	18 mm
Number of placed implants	23	76	85	8
Number of failed implants	7	9	4	0
Percent failure	30	12	5	0

TABLE 5 Odds Ratio (OR) and 95% Confidence Intervals (CI) for Gender, Smoking, Implant Length and Position, Resorption of Planned Implant Position, and Reconstruction Technique

Factor	OR	95% CI	OR*	95% CI
Gender				
Male	1.0			
Female	10.18	1.33–77.90	8.22	1.04–64.95
Smoking				
Nonsmoker	1.0			
Smoker	0.48	0.15–1.50	0.42	0.12–1.24
Length of implant				
15–18 mm	1.0			
10–13 mm	4.29	1.38–13.35	2.51	0.69–9.14
Position of implant				
15/25,13/23,12/22	1.0			
11/21	2.61	1.01–6.75	2.05	0.69–6.12
Resorption of planned implant position				
3–5	1.0			
6	5.56	1.93–16.07	3.91	1.13–13.48
Reconstruction				
Interpositional	1.0			
Onlay/Inlay	3.69	0.48–28.73	2.66	0.30–23.70

*OR from a multiple logistic regression analysis with gender, smoking status, length of implant, position of implant, crista resorption, and reconstruction technique included as explanatory.
In univariate analysis, significant differences were found for gender implant length, implant position, and resorption in planned implant position. Gender and resorption remained significant after adjustment for the other factors.

1-year follow up, 2.2 ± 0.5 mm at the 2-year follow up, and 2.2 ± 0.4 mm apical to the reference level at the 3-year follow up. The change in marginal bone level from baseline to the 3-year follow up was 0.3 ± 0.3 mm.

RFA. Resonance frequency registrations were performed on 190 out of 192 implants, at the time of implant placement. Two implants were impossible to measure, as the transducer could not be positioned because of lack of space. The mean ISQ for the implants at placement was 61.9 ± 9.5 and 61.8 ± 5.5 after 3 years of loading (Figure 6). There was a significant increase in the ISQ value between abutment connection (60.2 ± 7.3) and 6 months of bridge loading, 62.5 ± 5.5 ($p = .05$).

The mean ISQ for successful implants at the time of placement was 61.0 ± 9.4 compared to 55.9 ± 11.1 for failed implants ($p = .11$). When comparing individual implants, the mean ISQ at placement for 170 successful implants was 62.6 ± 11.1 compared to 54.9 ± 11.1 for 20 failed implants (Figure 7). There was a significant dif-

TABLE 6 Life Table for All Originally Placed Implants (n = 222) in 29 Patients

Time	Number of Entering Implants	Number of Failed in Interval	Number of Dropouts	Success Rate within Group (%)	CSR (%)
1	222	13	0	94.1	94.1
2	209	4	8	98	92.3
3	197	4	21	97.9	90.3
4	172				

Intervals: 1, placement to abutment surgery; 2, abutment surgery to 6 months of loading; 3, 6 months of loading to 3 years of loading; 4, >3 years.

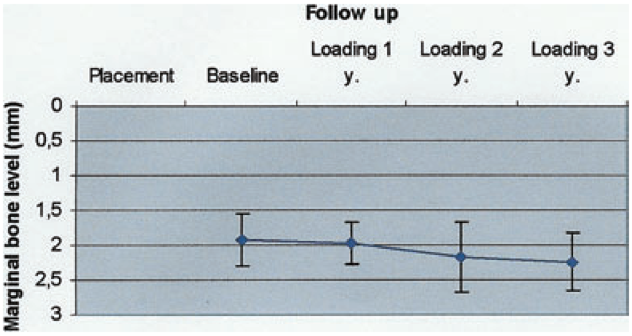

Figure 5 Changes in marginal bone level between baseline registration (bridge delivery) and the 3-year follow up.

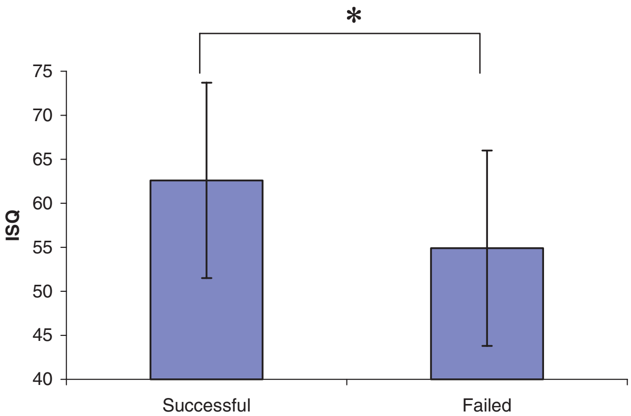

Figure 7 Comparison between successful implants (n = 170) and failing implants (n = 20). There was a significant difference in implant stability quotient value between successful and failed implants at placement (p = .004).

ference ($p = .004$) between successful and failed implants when individual implants were compared.

Significant differences were found when comparing anterior and posterior placements of implants at the first and last registration (p = .019, p = .024; Figure 8). For posteriorly placed implants, there was a significant increase when comparing the ISQ value at the abutment connection with that after 6 months of loading (p = .032) and 3 years of loading (p = .026).

There was a significant difference ($p < .001$) in ISQ value at the time of implant placement when 10 and 13 mm (n = 97) implants were compared with longer implants (n = 93). The mean ISQ was 58.6 ± 11.1 for shorter implants and 65.1 ± 10.7 for longer implants (Figure 9).

Literature Survey

A total of 23 publications[3–7,11,16–32] met the criteria listed. In four papers,[4,11,17,22] three, two, two, and two different patient groups were described and analyzed as separate patient groups. This gives 28 separate patient groups within which a total of 556 patients with edentulous maxillae could be identified (range: 1–75; per study: 16 [median], 20 [mean]). Gender was reported in 21 of the patient groups: two-thirds of the patients were women (66%). The patient groups had a mean age at the time of the bone graft of 54 years (range: 46–63 years). In patients where the reconstruction was performed with onlay or sinus inlay together with additional techniques, classification was made according to the bone-grafting technique that was employed for the majority of the implants. The use of the onlay bone-grafting technique, alone or with additional sinus inlay or sinus inlay together with nasal inlay, is described in 14 groups (50%). Sinus inlay alone or with nasal inlay is reported in eight groups (29%) and an interpositional bone-grafting technique in six groups

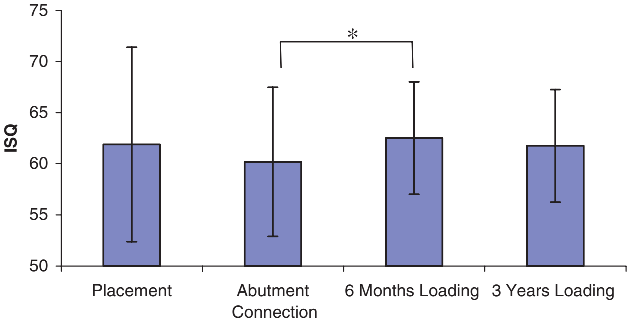

Figure 6 Comparison of implant stability quotient values among four different registrations. Statistically significant differences were found between the registrations at the abutment connection and the 6-month follow up (p = .05).

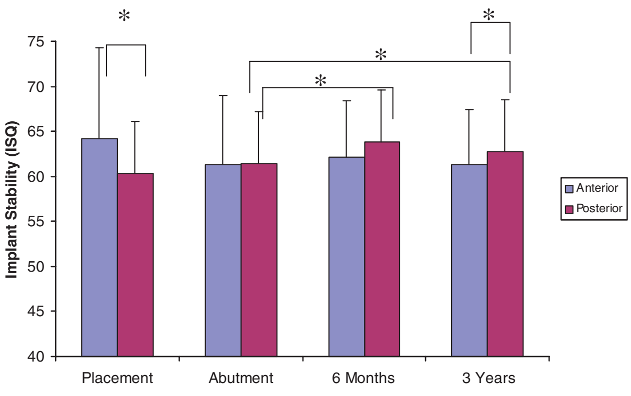

Figure 8 Comparison between implant stability quotient values for anteriorly and posteriorly placed implants. Significant differences were found when comparing anteriorly and posteriorly placed implants at the first and last registrations (p = .019; p = .024). For posteriorly placed implants, there was a significant increase when the ISQ value at the abutment connection was compared with the 6 months of loading (p = .032) and 3 years of loading (p = .026).

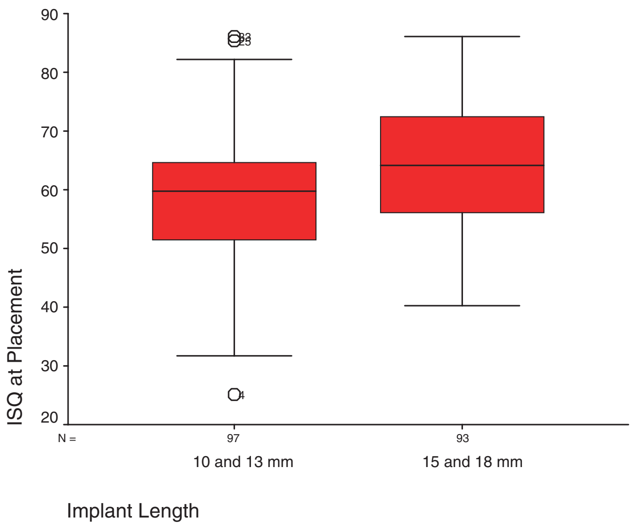

Figure 9 Comparison of implant stability quotient value between 10 and 13 mm implants ($n = 97$) and 15 and 18 mm implants ($n = 93$) at the time of implant placement. A significantly higher ISQ ($p < .001$) was found for 15 and 18 mm implants.

(21%). The anterior iliac crest was described as the donor site in 75% of groups (21 groups). Other donor sites mentioned were posterior iliac crest (two groups); mandibular symphysis (two groups); and calvarium, lateral sinus wall, and rib (one group for each).

In 15 out of 28 (54%) patient groups, the implants and the bone graft were placed simultaneously (one-stage technique). In nine patient groups, the implants were placed in a later procedure and in four patient groups, some implants were placed using a one-stage technique and some using a two-stage technique. The healing time between bone grafting and implant placement in the two-stage technique varied between 3 and 7 months with a majority having 6 months of healing. The minimum follow-up time ranged between 12–60 months with a mean of 22 months and a median of 13 months. A total number of 2965 implants were included in the 28 patient groups (range: 6–326; mean per group: 106; median: 92). During the follow-up time, a total number of 490 implant failures were reported which gives a survival rate of 83% for all reported patients after a minimum of 12 months.

The number of placed implants, failed implants, and survival rate (percent) for the three different grafting techniques are presented in Table 7. No significant differences were found between the grafting techniques. Table 8 presents the number of placed implants, failed implants, and survival rate when the material is divided into three different groups with respect to treatment sequences. A significant difference was found between one-stage and two-stage techniques in favor of the delayed technique (chi-square test; $p = .039$).

DISCUSSION

The reconstruction of the atrophic edentulous maxilla with autogenous bone and endosteal implants is today a well-established treatment with a good prognosis.[3–7,11,16–32] The literature also reports improvements in the patients' quality of life.[33] A literature survey with specific inclusion criteria provides the reader with the possibility of summarizing data from multiple studies concerning a specific subject, but a retrospective survey of the literature also restricts the possibility of drawing conclusions. Jensen and colleagues[34] reported from the Sinus Consensus Conference where they analyzed a retrospective material concerning sinus floor augmentation. They concluded that the material was so multivariable and multifactorial that it was difficult to draw definitive conclusions. In the present literature survey, the number of patients was limited (mean: 20

TABLE 7 Literature Survey: Number of Placed Implants, Failed Implants, and Survival Rate for Onlay, Sinus Inlay, and Interpositional Bone-Grafting Techniques

	Number of Placed Implants	Number of Failed Implants	Survival Rate (%)
Onlay bone grafting	1407	223	84
Sinus inlay bone grafting	1074	190	82
Interpositional bone grafting	484	77	84

No significant differences were found between the grafting techniques.

TABLE 8 Literature Survey: Number of Placed Implants, Failed Implants, and Survival with Respect to Sequence of Treatment

	Number of Placed Implants	Number of Failed Implants	Survival Rate (%)
One-stage technique	1500	317	79
Two-stage technique	740	91	88
One- and two-stage techniques	725	82	89

A significant difference was found between one-stage and two-stage techniques (chi-square test, $p = .039$).

patients/article) – nevertheless, this is reasonable considering that reconstruction in a patient with an atrophic edentulous maxilla with bone and endosteal implants is an extensive treatment. Esposito and colleagues[35] found that the study design for trials of oral implants is generally poor and stated that, "Well-designed, large, randomized clinical trials (RCT) are considered the most scientifically sound method of minimizing bias." Multicenter cooperation would be needed to enlarge the clinical material.[36]

The present literature survey reports several donor sites for the bone graft, but the anterior iliac crest is the most commonly used. A large quantity of bone is required for reconstruction of the edentulous atrophic maxilla. In the clinical study, most of the planned implant sites had to be reconstructed regarding both height and width. The anterior iliac crest can offer large quantities of bone and it is a rather safe donor site.[33] These factors make the anterior iliac crest the first choice for a grafting area. The literature survey identified three main techniques for bone reconstruction: onlay, sinus inlay, and interpositional grafting. The resorption of the alveolar process produces three-dimensional changes in jaw relation,[2] and the choice of the different reconstruction method can be made depending on the status for the actual patient. The implant survival rate in the literature survey did not differ according to the grafting procedures, which was in line with the result in our clinical study with a nonsignificant difference between interpositional and onlay/inlay bone grafting. These results indicate that, regardless of the resorption pattern in the maxilla, a treatment with a high rate of success can be performed. This conclusion can also be supported by a study on the interface between bone graft and titanium implants: Sjöström and colleagues[37] found that regardless of whether onlay or interpositional bone grafting techniques were used, the osseointegration on titanium test implants was similar. The literature survey indicates that the one-stage technique is the most commonly used technique, but that the two-stage technique results in higher survival rates, 79% versus 88%. One reason for this difference is probably that in the two-stage situation, the revascularization of the bone graft is better and the surgical trauma, when placing the implants, stimulates an immediate healing response.[38] The two-stage technique also has the advantage that it allows for the correct positioning of the implants.[39] The implant survival rate, according to the literature survey, concerning the two-stage technique is comparable with the results after 3 years of loading in the present clinical study, 88% versus 90%. On the other hand, for the patients in this actual clinical follow up, the failure rate was 10%, which is interesting to analyze. The literature concerning implant therapy is gradually shifting from reports of success rates to analysis of complications and identification of risk factors associated with implant failure.[36,40] In our clinical study, 7 out of 10 patients lost one or two implants, which really did not affect the supraconstruction. In one patient, 5 implants were lost and resulted in an additional reconstructive procedure. Multiple implant failures are often clustered around a few patients in the studies.[16,23,41] Dependency exists among implants in the same patient/jaw and will affect the survival rate in the whole study. Herrmann and colleagues[42] suggested that only one randomly selected implant from each patient should be considered when calculating the success rates.

The reasons for implant failure are frequently discussed in the literature but no clear, single reason for failure is easy to identify because most failures do not exhibit clear causes.[43] We found that women had a significant increased risk for implant failure. This finding can perhaps be explained in factors in the bone graft or healing for the bone graft. Several authors[40,44,45] have reported smoking as a risk factor, but we could not find any connection between smoking and implant failure in our patients. Higher failure rates are reported[10,46,47] for shorter implants. The available bone volume determines the implant length at placement, and low jawbone volume, together with poor jawbone quality, negatively affected the result.[48] When analyzing the effect of implant length and implant position on implant survival, we found nonsignificant differences. On the other hand, the class 6 resorption in the planned implant position, prior to reconstruction had a significant increased risk for implant failure. One can speculate that, the more severe the resorption of the planned implant position is prior to reconstruction, the higher is the risk for implant failure. Loading conditions on the bone graft and implants are also a factor that can affect the result. Becktor and colleagues[46] found, in a study of patients with edentulous atrophic maxillae reconstructed with autogenous bone grafts, that one reason for early implant failure could be the traumatic influence from the opposing arch during the healing period for bone grafts and implants. The patients in the present study received a new prosthesis 8 weeks after the bone graft and for the time between abutment connection and bridge delivery, the patients were told to minimize the wearing of the prothesis as much as possible. Becktor and colleagues[46] also noted that more failures occurred if the dental arch in the mandible gave unilateral occlusal support. As the present study included only one patient with unilateral occlusal support, no conclusions can be drawn or comparisons made. The possibility of predicting implant failures is an important prognostic factor for the long-term outcome of reconstruction in patients. For example, it would allow adjustments to be made to healing times or loading conditions before failures occurred. Many different techniques are reported but there is little prognostic accuracy. In a review of diagnostic parameters for monitoring peri-implant conditions, the authors concluded that the Periotest™ (Gulden-Medizintechnik, Bensheim an der Bergstraße, Germany) seems to have little prognostic accuracy for early signs of implant failure.[49]

Johansson and colleagues[50] showed in a study on cutting torque measurements that it was not possible to identify implants at risk of failure. This result is also supported in an animal study of mini-pigs where no simple relationship was found between placement torque and implant failure.[51]

Esposito and colleagues[52] concluded that radiographic examination together with the implant mobility test seem to be the most reliable parameters in assessing the prognosis for osseointegrated implants.

The major change in the marginal bone level occurs during the first year after placement and after that the bone level stabilizes. The results in our study are comparable to those in other studies for both grafted[41] and nongrafted maxillae.[53] Åstrand and colleagues[53] reported a steady state on the marginal bone level in a majority of cases after 3 years. In a 10-year follow up of patients who received reconstruction of bone grafts and implants, Nyström and colleagues[41] reported stable marginal bone level after 3 years and concluded that a predictable result could be seen at the 3-year follow up.

The changes in RF value between placement and abutment connection have been reported earlier[11]: implants with a high RF value at the time for placement showed a reduced value by the second registration and implants with low RF value showed an increased value. This was also found out by Nedir and colleagues.[14] Up to the 3-year follow up, there was a nonsignificant difference compared to the 6-month registrations. There are not many longitudinal follow-up studies on implant stability using RFA: Hallman and colleagues[54] performed RF registrations in a 3-year follow up on implants placed in grafted sinuses. The RF values were similar to those we obtained at the 3-year follow up, but these results are not directly comparable as the grafting technique and grafting material differed. There was a significant difference between anteriorly and posteriorly placed implants at placement and after 3 years of loading. This difference between anterior and posterior implants was not found by Bischof and colleagues[13] at implant placement or after 12 weeks of loading. Balleri et al[55] found a nonsignificant difference after 1 year of loading between anterior and posterior placed implants. One explanation may be that the maxillae in our study were reconstructed with bone grafts. However, there was a significant difference for posterior implants between abutment connection and the two registrations for loaded implants. One can speculate whether the change in stability is because of the fact that the implants are loaded. By making surgical changes (changed drill dimension), we can manipulate the primary stability and the secondary stability after which the remodelation in the interface starts. With repeated ISQ registrations, we can follow the changes in stability during healing. Glauser and colleagues[15] made monthly ISQ registrations during the first 3 months and found that some of the failing implants had high RF values at the time of placement but after 1 to 2 months, the values fell. With a single ISQ registration at the time of implant placement, the possibility of identifying failing implants is limited, but the ISQ value probably indicates the risk of failure. In our study, we found a nonsignificant difference on the patient level between ISQ for successful and that for failing implants at the first registration. However, there was a significant difference between ISQ for failing and successful implants when individual implants were compared. When comparing the ISQ values for different implant lengths at placement, there was a significant difference between short and long implants. This result would indicate that implant length correlates to the ISQ value. However, our findings in this respect were not found by Balleri and colleagues[55] or Bishof and colleagues.[13] The possibility to compare the studies is, however, limited because the patients in our clinical study were reconstructed with autogenous bone grafts and the implants were placed after a final drill diameter of 2.85 mm.

One important factor for the prognosis of the reconstruction may be the bone graft itself. Blomqvist and colleagues[56] found a significantly reduced implant success rate in a group of patients who had their atrophic edentulous maxillae reconstructed with autogenous bone grafts and endosteal implants. When analyzing the relative bone mass density for these patients and comparing it with a group of age- and sex-matched patients, there was a significant difference. Possible factors in the patient's own bone graft or the bone remodeling process might indicate the prognosis for the reconstruction of the atrophic edentulous maxilla.

CONCLUSION

This 3-year clinical follow up with radiological examinations and RFA measurements indicates a predictable and stable long-term result for patients with atrophic edentulous maxillae reconstructed with autogenous bone and delayed placement of endosteal implants. The ISQ value at the time of placement can probably serve as an indicator of level of risk for implant failure.

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