Prospective, Multicenter Evaluation of Trabecular Metal-Enhanced Titanium Dental Implants Placed in Routine Dental Practices: 1-Year Interim Report From the Development Period (2010 to 2011)

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ABSTRACT

Background: A prospective, multicenter study is currently evaluating a novel titanium implant with a highly porous tantalum midsection (tantalum material [TM]) placed in an uncontrolled patient population.

Purpose: Interim 1-year results from the development period (2010–2011) are reported.

Materials and Methods: Investigators in 22 clinical sites located in five European countries randomly selected and treated partially edentulous patients in accordance with the implant’s instructions for use and the investigators’ professional judgments. Oversight was provided by the local institutional review boards. Subjects were treated with 1 to 2 TM dental implants in maxillary or mandibular location(s).

Results: To date, 105 patients with 57 maxillary and 88 mandibular implants have completed 1 year of clinical monitoring. Within this interim group, 28 patients had concomitant health conditions that may elevate risks for long-term crestal bone loss and/or implant survival. Three implants failed due to local or systemic infection, and four implants failed to integrate. Cumulative implant survival was 95.2% (n = 138/145) with 0.43 ± 0.57 mm of mean marginal bone loss in this interim group.

Conclusion: TM dental implants were clinically effective under various clinical conditions in an uncontrolled patient population with and without concomitant health conditions.

KEY WORDS: osseoincorporation, titanium–tantalum implant, trabecular metal

INTRODUCTION

The phenomenon of bone fusing to titanium implants was first discovered by Bothe and colleagues in 1940 and was reported again in 1951 by Leventhal. In 1977, Branemark and colleagues scientifically documented
the methods for predictably achieving and maintaining bone fusion to titanium implants through a process they called osseointegration. Actual bone attachment to an osseointegrated implant has been estimated to typically range from 50% to 80% of the surface. A variety of factors, such as the character of the implant surface and the nature of the surrounding tissues, can influence the overall percentage of bone attachment. Various modifications to dental implant surfaces, such as grit-blasting, acid-etching, coating, or a combination of procedures, have been introduced over the past three decades in an attempt to increase the overall percentage of bone attachment. In orthopedic medicine, research has also focused on development of porous implant coatings to mechanically supplement osseointegration through additional bone ingrowth into the implant surface. Numerous studies since the 1970s have reported that a coating’s pore size and porosity are determining factors for successful bone ingrowth. For example, researchers found that while a pore size of 100 μm would be generally acceptable for bone ingrowth, pores 150 μm would be needed for osteon formation inside a porous material, and pores more than 300 μm in size would be required to support potential ingrowth of both bone and vascular structures.

Because pore sizes tended to be irregular and porosity extremely limited in applied surface coatings, orthopedic researchers used a biomimetic approach in developing a highly porous, tantalum material (TM) (Trabecular Metal™ Material, Zimmer TMT, Parsippany, NJ), which simulates the structure and more closely approximates the elasticity of trabecular bone than titanium and other major surgical metals. The porous material is fabricated by coating a vitreous carbon skeleton with elemental tantalum through a chemical vapor deposition process. The final material provides up to 75% to 80% porosity through a network of interconnected pores (size = ∼440 μm) and dodecahedron-shaped cells (size = ∼540 μm) in regular sizes and shapes. The high degree of porosity has been reported to support the formation of bone and vascular structures inside the material. Since 1997, this porous TM has been used extensively in orthopedic hip, knee, and spine implants to supplement anchorage through a combination of bone ingrowth and bone ongrowth, which has been termed osseoincorporation.

Based on its extensive clinical use in orthopedics, dental researchers modified a conventional tapered, multithreaded, root-form, titanium dental implant design by replacing the threads in the midsection of the implant body with an unthreaded sleeve of the highly porous TM (Figure 1). The cervical, apical, and internal implant structures are made of titanium alloy (Ti-6Al-4V grade 5) with a microtextured surface. The cervical region of the implant includes a series of radial microgrooves and surface microtexture that either extends to the top of the implant or optionally ends below a 0.5-mm-wide section of machined titanium surface (Figure 1).

Unlike cervical microthreads, radial microgrooves feature a “scalloped” or “barbed” geometry. The microgrooves slope coronally at a 15- to 21-degree angle, range from 50.8 to 76.2 μm in depth depending on the area of slope, and are 279.4 μm in vertical height (base to top of groove). In a series of in vitro and in vivo cellular studies, Chehroudi and colleagues reported that horizontal microgrooves were effective in impeding epithelial downgrowth. In a later study, Chehroudi and colleagues found that fibroblast cells blocked epithelial downgrowth by inserting into horizontal microgrooves.
that were ≥10 μm deep. At the histologic level, Hall and colleagues reported that microgrooves 110 to 200 μm wide and 70 μm deep stimulated bone to preferentially form within and along the microgrooves in the rabbit model and that grooves 110 μm in width significantly increased resistance to shear forces. The researchers concluded that such microgrooves may be one way to optimize implant stability in suboptimal clinical conditions. The present microgroove design is thus intended to facilitate osseointegration via crestal bone growth into microgrooves, and the sloped geometry is designed to discourage plaque accumulation and/or bacterial colonization in the event of exposure to the intrasulcular or intraoral environments. The radial microgrooves are positioned 635 μm below the top of the implant to preserve the mechanical strength of the implant’s prosthetic platform.

Extending cervical microtexture to the top of the implant in the canine model has also been reported to reduce the amount of peri-implant crestal bone loss without adversely affecting soft tissue health; however, concern about the possibility of increased bacterial attachment to microtextured implant surfaces as compared with machined (turned) surfaces exposed to the gingival crevice in humans has been expressed in the dental literature. After 6 months of plaque accumulation in dogs, the roughened surfaces of acid-etched implants, which have been previously reported to be slightly rougher (Ra = 803 ± 257 nm) than the present microtextured surface (Ra 756 ± 73 nm), failed to influence any greater plaque formation or establishment of inflammatory cell lesions in the peri-implant mucosa than control implants with machined surfaces. Based on these findings, cervical microgrooves and surface microtexture were incorporated into the cervical sections of TM dental implants. For patients who may have an elevated risk of crestal bone loss, such as smokers or patients with a history of periodontal disease, a 0.5-mm-high machined surface option is available for clinicians who may still be concerned about potential exposure of the microtextured surface (Figure 1). The biocompatibility and corrosion resistance of all three materials (titanium, tantalum, vitreous carbon) used in the implant design have been extensively documented and clinically demonstrated over more than 15 years of use in orthopedic implants. Preliminary research has found that TM dental implants were clinically effective when immediately provisionalized out of occlusion within 24 hours of implant placement and definitively restored in occlusion within 14 days of placement in a controlled patient population. There is a little documentation, however, on the clinical functioning of TM dental implants placed in an uncontrolled patient population encountered in routine dental practices.

This article reports on the 1-year interim results of a nonrandomized, noninterventional, prospective, multicenter evaluation of TM dental implants placed in an uncontrolled population during the implant development period of 2010 to 2011.

MATERIALS AND METHODS

The objective of this 5-year noninterventional study was to evaluate the functioning of TM dental implants in a cross section of patients that clinicians would routinely treat in their practices. Noninterventional studies are designed to help avoid manufacturer bias by allowing products to be used as they would be in normal dental practices. Results are systematically documented and analyzed to determine statistically significant outcomes. A longitudinal data collection program (LDCP) was established to monitor the study and provide investigators with a secure method of data collection through digital case report forms housed in a password-protected database. Patient selection and case planning were left to the professional judgment of the investigators, all of whom had years of experience in placing multiple implant systems. Treatment was limited, however, to two study implants per patient, and no study device could be placed adjacent to another dental implant. This study complies with the declaration of Helsinki and Good Clinical Practice guidelines and is being conducted under the auspices of the local institutional review boards. The 22 study centers are located in Germany, Italy, the Netherlands, Spain, and France. A total of 268 subjects have been enrolled in the LDCP to date and treated per protocol with 377 TM dental implants (reference group). This interim report covers a subgroup of all subjects whose implants were placed during the implant development period from October 2010 to June 2011 and who have completed 1 year of clinical monitoring after implant placement (focus group).

Patient Selection and Evaluation

To help ensure clinical safety and study compliance, patients were required to meet minimal selection
criteria (Table 1). After discussing the treatment plan, alternative options, and answers to patient questions, each subject provided signed informed consent prior to implant treatment.

Preliminary patient evaluations included careful review of medical and dental histories, clinical and radiographic examinations, evaluation of oral hygiene, and assessment of the patient’s ability to commit to study procedures and clinical monitoring. A diagnostic workup was performed to assess the volume and location of available bone and the esthetic and functional needs of the patient. Working casts were fabricated to determine the jaw relationships, available occlusal dimension, proposed implant position(s), crown/root ratio(s), and potential complications. This allowed the fabrication of a prosthetic wax-up and surgical template to guide placement of the implants relative to the planned prosthesis.

**Treatment**

Case planning and surgical procedures were left to the professional judgment of each investigator in accordance with the product’s instructions for use (IFU). At the time of implant surgery (Figures 2–6), patients were administered anesthesia and prophylactic antibiotics according to their needs and the preference of the investigator. All TM dental implants used in the study were 4.1, 4.7, or 6.0 mm in diameter and 10, 11.5, or 13 mm in length. Investigators were required by the study protocol to record implant insertion torque and were also encouraged to provide additional diagnostic information, such as resonance frequency analysis (RFA) values. Intraoral radiographs and standardized periapical radiographs (XCP, Rinn Dentsply, York, PA, USA) were taken at surgery and annual monitoring appointments. After surgery, decisions regarding the use of prophylactic antibiotics and analgesics, time of suture

**Table 1 Patient Selection Criteria**

| Inclusion | Exclusion |
|-----------|-----------|
| At least 18 years of age | Preexisting implant adjacent to the proposed study treatment site |
| Partially dentate with missing molar(s) or premolar(s) | Pregnancy |
| In need of implant therapy to replace one or more missing posterior teeth | Lactating mothers |

**Figure 2** A 43-year-old female presented with a missing mandibular left molar and a thin, soft tissue biotype (contributed by Guillermo Pradies, DDS).

**Figure 3** Preoperative view of the edentulous site. The subject was assessed as having Type 2 bone. An implant osteotomy was prepared under copious external irrigation by sequential cutting with internally irrigated drills in graduated diameters (contributed by Guillermo Pradies, DDS).

**Figure 4** Buccal view of the implant mount before its removal. The implant was threaded into the prepared receptor site per IFU (contributed by Guillermo Pradies, DDS).
removal, and the type of implant restoration were left to the investigators based on patient needs.

**Monitoring**

All treatment timelines were established by the investigators. Osseointegration was determined by clinical and radiographic examinations, which included attempted gentle torquing and manual palpation prior to determine implant stability prior to prosthetic loading, and an absence of irresolvable clinical symptoms, such as pain or suppuration, with or without the presence of peri-implant radiolucency on periapical radiographs. Crestal bone loss was summarized as the mean of radiographic mesial and distal changes in bone height from the time of placement to the 1-year evaluation (Figures 7 and 8).

**Statistical Analysis**

Continuous data were summarized by descriptive statistics of group size N, average, standard deviation, median, and range. Categorical data were summarized by descriptive statistics of frequency and percentage. All analyses were performed on a personal computer with a statistical software (sas 9.2 TS Level 1M0 XP PRO Platform, SAS Institute Inc., Cary, NC, USA).

**RESULTS**

The initial interim focus group consisted of 116 subjects treated with 160 implants. From this group, 11 patients with 15 implants were subsequently excluded for IFU contraindications (heavy smokers >140 cigarettes/week, alcoholic and substance abuse, uncontrolled systemic
conditions), protocol violations, and iatrogenic surgical errors (Table 2). The final interim focus group consisted of 145 implants placed in 105 subjects (50 men, 55 women) with a mean age of 55.2 ± 11.7 (range = 22–77) years. Within this group, 26.7% (n = 28) of the subjects with 43 implants had concomitant health conditions: smoking (n = 17), history of periodontitis (n = 11), history of osteoporosis (n = 2), history of bruxism or tooth clenching (n = 4), history of myocardial infarction or cardiac disease (n = 4), and intraoral infection that affected the implant site (n = 1). Eight (28.6%) of these subjects had two or more concomitant health conditions. One subject had a history of implant failure near the treatment site.

Treatment data are summarized in Table 3. Patients were treated with 145 (mandibular = 88, maxillary = 57) dental implants placed in molar (mandibular = 78; maxillary = 45) or premolar (mandibular = 10; maxillary = 12) locations. The majority of implants (n = 111, 76.6%) were placed in patients with a thick soft tissue biotype, and the remaining 34 (23.5%) implants were placed in patients with a thin tissue biotype. Because of ridge deficiencies, simultaneous bone grafting was performed during placement of 43 (29.7%) implants, and 18 (12.4%) implants were placed in previously augmented sites. A total of 16 implants (11.0%) were immediately placed in tooth extraction sockets, 12 of which required simultaneous guided bone regeneration to address buccal dehiscence defects. At least 11 (8.6%) implants were placed in grafted sinuses.

During surgery, clinicians were asked to report the patient’s bone density using the Lekholm-Zarb³⁹ scale. Assessments were based on tactile feedback during drilling, and the investigator’s analysis of computed tomography scans was taken during initial patient evaluations. Of the 145 implants placed, implant stability was assessed either by tactile feedback (n = 135; 93.1%), RFA (n = 6; 4.1%), or a combination of RFA and tactile feedback (n = 1; 0.7%). Most implant sites were reported to consist of type 2 bone (n = 63; 43.5%), followed by type 3 (n = 48; 33.1%), type 4 (n = 18; 12.4%), and type 1 (n = 16; 11.0%) bone, respectively. When placing the study implant in type 4 bone (soft bone), an osteocompressive surgical technique was recommended by the manufacturer but was not specified by the IFU. This was accomplished by ending the preparation of the implant osteotomy with an intermediate drill and allowing the tapered implant to compress or condense the walls of the osteotomy as the implant was placed. There were 45 cases wherein the soft bone surgical protocol was used in type 3 (n = 32, 22.1%), type 2 (n = 12; 8.3%), and type 1 (n = 1; 0.7%) bone. All implants were still able to be completely seated despite the under-prepared osteotomies. Correct use of the osteocompressive or soft bone surgical technique was reported for 18 (12.4%) implants placed in type 4 bone. Study implants were restored with fixed partial dentures, removable partial dentures, or single-tooth restorations.

There were 10 reported nonfailure-related adverse events (Table 4). Radiographic evaluations of six implants in five subjects showed peri-implant radiolucency at the 6-month monitoring appointment. All six implants, which had been placed into fresh sinus grafts, were clinically functioning without any clinical symptoms of failure, such as pain, suppuration, or implant mobility. At the 1-year follow-up, the peri-implant radiolucency had completely resolved around all six implants. In one additional patient, peri-implant radiolucency was not observed around the implant until the 1-year follow-up; however, the implant has continued to function with no adverse clinical symptoms and is being closely monitored. One screw-retained, single-tooth restoration loosened in one subject at the 1-year follow-up and was retightened. In another patient, two prosthetic screws retaining a fixed partial denture loosened at 6 months and again at the 1-year follow-up. The prosthesis retention screws were retightened at both appointments, and the patient continues to be monitored.

A total of seven implants failed in six subjects: three implants in three subjects were explanted and listed as

| TABLE 2 Reasons for Exclusions | Patients (n) | Implants (n) |
|-------------------------------|-------------|-------------|
| IFU contraindications         |             |             |
| Smoking more than 140 cigarettes per week | 3 | 4 |
| Uncontrolled systemic conditions (diabetes) | 1 | 2 |
| Alcoholism, other substance abuse, or mental instability | 2 | 4 |
| Protocol contraindications    | 1           | 1           |
| Iatrogenic surgical errors    | 4           | 4           |
| Total exclusions              | 11          | 15          |

IFU, instructions for use.
## TABLE 3 Distribution of Treatment by Implant Placement

| Implant data                  | n (%)          |
|-------------------------------|----------------|
| **Implant length**            |                |
| 10 mm long = 79 (54.5)        |                |
| 11.5 mm long = 52 (35.9)      |                |
| 13 mm long = 14 (9.6)         |                |
| **Implant diameter**          |                |
| 4.7 mm = 125 (86.2)           |                |
| 6.0 mm = 20 (13.8)            |                |
| **Collar design**             |                |
| Machined = 83 (57)            |                |
| Textured = 62 (43)            |                |
| **Placement data**            |                |
| **Mandibular jaw**            |                |
| All = 88 (60.7)               |                |
| Molar = 78 (53.8)             |                |
| Premolar = 10 (6.9)           |                |
| **Maxillary jaw**             |                |
| All = 57 (39.3)               |                |
| Molar = 45 (31.0)             |                |
| Premolar = 12 (8.3)           |                |
| **Time of placement**         |                |
| Fresh extraction socket = 16 (11.0) |        |
| Healed extraction site = 129 (89.0) |          |
| **Maximum insertion torque**  |                |
| 10–19 Ncm = 7 (4.8)           |                |
| 20–29 Ncm = 26 (17.9)         |                |
| 30–44 Ncm = 57 (39.3)         |                |
| 45–59 Ncm = 45 (31.1)         |                |
| 60 Ncm = 10 (6.9)             |                |
| **Soft tissue biotype**        |                |
| Thick = 112 (77.24)           |                |
| Thin = 44 (22.76)             |                |
| **Smoking**                   |                |
| Nonsmokers = 125 (86.21)      |                |
| Smokers = 20 (13.79)          |                |
| **Surgical protocol**         |                |
| One-stage = 90 (62.1)         |                |
| Two-stage = 55 (37.9)         |                |
| **Bone type**                 |                |
| Type 1 = 16 (11.0)            |                |
| Type 2 = 63 (43.5)            |                |
| Type 3 = 48 (33.1)            |                |
| Type 4 = 18 (12.4)            |                |
| **Insertion protocol**        |                |
| Standard = 82 (56.6)          |                |
| Osteocompressive = 63 (43.4)  |                |
| **Vertical positioning**       |                |
| Supracrestal = 11 (7.6)       |                |
| Crestal = 108 (74.5)          |                |
| Subcrestral = 26 (17.9)       |                |
| **Bone graft data**           |                |
| **Distribution by implant site** |           |
| Bone grafts = 62 (42.8)       |                |
| No bone grafts = 83 (57.2)    |                |
| **Time of grafting**          |                |
| Before implant surgery = 18 (29.1) |            |
| Simultaneous with implant surgery = 44 (70.9) |          |
| **Type of materials**         |                |
| Xenograft = 34 (54.8)         |                |
| Autograft = 13 (21.0)         |                |
| Allograft = 6 (9.7)           |                |
| Mixture of more than one graft types = 4 (6.5) |            |
| Alloplast = 4 (6.5)           |                |

*1 implant placed in prior grafted site has no info on graft type.
failures due to local or systemic infection (Table 5). The remaining four implant failures in three subjects failed to integrate and were explanted (Table 5). The patients were successfully retreated outside of the study. Based on the seven failures to date, the cumulative interim implant survival rate for all implants placed during the developmental period was 95.2% \( (n = 138/145) \) after 1 year of clinical monitoring. Gingival health \( 40 \) and plaque \( 41 \) indices were recorded at all monitoring appointments (Table 6). After 1 year of clinical functioning, 90.8% \( (n = 99) \) of the implants had no gingival inflammation, and 78.0% \( (n = 85) \) had no plaque; however, each of these values represented a slight increase in mild gingivitis and light plaque scores recorded at the 6-month follow-up (Table 6).

Cumulative peri-implant marginal bone loss (mesial and distal sites combined) for 115 implants was \( 0.43 \pm 0.57 \) 1 year after placement (Table 7). It is important to note that 17 subjects who smoked less than 140 cigarettes per week were included in this uncontrolled

| TABLE 4 Summary of Nonfailure-Related Adverse Events |
|------------------------------------------|
| Location |
| Quadrant | Tooth | Problem | Treatment | Outcome |
|-----------|--------|---------|-----------|---------|
| Implant-Related Adverse Events |
| Maxillary left | First molar | Peri-implant radiolucency* | Monitoring | Unresolved1 |
| Mandibular left | Second molar | Peri-implant radiolucency2 | Monitored | Resolved |
| Maxillary right | First molar | Peri-implant radiolucency2 | Monitored | Resolved |
| Maxillary left | First molar | Peri-implant radiolucency2 | Monitored | Resolved |
| Maxillary right | First molar | Peri-implant radiolucency2 | Monitored | Resolved |
| Mandibular right | First molar | Peri-implant radiolucency2 | Monitored | Resolved |
| Mandibular left | First molar | Peri-implant radiolucency2 | Monitored | Resolved |
| Prosthesis-Related Adverse Events |
| Maxillary right | First molar | Loose prosthesis | Retightened | Resolved |
| Mandibular left | Second premolar | Loose prosthesis | Retightened | Resolved |
| Mandibular right | Second molar | Loose prosthesis | Retightened | Resolved |

*Observed radiographically at 1 year with no implant mobility, suppuration, or pain.
†Implant is still functioning without clinical symptoms and is being closely monitored.
‡Observed radiographically at 6 months with no implant mobility, suppuration, or pain.

| TABLE 5 Summary of Failures |
|------------------------------------------|
| Location |
| Quadrant | Tooth | Nature of Complication | Cause | Potential Risk Factors* | Time to Failure (weeks) |
|-----------|--------|------------------------|-------|-------------------------|------------------------|
| Maxillary right | Second premolar | Failure to integrate | Unknown | Smoker1 | 12 |
| Maxillary left | Second premolar | Failure to integrate | Unknown |  | |
| Maxillary right | Second molar | Failure to integrate | Patient induced2 | None | 16 |
| Mandibular right | Second molar | Failure to integrate | Infection | None | 23 |
| Mandibular left | First molar | Infection | Unknown | None | 31 |
| Maxillary right | First molar | Infection | Systemic | Multiple3 | 22 |
| Maxillary right | First premolar | Infection | Unknown | Multiple4 | 4 |

*Assessment per case report forms.
1Patient was a smoker (40 cigarettes per week).
2Patient chewed ice cubes during implant healing.
3Type 4 bone, grafted sinus, infection started with sinusitis.
4Smoker, lost implant after hospitalization.
population (Table 2). Mean crestal bone loss among smokers \( (n = 15 \text{ subjects, 20 implants}) \) was \( 0.5353 \pm 0.6833 \text{ mm} \) as compared with \( 0.4226 \pm 0.5605 \text{ mm} \) for nonsmokers \( (n = 90 \text{ subjects, 125 implants}) \) \( (p = .1955) \) (Table 7). By soft tissue biotype, mean crestal bone loss was \( 0.4016 \pm 0.5893 \text{ mm} \) for thick tissue \( (n = 81 \text{ subjects, 112 implants}) \) as compared with \( 0.5652 \pm 0.4872 \text{ mm} \) for thin tissue \( (n = 24 \text{ subjects, 33 implants}) \) \( (p = .2215) \) (Table 7). By implant neck design (Figure 1), mean crestal bone loss was \( 0.4074 \pm 0.5350 \text{ mm} \) for implants with \( 0.5 \text{ mm} \) of machined implant necks \( (n = 62 \text{ subjects, 83 implants}) \) as compared with \( 0.4762 \pm 0.6295 \text{ mm} \) for implant with fully textured cervical regions \( (n = 43 \text{ subjects, 62 implants}) \) \( (p = .5315) \) (Table 7).

**DISCUSSION**

The present noninterventional study is being conducted in an uncontrolled population. The purpose of this study design is to minimize the manufacturer bias and provide results that reflect outcomes achievable in actual dental practices. Consequently, this interim report includes a large number of patients \( (26.7\%; n = 28) \) with concomitant health conditions. Within this group, the most frequent risk factor for crestal bone loss and implant failure was smoking \( (n = 17; 11.7\%) \), which was also reported in combination with other health risk factors in several patients. Despite over two decades of research on the effects of smoking on dental implants, controversy still persists. Some meta-analyses\(^ {42} \) and systematic reviews\(^ {43} \) have reported that smoking enhanced risks of biologic complications, such as peri-implantitis and implant failure, while individual studies have reported that smoking had no significant impact on the prognosis of implants with grit-blasted, acid-etched, or anodic oxidized surfaces.\(^ {42} \) In addition, definitions of what constitutes “light” smoking from “heavy” smoking remain inconsistent, and it is still unknown if the risks of

| TABLE 6 Periodontal Health |
|---------------------------|
| **Index** | **Value** | 6 Months | 1 Year |
| | | **n** | **%** | **n** | **%** |
| Gingival health | 0 = No inflammation | 109 | 91.59 | 99 | 90.82 |
| | 1 = Mild gingivitis | 8 | 6.72 | 9 | 8.25 |
| | 2 = Gingivitis | 2 | 1.68 | 1 | 0.91 |
| Plaque accumulation | 0 = No plaque | 96 | 80.67 | 85 | 77.98 |
| | 1 = Light plaque | 18 | 15.12 | 22 | 20.18 |
| | 2 = Moderate plaque | 5 | 4.21 | 2 | 1.83 |

| TABLE 7 Implant-Level Cumulative Marginal Bone Loss at 1 Year (mm) |
|---------------------------|
| **Category** | **Variable** | **n** | **Mean ± SD** | **p Value** |
| All implants | Mesial bone change | 105 | 0.45 ± 0.60 | N/A |
| | Distal bone change | 105 | 0.42 ± 0.68 | N/A |
| | Cumulative bone change | 105 | 0.43 ± 0.57 | N/A |
| Type of cervical microtexture | Microtextured\(^ {1} \) | 62 | 0.4762 ± 0.6295 | .5315\(^ {\ddagger} \) |
| | Machined* | 83 | 0.4074 ± 0.5350 | |
| Implants placed in smokers | Nonsmokers | 103 | 0.4226 ± 0.5605 | .1955\(^ {\ddagger} \) |
| | Smokers | 12 | 0.5353 ± 0.6833 | |
| Soft tissue biotype | Thick | 92 | 0.4016 ± 0.5893 | .2215\(^ {\ddagger} \) |
| | Thin | 23 | 0.5652 ± 0.4872 | |

\(^ {1} \text{Microtextured} = \text{microtextured surface extends to the top of the implant’s cervical region.} \\
\(^ {\ddagger} \text{t-Test.} \\
\(^ {\ddagger} \text{Wilcoxon Rank Sum Test.} \\
\text{N/A, not applicable; SD, standard deviation.} \)
Crestal bone loss and implant failure can be mitigated by decreasing the amount of smoking that a patient does. In a recent analysis that aimed to identify predictors of implant failure and peri-implant bone loss, Verhaeke and colleagues reported that smoking was the most identified predictor of both adverse outcomes.

In the present interim analysis, 10 (6.9%) of the subjects had a history of periodontitis but did not have active infections at the time of implant placement. Although a history of periodontitis does not appear to adversely affect implant survival in itself, research has suggested that patients with a history of the disease may have an increased risk of peri-implant bone loss and/or of developing peri-implantitis over time. The degree of risk significantly increases if the periodontitis patient also smokes. If left untreated, progressive bone loss can ultimately result in component fracture and/or implant failure.

One patient in the focus group had osteoporosis, a condition characterized by poor bone density, bone resorption, and bone fracture in areas of the skeletal system that are affected; however, other sites remote to the diseased tissue in the same skeletal system can remain unaffected. In such cases, implant placement in the edentulous jaws of osteoporotic patients has been reported to provide beneficial mechanical stimulation to help prevent further resorption of the jawbone, provided there was adequate bone volume and density to support the implants. Other studies, however, have found correlations between systemic and oral bone mineral densities and that osteoporosis was a risk factor for the progression of periodontal disease.

Three study subjects were reported to have bruxism, which is defined as “a stereotyped movement disorder characterized by grinding or clenching of the teeth during sleep.” Because nocturnal bite force during bruxism can exceed the amplitude of maximum voluntary bite force during daytime, there is a clinical concern that subjecting dental implants to bending overload during periods of bruxing can ultimately result in a sequelae of crestal bone loss, propagation of fatigue striations in the implant metals, and ultimate fatigue fracture of the implant system. Other researchers, however, have stated that evidence of a causal relationship between bruxism and implant failure has yet been demonstrated. Methods to prevent overloading of implants in bruxers include avoiding implant placement in the posterior jaw, reducing occlusal contacts, and using an occlusal night guard.

Four study subjects had a history of myocardial infarction or cardiac disease, both of which have been correlated with increased susceptibility to periodontitis, chronic inflammation, and poor oral health. While these factors may have a deleterious effect on long-term implant health, they have not been found to adversely impact the patient’s ability to achieve osseointegration. In extreme cases, poor cardiac health may impact a patient’s ability to undergo some surgical procedures, and in such cases, consultation with the patient’s physician is highly recommended before implant surgery.

One patient had a history of infection that affected the implant site, but the infection was resolved and there was no clinical evidence that it posed a risk factor for implant survival. Another patient had a history of implant failure near the treatment site. The failure of osseointegrated implants has been described as a complex, multifactorial process that cannot always be attributed to clinical factors alone. While some research in the dental literature has suggested a possible genetic predisposition for implant failure, there is currently no evidence to suggest that the past implant failure in this patient could be attributed to anything more than clinical factors. The remaining six patients in this interim focus group had two or more concomitant health conditions, which may compound their risks for long-term bone loss and/or implant survival.

Bone density was assessed by tactile feedback alone while preparing implant osteotomies in 93.1% (n = 135) of the study sites. In an unrelated study, subjective assessments of bone density based on tactile feedback during drilling were correlated with histological analyses of the same bone sites. The researchers found that clinicians could accurately identify hard (type 1) and soft (type 4) bone but could not accurately identify the intermediate (types 2 and 3) bone densities. Consequently, assessment of bone density only by tactile feedback in the present study should be viewed with caution.

Despite the ability to accurately detect soft (type 4) bone via tactile feedback during osteotomy preparation, the soft bone surgical protocol was used in 45 implant sites with reportedly greater bone density. Placing a tapered implant into a slightly underprepared osteotomy has been advocated to improve primary
stability in soft bone, but the technique may lead to high compression forces and elevated insertion torque values in bone with greater density. Concerns have been raised that such cases may impair local microcirculation, cause osteocyte necrosis, and result in bone resorption. One study, however, investigated implants placed at high insertion torques up to 176 Ncm and found that it did not impair osseointegration or lead to greater bone loss than control implants that were placed at lower torque with a nonosteocompressive technique. Additional research is needed to better understand the benefits and risks of osteocompressive surgical techniques in dense and moderately dense bone.

At the 1-year follow-up, one study implant had peri-implant radiolucency without any adverse clinical symptoms, such as pain, suppuration, or mobility. It is unknown if the peri-implant radiolucency was present but not observed in earlier radiographs or if the radiolucency developed after the 6-month monitoring appointment. The implant continues to function without symptoms of clinical failure, however, and is being closely monitored for future changes.

Implants in this interim analysis achieved 95.2% survival in the uncontrolled patient population. While all implants were placed by surgeons well experienced in placing multiple implant systems, none had prior experience in placing the study device. Although some surgical errors may have been made as part of a clinical learning curve, none was beyond what any other experienced clinician might experience in placing an unfamiliar device. These outcomes represent the earliest clinical evaluations of TM dental implants, which occurred during the development period of 2010 to 2011. Outcomes from this development period will be compared with implants placed during the postdevelopment period in future reports from this prospective study.

CONCLUSIONS

Interim study findings indicated that TM dental implants were clinically effective under various clinical conditions in an uncontrolled cross section of patients with and without concomitant health conditions.

DISCLOSURE

This study was funded by Zimmer Dental Inc., Carlsbad, CA, USA.

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