

Crestal Bone Changes Around Titanium Implants. Part I: A Retrospective Radiographic Evaluation in Humans Comparing Two Non-Submerged Implant Designs With Different Machined Collar Lengths

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Background: Experimental studies demonstrated that peri-implant crestal hard and soft tissues are significantly influenced in their apico-coronal position by the rough/smooth implant border as well as the micro-gap/interface between implant and abutment/restoration. The aim of this study was to evaluate radiographically the crestal bone level changes around two types of implants, one with a 2.8 mm smooth machined coronal length and the other with 1.8 mm collar.

Methods: In 68 patients, a total of 201 non-submerged titanium implants (101 with a 1.8 mm, 100 with a 2.8 mm long smooth coronal collar) were placed with their rough/smooth implant border at the bone crest level. From the day of surgery up until 3 years after implant placement crestal bone levels were analyzed digitally using standardized radiographs.

Results: Bone remodeling was most pronounced during the unloaded, initial healing phase and did not significantly differ between the two types of implants over the entire observation period ($P > 0.20$). Crestal bone loss for implants placed in patients with poor oral hygiene was significantly higher than in patients with adequate or good plaque control ($P < 0.005$). Furthermore, a tendency for additional crestal bone loss was detected in the group of patients who had been diagnosed with aggressive periodontitis prior to implant placement ($P = 0.058$). In both types of implants, sand-blasted, large grit, acid-etched (SLA) surfaced implants tended to have slightly less crestal bone loss compared to titanium plasma-sprayed (TPS) surfaced implants, but the difference was not significant ($P > 0.30$).

Conclusion: The implant design with the shorter smooth coronal collar had no additional bone loss and may help to reduce the risk of an exposed metal implant margin in areas of esthetic concern. *J Periodontol* 2005;76:791-802.

KEY WORDS

Aggressive periodontitis; bone loss/prevention and control; bone remodeling; chronic periodontitis; comparative retrospective study; comparison studies; crestal bone changes; dental implants; follow-up studies; human studies; long-term data; non-submerged implants; oral hygiene; periodontitis; radiography.

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The implant system used in this study was initially designed as a one-piece, nonsubmerged implant approach.[¶] Thus, only one surgical procedure was needed prior to prosthetic restoration.¹⁻³ Schroeder and collaborators used two surfaces on the same implant, whereby the rough/smooth implant border was placed at the level of the alveolar crest according to standard surgical procedures.⁴⁻⁶ The relatively smooth, machined coronal portion was designed to end slightly above the gingival margin of the peri-implant soft tissues, thus making the microgap or interface between implant and restoration easily accessible for oral hygiene, resulting in a supra-epigingival location of the crown margin. At present, these implants have two different surfaces, a machined, relatively smooth titanium surface at the coronal part (length 2.8 mm) and a rough titanium plasma-sprayed (TPS), or a sandblasted, large-grit, acid-etched (SLA) surface on the apical threaded part.

In the early days of implant dentistry, some 40 years ago, edentulous patients had the greatest need for oral rehabilitation. Implant-supported restorations, such as bar-supported overdentures^{7,8} or fixed partial dentures⁹⁻¹¹ were placed in these patients for improved denture retention. Soon, an increasing number of implants were also placed in partially edentulous patients.^{6,12-17} Based upon encouraging long-term results with implant-supported fixed partial dentures as well as overdentures,¹⁸ the indications for implant treatment were extended. Today, there are even more treatment options such as single tooth restorations in areas of esthetic concern,¹⁹ immediate placements into extraction sockets,²⁰ or temporary palatal implants for orthodontic anchorage.^{21,22}

In recent years, patients' esthetic expectations regarding implant-supported restorations have significantly increased. A supra-epigingival location of the crown margin (microgap/interface), according to originally defined standard surgical procedures,⁴⁻⁶ is no longer acceptable from an esthetic point of view. Consequently, to avoid a visible titanium implant shoulder in esthetically demanding sites, implants are placed deeper into the bone than in areas of less esthetic concern, thus achieving a subgingivally located implant shoulder following healing. To attain such a result, there have been clinically driven recommendations to change the standard surgical protocol when using implants in the esthetic area. It has been recommended that the rough/smooth implant border of nonsubmerged implants be moved to slightly below the crest of the alveolar bone, resulting in a microgap/interface being located 1 to 2 mm below the gingival margin.¹⁹ To accomplish such a subgingivally located implant shoulder, the apical part of the relatively smooth, machined titanium surface is placed subcrestally. However, there is evidence both from experimental²³⁻²⁶ as well as from clinical²⁷ studies that relatively smooth,

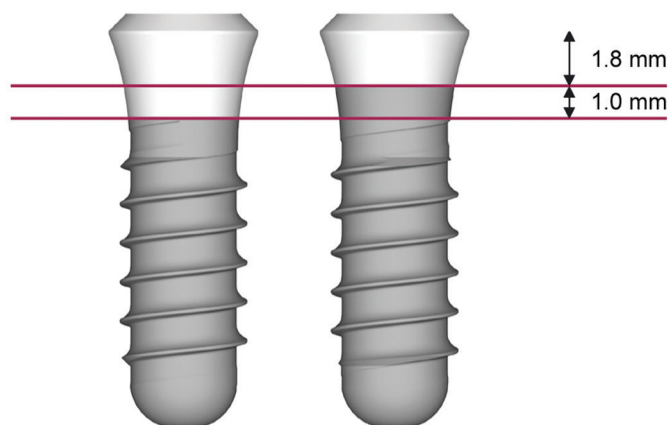


Figure 1. Schematic (true to scale) of type A (left) and type B (right) full-body screw implant. Type B implants exhibit their rough/smooth implant border 1 mm more to the coronal aspect of the implant, resulting in a 1.8 mm coronal portion vs. 2.8 mm for type A implants, respectively.

machined titanium surfaces are associated with additional crestal bone loss in such scenarios. It has therefore been recommended that the placement of the rough/smooth implant border into a subcrestal location is not favorable from a biological standpoint especially in esthetic regions or in areas of limited vertical bone height. Based upon experimental data, changes in crestal bone height around dental implants directly influenced the location of the gingival margin according to the principle of the biologic width.²⁸⁻³⁰ Thus, such a placement technique might also pose a long-term risk of recession of peri-implant soft tissues, producing an esthetically unsatisfactory result.

As a consequence, a new implant line[#] was developed with a 1.8 mm (type A) instead of a 2.8 mm (type B) coronal portion with a relatively smooth, machined titanium surface. Thus, the only difference between the two types is an extension of the roughened surface by 1 mm towards the coronal aspect of the implant (Fig. 1). The rationale for this new design was to align the rough/smooth implant border with the crest of the bone, and at the same time, to achieve a slight subgingival location of the implant shoulder (microgap/interface) without the risk of any additional crestal bone loss.

Little information is available from clinical studies as to the performance of the newer implant design in general, and in particular, related to crestal bone level changes over time. In a recent study on 21 such implants,³¹ the mean value for the distance from the microgap/interface to the first bone-to-implant contact (MG:fBIC) after 32 months was lower than those reported in previous studies for the original implants,

¶ ITI Standard Implant System, Institut Straumann AG, Basel, Switzerland.
ITI Esthetic PLDS Implant System, Institut Straumann AG.

and in single-tooth gaps; e.g., crestal bone loss occurred to the level of the rough/smooth implant border. However, no control group with the original implants was included in that particular study.³¹ The purpose of this retrospective clinical study was to evaluate crestal bone level changes radiographically in a standardized fashion over a period of up to 3 years in humans in a direct comparison of implants with a 2.8 mm coronal portion (implant type A)[¶] versus type B implants exhibiting a 1.8 mm machined coronal portion.[#]

MATERIALS AND METHODS

Patient Selection

All patients in this study had been treated between 1996 and 2000 by one of the authors (DCH) in a private periodontal practice. Prior to implant placement, all sources of inflammation (gingivitis, periodontitis, endodontic infections/lesions) were eliminated or reduced. A total number of 223 implants were initially inserted in 75 patients. Patients were then placed in an individually designed maintenance care program with regular visits to the dental hygienist at intervals of 3 to 6 months, according to periodontal needs. At every appointment, a dental hygienist assessed the plaque control levels and oral hygiene was rated as good, adequate, or poor. After evaluating all patient records, an overall hygiene rating was assigned to every patient. Complications, such as peri-implantitis, were treated according to an evidence-based implant maintenance and treatment protocol.³²

There were no restrictions regarding implant location, prosthetic restoration, or surgical technique used. In this study, seven implants were excluded since there was no adequate baseline radiographic information available. Six implants were lost during the healing phase, and four were eliminated from further analysis because the patient was unwilling to participate in a regular maintenance care program. Three implants could not be followed-up since the patient moved away, one patient died before a 1-year follow-up radiograph could be taken on one implant, and one implant was excluded in a patient who developed a tumor shortly after implant placement. This resulted in 68 patients with a total of 201 implants which were evaluated for this study.

Implant Placement

Overall, 100 type A and 101 type B implants were placed according to standard surgical procedures,⁴⁻⁶ meaning that the rough/smooth implant border for both implants was aligned with the level of the crest of the bone (Fig. 1). Special care was taken to avoid a supracrestal exposure of the roughened surface of the implant. However, in a few cases, when the implant could not be placed perpendicular to the bone surface due to anatomical or prosthetic reasons, the

Table 1.

Implant Distribution Relative to Restoration/Implant Type by Location

Restoration Type	Type A	Type B
Edentulous maxilla denture	2	7
Edentulous mandible denture	1	4
Posterior maxilla single crown	3	6
Posterior maxilla fixed partial denture/splinted crowns	32	46
Posterior mandible single crown	9	2
Posterior mandible fixed partial denture/splinted crowns	51	25
Anterior maxilla single crown	0	1
Anterior maxilla fixed partial denture/splinted crowns	2	7
Anterior mandible single crown	0	3
Anterior mandible fixed partial denture/splinted crowns	0	0
Total	100	101

rough/smooth implant border of the implant was slightly exposed to peri-implant soft tissues on one aspect of the implant. Ninety-nine implants (49.3%) were placed in the lower, and 102 (50.7%) in the upper jaw, respectively (Table 1).

Thirteen patients (19.1%) received only one implant, while two implants were placed in 30 patients (44.1%). Thirteen patients (19.1%) were provided with three or four implants, whereas ten patients (14.7%) got five to seven implants. Ten or eleven implants, respectively, could be placed in two patients (3.0%). Twenty-one patients (30.9%) received type B implants exclusively and 18 patients (26.5%) were provided with implant type A only. Twenty-nine patients (42.6%) received at least one of each type of implant. In 10 patients (14.7%), at least two of each type of implant were placed. Sixty-six of the type B implants had SLA surfaces, while 55 of the type A implants had SLA surfaces.

Nineteen of the implants were inserted after a sinus floor augmentation (external sinus lift) that was performed 8 to 10 months prior to implant placement using the lateral wall approach.³³ In another 15 cases, a sinus floor augmentation was carried out simultaneously with implant placement (internal sinus lift) using the osteotome technique.³⁴ Fourteen of the implants were placed immediately after tooth extraction.

Prosthetic Restoration

Twenty-four of the implants were restored with single porcelain-fused-to-metal crowns, 76 of the implants with splinted crowns, 87 with fixed partial dentures, and 14 with removable full dentures (Table 1).

Radiographic Data Acquisition

Radiographic examinations were carried out on panoramic**†† or on periapical radiographs‡‡ §§ (Fig. 2), using a standardized right-angle³⁵ combined with a paralleling technique using a rigid film-holder (90° angulation) and a beam guiding rod.³⁶ Radiographs were taken shortly after implant placement and compared to those taken at various subsequent post-placement times to evaluate crestal bone level changes. The measurement pairs (mesial/distal aspect) were dated relative to the time of implant placement and divided into six categories: 1) baseline: initial radiograph after placement; 2) early healing (unloaded/loaded): radiograph taken 4 to 6 months after placement; 3) late healing (loaded): radiograph taken >6 to 11 months after placement; 4) 1-year follow-up: radiograph taken >11 to 23 months after placement; 5) 2-year follow-up: radiograph taken >23 to 35 months after placement; and 6) 3-year follow-up: radiograph taken >35 to 47 months after placement. Measurement pairs that did not correspond to any of the six categories (e.g., radiograph taken 48 months or more after placement) were excluded. If more than one measurement pair was assigned to a time category for an implant, the pair having the shortest time interval was selected for analysis, except for category 3 (late healing [loaded]) for which the pair having the longest time interval was selected. Preference was given to measurement pairs obtained from periapical radiographs that were chronologically equivalent to panoramic radiographs.

Differences between implant types controlling for the possible confounding factors were analyzed using mixed-model analysis of variance (ANOVA). In order to evaluate differences in the functional response of the two types of implants, power analysis suggested that a sample of 100 implants of each type would be sufficient to detect radiographic differences of clinical importance; i.e., that different crestal bone loss patterns would occur when comparing implants with a 1.8 mm versus a 2.8 mm long machined coronal portion.

All radiographs were scanned at 600 dpi with a 14-bit grayscale^{|||} to determine proximal bone level changes digitally using a customized personal computer^{¶¶} combined with a high-resolution monitor.^{###} Linear measurements of crestal bone levels (distance from the microgap/interface to the first bone-to-implant contact [MG:fBIC]; Fig. 3) were then performed parallel to the implant long axis both on the mesial and distal aspect of each implant at a 1/100 mm using specialized software.^{***}

A computer-assisted calibration was carried out for each single site by evaluating the given distance between several threads (pitch: 1.25 mm [ϕ 4.1 mm/4.8 mm]; pitch: 1.00 mm [ϕ 3.3 mm]), even if there were multiple implants on the same radiograph (Fig. 3). This calibration ensured a correct measurement even if the implant was slightly angulated on the radiograph.³⁷ Crestal bone level changes were assessed by a single observer (MPH), measuring 1,770 separate MG:fBIC distances. Difficult readings were verified by two other experienced interpreters (DCH; JSH) reaching consensus. Measurements were excluded if the first bone-to-implant contact could not be confidently identified.

Data Analysis

The following parameters were noted for each patient in the study: gender, age, periodontal disease classification, oral hygiene, and smoking status. The classification of periodontitis was based on the level of bone loss detectable on radiographs in correlation to the age of the patient, attachment loss per time interval, and presence or absence of significant amounts of calculus, as well as the pattern of bone loss within the arch (tooth type). Patients were divided into three categories: No history of periodontitis, chronic periodontitis, or aggressive periodontitis.³⁸

The parameters that were recorded for each implant were: location within the arch, type of implant used, diameter, length, surface characteristics (TPS or SLA), applied surgical technique, type of prosthetic restoration, fixation (screw-retention versus cementation), marginal integrity of restoration (presence or absence of a visible microgap on the radiograph), and presence or absence of an adjacent tooth (mesial or distal).

RESULTS

Clinical Data

In this study, 48 patients were female (70.6%) and 20 were male (29.4%). Mean age was 58.9 years with a standard deviation of 11.2 years, and ranged from 28 to 83 years; median age was 58.5 years. Prior to implant placement, 19 patients had no history of periodontitis (28.0%), 33 had chronic periodontitis (48.5%), and 16 patients had a diagnosis of aggressive periodontitis (23.5%). The dental hygiene classification was good for 17 (25.0%), adequate for 42 (61.8%), and poor for nine (13.2%) patients. Fifteen patients were smokers (22.1%).

** Kodak T-Mat G/RA, Eastman Kodak Company, Rochester, NY.

†† TM 2002 Planmeca Proline CC, Planmeca Group, Helsinki, Finland.

‡‡ Kodak IP-21, Eastman Kodak Company.

§§ Heliudent MD, Siemens AG, Munich, Germany.

||| Umax 5450, UMAX Technologies, Inc., Dallas, TX.

¶¶ AMD Athlon 1.2 Ghz, Advanced Micro Devices, Sunnyvale, CA.

Sony CPD-E220, Sony Corporation of America, New York, NY.

*** ImageTool, Version 1.28, University of Texas Health Science Center at San Antonio, San Antonio, TX.

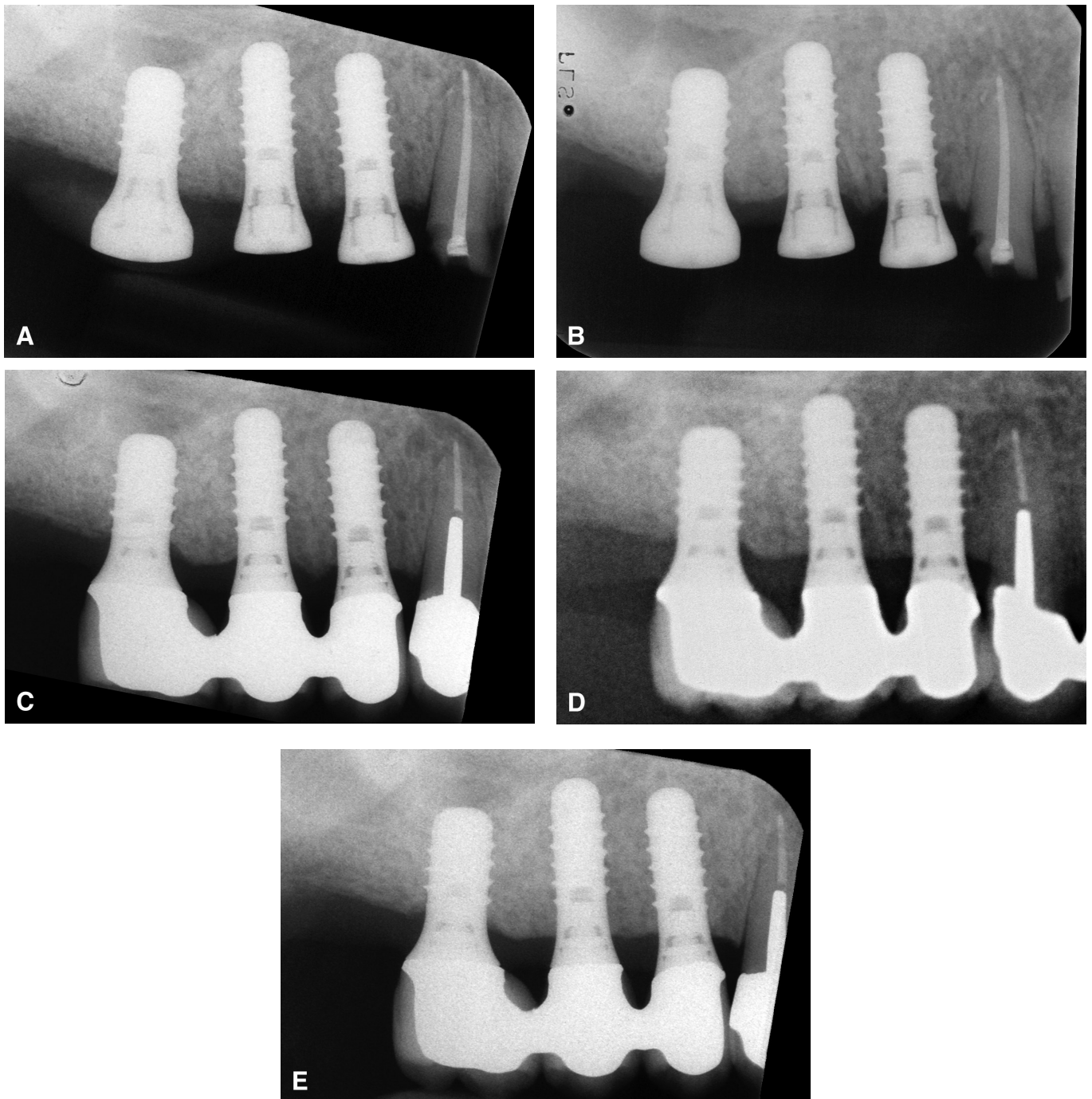


Figure 2.

Sample radiographs illustrating crestal bone level changes over time: **A)** Periapical radiograph showing status 1 week after implant placement with three full-body screws in situ (tooth 14: type B implant ϕ 4.1 mm, length 10 mm; tooth 15: type B implant ϕ 4.1 mm, length 10 mm; and tooth 16: type A implant ϕ 4.8 mm, length 8 mm). **B)** Periapical radiograph demonstrating early healing 2.3 months after implant placement. **C)** Periapical radiograph exhibiting hard tissue integration 2.8 months after implant placement at the day of restoration (cement-retained, splinted crowns). Note that crestal bone remodeling to about the level of the rough/smooth implant border already took place at this early stage of healing. **D)** Corresponding section of a panoramic radiograph illustrating hard tissue integration 11.5 months after implant placement. **E)** Long-term periapical radiograph revealing hard tissue integration 25 months after implant placement. Note that crestal bone levels have been stable during this long-term observation period.

Baseline radiographs showing 140 (69.7%) of the 201 implants were taken within one week of implant placement, 52 (25.9%) baseline radiographs were

taken between 1 week and 1 month of placement, and nine (4.5%) baseline radiographs were taken between 7 weeks and 14 weeks of placement. Although all 201

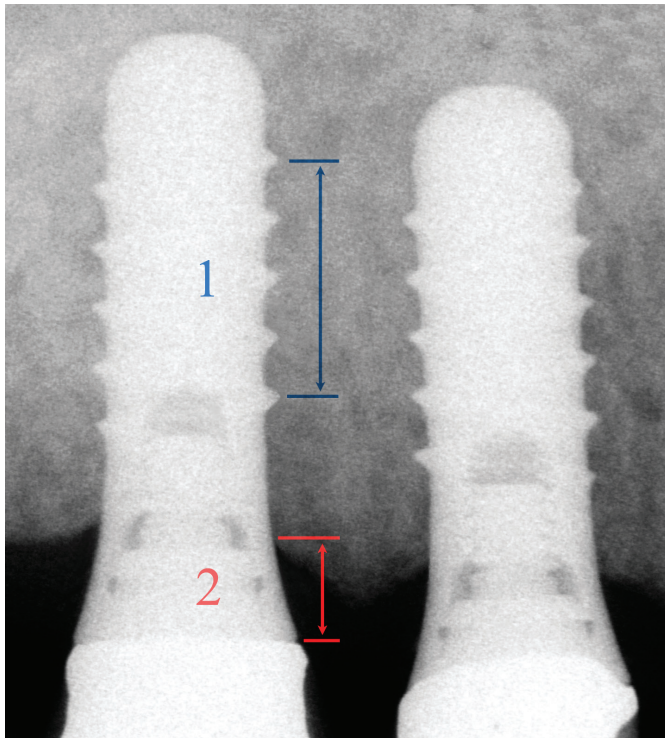


Figure 3.

Prior to computer-assisted linear measurements of crestal bone levels (red line), a calibration procedure was carried out (blue line) by evaluating the given distance between several threads at every single site (pitch: 1.25 mm), even if there were multiple implants on the same radiograph.

implants had a baseline radiograph, some follow-up radiographs were missing. Ninety-six implants (47.8%) had a radiograph during the early healing period (unloaded/loaded) and 88 implants (43.8%) had a radiograph taken during the late healing period (loaded). Radiographic documentation was available for 171 implants (85.1%) at 1 year, for 81 implants (40.3%) at 2 years, and for 33 implants (16.4%) at 3 years.

Quantitative Data

A total of 885 pairs of mesial/distal MG:fBIC measurements were obtained from the radiographs. After the initial exclusions and exclusions due to redundancy, 670 pairs of mesial/distal MG:fBIC measurements remained in the analysis. Of these, 336 were obtained for the 100 type A implants and 334 for the 101 type B implants. On periapical radiographs, 497 pairs (74.2%) were measured, and 173 mesial/distal measurements (25.8%) were based upon panoramic radiographs.

The total number of implants received was significantly correlated with age (Spearman $\rho = 0.250$, $P < 0.040$) and the level of periodontitis prior to implant placement (Spearman $\rho = 0.325$, $P < 0.010$), but there

were no significant correlations ($P > 0.07$) between age or the level of periodontitis prior to implant placement and the number of type A or B implants received. No significant correlations ($P > 0.25$) between the level of oral hygiene and number of implants received (total, type A or type B) were observed. The number of implants received (total, type A or type B) was not significantly different by Mann-Whitney U test for gender ($P > 0.30$) or smoking status ($P > 0.50$).

In general, MG:fBIC values for the mesial/distal pairs had small differences, except for baseline radiographs. Implants placed on an inclined plane had the potential of the first bone-to-implant contact (fBIC) being positioned at or slightly above the rough/smooth implant border on either the mesial or distal side of the implant. When this occurrence was evidenced by the baseline radiograph, a benchmark value of 0 mm was assigned for MG:fBIC. Among the 101 type B implants, 28 had at least one baseline MG:fBIC of 0 mm, while eight of 100 type A implants had at least one baseline MG:fBIC of 0 mm ($P < 0.001$). Conditions associated with placement such as incline likely contributed to the frequency of baseline mesial/distal pairs that varied by more than 1 mm as evidenced by 20 of 101 type B implants and 13 of 100 type A implants ($P > 0.15$). However, as the fBIC tended to remodel to the rough/smooth implant border, the frequency of large mesial/distal differences diminished. Only one of 96 mesial/distal pairs observed during the early healing period (unloaded/loaded) differed by more than 1 mm. Only two of 88 mesial/distal pairs observed during the late healing period (loaded) differed by more than 1 mm. None of the 171 mesial/distal pairs observed during the 1-year follow-up period differed by more than 1 mm. Five of the 81 two-year and three of the 33 three-year follow-up mesial/distal pairs differed by more than 1 mm. As a consequence of these results, the analysis was conducted using three MG:fBIC values: Mesial alone (Fig. 4A), distal alone (Fig. 4B), and the average of mesial and distal values (Fig. 4C).

Type B implants were more likely to be placed in esthetic sites than type A implants (Table 1). Of 102 implants placed in maxilla sites, 63 were type B implants, while 61 of 99 implants placed in mandible sites were type A implants ($P < 0.001$). Twenty-three of 27 implants placed in anterior sites (number 6 [FDI: 13] through 11 [23] and 22 [33] through 27 [43]) were type B implants, while 96 of 174 implants placed in posterior sites were type A implants ($P < 0.001$). Sixty of 97 implants placed adjacent to a tooth were type B implants, while 63 of 104 implants placed in edentulous areas were type A implants ($P < 0.005$). Sixty-six of the type B implants had SLA surfaces, while 55 of the type A implants had SLA surfaces ($P > 0.10$); hence, the SLA/TPS ratio was similar. Frequencies for types of prosthetic restoration associated with either

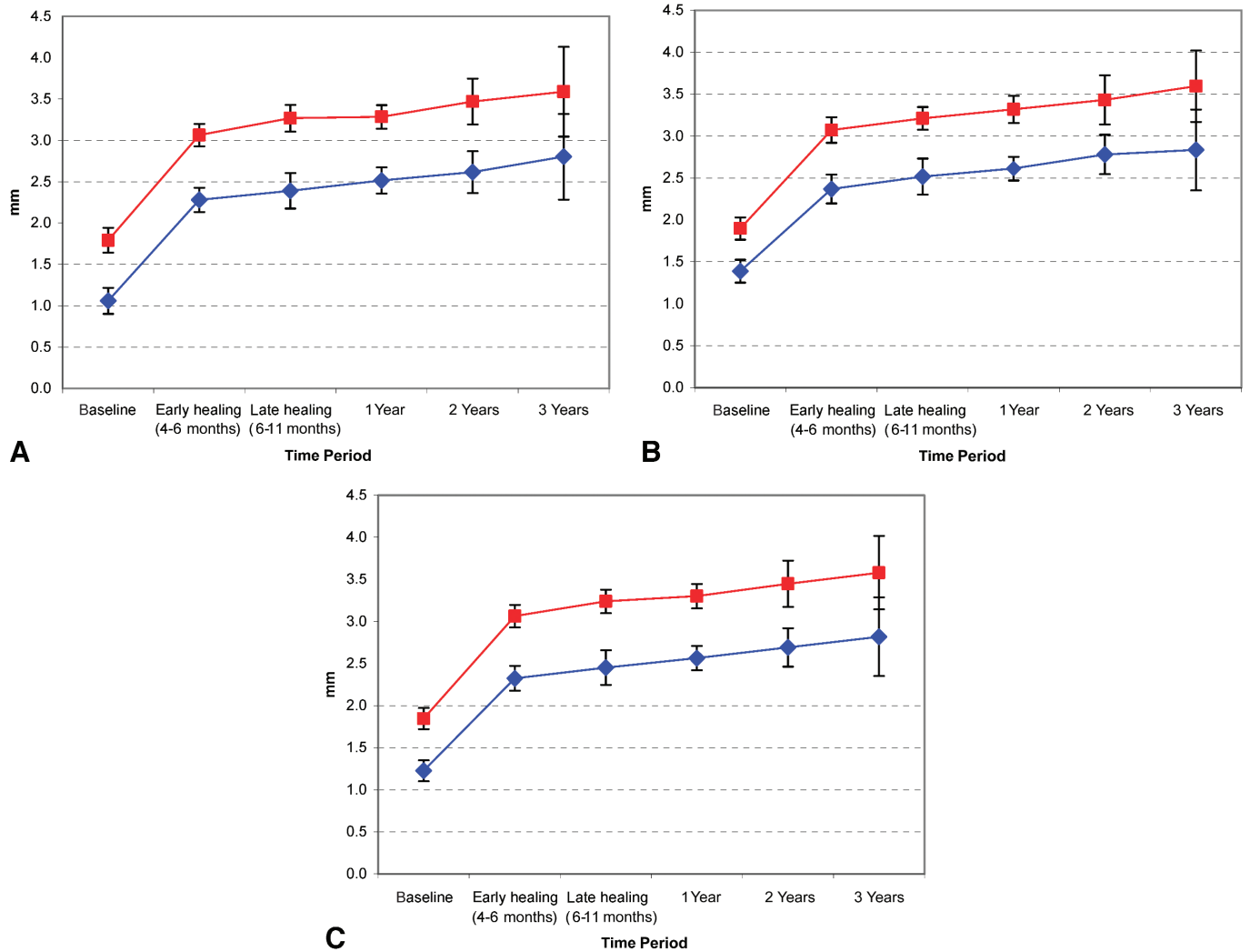


Figure 4.

Distances from the MG:fBIC for mesial sites **A**), distal sites **B**), and for average mesial/distal sites **C**) comparing type A (red dots/lines) versus type B implants (blue dots/lines) from baseline up to 3 years of loading (mean values [mm]; error bars show 95.0% confidence interval of mean). For both implant designs, baseline values were significantly lower than all healing and follow-up time periods ($P < 0.001$). In addition, for each time period, type A implants had significantly greater means for mesial, distal, and average mesial/distal MG:fBIC values compared to type B implants ($P < 0.005$). Note that the lines run almost parallel, indicating nearly the same amount of bone loss over the 3-year period for both implant types.

implant were not significantly different ($P > 0.20$). Twenty-five of 33 implants with screw-retained fixation were type B implants, and 90 of 163 implants with cemented fixation were type A implants ($P < 0.005$). Only six type B and seven type A implants did not have marginal integrity ($P > 0.70$), as judged by radiographic examination. Among the 101 type B implants, 16 had a diameter of 3.3 mm and 85 a diameter of 4.1 mm, while the type A implants tended to have wider diameters: 3.3 mm for 12, 4.1 mm for 43, 4.8 mm for 30, and 6.5 mm (wide neck) for 15 ($P < 0.001$). Type B implants tended to be longer (12 mm for 22, 10 mm for 47, and 8 mm for 32 implants) compared with type A implants (12 mm for 12, 10 mm for 30, 8 mm for 51, and 6 mm for 7 implants) ($P < 0.001$).

Among the possible confounders, the only factor that significantly influenced the MG:fBIC values at 1-year follow-up was the level of oral hygiene ($P < 0.005$), while the level of periodontitis prior to implant placement had a marginal effect ($P = 0.058$). The mean of 1-year MG:fBIC values for implants placed in patients with poor plaque control was significantly greater than that of patients displaying adequate or good oral hygiene (3.47 ± 0.74 mm versus 2.87 ± 0.75 mm, $P < 0.005$), indicating a tendency of increased bone loss during healing for patients with poorer plaque control. However, the interaction between these factors and type of implant was not significant for the mixed-model ANOVAs ($P > 0.25$). Also, Mann-Whitney U tests revealed that the levels of oral hygiene ($P > 0.35$) and

periodontitis prior to implant placement ($P > 0.50$) were not significantly different for type A versus type B implants, indicating that implant type analyses of 1-year MG:fBIC values were not biased by these factors. SLA surface implants had a slightly lower mean of 1-year MG:fBIC values than TPS implants (2.86 ± 0.78 mm versus 3.08 ± 0.74 mm, $P = 0.075$), but no significant differences were observed for SLA versus TPS within type A (3.24 ± 0.70 versus 3.39 ± 0.66 , $P > 0.30$) or type B (2.52 ± 0.68 versus 2.66 ± 0.63 , $P > 0.35$) implant types. Since the SLA/TPS ratio was similar in the two implant types, the general performance was not influenced by the different surface characteristics. Also, there was no significant difference between the means of 1-year MG:fBIC values for implants placed in smokers and non-smokers (3.00 ± 0.81 versus 2.92 ± 0.76 , $P > 0.50$).

The mixed-model ANOVA for mesial MG:fBIC values (Fig. 4A) detected significant main effects for type of implant ($P < 0.001$) and time period ($P < 0.001$), but the interaction between these two factors was not significant ($P > 0.90$). For each time period, type A implants had significantly greater means for mesial MG:fBIC values compared to type B implants ($P < 0.005$). Within type A implants, all subsequent time periods had significantly greater means for mesial MG:fBIC values compared to baseline ($P < 0.001$). Also, the 1- ($P < 0.025$) and 2-year ($P < 0.040$) follow-up means were significantly greater than the mean for the early healing period (unloaded). These results were also observed for type B implants, with baseline values being significantly lower than all healing and follow-up times ($P < 0.001$), and the early healing period values (unloaded) significantly lower than 1- ($P < 0.010$) and 2-year ($P < 0.025$) follow-up periods.

Similar to the mesial aspect of the implants, the mixed-model ANOVA for distal MG:fBIC values (Fig. 4B) showed significant main effects for type of implant ($P < 0.001$) and time period ($P < 0.001$), but the interaction between these two factors was not significant ($P > 0.40$). Again, for each time period, type A implants had significantly greater means for distal MG:fBIC values compared to type B implants ($P < 0.001$). Within type A implants, all subsequent time periods had significantly greater means for distal MG:fBIC values in relation to baseline ($P < 0.001$); in addition, the 1-year ($P < 0.010$) and 3-year ($P < 0.015$) follow-up means were significantly greater than the mean for the early healing period (unloaded). Similar results were also observed for type B implants, with baseline values being significantly lower than all healing and follow-up times ($P < 0.001$), and the early healing period values (unloaded) significantly lower than 1- ($P < 0.030$) and 2-year ($P < 0.020$) follow-up periods.

The same relationships also occurred when the mesial and distal findings were combined for each

implant. The mixed-model ANOVA for the average of mesial and distal MG:fBIC values (Fig. 4C) revealed significant main effects for type of implant ($P < 0.001$) and time category ($P < 0.001$), but the interaction between these two factors was not significant ($P > 0.60$). For each time period, type A implants had significantly greater means for average mesial/distal MG:fBIC values compared to type B implants ($P < 0.001$). Within type A implants, all subsequent time periods had significantly greater means for average mesial/distal MG:fBIC values compared to baseline ($P < 0.001$). The 1-year ($P < 0.005$), 2-year ($P < 0.015$), and 3-year ($P < 0.015$) follow-up means were significantly greater than the mean for the early healing period (unloaded). Similar results were observed for type B implants, with baseline values being significantly lower than all healing and follow-up times ($P < 0.001$), and early healing (unloaded) being significantly lower than 1-year ($P < 0.005$) and 2-year ($P < 0.010$) follow-up periods.

The fact that the interaction between type of implant and time category was not significant for all three mixed-model ANOVAs suggested that bone remodeled at similar rates for both types of implants. To confirm this, unpaired Student *t* tests were performed comparing the change from baseline to one-year follow-up (available for 85.1% of all implants) for type A versus type B implants. The mean changes for mesial ($P > 0.50$), distal ($P = 0.099$), and average mesial/distal ($P > 0.20$) MG:fBIC values were not significantly different for the two types of implants. To ensure that between patient variability did not influence these results, the analysis was repeated for the subsample of 29 patients who received both types of implants. After controlling for between patient variability using mixed-model ANOVAs, the results were virtually identical, with the mean changes for mesial ($P > 0.40$), distal ($P > 0.10$), and average mesial/distal ($P > 0.70$) MG:fBIC values not significantly different for the two types of implants.

DISCUSSION

In this retrospective clinical study, it was demonstrated that crestal bone loss around roughened, nonsubmerged titanium implants started during the initial, unloaded healing phase in both implant designs similarly. Thereafter, slight but significant crestal bone loss could be identified up to 3 years after implant placement. At the 1-year follow-up, crestal bone loss for implants placed in patients exhibiting poor oral hygiene was significantly higher than in patients with adequate or good plaque control. Furthermore, a tendency for additional crestal bone loss could be detected for implants in patients who had been diagnosed with aggressive periodontitis prior to implant placement.

The first studies on crestal bone loss around type A implants were published in the early 1990s.^{15,39} One

hundred such implants were placed according to standard surgical procedures, so that the rough/smooth implant border was aligned with the crest of the bone.⁴⁻⁶ In these studies, bone levels remodeled on average approximately 1 mm below the rough/smooth implant border after 1 or 2 years of loading. The data from the current study confirms these findings, with crestal bone levels remodeling at the early healing evaluation time about 0.3 mm below the rough/smooth implant border for type A implants, and about 0.5 mm for type B implants, respectively, demonstrating again that crestal bone levels are influenced by the location of the rough/smooth implant border in relation to the crest of the bone for both implant designs.

Initial crestal bone loss (between baseline and early healing) may also have occurred when implants had to be placed in an uneven bone surface. In order to avoid a supracrestal exposure of the rough surface, the exact placement of the rough/smooth implant border was determined by the side with the lowest bone level. Accordingly, the rough/smooth implant border was located at the lowest level of the bone crest; all other parts of the implant were slightly below the bone crest level. For example, if the bone level was somewhat lower on the buccal side, then the mesial, distal and oral side of the rough/smooth implant border would be located subcrestally. Implants located adjacent to a natural tooth were often placed on an inclined plane, where the tooth-directed side of the implant was placed deeper into the bone than the side directed towards a free-end situation. The resulting difference in MG:fBIC values was most pronounced in the first postoperative measurement and decreased quickly, as the first bone-to-implant contact tended to remodel to the rough/smooth implant border. This hypothesis can be further supported by findings of a recent prospective pilot study on 21 type B implants,³¹ where the authors measured significantly lower MG:fBIC distances for implant sites adjacent to a natural tooth than for implant sites that were directed towards another implant or a free-end situation. The difference was most pronounced in the first postoperative measurement and was reduced considerably after 32 months.

Initial crestal bone loss below the level of the rough/smooth implant border at the time of early healing may be related to two factors: 1) the formation of a biologic width dimension combined with crestal bone remodeling to about the level of the rough/smooth implant interface²⁸⁻³⁰ and 2) the physiologic response to the microgap/interface at the connection to the superstructure.²⁴⁻²⁶ It has been demonstrated that bacteria are present in such microgaps (interfaces),^{40,41} may form a reservoir,⁴² and that the host reacts with an inflammatory response which may have resulted in the tissue remodeling.⁴³

At the 1-year follow up, crestal bone levels went about 0.5 mm below the rough/smooth implant bor-

der for type A implants, and 0.7 mm for type B implants. At the 2-year follow up, crestal bone levels remodeled about 0.7 mm below the rough/smooth implant border for type A implants, and 0.8 mm for type B implants. In general, however, it can be speculated that such a small amount of initial crestal bone loss (± 1 mm; $\pm 10\%$ of implant length) should not jeopardize the success of the implant but may actually reflect physiologic bone remodeling. In both types of implants, SLA surfaced implants tended to have slightly less crestal bone loss compared to TPS surfaced implants, but the difference was not significant. Since the distribution of the SLA and TPS surfaces was similar for the two implant types, there was no influence on the general result comparing bone loss.

This study showed a tendency for additional crestal bone loss in the group of patients who had been diagnosed with aggressive periodontitis prior to implant placement. The reason for this additional bone loss in these patients is not known. Previous studies on type A implants,^{15,39} however, have not analyzed the patient pool prior to implant placement as to the incidence of different types of periodontal disease and, therefore, cannot be used for comparison.

Looking at bone level changes long-term, for both implant designs, it is evident that after an initial bone loss (early healing), bone levels only changed at about 0.1 mm to 0.2 mm per year. This phenomenon has similarly been described for two-piece implants, where about 2 mm of initial bone loss (time of prosthesis placement to 1 year of loading) occurred, and in consecutive years, also about 0.1 mm to 0.2 mm of crestal bone was lost annually.^{10,11}

In all the studies discussed, standardized radiographic procedures were applied based upon a right-angle technique³⁵ combined with a paralleling technique utilizing a rigid film-holder (90° angulation) and a beam aiming device.³⁶ Recent studies have shown that distortion and angulation errors can be significantly reduced, and that per-implant crestal bone levels can be identified with high precision using this technique.^{26,44} As used in the present study, such measurements are reliable when compared to histometric measurements.²⁶ In order to obtain the most precise readings, computer-assisted calibrations were carried out on every implant site measured by evaluating the given distance between several implant threads on the digitized radiograph.

An important aspect of this study is the fact that crestal bone level remodeling occurred during the initial phase of unloaded healing. No such human clinical data exist so far. However, a series of recent experimental studies have shown that crestal bone remodeling is not dependent on whether implants are being loaded or not, and that these physiological changes are initiated as soon as an implant structure penetrates the ectodermal integrity.^{24-26,28-30}

In this study, crestal bone levels remodeled to about the rough/smooth implant border in a similar fashion, not dependent on whether a 1.8 mm versus 2.8 mm coronal machined collar implant was placed. These results are in accordance with a previous clinical study²⁷ as well as a series of recent experimental studies evaluating different nonsubmerged/submerged and one-piece/two-piece implant designs in a side-by-side comparison.²⁴⁻²⁶ According to these studies, crestal bone levels remodeled to about the level of the rough/smooth implant border with a one-piece, nonsubmerged implant design using a standard surgical procedure in non-esthetic sites⁴⁻⁶ being placed with the rough/smooth implant border at the bone crest level. For two-piece, non-submerged implant designs exhibiting the micro-gap/interface 1 mm above the crest of the bone at time of implant placement in esthetic sites,¹⁹ crestal bone levels remodeled to the more apically located (approximately 1.5 mm) rough/smooth implant border of such implants. In dogs, such physiological changes occurred within 4 weeks after implant placement and did not change within the observation period of 6 months which would equal about 9 months in humans.⁴⁵

Another finding of this study is that patients presenting with poor oral hygiene throughout the observation period lost significantly more crestal bone around both implants than patients showing adequate or good plaque control. These clinical results confirm experimental data in dogs in which different implant designs exhibiting various surface characteristics were investigated in a split-mouth design.^{46,47} One group was well maintained (oral hygiene), while the other group had ligatures placed around the gingival margin of the implants, thus allowing for plaque accumulation. It was demonstrated that all implants were equally susceptible to peri-implant breakdown, and that minimal bone changes occurred in the well-maintained group. These results highlight the importance of successful plaque control and an individually customized maintenance program for all implant patients.

Since this study dealt with a patient cohort of a private periodontal practice, there were several possible confounders that may have influenced crestal bone loss as well. These were primarily the level of oral hygiene, the history of periodontitis, and smoking status. However, the interaction between these factors and type of implant was not significantly different for the two implant designs, indicating that the results were not biased by these factors. Nevertheless, it is possible that the high percentage of patients with a history of periodontitis in this study led to a higher crestal bone loss for both implants equally.

Mombelli and coworkers identified periodontal pathogens in the peri-implant microflora both around one- and two-piece titanium implants 3 and 6 months after implant placement in partially edentulous patients

with periodontitis.⁴⁸ No such pathogens were identified around implants in periodontally healthy individuals or edentulous patients.⁴⁸ Significantly more peri-implant crestal bone loss has also recently been described around two-piece implants in a 5-year retrospective long-term study in patients who had been diagnosed with periodontitis prior to implant placement as opposed to periodontally healthy patients.⁴⁹ Furthermore, 10-year prospective data on one-piece implants showed lower implant survival and higher complication rates in patients with a history of chronic periodontitis prior to implant placement.⁵⁰ In the present study, more crestal bone loss could be detected for both implant designs in patients with aggressive periodontitis prior to implant placement, as opposed to patients with chronic periodontitis or periodontally healthy individuals. In none of the quoted studies above, however, have patients with chronic periodontitis been distinguished from patients with a history of aggressive periodontitis. The results of this study therefore indicate that patients with a history of aggressive periodontitis may have the highest risk of peri-implant crestal bone breakdown and should be well maintained at frequent recall visits.

The results of this study indicate that there is no additional crestal bone loss when placing implants with their rough/smooth implant border at the bone crest level exhibiting a shorter (1.8 mm; type B implants) as opposed to a slightly larger (2.8 mm; type A implants) machined coronal portion over a period of 3 years post-implant placement. This may be of importance in areas of esthetic concern based upon the principle of the biologic width,²⁸⁻³⁰ eventually reducing the risk of an exposed metal implant shoulder. However, these findings need to be confirmed over a longer time period to assure that the position of the alveolar bone and soft tissues around the shorter implants is stable.

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Accepted for publication September 23, 2004.