Immediately Loaded Implants with or without Abutments Supporting Fixed Partial Dentures: 1-Year Results from a Prospective, Randomized, Clinical Trial

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ABSTRACT

Purpose: To evaluate 1-year implant survival and marginal bone loss around implants that support fixed partial dentures loaded immediately or after 3 months, and effects from abutment usage.

Materials and Methods: In this 2005 to 2009 randomized, parallel-group, clinical trial, 50 partially edentulous patients each received three Brånemark TiUnite™ implants (Nobel Biocare®, Göteborg, Sweden), mostly in the posterior maxilla. Two implants were fitted with abutments: a TiUnite™ surface and a machine-milled surface; the suprastructure was attached directly at implant level for the third implant. After randomized allocation, implants were immediately loaded with a fixed temporary bridge (test group) or left unloaded for 3 months (control group). A permanent fixed suprastructure replaced the temporary bridge after 6 months (test). Hard and soft tissues were examined during pretreatment and surgery plus 2 days, 14 days, 4 weeks, 3 months, and 1 year after surgery.

Results: After 1 year, four implants were lost in the test and two in the control groups (1-year survival rates of 94.9% [test] and 97.2% [control], with no significant intergroup difference). Resonance frequency analysis values indicated a similar pattern in both groups, with implant stability quotient (ISQ) reduction between 2 and 4 weeks. The test group had a significantly lower ISQ than the control group at these appointments. After 1 year, marginal bone losses around the implants were, on average, 1.32 mm (test, standard error of the mean [SEM] 0.08) and 1.24 mm (control, SEM 0.08), with no significant intergroup difference. Significantly larger marginal bone loss was observed at implants without abutment compared with implants with abutment.

Conclusions: For both groups, this study showed similar implant survival rates and marginal bone loss. Larger bone loss was found at implants loaded without attached abutments.

KEY WORDS: bone, dental implants, dental prosthesis, jaw disease, osseointegration, rehabilitation

INTRODUCTION

Edentulousness rehabilitation with osseointegrated titanium implants has been performed since the 1970s[1] and is extensively scientifically documented and considered highly predictable and safe. Treatment times shortened successively[2,3] and in selected patients, it is possible to

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effectively load implants immediately or early after their placement. Consequently, many patients now undergo treatment with immediate loading, that is, implants are loaded within 24 to 48 hours after surgery.[3,4] While most studies considered implant survival to be the only success criterion, an improved, expanded success criterion includes long-term hard and soft tissue stability around the implant(s) and long-term restorative component stability. Albrektsson and colleagues identified the parameters that affect the establishment and maintenance of osseointegration.[5] These were reconsidered in relation to immediate loading to improve chances of fulfilling success criteria. Among these, status of the bone and implant site and implant loading conditions were asserted to be decisive for implant success, while other parameters (e.g., implant material characteristics and surgical approach) may compensate suboptimal bone sites and loading conditions.[6] In recent years, abutment use has been challenged because it is redundant for prosthetic construction, adds unnecessary extra costs for patients, increases the risk of leakage with double connections, and complicates the suprastructure's esthetic optimal emergence profile. However, abutment use can be advocated for other reasons, for example, to protect endosseous implants from excessive load and to reduce the risk of bacterial leakage close to implants and bone crests. Succesful incorporation of an oral implant relies to the osseointegration mechanism and also to the adhesion of surrounding soft tissue to seal the tissues from bacterial challenge.[7] Recently, in a human histological study, it was shown that an oxidized titanium surface provided an enhanced mucosal attachment by affecting the orientation of collagen fibers.[8] However, this was found after a short time of healing (8 weeks). Therefore, it remains to be shown whether this attachment remains after longer follow-up.

In general, marginal bone loss around dental implants might lead to osseointegration failure. Studies reported marginal bone loss of 0.9 to 1.8 mm during the first year of loading and 0.05 to 0.13 mm annually thereafter.[9–11] An implant's success is defined as less than 1.5 mm of marginal bone loss during the first year after prosthesis insertion and less than 0.2 mm of annual bone loss thereafter.[12] Therefore, minimizing marginal bone loss is crucial in early treatment and loading stages.

There is no clear single known cause for marginal bone loss. Experiments have shown that accumulating plaque in the peri-implant area leads to inflammatory reactions and subsequent tissue breakdown.[13–16] Another mechanism may involve bacterial colonization in the implant-abutment interface (microgap), which results in bone loss.[17–22] Besides microbiological explanations, biomechanical influence on bone remodelling around implants is debatable. Finite element analysis has suggested that loading forces affect the implant-bone interface that leads to marginal bone loss.[23] However, animal experiments revealed contradictory results.[24–27] Human experimental investigations are not yet available, perhaps due to obvious difficulties in designing discriminating treatment protocols and in establishing proper inclusion–exclusion criteria.

The aim of this study was to evaluate (i) implant failures and marginal bone loss in patients subjected to immediate or conventional loading and (ii) influence of abutment use and abutment surface design on marginal bone loss.

MATERIALS AND METHODS

Study Design and Patient Selection

The regional ethical review board for research at Linköping University (Document No. M102-05) in Linköping, Sweden approved this prospective, randomized, double-blind, parallel-arm clinical trial, which was run as per these guidelines/requirements: Good Clinical Practice,[28] International Conference on Harmonization Guidelines,[29] and the Declaration of Helsinki for patients participating in clinical studies. CONSORT guidelines for clinical studies were adopted.[30] The study was conducted on partially edentulous patients who had been referred for prosthetic rehabilitation to the Institute for Postgraduate Dental Education in Jönköping, Sweden. All the examinations and interventions occurred in the periodontology and prosthetic dentistry departments. The study is independent; no financial supporters influenced it.

From 2005 to 2008, two hundred patients were screened for eligibility. One patient declined to participate and one hundred forty-nine did not meet inclusion criteria (Figure 1). Fifty subjects – 32 women and 18 men (average age: 67; range 35–87) – met inclusion criteria and were treated. All patients were eligible for examination after 1 year. The inclusion criteria were the following: (i) partially edentulous, healthy adult individuals as per American Society of Anesthesiologists (ASA) classes I and II[31]; (ii) necessary dental pretreatment must have

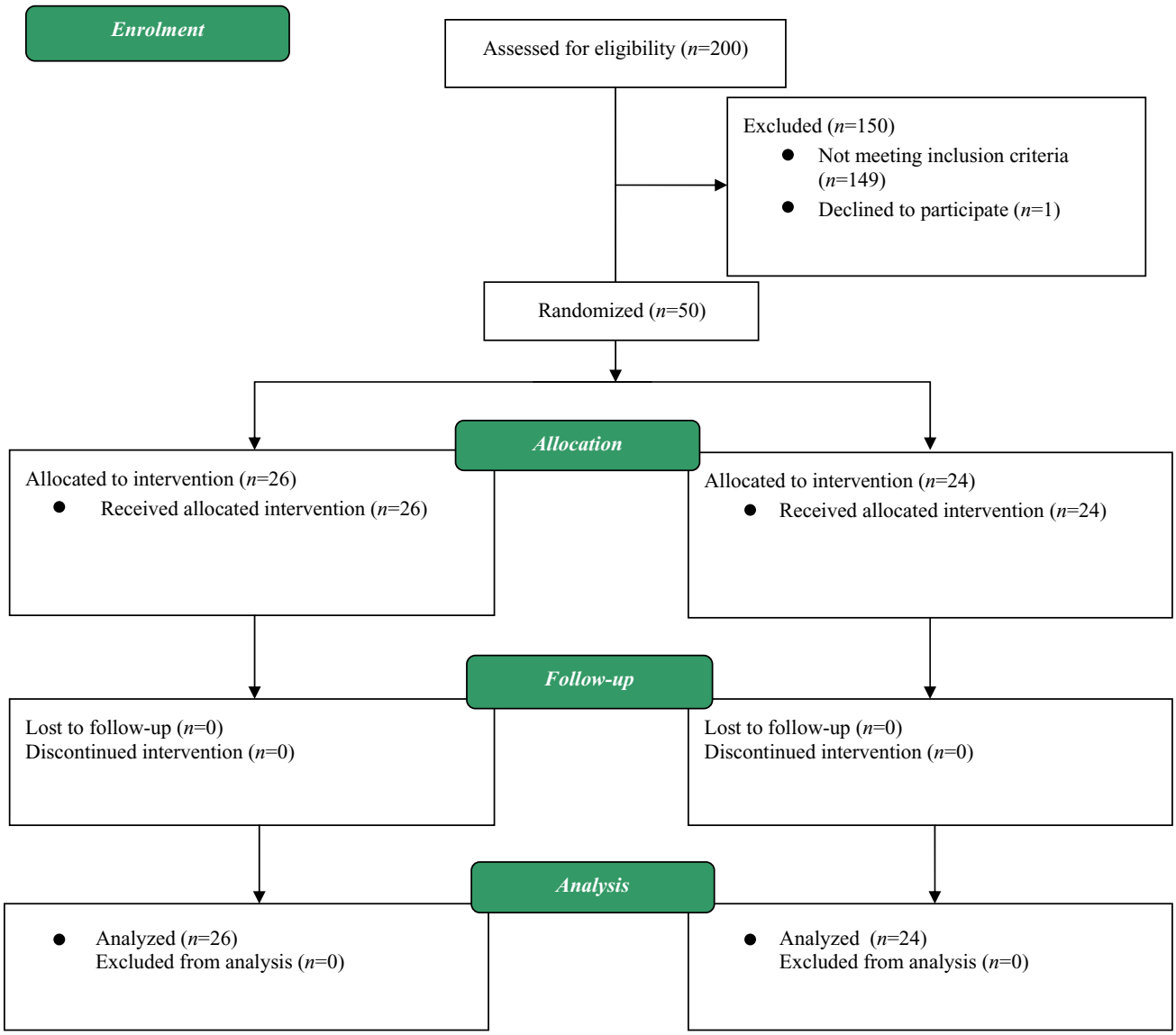

Figure 1 CONSORT flow chart from study launch to 1-year examination.

been done; (iii) tooth extraction in the surgical area must have been done more than 3 months before implant placement; (iv) surgery needed for bone augmentation must have been performed at least 6 months before implant placement; and (v) opportunities must exist for installing three implants with good primary stability, with at least 1-mm coverage of surrounding bone. The exclusion criteria were the following: (i) smoking (>10 cigarettes/day); (ii) drug abuse; (iii) immune-suppressing or blood-thinning medication; (iv) history of radiotherapy in head and neck region; (v) recent cardiovascular illness; (vi) sinusitis; (vii) severe malocclusion such as extreme intermaxillar sagittal and transversal discrepancy; and (viii) known bruxism.

Table 1 displays recruited subjects' medical status, smoking habits, periodontal disease experience,[32] intermaxillary relations, and occlusal support.[33] No significant differences were found between the test and control groups. At 10 test implant sites and 16 control implant sites, previous bone augmentation was done using sinus lifting with placement of a bone substitute (no significant difference between the groups). Each patient was thoroughly informed of overall requirements and procedures after explaining the following: (i) study's purpose; (ii) planned treatment; (iii) alternative procedures; (iv) potential risks; (v) possible complications; and (vi) proposed treatment benefits. All information was given in verbal and written forms. Thereafter,

TABLE 1 Patients' Age, Sex, Medical Status, Smoking, Periodontal Disease Experience, Intermaxillary Relation, and Occlusal Support

	Test ($n = 26$)	Control ($n = 24$)
Age (mean [SEM])	68.0 (1.3)	66.1 (1.1)
Gender (n, female/male)	16/10	16/8
Concurrent disease		
Cardiovascular disease	12	9
Diabetes mellitus, type II	2	1
Rheumatoid arthritis	0	1
Tumor disease	3	3
Osteoporosis	1	0
Respiratory disease	1	0
Medication		
Blood pressure medication	11	11
Statins	2	7
Low-dose antiplatelet drugs	7	8
Corticosteroids	0	1
Hypothyroid medication	2	0
Other hormone medication	1	0
Smokers (≤10 cigarettes/day)	8	7
Periodontal disease experience		
No loss of marginal bone	11	9
Horizontal loss ≤1/3 of marginal bone	9	7
Horizontal loss >1/3 of marginal bone ± angular defects and/or furcation involvements	6	8
Intermaxillary relation		
Angle class I	24	21
Angle class II	1	3
Angle class III	1	0
Eichner index		
A1–A3	3	2
B1	4	2
B2	7	2
B3	11	12
B4	1	6

SEM = standard error of the mean.

participants signed the informed consent document. The included patients were randomly assigned to a test group or a control group. Patients were allocated a code number during randomization. Randomizations were done with IBM SPSS (IBM, Chicago, IL, USA) using computer-generated sequences. These were concealed to the surgeon until implants were placed. Due to a logistical error, one patient was erroneously assigned to the test group. Therefore, 26 patients were assigned to the test group and 24 to the control group. Within each patient, the implants were randomly assigned to receive an abutment with a TiUnite™ surface (Nobel Biocare®, Göteborg, Sweden), a machine-milled surface, or no abutment.

Implants and Abutments

Brånemark Mark III implants (Nobel Biocare®) with a TiUnite™ oxidized surface were used with titanium abutments (Multiunit abutment™, Nobel Biocare®) that had two surface designs: one with a commercially available machine-milled surface and one with a TiUnite™ surface that was especially manufactured for this study. The most commonly used implant length was 13 mm (65%), followed by 10 mm (28%). Only two implants were <10 mm; none were >13 mm. Similarly, regular-platform implants (Ø3.75 mm) were most frequently used (80%), while narrow platform implants (Ø3.3 mm) were used in the other sites. Both implant lengths and dimensions were evenly distributed between the two groups in which a total of one hundred fifty implants were placed.

Clinical Procedures

One of the authors (C.S.) performed all the surgeries. Peroral sedation was given using Stesolid, 5 or 10 mg (Alpharma AB, Stockholm, Sweden). Local anesthesia was administered using either Xylocain Dental Adrenalin 2% (12 μg/mL) or Citanest Dental Octapressin 3% (both in Dentsply Limited, Skarpnäck, Sweden). Elevation of mucoperiosteal flaps buccally and lingually followed a crestal incision. Implant site preparation was done under thorough rinsing with sterile saline. Implants were placed at a center-to-center distance of at least 7 mm. The flaps were relocated using Vicryl® sutures (Johnson & Johnson, Solna, Sweden). Peroral antibiotics were prescribed postoperatively (either kåvepenin [AstraZeneca AB, Södertälje, Sweden] 2 g two times daily for 5 days or Dalacin [Pfizer AB, Täby, Sweden] 300 mg two times daily for 5 days). Patients were instructed to refrain from mechanical brushing in the operated area and instead rinse with chlorhexidine 0.1% (Hexident, Ipex Medical AB, Solna, Sweden) for 4 to 6 weeks. Sutures were removed 2 weeks after surgery as judged by the course of healing. Maintenance care was given as indicated.

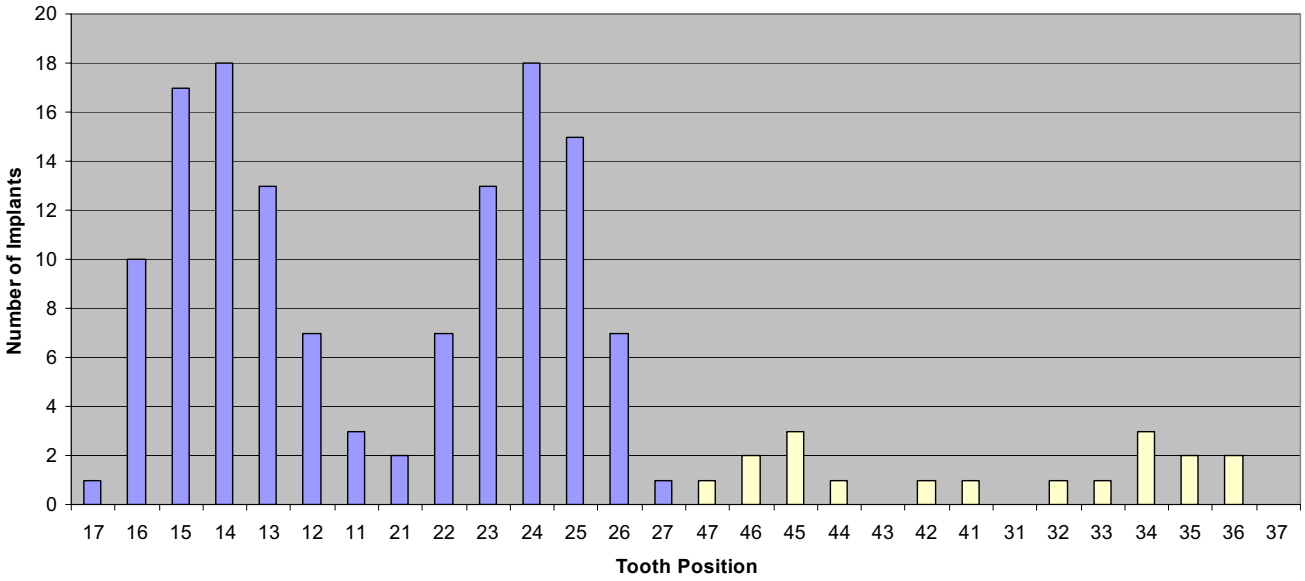

Figure 2 Distribution of implant sites.

Three implants were placed in the partially edentulous jaw. Two implants were fitted with abutments: one abutment with a machine-milled surface and one with a TiUnite™ surface; the construction was attached directly to the third implant. Most patients received the treatment in the posterior maxilla (Figure 2). Table 2 shows bone quality and volume at implant sites as per criteria of Lekholm and Zarb.[34] The most common bone quality was 3 (73%). Distribution of bone resorption was A (42%), followed by B (33%) and C (23%). The average bone crest width was 6.65 mm (standard error of the mean [SEM] = 0.18) in the test group and 7.19 mm (SEM = 0.17) in the control group, hence, significantly wider in the control group ($p < .05$). The osteotome technique was used at 15 implant sites (4 test and 11 control, $p < .05$). Particulate autogenous bone, with a guided tissue regeneration barrier, was applied at two sites in the test group and particulate autogenous bone alone was placed at nine sites (five test and four control).

After implant surgery, the test group received an implant-supported temporary bridge within 2 days. A final bridge was manufactured after 6 months. The control group had one-stage implant surgery with implants loaded with a permanent bridge after 3 months. One of the authors (C.G.) performed the prosthetic treatment. Both temporary and permanent bridges were screw retained. Temporary acrylic bridges were manufactured with bridge cylinders in metal and built with slight occlusal contacts in centric occlusion and group contacts in functional movements without cantilever units to avoid excessive functional loading during the early follow-up period. The permanent bridge consisted of titanium frameworks (Procera™, computer numeric controlled [CNC] milled by Nobel Biocare®) covered with porcelain and was designed with freedom-in-centric and no steep cuspal inclinations or extreme lateral contacts. One dental technician made all the prostheses. After temporary and final fixed partial

TABLE 2 Bone Quality and Volume at the Implant Sites Using the Criteria of Lekholm and Zarb[46]

		Bone Resorption (Test/Control)						
		A	B	C	D	E	Total	Missing Value
Bone quality	2	2/2	4/5	2/2	0/0	0/0	8/9	
	3	26/19	18/15	9/13	1/1	0/1	54/49	
	4	5/6	2/2	0/6	0/0	0/0	7/14	
Total		33/27	24/22	11/21	1/1	0/1	69/72	9/0

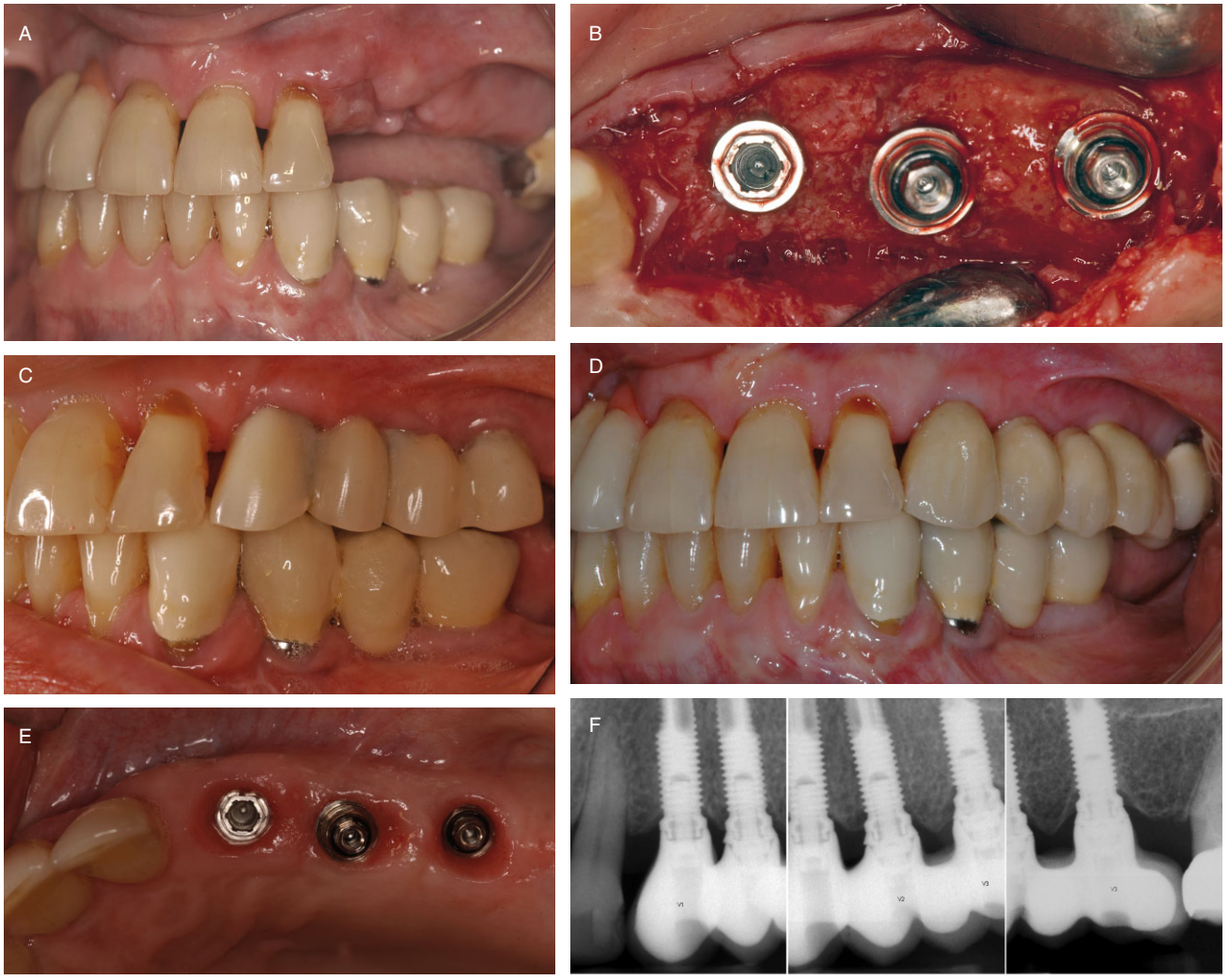

Figure 3 Clinical and radiographic images from a representative test patient. *A*, Preoperative view. *B*, Three implants placed in the left maxilla. *C*, Temporary fixed prosthesis placed 2 days after surgery. *D*, Permanent fixed prosthesis placed 6 months after surgery. *E*, Soft tissue appearance at 1-year follow-up. *F*, Intraoral radiographs at 1-year follow-up. Composite image.

prosthesis placement, the clinic's dental hygienists instructed patients on oral hygiene. Repeated instructions were given, if needed, at scheduled follow-up visits. Figure 3 shows clinical and radiographic images from a test patient.

Examinations

All clinical assessments were made after suprastructure removal, with measurements taken after 2 days, 2 weeks, 4 weeks, 3 months, 6 months, and 1 year. An examiner, who was unaware of the given treatment (U.A.), performed the main examinations (pretreatment plus 3 months, 6 months, and 1 year after surgery). Two of the authors (C.G. and C.S.) took the measurements during surgery plus 2 days, 2 weeks, and 4 weeks after surgery. For practical reasons, the measurements were not blinded. Resonance frequency analysis (RFA) – using an Ostell® mentor device (Ostell AB, Göteborg, Sweden) – measured the implant stability quotient (ISQ) during and after surgery. Biological and technical complications, such as dehiscence, mucositis, hyperplasia, screw loosening, and porcelain fractures, were recorded at each follow-up appointment. Occlusal parameters and jaw function and changes in oral and health status were registered.

Intraoral radiographs, using a paralleling technique, were obtained immediately after implant placement and 1 year. In the control group, radiographs were also obtained even at time of loading, thus after 3 months. Distance was recorded between a reference point

(implant/abutment junction or implant head-prosthetic construction) and the marginal bone level on the implants' mesial and distal sides. When reading film images, a magnifying lens (×7) with a measuring scale divided in tenths of millimeters was used. When reading digital images, the picture archiving and communication system's built-in measuring function corrected for magnification. One of the authors (K.G.) took all the measurements and was not aware of the treatment allocation.

Statistics and Power Analysis

All data were transferred to IBM SPSS. The primary outcome was peri-implant marginal bone loss after 1 year. Based on the literature, expected bone loss 1 year after conventional loading is 1.2 mm. A difference of 0.4 mm between the groups, with a standard deviation of 0.8 mm and 80% power with $\alpha < 0.05$, gave a sample size of 63 implants in each group. Means (SEM) or medians (min–max) were calculated for each parameter. Changes over time were expressed as means. Student's *t*-test, the Mann-Whitney test, and analysis of variance were used for group comparisons. Correlation and regression models were used to analyze factors that influenced outcome variables after 1 year.

RESULTS

Surgical and Postoperative Events

The surgical procedure was uneventful in all cases. Figure 4 shows biological complications up to 1 year. Events were limited, mainly of a reversible character, and similarly distributed between the two groups. Although in one test patient a substantial clot formation was found at day 2, therefore, it was impossible to fulfill all scheduled assessments at this appointment. One test and two control implants were accidentally unscrewed (one to two threads) during manipulation at follow-ups and thereafter retightened and became stable and were loaded. Rotational instability was found at two test and four control implants up to 3 months. Both test implants were unloaded and became stable. One of the control implants was lost (Table 3), and the other three were stable at the 3-month examination. Tender implants were noted at various time points, a symptom that did not lead to specific intervention.

Implant Failures

Six implants were lost during the first year: four implants in three patients in the test group and two implants in two patients in the control group with no

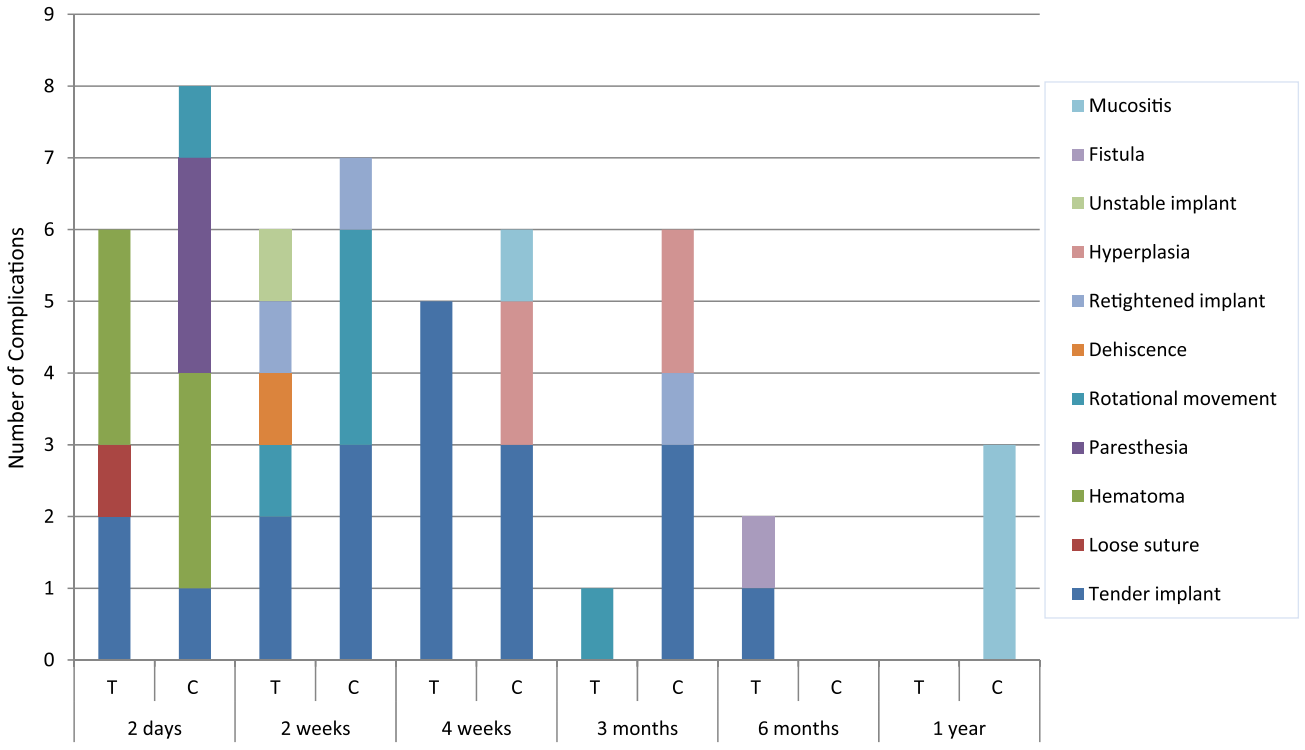

Figure 4 Biological complications from day 2 to 1-year examination. (T = test. C = control.)

TABLE 3 Characteristics of Failed Implants

Patient	Group	Age	Smoking	Site	Bone Quality*	Implant Length (mm)	ISQ at Surgery	ISQ at Failure	Failure (Days after Surgery)
1	Test	81	No	11	3	13	50	0	252
1	Test	81	No	22	3	13	58	0	252
2	Test	79	No	13	3	13	68	41	29
3	Test	61	Yes	36	3	10	69	55	112
4	Control	74	No	45	2	10	69	0	29
5	Control	59	No	14	3	10	Missing	Missing	38

*Lekholm and Zarb.[34]
ISQ = implant stability quotient.

significant difference between the groups (see Table 3). Two implants were removed from patient #1. A full-arch prosthesis was built on the remaining study implant with seven previously placed implants. The patient was then excluded from the study. In the other cases, after implant failures, a new implant was placed after appropriate healing in two patients (one in each test group and control group). In one control patient, reoperation was performed; however, also this newly placed implant failed to integrate. Therefore, this patient had the prosthetic construction on two implants. Reoperated sites were excluded for further measurements. All other implants remained stable throughout the first year. The survival rate after 1 year was 94.9% in the test group and 97.2% in the control group.

RFA

In the control group, the mean ISQ increased slightly up to 2 weeks; thereafter, it decreased to its lowest point at 4 weeks. In the test group, a slight mean ISQ increase was observed at 2 days followed by a slight decrease at 2 weeks and a slight increase at 4 weeks, roughly the same level from surgery to 4 weeks. Thereafter, the ISQ increased with the same pattern in both groups. Higher ISQ was found in the control group throughout the first year – significantly higher only at 2 and 4 weeks (Figure 5). In three test patients, four implants showed lowered ISQs after 2 to 4 weeks and were unloaded. Thereafter, ISQs improved, which allowed loading within 3 to 4 months. These implants were included in the statistical analyses.

Prosthetic Treatment and Follow-Up Events

The final prosthesis comprised three units in 28 patients and four units in 22 patients. Six patients received a bridge with a cantilever unit. Figure 6 displays technical complications up to 1 year; they were mainly uncomplicated and easy to solve. Minor porcelain chipping was observed, but few needed repair by a dental technician. Other complications were mostly treated chair side.

Marginal Bone Loss

Two hundred sixty out of a total of two hundred eighty-eight implant sides (one hundred forty-four implants) were eligible for evaluation of marginal bone loss. After 1 year, bone loss was, on average, 1.32 mm (SEM = 0.08) and 1.25 mm (SEM = 0.08) in test and control groups, respectively, with no significant intergroup difference. Analyses of both groups revealed significantly larger mean bone loss at implants without abutment compared with implants with machine-milled or TiUnite™ abutments (Table 4). When analyzing the groups separately, significantly larger bone loss was found in the test group at implants without abutment compared with implants with a machine-milled abutment. In the control group, mean bone loss was 0.44 mm larger at implants without abutment compared with implants with an abutment and slightly beyond statistical significance ($p = .054$ and .056, machine-milled and TiUnite™ abutments, respectively).

In the control group, significantly larger bone loss occurred between surgery and start of loading (1.06 mm [0.09]) than between start of loading and 1 year (0.20 mm [0.07]) ($p < .05$). Another analysis compared bone loss around implant sites facing a tooth, an implant, or none. No significant within-group or intergroup differences were found.

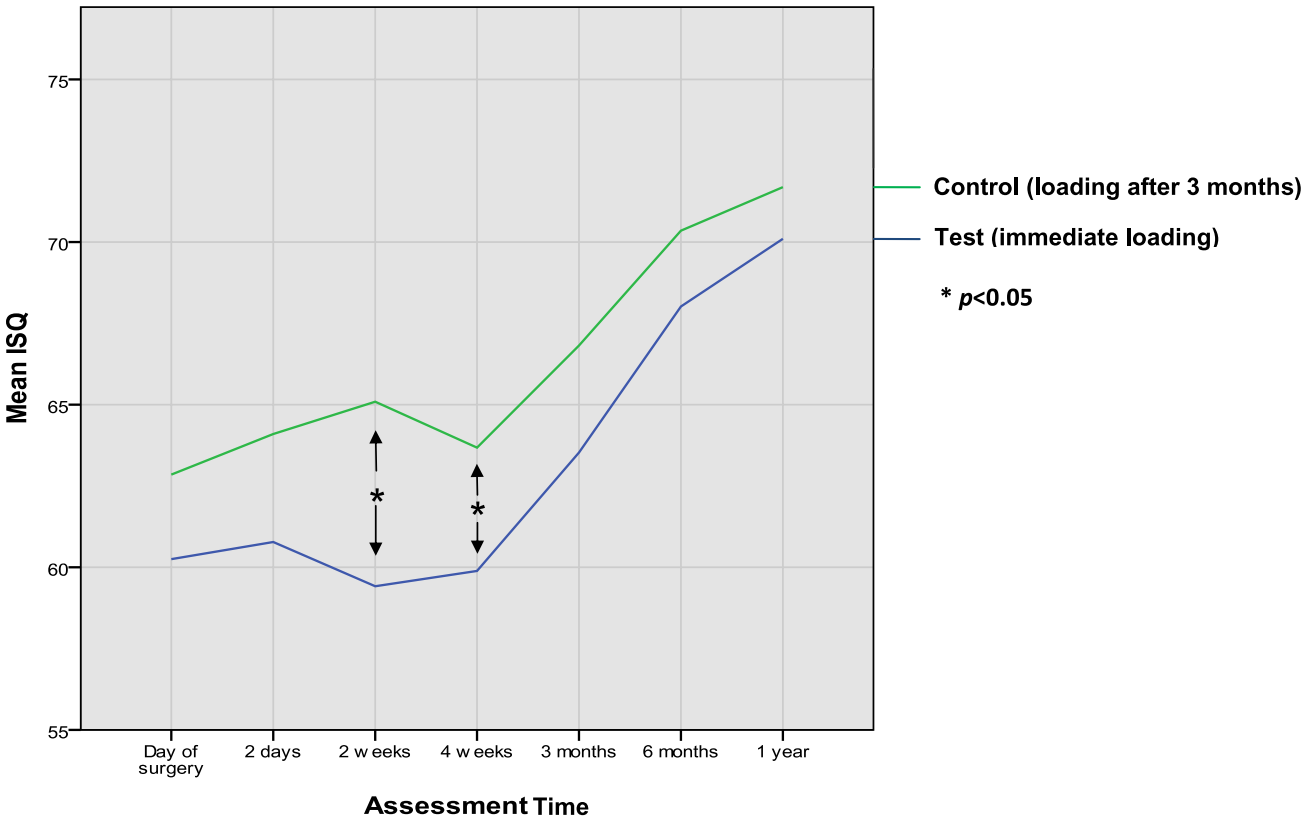

Figure 5 Mean implant stability measurements (implant stability quotient [ISQ]) during follow-up.

Regression Analyses

Regression analyses on test and control data (pooled, data not shown), which used implant failure and marginal bone loss as dependent variables, could not demonstrate any correlation to bone quality, resorption, or crest width. Accordingly, the ISQ as measured during surgery and follow-up was not found to correlate to the dependent variables. Medical status, smoking habits, periodontal disease experience, and bone enhancement procedures did not correlate to these outcomes. The ISQ at surgery showed a highly significant correlation to assessments of bone quality and degree of resorption ($p < .0001$ and $p < .01$, respectively).

DISCUSSION

This study found no greater loss of immediately loaded implants than those conventionally loaded. This finding is aligned with recently published reports of immediate implant loading in partially edentulous individuals.[35–37] However, in some cases, decreased implant stability (as indicated by a decreased ISQ) rendered unloading. Most likely, this action stabilized these implants and contributed to the comparable survival rates between the groups. Calandriello and Tomatis[38] described a similar approach in a 5-year study on posterior single implants. Other authors[39–41] reported high survival rates with a more aggressive approach – not unloading questionable implants as done in this study or having all suprastructures in full function during the course of the study.[42] However, in the study of Cannizzaro and colleagues,[42] soft bone rendered secondary exclusion from the study. This highlights the importance of high initial primary stability for survival of immediately loaded implants.

Results from this 1-year prospective study in the control group show that most marginal bone loss observed around implants occurred during the early follow-up phase, in accordance with reports by Åstrand and colleagues.[43,44] In the control group, significantly greater bone loss was found between implant placement and start of loading than afterward (3 months to 1 year). The reason for this initial loss relates to the surgical trauma and subsequent wound healing and bone adaptation or remodeling.

In general, bone quality type 4[34] has been shown to correlate with implant failure.[45] Furthermore, it has

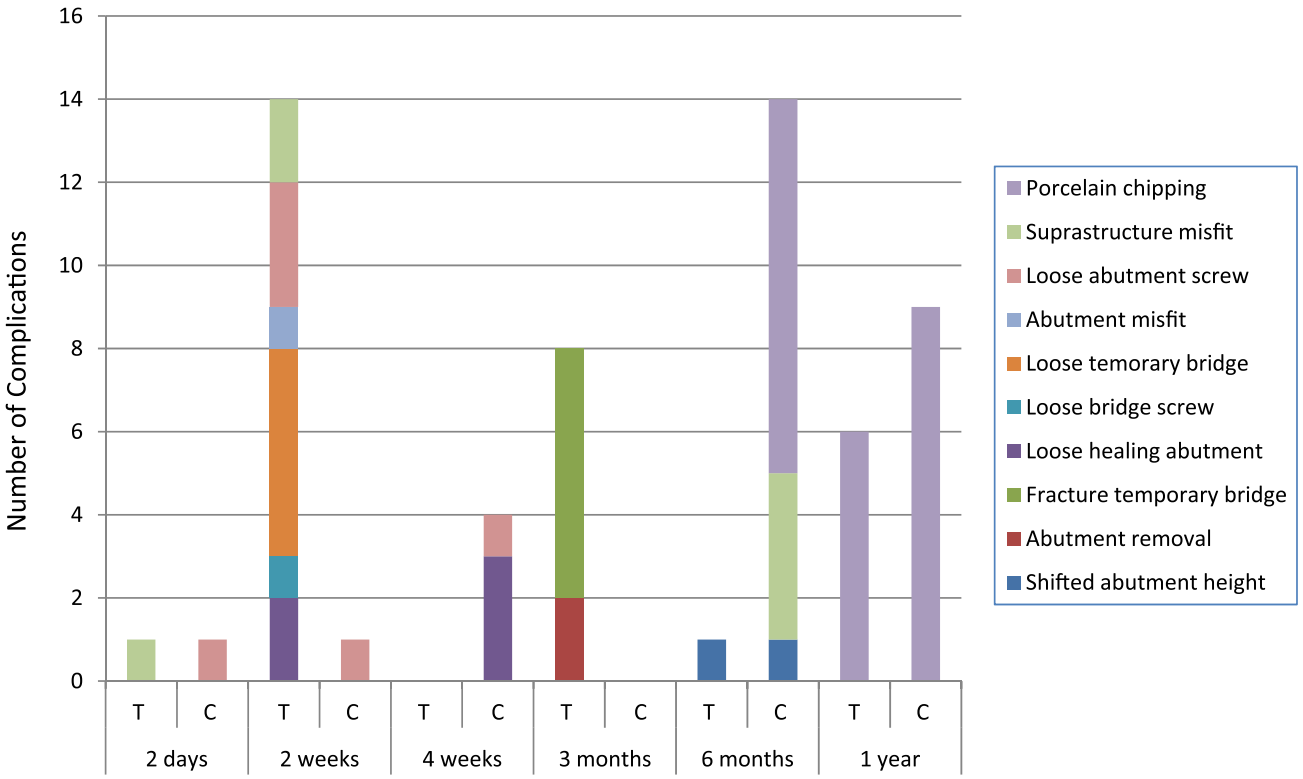

Figure 6 Technical complications from day 2 to 1-year examination. (T = test. C = control.)

been shown that the criteria of Lekholm and Zarb are related to other criteria such as insertion torque values and RFA.[46] In this study, the most common bone volume was A or B. Bone quality was mostly 3, while 15% type-4 sites were recorded (see Table 2). No implants were lost in these sites. None of these parameters correlated to implant failure or marginal bone loss. Some authors have shown that it is difficult to surgically discriminate between type-3 and type-4 bones,[47] which may explain why our findings deviate from the study of Herrmann and colleagues.[45] In implant surgery protocols, a 5- to 6-mm bone crest width is commonly claimed to be needed to avoid jeopardizing nutrition of bone surrounding an implant, which further leads to marginal bone loss. In this study, the average crest width was well above 6 mm, which might explain the absence of correlation to implant failure or marginal bone loss. Further studies are needed to clarify the lower threshold of bone width that is needed to keep marginal bone surrounding an implant.

TABLE 4 Mean (Standard Error of the Mean) Marginal Bone Loss at Implant Sides in Millimeter from Surgery to 1 Year with Regard to Suprastructure Connection

	No Abutment	Abutment (Machine Milled)	Abutment (TiUnite™)	Total
Test	1.65 (0.12)	0.97 (0.17)	1.32 (0.13)	1.32 (0.08)
(*n*)	*(48)*	*(43)*	*(44)*	*(135)*
Control	1.54 (0.12)	1.10 (0.14)	1.10 (0.13)	1.25 (0.08)
(*n*)	*(43)*	*(41)*	*(41)*	*(125)*
Total	1.60 (0.08)	1.04 (0.1)	1.21 (0.09)	
(*n*)	*(91)*	*(84)*	*(85)*	

* $p < .05$; ** $p < .01$; *** $p < .001$.
n = number of mesial and distal implant sides eligible for analysis.

RFA has been thoroughly studied and validated to removal torque testing in in vitro and animal models and extensively used in clinical studies (for review, see Sennerby and Meredith[48]). In this study, the mean ISQ decreased between 2 and 4 weeks in the control group, while the mean ISQ in the test group was roughly the same from surgery until 4 weeks postoperatively with a significantly lower ISQ in the test group at 2 and 4 weeks. Both groups showed improving stability thereafter. As mentioned above, some implants showed a lowered ISQ during initial healing. Unloading these implants subsequently improved the stability, which demonstrates the benefits of RFA, especially when performing immediate and early implant loading or treating compromised implant cases.[49,50] The dip in implant stability in the first postoperative weeks is most likely related to inflammatory, resorptive, and remodelling activities during healing, as demonstrated in different animal models.[51,52] As judged by the decreasing ISQ values in the test group from 2 days to 2 weeks, immediate loading seems to act in concert with the biological activities that prolong the period of low stability. Although new implant surface and chemistry designs have shortened and improved osseointegration, the initial implant stability dip is still present and remains a challenge for future research and development.

Significantly greater bone loss was found at implants with no abutment than at implants provided with abutments (irrespective of abutment surface topography) when test and control group data were pooled (see Table 4). The same difference was found in the test group when comparing implant level and machine-milled abutment level. To our knowledge, this study is the first to report that abutment use reduces the risk for bone loss for this implant system. However, longitudinal observations are desired to analyze if the exclusion of abutments represents a true risk factor for marginal bone loss in the long term. Biomechanically, loading an implant without an abutment may cause higher stress peaks in the bone-implant interface, which results in bone resorption.[53] From a biological view, excluding abutments may cause a potential microbial challenge at the suprastructure-implant interface close to the bone, which leads to inflammation and bone resorption.[54,55]

Schupbach and Glauser[8] compared the machined, acid-etched, and oxidized implants in a human histologic study. They found connective tissue fibers obliquely orientated in the apical portion around oxidized implants only. This implies a strengthened mucosal attachment that may prevent bacterial colonization and subsequent marginal bone loss. On the contrary, some experimental animal studies suggested that an oxidized (TiUnite™) implant surface may result in faster marginal bone loss.[56] Our study failed to support the findings both by Schupbach and Glauser[8] and Albouy and colleagues[56] in that no difference on marginal bone loss could be demonstated between machine-milled and TiUnite™ abutments. However, it may be that a study period of 1 year is too short to reveal such bone loss. Sites compromised by bone loss related to surgical factors (e.g., trauma, overheating, and bone compression), site factors (e.g., compact bone, thin bone, or poorly vascularized bone), or patient-related factors (e.g., health status and smoking) may be more sensitive to progressive bone loss if the contiguous implant surface is designed with a degree of surface roughness.

The bone-tissue alteration pattern did not vary among tooth-implant, interimplant, and implant-edentulous proximal sites. Chang and Wennström[57] found lower marginal bone loss after 3 years of loading at implant sites facing a tooth than at sites facing a neighboring implant in a study on marginal peri-implant-bone reactions around conventionally loaded fixed partial dentures. Varying outcomes between our studies are currently difficult to explain. It may be that such variation will develop after loading periods longer than 1 year. It is well known that implant-supported prostheses generate more technical complications than tooth-supported prostheses.[58,59] Svensson and Trulsson demonstrated that the absence of mechanoreceptors in the peri-implant bone results in inadequate sensory information for both low-contact and high-biting forces, which in turn may lead to damage.[60] Early technical complications in the test group may be related to difficulties in handling the prosthetic interventions in a newly operated area. In general, the technical complications in this study were mainly of less severity and were easy to solve (see Figure 6). Minor porcelain chipping was observed in both groups in the later follow-up phase. An explanation for this complication may be technical difficulties associated with porcelain fusing to titanium core.[61] However, we used CNC-milled cores and it may be assumed that this technique facilitated porcelain fusing. On the other hand, dental technology

is dependent on the individual technician's skill for handling of materials and technology.

Most implants in this study were placed in the posterior maxilla, which represents a vulnerable position that is exposed to high occlusal and lateral forces.[62] The suprastructures were designed with freedom-in-centric and avoided steep cuspal inclinations and extreme lateral contacts. These measures of precaution were most likely beneficial to the study outcome.

While having sufficient power, this study was run on a limited number of individuals. Experienced clinicians treated well-maintained patients, and a strict follow-up maintenance protocol was used, which most likely affected the successful results. Therefore, before general recommendations can be made, further study with larger cohorts and multicenter approaches is desired. In addition, longer follow-up times are needed to reveal if the reported differences in marginal bone loss will change in the long term.

CONCLUSIONS

This study showed similar survival rates for immediate and delayed loading of implants in partially edentulous patients after 1 year. Similar marginal bone level changes were found for both groups. Higher marginal bone loss was found at implants loaded without an attached abutment.

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