RETROSPECTIVE CLINICAL EVALUATION OF TAPERED SCREW-VENT IMPLANTS: RESULTS AFTER UP TO EIGHT YEARS OF CLINICAL FUNCTION

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Uncertainty about the causes of peri-implant bone loss and difficulties in measuring it often have resulted in omission of bone loss data from published long-term implant studies. This nonrandomized, uncontrolled, retrospective study evaluated the clinical outcomes of treatment with tapered, multithreaded implants with a special emphasis on peri-implant crestal bone status. Chart reviews were conducted of 60 patients who had been treated with 267 implants for the placement of 1 or more missing and/or unsalvageable teeth, and who met general inclusion criteria for dental implant therapy. In all cases, marginal bone changes were calculated from the cementoenamel junction (CEJ) or the implant neck to the crestal bone level with standardized radiographs taken at implant placement (baseline) and during annual follow-up. After a mean follow-up of 7.5 years, implant survival was 98.5% (263/267) for all implants placed, and implant success was 96.2% (253/263) for all surviving implants. No discernible bone loss was evident in 88% of surviving implants. Crestal bone loss was observed in 25% (15/60) of total study subjects and in 12% (32/263) of all surviving implants: 29 implants exhibited 1 mm of bone loss and 3 implants lost 2 mm of bone. Low-density maxillary jawbone and more extensive bone remodeling, which were required around implants immediately placed into extraction sockets, were the probable causes of observed bone loss in this study. Implants exhibited excellent long-term outcomes with little or no bone loss.

Key Words: bone loss, implants, density, extraction sockets

INTRODUCTION

Since the developmental period of modern implant dentistry, the general clinical assumption has been that surgical insult and subsequent bone remodeling would inevitably result in "saucerization" and sometimes in additional bone loss around the cervical region of the implant. The overriding clinical question, therefore, was not whether bone loss would occur, but how much bone loss should be considered normal and acceptable. Since the 1970s, the definition of acceptable crestal bone loss has evolved from "not more than one third of the peri-implant bone height"[1] for blade implants to "$<$1 mm during the first year of functional loading followed by $<$0.2 mm per year thereafter"[2] for root-form implants. It should be noted that calculations for root-form implants traditionally have discounted any bone level changes that occurred during the submerged healing period of the 2-stage surgical technique because such bone loss was deemed inevitable.

The attempt to precisely quantify crestal bone loss has been a clinical challenge because clinicians must rely on secondary assessment methods that are less

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invasive and less precise than direct histologic measurement. For example, Isidor[3] found that probing depth values were 1.1 to 3.9 mm shorter, and radiographic assessments of crestal bone levels were 0.5 to 0.1 mm shorter, than actual direct bone measurements. Although the accuracy of radiographic assessments has improved through the use of standardized imaging techniques and digital enhancement technologies, lingual, palatal, and buccal surfaces are obscured by the implant, and small incremental bone changes (eg, $<$0.2 mm per year[2]) in the distal and mesial regions that are visible on radiographs have traditionally fallen within the standard deviation (0.01–0.51 mm) of computer-assisted measurement systems, which adds a margin of error in assessing losses that are less than 1 mm.[4] Research[5] in 3-dimensional imaging technologies may one day provide clinicians with a safe and effective modality that can be used routinely for evaluating the full range of marginal bone changes around dental implants.

The causes of peri-implant bone loss are complex and are only partially understood. Surgical trauma,[6–15] occlusal overloading,[6,16–19] and bacterial infection[6,20–24] have been extensively debated for several decades as possible causes of crestal bone loss and implant failure. Disruption of the vascular network through elevation of the mucoperiosteum during surgery has been attributed to approximately 1 mm of peri-implant bone loss or saucerization that traditionally has been reported to occur around the cervical ends of implants at stage 2 surgery, but this hypothesis is not universally supported because similar saucerization does not appear around natural teeth after soft tissue elevation for osseous surgery.[25]

A prospective study conducted by the US government measured the residual facial plate thickness of more than 3000 implant osteotomies.[26] Researchers found that peri-implant bone loss decreased and some evidence of bone gain was observed as the residual facial bone plate approached 1.8 to 2 mm in thickness, but a decrease in facial plate thickness to below this range resulted in a corresponding increase in facial bone loss and implant failure.[26]

Implant placement in lower-density bone, such as the maxillary jaw, and alcohol and tobacco use by patients also have been associated with increased peri-implant bone loss in the dental literature.[27,28] Truhlar and associates[29] evaluated clinician estimates of bone density during osteotomy preparations for 2839 implants placed in a prospective, multicenter study. The highest bone density was reported to be located in the anterior mandible, followed by decreasing bone density in the posterior mandible, anterior maxilla, and posterior maxilla, respectively.[29] Using finite element analysis (FEA), Petrie and Williams[30] examined peri-implant crestal and cancellous bone strains in relation to bone properties and loading conditions. In cancellous bone models with a lower range of Young's modulus values, 50% of patients experienced hyperphysiologic peri-implant crestal strains in the region where saucerization of the peri-implant crestal bone is commonly reported.[30] Within the higher range of Young's modulus values, however, excessive bone strains were present in only 25% of cancellous bone models.[30]

In an attempt to reduce stress concentrations in the crestal bone region, some manufacturers have added cervical microthreads to their implant designs. Although adequate, prospective, comparative research data are lacking, short-term results have been mixed,[31,32] and long-term results[33] suggest that any possible benefit of cervical microthreads may disappear after 5 years in function. It is currently unknown whether the perceived benefits of cervical microthreads will outweigh the potential hygiene risks of thread exposure should bone recession occur.

Longitudinal outcome studies of implants placed in patients with periodontitis have reported mixed outcomes pertaining to bone loss and implant survival, but data remain limited. In a systematic literature review of 13 studies that reported bone level changes during more than 5 years of clinical follow-up, Van der Weijden and colleagues[34] concluded that the outcomes of implant therapy in patients with periodontitis may be different in terms of bone loss and implant survival as compared with outcomes in patients without a history of periodontal disease.

Concern about possible bacterial colonization of the implant-abutment microgap within the biologic width has led some clinicians to advocate moving the microgap away from the outer circumference of the implant with the use of an abutment that is smaller in diameter than the implant itself (platform switching). Maeda and coworkers[35] used FEA to evaluate whether platform switching provided any biomechanical advantages and found that it helped to shift the stress concentration area away from the cervical bone-implant interface, but it increased stress in the abutment screw and/or the abutment body. Excessive occlusal stresses directed at the abutment fixation screw have been cited as a leading cause of screw loosening.[36] If left untreated, abutment screw loosening can potentially lead to bone loss, component breakage, and even implant failure.

Todescan and colleagues[37] evaluated the influence of the implant-abutment microgap on peri-implant

tissues in the mandibles of 4 canines. Researchers placed implants and abutments ($n = 24$) in matching diameters 1 mm above, 1 mm below (countersunk), and level with the crestal bone.[37] Standard abutments were placed on the implants after a 3-month nonsubmerged healing period, and the animals were allowed to function for 3 months before sacrifice.[37] Histologic evaluation revealed that placing the implant-abutment microgap deeper within the bone did not result in additional bone loss, and that implants with countersunk microgaps had the least bone loss of the 3 study groups.[37] In humans, results of comparative short-term clinical studies have been mixed regarding the clinical efficacy of platform switching,[38,39] and long-term comparative data are needed before definitive conclusions can be drawn to adequately support evidence-based treatment planning.

Contemporary dental implant studies generally exclude data on peri-implant marginal bone changes because of uncertain origins and the complexities associated with obtaining and evaluating standardized radiographs. Consequently, long-term data on peri-implant marginal bone changes are currently lacking. This article reports on a long-term, retrospective clinical evaluation of tapered, multithreaded implants after 7 years of clinical function, with special emphasis on peri-implant crestal bone status.

Materials and Methods

This nonrandomized, uncontrolled, retrospective study examined the clinical outcomes of tapered, multithreaded implants with microtextured surfaces (Tapered Screw-Vent MTX, Zimmer Dental Inc, Carlsbad, Calif) placed in 2 private dental practices. Retrospective chart reviews were conducted of all patients who presented for treatment for 1 or more missing and/or unsalvageable teeth, and who met general inclusion criteria for dental implant therapy (Table 1).

All patients were subjected to a preliminary evaluation that included careful review of their medical and dental histories, detailed clinical and radiographic examinations, evaluations of oral hygiene, and assessment of their ability to commit to long-term follow-up. A diagnostic workup was performed to evaluate the volume and location of available bone and the esthetic and functional needs of the patient relative to his or her expressed desires. A study cast was fabricated and was mounted on a semiadjustable articulator with a face bow transfer and vertical registration to determine the jaw relationships, available occlusal dimension, proposed implant position(s), crown-root ratio, and potential complications. This allowed creation of a prosthetic wax-up and fabrication of a surgical template to guide placement of the implants relative to the planned prosthesis. The treatment plan and alternative options were discussed, and signed informed consent was obtained from each patient, prior to treatment.

Patients were instructed in the use of chlorhexidine digluconate for the chemical control of plaque, which commenced 3 days prior to surgery and continued for 10 days postoperatively. Antibiotic prophylaxis involved daily administration of 2 g of amoxicillin and clavulanic acid, beginning 2 hours before surgery and continuing for 5 days thereafter. On the day of surgery, the patient was anesthetized via local infiltration in the maxilla, inferior alveolar block in the mandible, or general sedation, depending on the desires of the patient and the preferences of the clinician. In some cases, midcrestal and terminal vertical releasing incisions were made, followed by elevation of a mucoperiosteal flap that was kept small to preserve the periosteal vascular supply. In other cases, drilling was performed directly through the soft tissue without incisions or flap elevation, to facilitate healing and minimize invasion, pain, edema, bleeding, and hematoma associated with conventional implant placement, and to preserve the existing vascular network and soft tissue architecture. For patients who required extraction, a gentle avulsion technique was used to minimize trauma to surrounding tissues, and the sockets were thoroughly debrided. Osteotomies were prepared with the aid of a surgical template, and implants were placed in accordance with the manufacturer's protocol. In cases in which implants were placed into fresh extraction sites, coronal gaps greater than 1 mm were grafted with autogenous bone or β-tricalcium phosphate mixed with blood and covered with a resorbable barrier membrane (BioMend, Zimmer Dental Inc). Some implants were subjected to delayed loading after a conventional submerged healing period; other implants were loaded immediately with provisional restorations.

Marginal bone changes were calculated from the cementoenamel junction (CEJ) or the implant neck to the crestal bone level with the use of standardized radiographs taken at implant placement (baseline) and during annual follow-up. A transparent implant template with a 1.0-mm grid that was 25% enlarged to help compensate for radiologic distortion was placed over each radiograph to calculate marginal bone changes relative to the top of the implant.

TABLE 1

Criteria for implant treatment

Inclusion	At least 18 years of age
	Adequate available bone to accommodate an implant
	Systemically and dentally healthy
	Demonstrated ability to maintain oral hygiene
	Willingness and ability to commit to follow-up
	Provided signed informed consent
Exclusion	Lack of skeletal maturity
	Ridges that required significant augmentation for implant site development
	Uncontrolled diseases or conditions that could impede bone healing or soft tissue health
	Mental, emotional, or lifestyle factors that could adversely affect treatment and follow-up

Because of difficulty in measuring slight variations and an inability to control for exact radiologic distortion with this technique, bone loss was recorded in incremental ranges of 0 to 0.5 mm, 0.5 to 1 mm, 1 to 1.5 mm, 1.5 to 2 mm, and >2 mm.

At annual prophylaxis appointments, data were recorded on how the implants were performing. Plaque, gingival depth, and probing depth indices were used as references for monitoring the health of the peri-implant mucosa. Crevicular depth measurements were taken of the mesial, distal, lingual, and buccal sides with the use of a periodontal probe (Hu-Friedy, Chicago, Ill). Implant-related problems were treated, and failed implants were removed and were recorded in the database as failures. Patients were subsequently treated outside of the study for failed implants.

Survival and success criteria

Table 2 summarizes criteria used for evaluating implant clinical survival and clinical success. Survival meant that an implant was immobile when manually tested, did not exhibit peri-implant radiolucency, had no irresolvable clinical symptoms or mechanical problems, was clinically intact, and fully met its prosthodontic purpose. All clinically failed implants were removed and were recorded as failures in the database. Patients with failed implants were subsequently treated outside of the study. Implants were considered successful if they met implant survival criteria, had no non–failure-related adverse events, did not have peri-implant bone loss that exceeded 1.5 mm, and met the patient's clinical and esthetic needs and expectations.

Statistical analyses

An indicator of clinical success (absence of bone loss >1.5 mm, absence of non–failure-related adverse events, and absence of implant failure) and a set of 4 independent clinical end points (presence of bone loss, presence of bone loss >1.5 mm, implant failures, and non–failure-related adverse events) were evaluated individually, and findings were summarized in 2 separate analyses at implant and patient levels.

Analyses consisted of univariate tests for association between a series of potentially influential factors with each of the 3 clinical end points. Differences in distribution of dichotomous factors (ie, sex, quadrant, implant diameter, prosthesis loading time, jaw, bone graft use, and immediate loading status) were compared for each end point (present vs absent) with the Fisher exact test. Distributions of polychotomous factors (ie, implant size, health risk[s], tooth replaced, and prosthesis type) were compared for each end point (present vs absent) with the likelihood ratio χ^2 test. Differences in distributions of continuous factors (ie, age, months of prosthesis follow-up, and months of implant follow-up) were compared for each end point (present vs absent) through a comparison of averages with the 2-group Student *t* test. The assumption of the *t* test of equal sample variances at both levels of the study end point was assessed with the use of a folded F-test and a Bartlett test. If assumptions were found to be violated ($P < .05$), then a Wilcoxon nonparametric test was used to compare distributions of continuous variables between levels of the study end point.

Survival of the implant was examined by the Kaplan-Meier method, both at the implant level and at the patient level. Survival was summarized over the first 7 years of follow-up as measured from implantation as a baseline. Survival rates were expressed as the proportion of patients who had not experienced revision at the end of each follow-up interval divided by the number at risk for implant failure during the interval. Implants (patients) were considered as censored in analyses when follow-up ended prior to the 7-year anniversary.

To assess the effects on joints of potentially influential factors, a regression analysis was performed on the study end point that represented *any bone loss,* with any bone loss coded as 1 and the absence of any bone loss coded as 0. Given the coding of the response variable, the fitted model was predictive of a protective effect (absence of any bone loss, where greater odds indicated that bone loss was less likely). A repeated measures logistic model was fit to the dichotomous end point, and model terms represented categorical and continuous factors. The repeated measures model was fit by maximum likelihood with the use of a generalized estimating equation (GEE) approach, and

TABLE 2

Criteria for implant evaluations

Clinical survival	Implant is immobile when manually tested No peri-implant radiolucency No irresolvable clinical symptoms, such as pain, discomfort, numbness, and infection No irresolvable mechanical problems No fractured components Implant is fully functioning according to its intended prosthodontic purpose
Clinical success	Meets implant survival criteria Absence of fractured components Absence of non–failure-related adverse events Peri-implant bone loss does not exceed 1.5 mm Meets the patient's clinical and esthetic needs Meets the patient's expectations Cumulative implant survival is at least 90% after 5 years Cumulative implant success is at least 90% after 5 years

standard errors for model terms were estimated by the robust "sandwich estimator" method.

SAS for the personal computer (version 8.02, SAS, Inc, Cary, NC) was used in all analyses. Descriptive statistics (N, %) for each categorical variable and *P* values from Fisher exact and likelihood ratio χ^2 tests were generated via the FREQ procedure in SAS. Descriptive statistics (N, mean, median, standard deviation, minimum, and maximum) for each continuous variable were generated by means of the Univariate procedure in SAS. Student *t* tests and comparisons of sample variances between levels of each study end point were performed through the TTEST procedure in SAS. Nonparametric comparisons for continuous variables between levels of each study end point were performed with the NONPAR1WAY procedure in SAS. Repeated logistic regression analysis was performed via the GENMOD procedure in SAS, with specification of an exchangeable correlation structure. Kaplan-Meier estimates and corresponding 95% confidence intervals were estimated by means of the LIFETEST procedure in SAS. Statistical significance was inferred at the .05 level, and comparisons were not adjusted for multiplicity.

RESULTS

Patient demographics and implant treatment are summarized in Table 3. A total of 267 dental implants were placed in 60 patients: 176 implants were placed into existing edentulous sites, and 91 implants were placed immediately into fresh extraction sockets. Of 267 implants placed, a total of 4 implants failed (Table 4), which represented 1.5% of the implants placed (n = 4/267) and 7% of the study subjects (4/60). All 4 implants failed before prosthetic loading and were placed in the maxillary jaws of 4 different patients (1 implant failure per patient): lateral incisor (n = 1), cuspid (n = 1), first bicuspid (n = 1), and second bicuspid (n = 1). Three of the failed implants had been placed immediately into fresh extraction sockets and had failed to osseointegrate for unknown reasons; they were removed and the sites were retreated with replacement implants and were successfully restored outside of the study. The fourth implant (the first bicuspid) had been placed into an existing edentulous site and had failed secondary to an infection. The implant was removed, the site was debrided and successfully grafted, and the patient was successfully restored with the remaining surviving implants. All 4 implants were recorded in the database as failures, and the implants were removed from the study (Table 4). The 4 patients continued as study participants because their remaining implants were unaffected by the failures; no patients withdrew from the study.

The 263 surviving implants in all 60 patients were restored with fixed partial dentures supported by 238 implants, single-tooth restorations supported by 18 implants, removable partial dentures retained by 4 implants, and a removable complete denture retained by 3 implants (Table 3). Of these, 40 implants were loaded immediately with nonoccluding provisional prostheses (immediate loading group), and the remaining 223 implants were loaded after osseointegration was clinically confirmed (delayed loading group). Cumulative mean follow-up was 7.5 years (range, 6 to 8.25 years; mode, 6.5 years) for all 263 restored implants.

Cumulative survival rates were 98.5% (n = 263/267) for all implants placed; 99.4% (175/176) for all implants placed into healed edentulous sites; 96.7% (n = 88/91) for all implants immediately placed into fresh extraction sites; 97.7% (n = 169/173) for all maxillary implants; and 100% (n = 94/94) for all mandibular implants. Kaplan-Meier survival estimates at implant and patient levels were 0.98502 and 0.93333, respectively (Table 5).

Peri-implant bone loss (Table 6) was recorded in 12% (n = 32/263) of the implants, which corresponded to 25% (n = 15/60) of study subjects. The 15 patients who constituted the bone loss group were treated with a total of 99 implants; of these, 68% (67/99) exhibited no discernible bone loss. Among 32 implants that sustained crestal bone loss, 91% (n = 29) exhibited 1 mm of crestal bone loss and 9% (n = 3) exhibited 2 mm of bone loss. Success criteria for this

TABLE 3

Distribution of patients and implants

Patients					
Sex (No. of patients)		Health Risks (No. of patients)		Age, Years	
Males (26)	Females (34)	Periodontitis (32)	Smokers (2)	Mean, 53	Range, 18–78

Implants					
Time of Implant Placement*	Implant Diameter	Implant Lengths (No. placed)			
		8 mm	10 mm	13 mm	16 mm
Delayed	3.7 mm	2	26†	99	5
Delayed	4.7 mm	0	17	23	4
Immediate	3.7 mm	0	0	49†	17†
Immediate	4.7 mm	0	7	11†	7

Restorations					
Time of Implant Treatment (No. of implants)		Types of Restorations (No. of implants)			
Time of Implant Placement*	Implant Loading‡	Fixed Partial Denture		Removable Denture	
		Multiple Unit	Single Unit	Partial	Complete
Delayed (176)	Delayed (223)	160	11	2	3
Immediate (91)	Immediate (40)	78	7	2	0

*Time of implant placement: Delayed indicates healed extraction site or existing edentulous site; Immediate, fresh extraction site.
†One implant failed in this group.
‡Time of implant loading: Delayed indicates loaded after osseointegration; Immediate, loaded at time of implant placement.

study (Table 2) stipulated that peri-implant bone loss should not exceed 1.5 mm. Bone loss greater than 1.5 mm was observed in 1% (n = 3/263) of implants, which corresponded to 3.3% (n = 2/60) of study subjects; these implants were listed as unsuccessful (Table 4) but continued to function without additional bone loss or complications and are continuing to be monitored. Bone loss of 1 mm (traditional sauceriza-

TABLE 4

Adverse events*

Patient No.	Location		Implant, mm		Problem Area				
	Jaw	Tooth	Diameter	Length	Impl	Pros	Type	Resolution	Implant Status
4	XR	Lat	3.7	13	Yes	No	FTI 1	NI	Failure
30	XR	2Bi	4.7	13	Yes	No	FTI 1	NI	Failure
39	XL	Cus	4.7	13	Yes	No	FTI 1	NI	Failure
58	XR	1Bi	3.7	10	Yes	No	FTI 2	GS	Failure
	XR	Cus	3.7	10	No	Yes	Cem	RC	Unsuccessful
21	XL	Cus	3.7	13	No	Yes	PF	NC	Unsuccessful
	XR	Lat	3.7	13	No	Yes	PF	NC	Unsuccessful
31	XR	2Mo	4.7	10	No	Yes	PF	NC	Unsuccessful
34	NL	Lat	4.7	16	Yes	No	BL	Monitoring	Unsuccessful
36	XR	Cus	3.7	13	No	Yes	PF	NC	Unsuccessful
	XL	1Bi	3.7	13	No	Yes	PF	NC	Unsuccessful
54	NL	1Mo	4.7	13	No	Yes	CF	NC	Unsuccessful
2	XL	2Bi	4.7	13	Yes	No	BL	Monitoring	Unsuccessful
	NR	1Mo	3.7	13	Yes	No	BL	Monitoring	Unsuccessful

*XR indicates maxillary right; XL, maxillary left; NR, mandibular right; NL, mandibular left; Lat, lateral incisor; Cus, cuspid; 1Bi, first bicuspid; 2Bi, second bicuspid; 1Mo, first molar; 2Mo, second molar; Impl, implant; Pros, prosthesis; BL, bone loss >1.5 mm; FTI 1, failed to integrate, unknown cause; FTI 2, failed to integrate: infection; PF, porcelain fracture; CF, crown fractured; Cem, cement failure; NI, placed new implant; GS, grafted socket; RC, recemented crown; NC, placed new crown.

TABLE 5

Kaplan-Meier (K-M) estimates of implant failure and implant survival

	Implant Level			Patient Level		
Year of Follow-up	No. Failures (No. at risk)	K-M Survival Estimate	95% K-M Confidence Interval	No. Failures (No. at risk)	K-M Survival Estimate	95% K-M Confidence Interval
Year 1	4 (263)	0.98502	(0.9704, 0.9996)	4 (56)	0.93333	(0.8702, 0.9965)
Year 2	0 (263)	0.98502	(0.9704, 0.9996)	0 (56)	0.93333	(0.8702, 0.9965)
Year 3	0 (263)	0.98502	(0.9704, 0.9996)	0 (56)	0.93333	(0.8702, 0.9965)
Year 4	0 (263)	0.98502	(0.9704, 0.9996)	0 (56)	0.93333	(0.8702, 0.9965)
Year 5	0 (263)	0.98502	(0.9704, 0.9996)	0 (56)	0.93333	(0.8702, 0.9965)
Year 6	0 (263)	0.98502	(0.9704, 0.9996)	0 (56)	0.93333	(0.8702, 0.9965)
Year 7	0 (248)	0.98502	(0.9704, 0.9996)	0 (50)	0.93333	(0.8702, 0.9965)
Year 7+	0 (72)	0.98502	(0.9704, 0.9996)	0 (11)	0.93333	(0.8702, 0.9965)

tion) was recorded for 11% (n = 29/263) of all implants placed, which corresponded to 25% of study subjects (n = 15/60). Univariate analyses at the implant level revealed significant differences in distributions of sex (greater prevalence of bone loss in females than males, $P = .04$), implant length (greater prevalence of bone loss in 16-mm implants than in shorter implants, $P = .005$), loading time (greater prevalence of bone loss around implants in the delayed loading group than in the immediate loading group, $P = .03$), jaw (greater prevalence of bone loss in maxillary implants than in mandibular implants, $P = .03$), and anterior vs posterior jaw regions (greater prevalence of bone loss around implants placed in anterior jaw locations than implants placed in posterior jaw locations, $P = .03$).

At the patient level, univariate analyses revealed significant differences in the distribution of health risks (bone loss more prevalent in patients with identified health risks, $P = .03$) and in the numbers of dental implants placed (bone loss more prevalent in patients with 7 or more implants than in those with fewer implants, $P = .003$). No discernible bone loss was found for the remaining 88% (n = 231/263) of all implants placed, which corresponded to 75% of patients (n = 45/60). Because of the low prevalence of excessive bone loss >1.5 mm at implant (n = 3) and patient (n = 2) levels, associations between study variables and excessive bone loss at implant and patient levels were not investigated. The cause of the additional 1 mm of bone loss was not identified.

Prosthesis-related adverse events were observed in 2.7% (n = 7/263) of the implants, which corresponded to 8.3% of study subjects (5/60) (Table 4). Univariate analyses at the implant level revealed significant differences in the distribution of tooth locations (greater prevalence of cuspids with prosthesis-related adverse events than other tooth locations, $P = .05$) and in the distribution of anterior vs posterior regions of the mouth (greater prevalence of anterior restorations with prosthesis-related adverse events than posterior restorations, $P = .04$). At the patient level, univariate analyses revealed no significant differences in the distribution of study variables; this was likely due to the small number (n = 7) of prosthesis-related adverse events.

Clinical success (Table 2) was observed in 96.2% of surviving implants (n = 253/263), which corresponded to 100% of study subjects (60/60). Ten implants were deemed clinically unsuccessful (Table 4): 7 implants sustained prosthesis-related adverse events and each of 3 implants lost more than 1.5 mm of crestal bone (Tables 4 and 6). Univariate analyses at the implant level and at the patient level did not result in the identification of significant differences in the distribution of study variables between implants that were classified as clinically successful and those classified as clinically unsuccessful.

A logistic model for repeated measures (GEE) was used to estimate the odds of any bone loss vs no bone loss for observations at the implant level. Model terms were estimated for sex, jaw quadrant (maxillary left, maxillary right, mandibular left, mandibular right), jaw location (anterior vs posterior), implant size (length and diameter), health risks, delayed vs immediate placement into extraction sites, jaw (maxilla vs mandible), bone graft material (use vs nonuse), loading time (immediate vs delayed), type of prosthesis, and tooth location. Because of paucity in data categories, some variables were recategorized (eg, collapsed into fewer categories). This included implant length (8-mm and 10-mm lengths were combined), health risks (recategorized to none vs any), tooth replaced (collapsed into incisors, cuspids and bicuspids, and molars), and prosthesis type (fixed partial denture vs other).

Significant terms, odds ratios, 95% confidence intervals, and P values obtained from the logistic

TABLE 6

Cumulative crestal bone loss*

Patient		Implant							
				Placement			Restoration		
No.	Health Risks	Length, mm	Diameter, mm	Time	Jaw	Tooth Site	Loading Time	Type	Bone Loss, mm
2	None	13	4.7	I	XL	2 Bi	D	ST	2
		13	4.7	I	XR	1 Bi	D	ST	1
		13	3.7	D	NR	1 Mo	D	ST	2
3	None	13	3.7	D	XR	LI	D	FPD	1
7	None	10	4.7	D	NL	1 Mo	D	FPD	1
		10	4.7	D	NL	2 Mo	D	FPD	1
15	Perio	16	3.7	I	XR	LI	D	FPD	1
17	Perio	16	4.7	D	XL	1 Bi	D	FPD	1
18	Perio	13	3.7	D	XR	2 Mo	D	FPD	1
27	Perio	13	3.7	D	XR	Cu	D	FPD	1
		13	3.7	D	XR	1 Bi	D	FPD	1
29	Perio	13	4.7	I	XL	2 Mo	D	FPD	1
30	Perio	13	3.7	I	XL	2 Mo	D	FPD	1
33	Perio	13	3.7	D	XR	2 Bi	D	FPD	1
34	Perio	13	3.7	I	XR	Cu	D	FPD	1
		13	3.7	I	XR	1 Bi	D	FPD	1
		13	3.7	I	XR	2 Bi	D	FPD	1
		13	3.7	I	XL	CI	D	FPD	1
		13	3.7	I	XL	LI	D	FPD	1
		13	3.7	I	XL	Cu	D	FPD	1
		16	4.7	I	NR	LI	D	FPD	1
		16	4.7	I	NL	LI	D	FPD	2
37	Perio	16	3.7	I	XR	Cu	D	FPD	1
		16	3.7	I	XL	Cu	D	FPD	1
38	Perio	13	3.7	I	XR	Cu	D	FPD	1
		13	3.7	I	XL	LI	D	FPD	1
39	Perio	16	3.7	I	XR	CI	D	FPD	1
		16	3.7	I	XR	LI	D	FPD	1
		16	3.7	I	X L	CI	D	FPD	1
		16	3.7	I	XL	LI	D	FPD	1
		16	3.7	I	NL	2 Mo	D	ST	1
58	Perio	10	3.7	D	XR	2 Bi	D	FPD	1

*Perio indicates history of periodontitis; I, immediate placement into fresh extraction site; D, delayed placement into healed extraction site or existing edentulous site; XL, maxillary left; XR, maxillary right; NL, mandibular left; NR, mandibular right; 1, first; 2, second; Bi, bicuspid; Mo, molar; LI, lateral incisor; CI, central incisor; Cu, cuspid; D, delayed loading after placement until osseointegration was clinically confirmed; FPD, fixed partial denture; ST, single tooth replacement.

(GEE) model are presented in Table 7. After adjustments were made for terms included in the model, results reveal significantly lower odds of bone loss associated with implant length, jaw location, and tooth location. Shorter (8 mm and 10 mm) and medium-sized (13 mm) implants had significantly lower odds of bone loss than did longer implants (16 mm). With respect to the jaw, mandibular implants had significantly lower odds of bone loss than did maxillary implants. Finally, with respect to tooth location, implants placed in incisor locations had lower odds of bone loss than did implants placed in molar areas (which were not statistically significant); cuspid/bicuspid replacements had significantly lower odds of bone loss than did molar replacements. A repeated measures logistic model could not be fit to a dichotomous indicator of bone loss of >1.5 mm because of a limited number of implants ($n = 3$) and patients ($n = 2$) with bone loss beyond the 1.5-mm threshold. Similarly, a repeated measures logistic model could not be fit to a dichotomous indicator of clinical success because of a limited number of implants ($n = 10$) that were not classified as clinically successful (Table 4).

DISCUSSION

To assess the complex host of variables that affected the long-term outcomes of implants in this study, data were analyzed on a per-implant and a per-patient basis. Selected statistical analyses were designed to investigate the relationships between variables, and to

TABLE 7

Fit of repeated measures (GEE) logistic model of no bone loss: implant level data

Model Term	Contrast	Odds Ratio	95% Confidence Interval	*P* Value
Implant length	8 mm and 10 mm vs 16 mm	5.7	(1.4, 23.5)	.02
	13 mm vs 16 mm	3.8	(1.5, 10.1)	.007
Jaw	Mandible vs maxilla	3.2	(1.1, 9.2)	.03
Tooth replaced	Incisor vs molar	3.4	(0.6, 19.6)	.17
	Cuspid/Bicuspid vs molar	3.7	(1.4, 10.0)	.01

determine whether observed differences were statistically significant. Although implant survival and implant success rates often tend to slowly decline after 5 years in function, this trend was not observed in the present study. The 4 recorded implant failures occurred during the initial postoperative healing phase prior to prosthetic loading, and prosthodontic complications were clustered within the first year after loading. Clinical outcomes of 98.5% survival and 96.2% success for 267 implants after 5 years of clinical follow-up significantly surpassed the success criteria for this study (Table 2). One failure was caused by infection, but the 3 other implants failed to osseointegrate for unknown reasons. Other implants placed at the same time and in the same patients successfully osseointegrated and were restored. Implants placed into immediate extraction sockets had a 3.7% higher failure rate compared with implants placed into existing healed edentulous sites.

The finding that 88% of surviving implants exhibited no discernible peri-implant bone loss was also an excellent outcome; however, the question remains as to why the remaining 12% of implants exhibited any bone loss at all. The presence of circumferential microgaps around the cervices of implants at the time of placement into extraction sockets may account for most of the implants (29/32) that exhibited the traditional 1 mm of saucerization; however, 3 implants (3/32) lost 2 mm of bone. Although bone density, facial plate thickness, and alcohol use associated with crestal bone loss in the dental literature were not monitored, 81% (n = 26/32) of implants with bone loss in the present study were placed in maxillary jaws. Lower bone density may thus have been a contributing factor to observed bone loss. Although 12 of 32 patients with bone loss had a history of periodontitis, 20 patients with a similar history in this study exhibited no peri-implant bone loss; therefore, no inferences can be drawn regarding the influence of past periodontal disease on crestal bone loss.

Implants used in this study featured a 1-mm turned (machined) cervical collar above their microtextured surfaces. Although short-term clinical studies have demonstrated increased bone attachment to roughened surfaces as compared with machined surfaces,[40,41] no studies were identified that clinically demonstrated the ability of roughened surfaces to prevent crestal bone resorption. Conversely, implants with fully roughened cervical collars[42] have resulted in short- and long-term peri-implant bone loss rates comparable with those of conventional machined titanium implants: approximately 1.2 mm from placement to the first year of clinical loading, followed by approximately 0.2 mm of bone loss thereafter until steady state is achieved.[43–44] On the basis of these findings, it is doubtful that the 1-mm machined cervical collar contributed to observed crestal bone loss in the present study.

CONCLUSIONS

Implants exhibited excellent long-term outcomes with little or no bone loss.

NOTE

The authors claim no financial interest in any of the products mentioned in this article.

ACKNOWLEDGMENTS

The authors thank Daniel P. Reyner, MS, DrPH, of Zimmer Inc (orthopaedics division), for the statistical analyses, and Michael M. Warner, MA, of Zimmer Dental Inc, for assistance with medical writing.

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