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CLINICAL RESEARCH

Retrospective analysis of porous tantalum trabecular metal–enhanced titanium dental implants

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ABSTRACT

Statement of problem. The design of porous tantalum trabecular metal–enhanced titanium (TM) dental implants promises improved osseointegration, especially when grafting materials such as demineralized bone matrix are used; however, studies are lacking.

Purpose. The purpose of this retrospective study was to compare TM implants with conventional titanium alloy (Ti) implants with and without demineralized bone matrix in terms of peri-implant bone remodeling in the first year after implant loading.

Material and methods. A chart review was used for all patients receiving Tapered Screw-Vent Ti and TM implants. Implants were placed and restored by a single provider between 2011 and 2015. Peri-implant bone remodeling was compared by using a paired *t* test (α=.05).

Results. A total of 82 patients received 205 implants, 44 TM and 161 Ti implants (control). No implants failed in the TM group (survival rate of 100%), and 3 implants in total, 1 immediate, failed in the Ti groups (survival rate of 98.1%). TM implants exhibited a 0.28-mm bone gain on average, whereas the control group demonstrated 0.20 mm of marginal bone loss after the first year of implant loading. Multivariate logistic regression analysis demonstrated that the odds of having bone loss was 64% less (odds ratio: 0.36; 95% confidence interval: 0.14-0.94) in the TM group than in the Ti group after controlling for bone grafting, implant location, immediate placement, bone type, and pretreatment bone level.

Conclusions. TM implants exhibited less peri-implant bone loss than the control Ti implants. (J Prosthet Dent 2019;121:404-10)

The success of modern dental implants depends on improving bone-implant contact or osseointegration. Improving bone-implant contact can be accomplished by roughening the implant surface or fabricating a porous implant surface. The concept of incorporating 3-dimensional porous structure into implant fixtures is not new, with porous tantalum trabecular metal (PTTM) being first introduced into the orthopedic field in the early 1990s.[1] The porous scaffold of vitreous carbon was coated with tantalum to give the material a compressive strength and elastic modulus close to that of the native surrounding bone, and, at the same time, allowed neovascularization, bone ingrowth, and bone on-growth. This 3-dimensional osseointegration concept is known as osseoincorporation.[1]

Recently, PTTM has been incorporated into conventional dental implants. PTTM-enhanced titanium alloy (Ti) implants, known commercially as Trabecular Metal or TM dental implants (Zimmer Biomet Dental Inc), have shown promising results when immediately loaded[2] and have also been suggested for use in compromised bone and in conjunction with bone regeneration.[3] The design for TM dental implants has the PTTM portion in the middle third of the implant, while the apical and cervical

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Clinical Implications

TM implants may be appropriate for implant sites requiring bone augmentation. TM with and without demineralized bone matrix may prevent peri-implant bone loss. Demineralized bone matrix may improve bone augmentation regardless of implant types.

thirds of the implant are of titanium alloy similar to the conventional Tapered Screw-Vent design implants (Fig. 1).[1] The Ti screw-type design of the TM dental implants facilitates the surgical and prosthetic protocols, while the PTTM portion of the implant increases the implant-bone contact by approximately 80%.[4,5] This increased implant bone contact and osseoincorporation should improve the long-term clinical outcome. Studies comparing TM dental implants with conventional Ti alloy implants in terms of initial peri-implant bone remodeling are limited.

A retrospective study demonstrated promising results when using TM dental implants in conjunction with guided bone regeneration for immediate implant placement.[6] Recent clinical reports have proposed the use of demineralized bone matrix (DBM) putty (Puros DBM Putty; Zimmer Biomet Dental Inc) in conjunction with implant placement.[3,7,8] DBM putty has been advocated for its osteoinductive and osteoconductive properties provided by intrinsic growth factors, such as bone morphogenic proteins and collagen matrix scaffold.[9,10] DBM has also demonstrated good clinical outcomes for socket preservation.[11] DBM has been used widely in clinical practice; however, little is known about the clinical outcome of DBM when used with dental implant placement,[8] especially with TM implants.[3]

In the present study, TM implants were retrospectively examined and compared with Titanium alloy (Ti) implants, examining the survival rates and the clinical bone loss after loading. The study also examined the clinical effects of DBM when used with implant placement. The research hypotheses tested were that, when compared with Ti implants, the TM implants would show less bone loss after the first year of implant placement and would show more bone gain with DBM grafting.

MATERIAL AND METHODS

The protocol for this retrospective chart review was approved by the University of North Carolina Office of Human Research Ethics (IRB 15-3099). To be included in the study, the following inclusion criteria needed to be met: patient received either Zimmer TM implants (TM group) or Zimmer Tapered Screw-Vent implants (Ti group) and had restorations completed between January 2011 and December 2015. These implants were placed with or without DBM (Poros Demineralized Bone Matrix Putty with Bone Chips; Zimmer Biomet Dental Inc). The Ti implants were used before the commercial availability of the TM implants, and after TM implants became commercially available, they were often prescribed for immediate implant placement and implant placement with grafting such as for a peri-implant defect or crestal sinus lift. The patient had to be at least 18 years old and in good health (American Society of Anesthesiologists classification 1 or 2). Figure 2 demonstrates a summary of the treatment protocol. Implants with other types of bone grafting (non-DBM) or those using a barrier membrane were excluded. All surgery and prosthodontic treatment procedures were performed by 1 practitioner (S.B.).

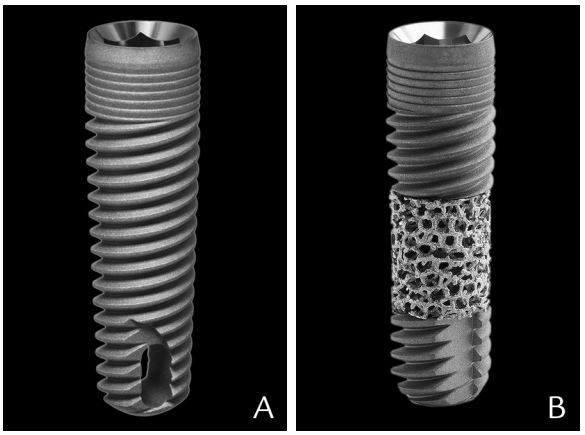

Figure 1. Dental implants evaluated. A, Titanium alloy tapered screw-vent implant (Ti). B, Porous tantalum trabecular metal–enhanced titanium (TM) dental implant.

The charts were reviewed by 3 investigators (A.R.E., R.K.A., C.J.G.) independent of the practitioner. The following patient demographic information was obtained: age, sex, race, and ethnicity. For each implant, the investigators documented the implant diameter and length, implant location, implant placement type (delayed or immediate placement), grafting materials if used, as well as clinical complications (delayed healing, postoperative pain or discomfort, and prosthetic complications).

Mesial and distal marginal bone loss was determined from periapical radiographs made at each treatment and recall visit (Fig. 3). The periapical radiographs were analyzed using MiPACS Enterprise Viewer v3.1.1404 software (Medicor Imaging). The long axis of the implant and the known length of the implant were used to calibrate the magnification of the radiographs and calculate the bone loss/gain in millimeters. However, owing to the retrospective nature of the study, only standardized digital radiographs with XCP Rinn were used. Peri-implant bone levels were determined in conjunction

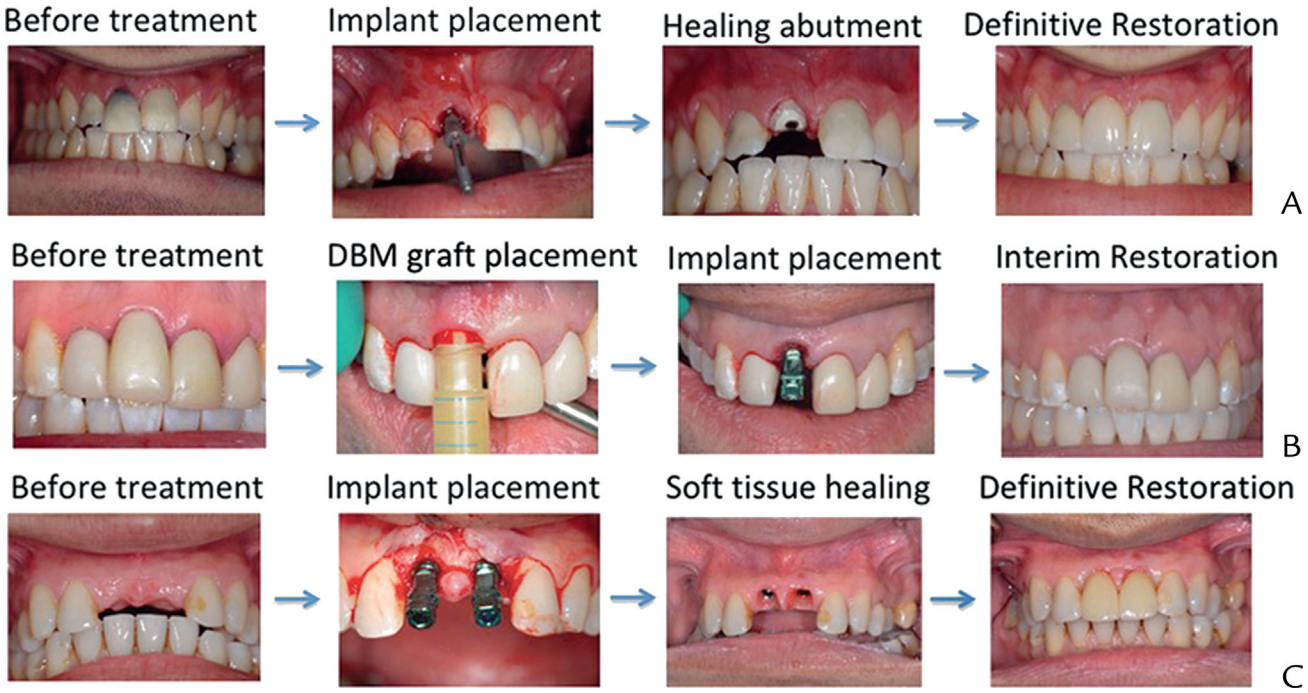

Figure 2. Treatment protocol and patient examples. A, Immediate Ti implant without grafting. B, Immediate Ti implant with DBM grafting. C, TM implants without DBM grafting.

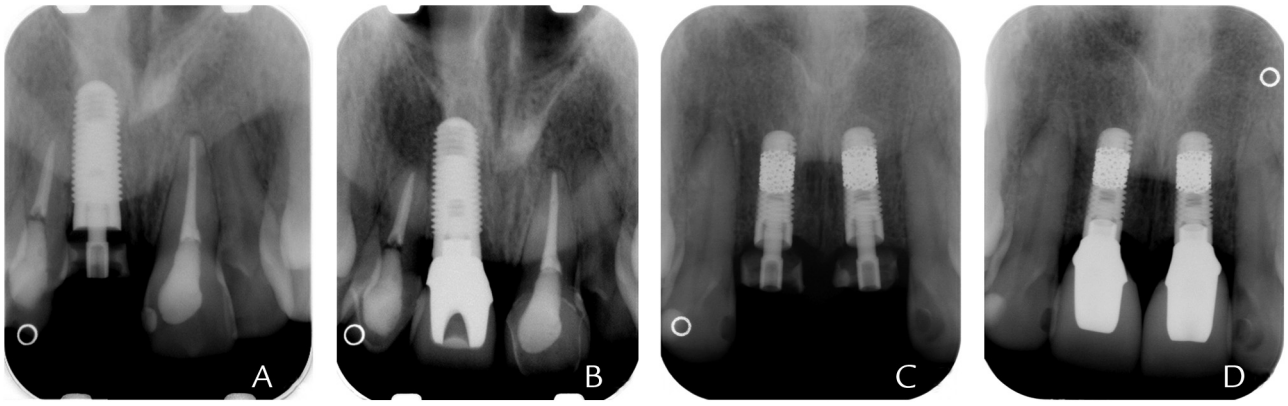

Figure 3. Representative radiographs used to evaluate peri-implant bone remodeling. A, Ti implant after placement. B, Ti implant 1 year after definitive restoration placement. C, TM implants after placement. D, TM implants 1 year after definitive restoration placement. Ti, titanium alloy.

with other clinical outcomes. The peri-implant bone levels were measured at the mesial and distal sites of the implant from preoperative and postoperative radiographs. Bone gain and loss were calculated by subtracting the postlevel from the prelevel values (a positive value indicating bone loss). The average of the mesial and distal bone levels was used for analysis. As most bone remodeling occurs within the first year of placement,[12] the analysis was focused within this time frame (Fig. 2). The 3 examiners were trained and calibrated for radiographic examination. The measurements from the 3 examiners were averaged.

The 3 phases in the analysis plan were identifying any preexisting differences between the 2 groups, using a complex ANOVA model with the appropriate main effects, interactions, baseline covariate, and factors identified in the first stage, and using a (complex) generalized estimating equation (GEE) model (binary outcome) with identical effects in the model. To identify any preexisting differences in demographic or implant characteristics, the 2 implant groups were first compared using chi-square tests. Any characteristic that differed was identified to be included in a multivariable model. A repeated-measures ANOVA was used to test for a difference in bone loss between the TM and Ti groups (effect of implant) as well as between the implants with bone graft (DBM) and without bone graft (effect of bone graft) while

Table 1. Demographic data

Characteristic	Ti (N=58) N	Ti (N=58) %	TM (N=21) N	TM (N=21) %	P*
Sex					
Female	25	60	5	33	.098
Male	18	43	10	67	
Ethnicity					
Asian	8	19	5	33	.639
African-American	5	12	1	7	
White	27	63	7	47	
American Indian	1	2	1	7	
Other	2	5	1	7	
Hispanic					
Yes	3	7	1	7	.967
No	40	93	14	93	
	Mean ±SD		Mean ±SD		
Age (y)	58.1 ±16.5		60.8 ±18.4		.604

SD, standard deviation; Ti, titanium alloy. Nine patients received both types of implants and were placed in implant group with largest count. *Calculated by using chi-square test or *t* test, as appropriate.

Table 2. Clinical characteristics

Characteristic	Ti (N=161) N	Ti (N=161) %	TM (N=44) N	TM (N=44) %	P*
Location					.006
Anterior mandible	12	7	1	2	
Posterior mandible	75	47	12	27	
Anterior maxilla	43	27	12	27	
Posterior maxilla	31	19	19	43	
Bone graft (DBM)					<.001
No	148	92	30	68	
Yes	13	8	14	32	
Immediate placement					.006
No	141	88	31	70	
Yes	20	12	13	30	
Implant failure					.362
No	158	98	44	100	
Yes	3	2	0	0	
Surgical complications					.990
No	65	97	32	97	
Yes	2	3	1	3	
Prosthetic complications					.220
No	68	99	33	94	
Yes	1	1	2	6	

DBM, demineralized bone matrix; Ti, titanium alloy. *Chi-square test.

covarying out the pretreatment bone level to control for the effects of other variables. Interaction between the type of implant and presence of bone graft was also included in the model. In addition, bone loss in millimeters was converted to a binary variable (yes/no), and multiple logistic regression model was used to analyze the odds of having bone loss in the TM group in comparison with the Ti group after controlling for bone grafting, implant location, and immediate placement.

RESULTS

During the 5 years reviewed, 82 patients received 205 implants, 44 TM and 161 Ti implants. As seen in Table 1, the 2 groups of patients had comparable demographics. Table 2 shows the characteristics of the implants. Significantly more Ti implants were placed in the posterior mandible than TM implants, which were most commonly placed in the posterior maxilla (P=.006). Bone grafts were less common in Ti implants (8% versus 32% in TM implants, P<.001), and fewer Ti implants were placed immediately after extraction (12% versus 30% in TM implants, P=.006). In terms of survival rate, no implant was lost in the TM group (100% survival), and 3 implants failed in the Ti group (98% survival). One Ti implant failed in a patient with immediate placement and 2 Ti implants failed with delayed placement. No periimplantitis or a clinical report of delayed healing or postoperative pain was reported in either group. Two surgical complications were reported: one in the Ti group and the other in the TM. The implants that failed initially did not have sufficient primary stability. The same type of implant was then placed after the sites had healed. One prosthetic complication of overdenture abutment loosening was reported in the Ti group. The overdenture abutment was replaced. Two prosthetic complications were reported in the TM group because of poor crown color, and 2 new crowns were fabricated.

Table 3. Average bone loss within levels of implant type and presence of bone graft material

Effect	N	%	Bone change (mm)[a] Estimate	95% CI	P[b]
Type of implant					.300
TM	35	24	−0.030	−0.480 to 0.420	
Ti	111	76	0.238	−0.174 to 0.650	
Bone graft material					.366
DBM absent	122	84	−0.036	−0.379 to 0.307	
DBM present	24	16	0.244	−0.314 to 0.802	
Type and bone graft interaction					.602
TM, DBM absent	22	15	−0.236	−0.774 to 0.301	
TM, DBM present	13	9	0.176	−0.518 to 0.870	
Ti, DBM absent	100	68	0.165	−0.152 to 0.481	
Ti, DBM present	11	8	0.312	−0.399 to 1.022	
Immediate placement					.004
No	122	84	0.255	−0.134 to 0.643	
Yes	24	16	−0.662	−1.199 to −0.124	
Implant location					.053
Anterior mandible	9	6	0.065	−0.625 to 0.755	
Anterior maxilla	43	29	−0.128	−0.570 to 0.314	
Posterior mandible	60	41	0.481	0.077 to 0.885	
Posterior maxilla	34	23	−0.002	−0.414 to 0.410	
Pretreatment bone level					<.001

CI, confidence interval; DBM, demineralized bone matrix; Ti, titanium alloy. [a]Least-square mean change from pretreatment bone level; positive value indicates bone loss and negative value indicates bone gain. [b]Repeated-measures mixed-model analysis of covariance.

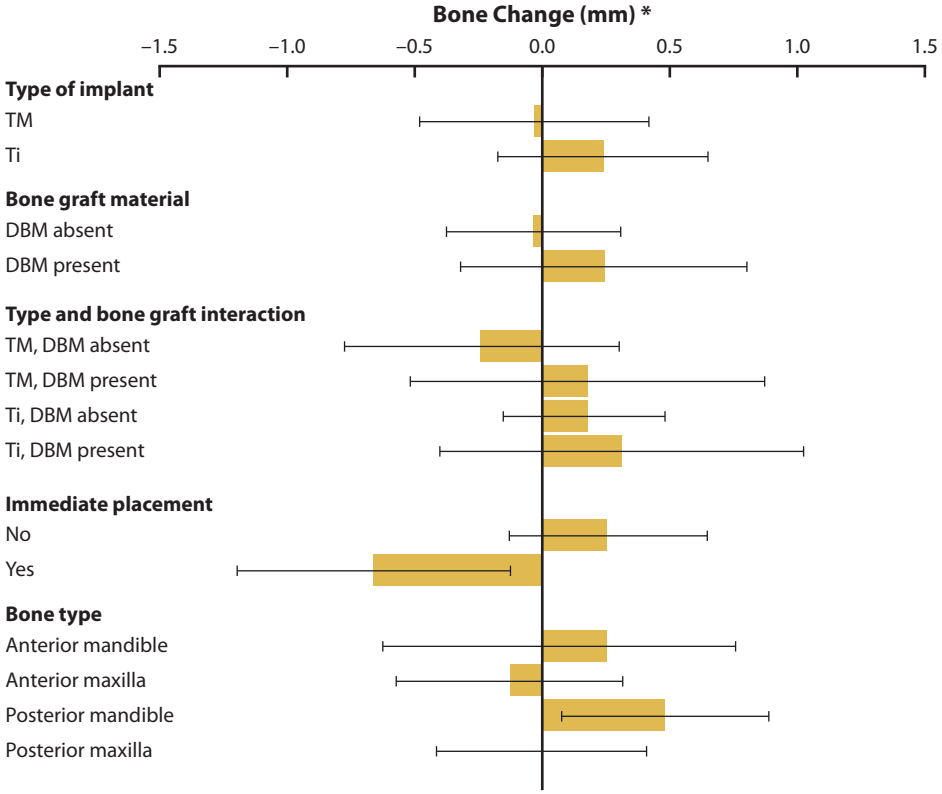

Figure 4. Mean peri-implant bone changes (95% CI). Least-square mean change from pretreatment bone level; positive value indicates bone loss and negative value indicates bone gain. *Values estimated from repeated-measures mixed-model ANCOVA. ANCOVA, analysis of covariance; CI, confidence interval.

Peri-implant bone remodeling after the first year of loading by different types of implants (Ti versus TM) and presence/absence of DBM were compared. For the total of 146 implants with a 1-year follow-up radiograph, the mean ±standard deviation (SD) bone loss after the first year of loading was 0.16 ±1.13 mm. The 111 implants in the Ti group had a mean ±SD bone loss of 0.28 ±1.03 mm, whereas the 35 implants in the TM group had a mean ±SD bone gain of 0.20 ±1.36 mm. The 122 implants without DBM showed a mean ±SD bone loss of 0.24 ±1.09 mm, and the 24 implants with DBM present had a mean ±SD bone gain of 0.22 ±1.27 mm.

To examine the effect of implant type and bone graft material, a multiway analysis of covariance model that included the following effects was used: the preexisting differences between the 2 implant groups identified in Table 2 (tooth location, bone graft material, and immediate placement), baseline bone level, implant type, and the interaction between implant type and bone graft material to examine the synergy of these 2 factors. Table 3 and Figure 4 summarize the results. After adjusting for all other factors, no statistically significant difference was found in the bone change when the TM and Ti implants were compared ($P>.3$). After taking into account the baseline bone level and the differing implant characteristics, the average TM implant had a gain in bone of 0.03 mm, and the average Ti implant had a bone loss of 0.24 mm, a difference of more than 0.26 mm, which is not statistically significant. Similarly, implants with DBM present lost an average of 0.24 mm of bone and those without DBM gained 0.04 mm, an amount not statistically different ($P>.6$). This interaction tests whether the type of implant effect is modified by the presence or absence of DBM and the nonsignificant P value indicates no evidence for a synergistic effect. In addition, a statistically significant bone gain was found associated with immediate placement on average 0.62 mm ($P=.004$) compared with bone lost in nonimmediate implants, 0.26 mm. This was a 0.92-mm difference (95% confidence interval [CI]=0.3-1.54 mm) and included a significant amount of bone gain in implants in the posterior mandible (95% CI=0.08-0.88 mm).

The bone remodeling (loss and gain) in millimeters was converted into a dichotomous variable with possible values of either bone gain or bone loss. The multiple logistic regression model demonstrated that the odds of having bone loss was 64% less (odds ratio: 0.36; 95% CI: 0.14, 0.94; $P=.050$) in the TM group in

comparison with the Ti group after controlling for other variables (Table 4).

DISCUSSION

This study is one of the first to compare TM with Ti implants and to show the effect of TM and DBM combination in a clinical practice. The overall bone loss of 0.03 ±1.46 mm after the first year of implant loading was similar to the 0.43 ±0.57 mm reported by Schlee et al[2] and similar to the 0.57 ±0.62 mm reported by Papi et al.[13] The study by Schlee et al[2] was a clinical trial of early loading of single TM implants, while Papi et al[13] studied implant-retained maxillofacial prostheses. The survival rate of the TM implants in the present study was 100% at the first year, similar to that reported by Papi et al.[13] A slightly lower survival rate of 95.2% in immediate TM implants was reported by Schlee et al.[2] A similar implant survival rate of 97.7% was reported by El Chaar and Castano[6]; however, in that study, the TM implants were used in conjunction with extensive bone grafting and augmentation. The increased number of Ti implant failures in the present study could be explained by the increased number of Ti implants placed with respect to TM implants. Although the difference in the survival rate of the 2 implants clinically was small, the TM group received a definitive prosthesis about 1-2 months earlier than the Ti group.

Both DBM and TM implants maintained peri-implant bone. The TM implants shows higher average bone gain than Ti implants. DBM also led to bone gain, regardless of the type of implant. However, the synergistic effect proposed previously in a clinical report[3] was not found in the present study. DBM and TM did not show statistical synergy in this study (P=.07 and .09). The PTTM portion of TM implants provides the scaffold for better bone regeneration through osseoincorporation that includes neovascularization and bone ingrowth.[1,3] No other grafting material besides DBM (Puros DBM with Bone Chip Putty) and no barrier membrane were used. The bone gain may be different with the presence of barrier membrane and/or other type of bone grafting.[6] The majority of bone gain in both groups was in the immediate implant placements, perhaps due to bone grafting. DBM may have aided in the improved bone regeneration process in immediate implant placement.

Preoperative chlorhexidine mouth rinse was used for all patients. The patients were instructed to use chlorhexidine mouth rinse at least 12 hours before and immediately before the surgery. No antibiotics were prescribed for a single implant without any bone grafting. Preoperative (12 hours) antibiotics were prescribed for patients with multiple implant placements and placement of those who received an implant with DBM. Similarly, postoperative (1 week) amoxicillin, clindamycin, or metronidazole was prescribed only after multi-implant placement and implant placement with DBM. In terms of pain control, narcotic medications were not prescribed for any of the patients in this study. Nonprescription pain medication such as ibuprofen or acetaminophen was recommended as needed. The antibiotic and analgesic regimens were based on previous studies[14,15] that reported little postoperative infection or pain with the implant treatment protocol followed.

The limitations of the study included its retrospective design and the single provider of all surgical and prosthetic procedures may have led to bias. For instance, the TM and DBM may have been overly prescribed in more difficult implant surgery when the provider anticipated bone loss. In addition, the participants were not randomized. Better care may have been taken of the patients with TM and DBM, in which the practitioner expected a worse outcome. Furthermore, converting loss of bone in millimeters into a dichotomous variable (bone loss=yes/no) led to loss of information. This may have influenced the statistically significant logistic regression because the logistic regression model predicts the likelihood of bone loss/gain. In addition, owing to the retrospective nature of the work, data were obtained from periapical radiographs, a prospective study with standardized radiographs or bitewing radiographs should be performed in the future to better compare the 2 types of implant.

Table 4. Bone loss within levels of implant type and presence of bone graft material

Effect	Percent[a]	OR	95% CI	P[b]
Type of implant				.050
TM	43	0.360	0.137-0.944	
Ti	67			
Bone graft material				.073
DBM absent	41	0.437	0.102-1.006	
DBM present	69			
Type and bone graft interaction				.960
TM, DBM absent	30	0.115	0.021-0.621	
TM, DBM present	57	0.351	0.083-1.475	
Ti, DBM absent	54	0.312	0.078-1.239	
Ti, DBM present	79			
Immediate placement				.018
No	74	5.155	1.299-20.408	
Yes	35			
Implant location				.199
Anterior mandible	70	2.096	0.454-9.677	
Anterior maxilla	34	0.459	0.167-1.260	
Posterior mandible	64	1.576	0.559-4.443	
Posterior maxilla	53			
Pretreatment bone level				.003

CI, confidence interval; DBM, demineralized bone matrix; OR, odds ratio; Ti, titanium alloy. [a]Least-square mean percentage bone loss estimated from model. [b]Odds ratios and statistical tests from repeated-measures logistic regression.

CONCLUSIONS

Based on the findings of this retrospective clinical study, the following conclusions were drawn:

1. PTTM-enhanced dental implants (TM implants) had a relatively lower risk of bone loss and higher probability for bone gain, especially in immediate implant placement.
2. Despite the fact that the use of DBM shows relatively less bone loss in both types of implant, bone graft did not have significant effect on marginal bone loss in the presence of different types of implants (TM versus Ti).
3. DBM may be a good alternative to autografts and other bone regenerative materials.

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