

Crestal Bone Changes Around Titanium Implants. A Radiographic Evaluation of Unloaded Nonsubmerged and Submerged Implants in the Canine Mandible

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CURRENT IMPLANT PLACEMENT UTILIZES both nonsubmerged and submerged techniques. However, the implications of the location of a rough/smooth implant interface as well as the location of a microgap between implant and abutment on crestal bone changes are not well understood. The purpose of this study was to radiographically evaluate crestal bone changes around unloaded nonsubmerged and submerged titanium implants in a side-by-side comparison. Fifty-nine (59) implants were placed at different levels to the alveolar crest in 5 foxhounds. Standardized radiographs were taken at baseline and at monthly intervals until sacrifice at 6 months. Radiographic assessment was carried out by measuring the distance between the top of the implant/abutment and the most coronal bone-to-implant contact (DIB), and by evaluation of bone density changes using computer-assisted densitometric image analysis (CADIA). DIB measurements revealed that in 1-part, nonsubmerged implants, the most coronal bone-to-implant contact followed at all time points the rough/smooth implant interface. In all 2-part implants, nonsubmerged and submerged, the most coronal bone-to-implant contact was consistently located approximately 2 mm below the microgap. In addition, CADIA values for all 2-part implants were decreased in the most coronal area-of-interest (AOI). All bone changes were statistically significant and detectable 1 month after implant placement in nonsubmerged implants or 1 month after abutment connection in submerged implants. Neither implant position nor individual dog effects were statistically significant. These results demonstrate that the rough/smooth implant interface as well as the location of the microgap have a significant effect on marginal bone formation as evaluated by standardized longitudinal radiography. Bone remodeling occurs rapidly during the early healing phase after implant placement for nonsubmerged implants and after abutment connection for submerged implants. *J Periodontol* 1997;68:1117-1130.

Key Words: Alveolar ridge; dental implants/methods; titanium; comparison study; bone regeneration; bone remodeling.

In the late 1960s and early 1970s, criteria for the predictable integration of endosseous dental implants were proposed. Fundamental experimental studies conducted

by Brånemark et al.¹ and Schroeder et al.²⁻⁴ demonstrated that titanium implants regularly healed with a direct bone-to-implant contact, called "osseointegration" or "functional ankylosis," respectively. Many clinical studies have demonstrated in recent years that implant integration can be achieved and maintained in various areas of the mouth on a long-term basis using submerged and nonsubmerged titanium implants.⁵⁻¹⁷ Implants utilized in these clinical studies, however, varied in many ways, in-

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cluding shape, size, component fit, surface characteristics, surgical placement, and restoration. At the beginning, research in the field of oral implants mainly focused on the integration of hard tissues. It was found that there was no significant difference in the healing patterns of hard tissues when comparing submerged to nonsubmerged implants;¹⁸ however, this study did not evaluate soft tissues.

Two basic approaches to the placement of endosseous implants emerged from these early studies: a submerged and a nonsubmerged technique. In the submerged approach, the implant is placed at or below the bone crest level underneath the soft tissues and allowed to heal for typically 3 to 4 months. A second-stage surgery is then required to uncover the implant and a secondary component, either a temporary healing cap or an abutment, is placed on top of the implant. The restoration is then placed on the abutment or, in some instances, directly onto the top of the implant. This procedure results in 2 gaps, one located generally at or below the alveolar crest, and the second one within or slightly above the soft tissues. In the nonsubmerged approach, the implant itself extends beyond the alveolar crest and there is only one microgap, located above or slightly below the gingival margin. No gap exists at or below the alveolar crest between the implant and the restoration or restorative components.

The significance of the existence and location of a microgap between implant components is not well studied or understood, although some data are emerging.¹⁹⁻²⁸ Longitudinal human descriptive studies documenting patient experience with implants over time have demonstrated that if the abutment loosens on the implant placed in the submerged approach, an inflammation ensues and, in some cases, an infection with a fistula is observed.^{17,29,30} Tightening the abutment eliminates the infection in these cases and the fistula resolves as well. This fact alone suggests that the loose connection at the gap or space between implant parts is responsible for the observed infection in the submerged implant. Recent clinical studies have also documented that microbial species, predominantly anaerobic bacteria, can be cultivated from internal surfaces of submerged implants or their restorative component parts.^{31,32} In summary, the impact of a gap in submerged implants on soft tissues appears to have a significant effect, whether there is an inflammation or an active infection detected clinically, or whether there is a subacute clinical inflammation. Less is known regarding the impact of the gap in submerged implants on the alveolar bone crest.

Other findings suggest that the submerged approach to endosseous implant placement has a significant impact on oral soft and hard tissues. One criterion of success used in many longitudinal human descriptive studies on submerged implants is that bone loss cannot exceed a mean of 1.5 mm in the first year of function nor greater than

0.2 mm on average in subsequent years. This criterion was suggested in the late 1980s^{33,34} and has been adopted in many publications.^{8,35-39} One-and-a-half (1.5) mm of bone loss results in the alveolar crest to the level of the first thread on machined titanium implants with an interthread dimension of approximately 0.6 mm. The reason for the accelerated loss of bone in the first year of restoration is not known, but one possibility is that the gap between components plays a role in this process. Although this pattern of bone loss is a generally accepted criterion of implant success, it is not known if this is an appropriate criterion for nonsubmerged implants or other types of submerged implants.

Recent data have demonstrated that the soft tissues around endosseous implants placed in the nonsubmerged approach are similar in dimension to the soft tissues around teeth. In a study by Cochran et al.,⁴⁰ implants were placed in the canine mandible and evaluated under both unloaded and loaded conditions. Peri-implant tissues were evaluated after early healing (3 months unloaded), short-term loading (3 months loaded), and longer-term loading (12 months loaded). Both mechanical and chemical plaque control was performed 3 times weekly up to 15 months after implant placement. The results indicated that in nonsubmerged implants a biologic width was physiologically formed and maintained as a stable dimension over the course of the study. This canine study⁴⁰ confirmed earlier work which indicated that epithelial structures similar to teeth were found around nonsubmerged implants and that the connective tissue around the same implants had a circular, scar-like configuration different in orientation and attachment than those found around teeth.⁴¹ The biologic width dimensions observed in the study by Cochran et al.⁴⁰ are supported by findings in human reports. For example, Buser et al.¹⁰ found that in 70 partially edentulous patients with 100 nonsubmerged implants, the distance from the top of the implant (placed 3 mm above the bone crest) to the most coronal bone-to-implant contact (DIB) was 3.79 mm and the probing depth averaged 2.74 mm. Thus, the calculated connective tissue dimension was 1.17 mm. Hence, this human study around nonsubmerged implants supports the biologic width dimensions found in the longer-term canine study⁴⁰ and the dimensions found around teeth.⁴²

As of today, there is no means to predictably describe the soft and most coronal hard tissue reactions around endosseous titanium implants placed in a nonsubmerged and submerged approach. Therefore, the purpose of the present study was to systematically examine nonsubmerged and submerged implants radiographically in a side-by-side comparison in a dog model. The hypothesis to be examined was that the interface between rough and smooth implant surfaces as well as the location of the microgap have a significant influence on peri-implant tissue formation during healing.

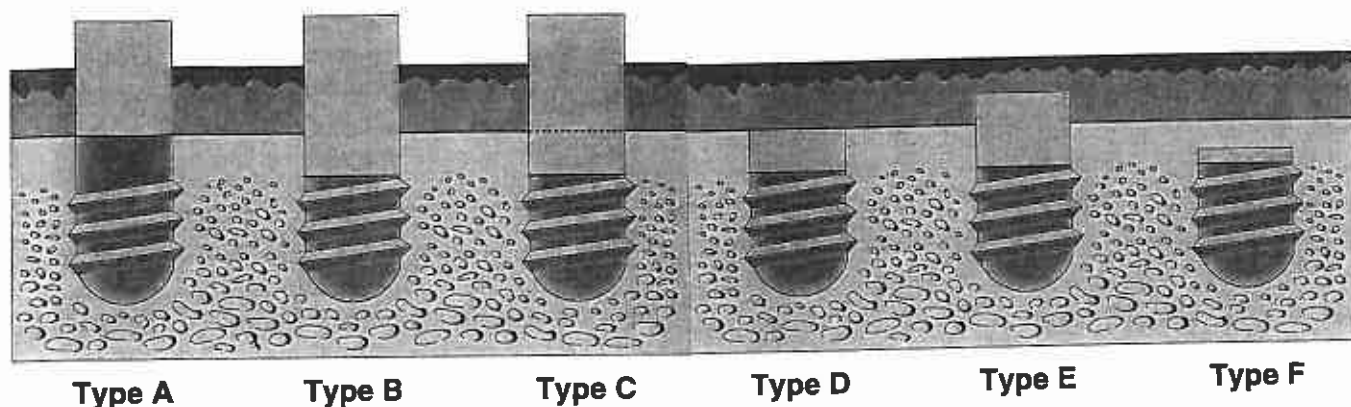


Figure 1. Placement of the nonsubmerged implants in relation to soft tissue and bone (true to scale). Note that types A and B are 1-part implants and all others are 2-part.

MATERIALS AND METHODS

Implant Designs and Surfaces

Six different types of cylindrical titanium implants (A through F) with a full-body screw design were made from grade IV commercially pure titanium[†] (Fig. 1). The outer diameter was 4.1 mm, and the total length was 9 mm. The rough, "apical" portion of each implant consisted of a sandblasted (large-grit) and HCl/H₂SO₄ acid-etched surface (SLA) with 2 levels of roughness, one being 20 to 40 μm peak to peak, and a superimposed second level at 2 to 4 μm peak to peak. The relatively smooth, "coronal" part of each implant had a machined titanium surface. The SLA surface was 6.0 mm in length for type A implants with the rough/smooth implant interface at the alveolar crest, and 4.5 mm for implant types B through F, with the rough/smooth interface located 1.5 mm below the crest. Types A and B were 1-part implants and types C through F were 2 parts, exhibiting a microgap of about 50 μm between implant and abutment. For types C and D, the microgap was located at the bone crest level; for types E and F, the microgap was located 1 mm above and 1 mm below the crest, respectively. Implant types A through C were placed using a nonsubmerged technique with types D through F placed using a submerged approach.

Study Animals

Prior to the start of the experiment, the protocol was approved by the Institutional Animal Care and Use Committee of the University of Texas Health Science Center at San Antonio (UTHSCSA). Five male, lab-bred American foxhounds were used in this study. At the beginning, these animals were approximately 2 years of age and had a body weight of about 30 to 35 kg. All animals were free of heart worms and were quarantined.

Surgical Procedures

Extraction. Tooth extractions were performed under general anesthesia and sterile conditions in an operating room using 4% thiopental-Na intravenous solution[‡] (0.4 ml/kg bw) as a premedication. The dogs were placed on a heating pad, intubated and inhaled with 1.5 to 2% isoflurane,[§] and monitored with an electrocardiogram during the surgery. After disinfection of the surgical site with 10% povidone-iodine solution/1% titratable iodine,[¶] 2% lidocaine HCl with epinephrine^{**} 1:100,000 was administered and all 4 premolars (P₁-P₄) and the first molar (M₁) were carefully extracted. Prior to extraction, the remaining teeth were scaled and cleaned, and P₂-M₁ were sectioned to avoid tooth fracture. Adaptation of the wound margins was achieved with interrupted sutures.

The day of surgery, the dogs received 20 mg of the analgesic nalbuphine^{††} s.c. BID (10 mg/ml). Three (3) ml of the antibiotic benzathine penicillin^{‡‡} with procaine penicillin G (150,000 I.U.) were administered s.c. SID every 48 hours for 7 to 10 days. For suture removal, after a period of 7 to 10 days, the animals were briefly anesthetized utilizing a combination (1.1 ml/15 kg bw) of xylazine^{§§} (7.1 mg/ml), acepromazine^{¶¶} (2.1 mg/ml), atropine^{‡‡‡} (0.1 mg/ml), and ketamine (50.0 mg/ml). Prior to suture removal, the local wound area was carefully cleaned with 0.12% chlorhexidine digluconate-soaked gauze.

Implant placement. Implants were inserted under the same surgical conditions as tooth extractions (sterility, operating room, anesthesia) after a healing period of 6

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[‡]Pentothal, Abbott Laboratories, North Chicago, IL.

[§]Erane, Ohmeda Carbide Inc., Liberty Corner, NJ.

[¶]Clinidine, Clinipad Co., Guilford, CT.

^{**}Henry Schein Inc., Port Washington, NY.

^{††}Nubain, Astra Pharmaceutical Products Inc., Westborough, MA.

^{‡‡}Pen-B, Pfizer Inc., Lee's Summit, MO.

^{§§}Miles Inc., Shawnee Mission, KS.

^{¶¶}Burns Veterinary Supply, Oakland, CA.

^{‡‡‡}Burns Veterinary Supply, Rockville Center, NY.

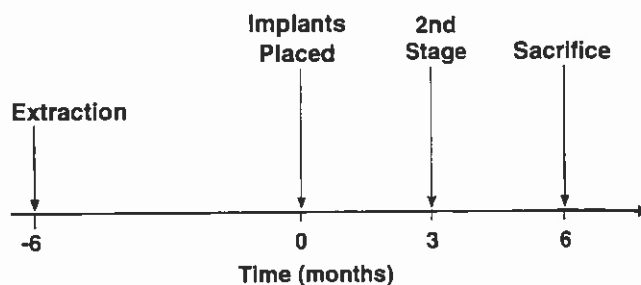


Figure 2. Study design.

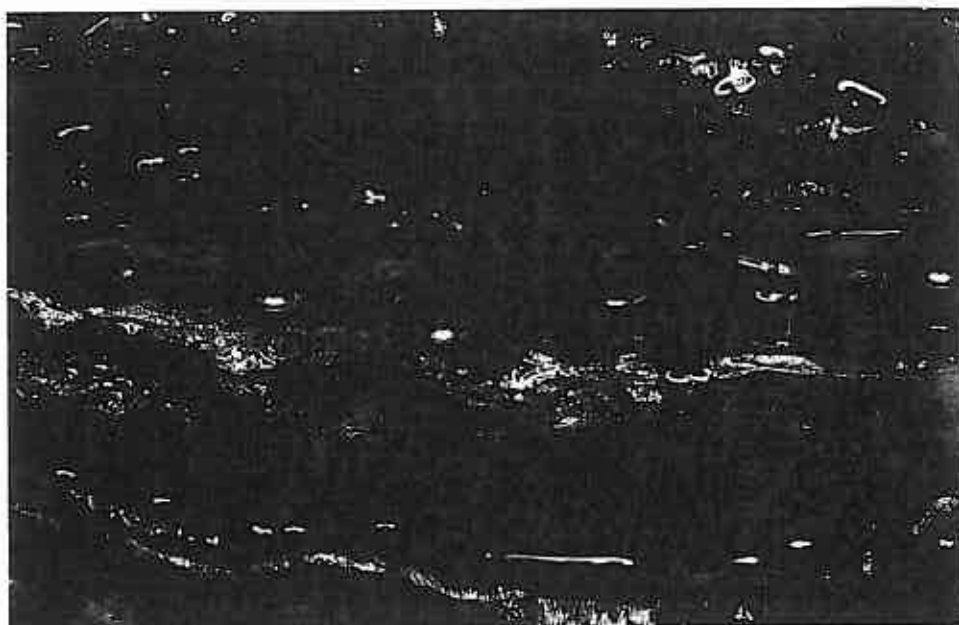


Figure 3. From right to left: Nonsubmerged implants types A through C and submerged implants types D through F in situ, immediately after placement.

months (Fig. 2). A crestal incision was made maximizing keratinized tissue on each side of the incision. Mucoperiosteal flaps were carefully reflected on the lingual and buccal aspect. Mental foramina were exposed prior to implant placement. The edentulous osseous ridge was carefully flattened with an acrylic bur and copious irrigation with chilled sterile physiologic saline. Measurements were made using a boley gauge to help distribute 6 test implants on each side of the mandible. Implant osteotomy was performed with torque reduction rotary instruments at 500 rpm using chilled saline. Implant types A through C were placed as nonsubmerged implants (Fig. 3); i.e., type C implants were already tightened together at the time of first-stage surgery, whereas type D through F implants were placed in a submerged approach. According to a randomized starting selection, one of each kind of test implant was placed per side and healing screws/abutments (type C) were placed on top of the implants. In this fashion, no implant type had a biased position in the arch.

One out of the possible 60 implants could not be placed, since the bone at this particular site was too soft and consequently, primary stability could not be achieved.

If necessary, periosteal relieving and contouring incisions were made on the buccal and lingual aspects to achieve tension-free wound closure, and a small V-shaped gingivectomy was performed for close adaptation of the mucosa to the transmucosal portion of the nonsubmerged implants. Horizontal mattress and interrupted sutures were placed. The day of surgery, the dogs received 20 mg of the analgesic nalbuphine s.c. BID (10 mg/ml). Three ml of the antibiotic benzathine penicillin (150,000 I.U.) with procaine penicillin G (150,000 I.U.) were administered s.c. SID every 48 hours for 14 days. The antibiotic gentamicin** (100 mg) was given s.c. on day 1 BID, and the same dosage SID from day 2 through 10 (50 mg/ml). To reduce swelling, the dogs received 2 ml

**Gentocin, Schering-Plough Animal Health Corp., Kenilworth, NJ.

of the anti-inflammatory dexamethasone*** i.m. SID on day 1 and day 4 (2 mg/ml). Sutures were removed after 7 to 10 days as described above. A soft diet was utilized for the duration of the study. In addition, oral hygiene procedures were carried out 3 times a week using a 0.2% chlorhexidine gel*** in combination with a soft toothbrush and a soft sponge.

Abutment connection. Three months after implant placement, abutments were connected for the submerged implant types D through F under the same surgical conditions as described above. After disinfection and local anesthesia, a midcrestal incision on top of these implants was made including small vertical incisions at the buccal and lingual aspect. A small full-thickness flap was elevated and implants were uncovered. Due to partially overgrowing bone, a minor osteotomy with hand instruments (chisel, mallet) had to be carried out, especially in type F implants, before the flat-head cover screws could be removed in the submerged implants. Individual abutments were connected and consequently all implants emerged to the same level. A slight V-shaped gingivectomy allowed for a close adaptation of the flaps around the abutments using interrupted sutures. Postoperative medication and suture removal were performed the same way as after extractions.

Four, 8, and 10 weeks after second-stage surgery, abutments were loosened and tightened immediately afterwards to imitate the placement of another healing abutment, impression taking, as well as the final installation of the prosthetic component.

Sacrifice. After a healing period of another 3 months, all dogs were sacrificed. Euthanasia was performed with an overdose of pentobarbital sodium*** i.v. (0.2 ml = 65 mg/kg bw). Mandibles were block-resected with an oscillating autopsy saw*** and the recovered segments with the implants were immersed in a solution of 4% formaldehyde combined with 1% CaCl₂ for histologic preparation and analysis.⁴³

Radiographic Evaluation

Image acquisition. At the time of implant placement, individual impressions^{††} were made using custom-made trays. At suture removal 7 to 10 days after surgery, baseline standardized periapical radiographs^{†††} were taken while the dogs were under general anesthesia. Exposure parameters were 70 kVp, 15 mA, and ¼ s at a focus-to-film distance of 37 cm. For better film quality, a manual development procedure^{****} was utilized and carried out ac-

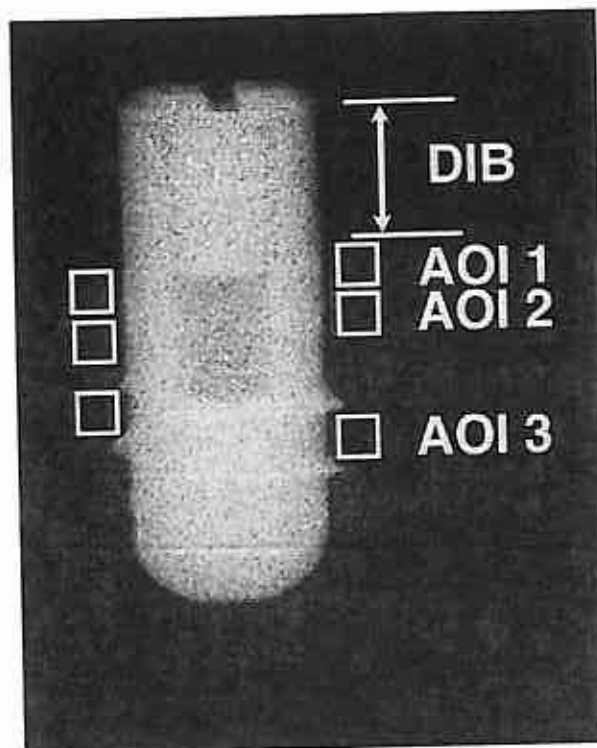


Figure 4. Baseline radiograph. Vertical line indicating linear measurements for the evaluation of the distance between the top of the implant and the most coronal bone-to-implant contact (DIB) which, with this implant, is identical with the bone crest. Boxes defining areas-of-interest (AOI) at 3 different levels, crest (AOI 1), middle-implant (AOI 2), and lateral-apical (AOI 3) for Computer-Assisted Densitometric Image Analysis (CADIA).

ording to manufacturer's recommendations. X-rays were repeated at monthly intervals until completion of the study.

Image capture and digitization. Radiographic image alignment and analysis was performed by 1 examiner. This has been shown to increase the consistency and reliability of the measurements.⁴⁴ The radiographs were converted to 640 (H) × 480 (V) pixel digital images using a calibrated video camera**** and a 50 mm lens with an aperture of 8.^{††††} The images were initially displayed on a 43 cm video monitor,^{††††} where they were checked for their sharpness as well as submitted to a first coarse alignment. The range of optical densities in the radiographic image was converted into 256 different pixel values. A value of zero represented black areas, whereas a value of 255 described the lightest area on the film. The transillumination was adjusted to bring the most coronal area adjacent to the implant, the crestal area (crest), to pixel gray values of 120 to 200 for optimum visualization (Fig. 4). The image was then digitized by a frame grabber

***Dexaject, Burns Veterinary Supply, Oakland, CA.

††PlakOut Gel, Hawe-Neos AG, Bioggio/TI, Switzerland.

†††Euthanasia-5 Solution, Henry Schein Inc., Port Washington, NY.

††††Stryker Co., Kalamazoo, MI.

††††President, Coltène/Whaledent Inc., Mahwah, NJ.

†††††Ultra-speed film, size 3, Eastman Kodak Co., Rochester, NY.

††††††MDX, Nu'Source International Inc., Crystal Lake, IL.

****CCD-72, Dage-MTI Inc., Michigan City, IN.

†††††Nikon, Tokyo, Japan.

†††††††Diamond Scan, Mitsubishi Electric Corp., Nagasaki, Japan.

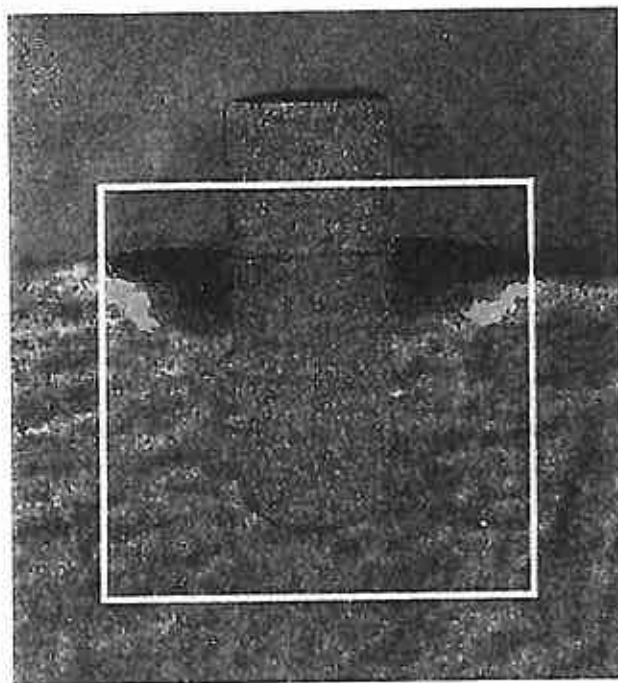


Figure 5. Color converted subtraction image of a 2-part, nonsubmerged type C implant comparing 6 months versus baseline data. Typical signs of remodeling are apparent. Red areas exhibit regions of bone loss; green areas show regions of bone gain. The white box encloses the area that was pseudocolored at the 95% confidence level over the inherent image noise present in the subtraction image. The darker bands under the red bone loss areas suggest presence of a wider area of bone loss, but the magnitude of the loss in these regions was not beyond the set 95% confidence level.

board,⁴⁴ supported by a personal computer. The calculated image pixel size in this investigation was 62 μm . After the baseline radiograph was digitized and saved in the computer memory, the follow-up radiograph was aligned with the baseline image using a real-time subtraction program. In this procedure, the superimposing images were moved back and forth and rotated with a micrometer driven stage until the best subtraction was visualized on the monitor. The follow-up radiograph was then digitized in this spatial orientation and saved on an optical disk.⁴⁵ The computer algorithms used in these analyses are part of a software package called "Computer Assisted Radiographic Evaluation" (CARE).⁴⁵

Crestal bone height (DIB). To assess changes in crestal bone height, the distance between the top of the implant/abutment, serving as a reference point, and the most coronal bone-to-implant contact (DIB) as appears radiographically were determined on the periapical radiographs at the mesial and distal aspect of each implant (Fig. 4).²⁴ Finally, the distance in 1-part implants (A, B) between

the rough/smooth implant interface and the most coronal bone-to-implant contact and in 2-part implants (C through F) between the microgap (or top of the implant in the first 3 months for implant types D through F) and the most coronal bone-to-implant contact was computed. The baseline and follow-up images were displayed simultaneously on the computer monitor with 8-fold magnification and measurements were registered. The change in crestal bone height was calculated by determining the theoretical position of the bone crest at the time of implant placement and comparing the actual DIB to that position at each radiographic time point; e.g., in type A implants at baseline, the DIB was $0.44 \text{ mm} \pm 0.31$ standard deviation (SD) above the theoretical bone crest, which was 3 mm below the top of the implant (Fig. 1).

Crestal bone density change (CADIA procedure). In the CADIA analysis, baseline and follow-up images were displayed and manipulated on a high resolution VGA monitor.⁴⁶ Differences in the overall distribution of gray values between the baseline and the follow-up radiographs, such as exposure, processing, and contrast differences, were adjusted by a nonparametric histogram matching algorithm.⁴⁶ To perform this procedure, an unchanged area common to both images was selected and outlined. The algorithm then adjusted the density and contrast of the follow-up radiograph to the density and contrast of the baseline image. After image density matching, the radiographic images were subtracted from each other and the image noise, which is defined as the standard deviation of pixel gray values in the subtraction image, was measured. Before the CADIA procedure was performed, a threshold value for the CADIA algorithm was set at twice as much as the noise in the subtraction image, thus excluding approximately 95% of the normal density variation. Only density changes that were more than the threshold to the negative or positive direction were taken into account when calculating the net-CADIA value. Once the threshold was set, the CADIA procedure was started by recalling the baseline image and positioning the measurement areas-of-interest (AOI) on the image with a trackball driven mouse (Fig. 4). The AOI were 16×16 pixel squares representing a measurement area of 1.0 mm^2 . The crestal area (Crest) described the most coronal area adjacent to the implant, whereas the middle-implant area (Mid-imp) was located just apical to the Crest area. Lateral-apical areas (Lat-ap) served as remaining sites. Finally, the program calculated the average density difference and the area of change in each AOI in mm^2 . Net-CADIA values were obtained by multiplying the measured density difference by the area changed (Fig. 5).

⁴⁴VFG-100, Imaging Technology Inc., Woburn, MA.

⁴⁵Panasonic Optical Disk Drive LF-7010, Matsushita Electric Industrial Co., Osaka, Japan.

⁴⁶NEC Multisync 4FG, NEC Corp., Tokyo, Japan.

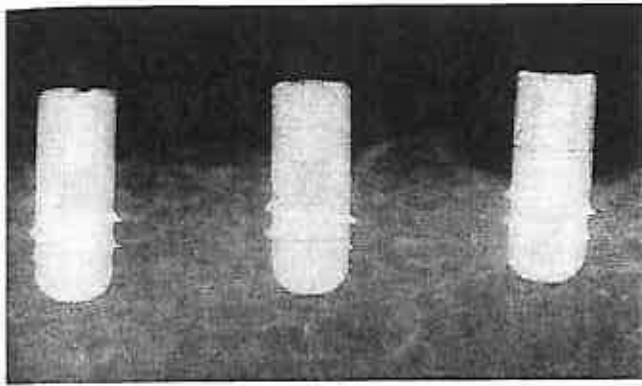


Figure 6A. Periapical standardized radiograph at 6 months after implant placement (sacrifice) showing crestal bone changes in the nonsubmerged group for implants types A through C (from left to right).

Statistical Analysis

A statistical software program^{***} was used to analyze the data. The measures of DIB and CADIA were approximately normally distributed, so parametric tests were performed.

In order to verify that the DIB and CADIA values obtained from the periapical radiographs were not influenced by examiner bias, 2 examiners independently determined the DIB and CADIA values for 1 of the dogs. A paired Student *t*-test was performed to determine if there was a difference between mesial and distal aspects for the DIB as well as the CADIA analysis. Due to anatomical limitations, the measure of CADIA changes could not be calculated for both the mesial and distal aspects for 10% of the implants, so if both aspects had data, the 2 values were averaged; otherwise the single CADIA change value was used. This was done separately for views at the three levels identified as Crest, Mid-imp, and Lat-ap. In addition, an analysis of variance (ANOVA) was carried out to determine if an implant site (mesial or distal position, left or right side in the arch) or an individual dog had an effect on the results.

RESULTS

Clinical Findings

After implant placement, healing was uneventful in all dogs. At the time of abutment connection, 3 months after implant placement (Fig. 2), all 59 implants showed successful tissue integration exhibiting ankylotic stability without clinical signs of peri-implant infection. No continuous peri-implant radiolucencies were apparent on the radiographs (Figs. 6A and 6B). Therefore, all 30 abutments of the submerged implant types D through F could be connected. After second-stage surgery, all implants maintained ankylotic stability and revealed a complication-free follow-up period. Although oral hygiene was

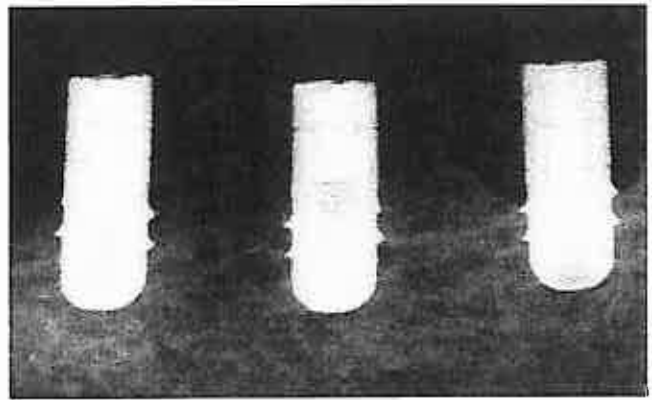


Figure 6B. Periapical standardized radiograph at 3 months after abutment connection, 6 months after implant placement (sacrifice), exhibiting crestal bone changes in the submerged group for implants types D through F (from left to right).

performed 3 times weekly, there was a variation of tissue response around the different implants. This response ranged from minimal inflammation to very inflamed tissue that was hyperplastic in nature. These responses will be detailed in the histologic analysis of these implants (unpublished data).

Statistical Findings

In terms of intra- and interexaminer variability, a total of 168 DIB values were compared, comprising 7 time points, 12 implants, and 2 aspects per implant. The largest difference was 0.2 mm, which was noted in 10% of the observations, while 50% varied by 0.1 mm and 40% were identical. The hypothesis of no difference between examiners was confirmed by paired Student *t*-test ($P > 0.6$). The overall mean difference between the mesial and distal aspect DIB values for all dogs, implants, and time points was less than 0.01 mm. The hypothesis of no difference between aspects was confirmed by paired Student *t*-test ($P > 0.4$). As a result, the two DIB values that were obtained for each implant at each time point were averaged. Average DIB values were then compared by 3-way analysis of variance (ANOVA) to determine if implant site influenced overall changes across time and changes across time within implant types. The interaction term of site by time was not significant ($P > 0.3$), as was the 3-factor interaction of site, time, and type ($P > 0.2$). The 3-way ANOVA was repeated substituting dog for implant site with similar results. The interaction term of dog by time was not significant ($P > 0.8$), as was the 3-factor interaction of dog, time, and type ($P > 0.9$). Since the 3-way ANOVA suggested that the interaction between time and implant type was highly significant ($P < 0.0001$), the comparisons of interest, which were changes in DIB values across time within implant types, were then performed with the effects of implant site and dog ignored. One-sample Student *t*-tests were performed for each im-

^{***}SAS Institute Corp., Cary, NC.

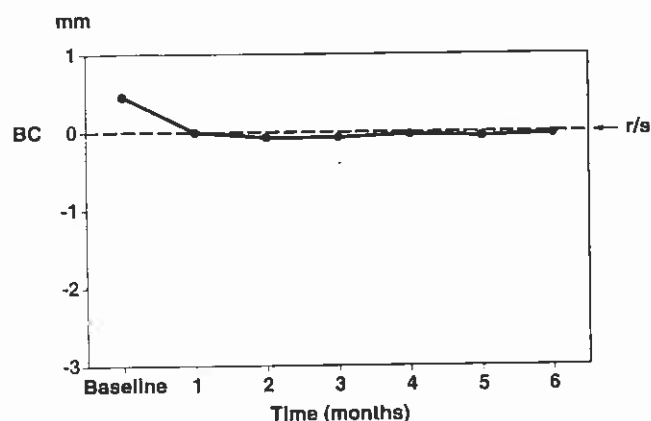


Figure 7. Line graph indicating crestal bone changes over time (continuous line) for 1-part, nonsubmerged type A implants. Note original bone crest level (BC; dashed line) and level of the rough/smooth implant interface (r/s) at the beginning of the study. No statistically significant differences were apparent comparing follow-up to baseline data.

plant type and each time on the crestal bone changes calculated from the DIB values. After applying the Bonferroni adjustment, *t*-tests with $P < 0.01$ were considered significant. As with the DIB data, CADIA changes across time within implant types were not influenced by implant site for views at Crest level ($P > 0.2$), Mid-imp level ($P > 0.9$), and Lat-ap level ($P > 0.9$). There was also no significant 3-factor interaction for dog, time, and type for all 3 levels ($P > 0.9$). The interaction between time and type was significant for the Crest CADIA ($P < 0.001$), but not for the Mid-imp ($P > 0.9$) or the Lat-ap AOI ($P > 0.7$). However, the main effect of time was significant for the Mid-imp ($P < 0.001$). For the Lat-ap AOI, time was not significant ($P > 0.9$), so no significant changes of CADIA were observed for the Lat-ap area. One-sample student's *t*-tests were performed for each implant type and each time on Crest, and Mid-imp CADIA data, with $P < 0.01$ considered significant after the Bonferroni adjustment.

Radiographic Evaluation

Crestal bone height (DIB). Due to the stent used for taking the standardized radiographs, all 59 implants could be well visualized over time and therefore included in the crestal bone height analysis. In general, the implants were clinically placed as drawn schematically in Figure 1. There was, however, slight variation of the edentulous ridge after flattening due to the natural slope of the arch. In certain cases, this resulted in a slight differential in bone level on the mesial and distal at the time of implant placement (see baseline, Fig. 7). For the remaining time points the crestal bone level followed the rough/smooth implant interface for 1-part, nonsubmerged implants, types A and B (Figs. 7 and 8). For type A implants, no statistically significant changes could be observed comparing all follow-up evaluations with the baseline data,

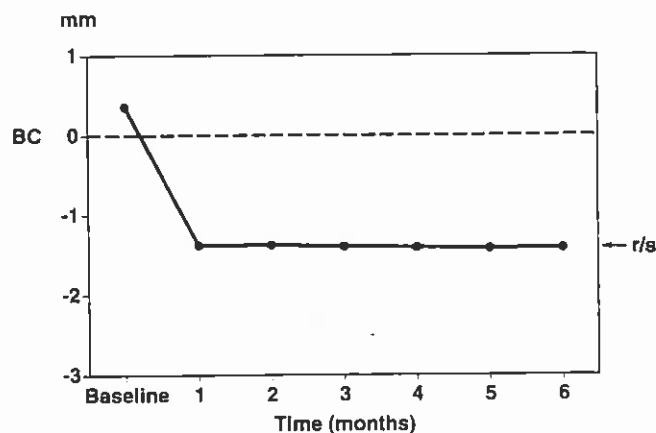


Figure 8. Line graph demonstrating crestal bone changes over time (continuous line) for 1-part, nonsubmerged type B implants. Note original bone crest level (BC; dashed line) and level of the rough/smooth implant interface (r/s) at the beginning of the study. Differences between follow-up and baseline data were statistically significant ($P < 0.0001$).

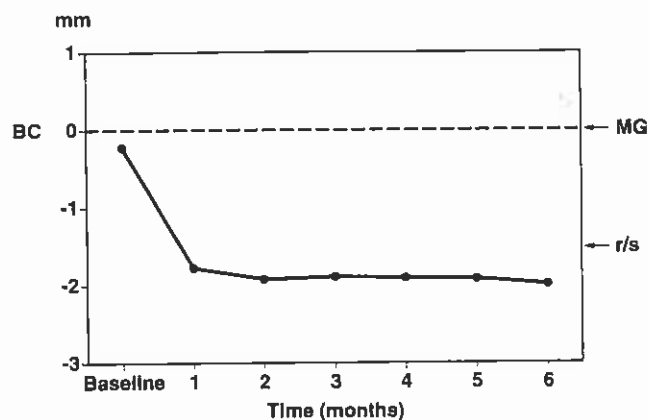


Figure 9. Line graph displaying crestal bone changes over time (continuous line) for 2-part, nonsubmerged type C implants. Note original bone crest level (BC; dashed line), level of the microgap (MG), and level of the rough/smooth implant interface (r/s) at the beginning of the study. Differences between follow-up and baseline data were statistically significant ($P < 0.0001$).

the time of implant placement ($P > 0.05$). The changes in the bone crest level observed around type B implants occurred within the first 4 weeks after implant placement. All follow-up DIB level readings were statistically significant ($P < 0.0001$) compared to baseline (implant placement).

For all 2-part implants, types C through F, the bone crest level changes appeared dependent on the location of the microgap (Figs. 9 through 12) with a distance between the microgap and the most coronal bone-to-implant contact being approximately 2.0 mm. In addition, these changes occurred irrespective of the technique employed, nonsubmerged (type C) or submerged approach (types D through F). For example, the only difference between the type C and type D implant was that the type D implant was submerged for 3 months. Once the abutment was

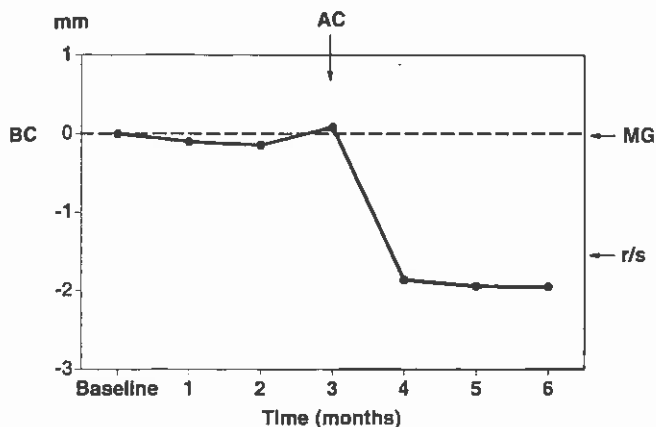


Figure 10. Line graph illustrating crestal bone changes over time (continuous line) for 2-part, submerged type D implants. Note original bone crest level (BC; dashed line), level of the microgap (MG), level of the rough/smooth implant interface (r/s) at the beginning of the study, as well as the time point of abutment connection (AC). Differences comparing the time points before and after abutment connection were statistically significant ($P < 0.0001$).

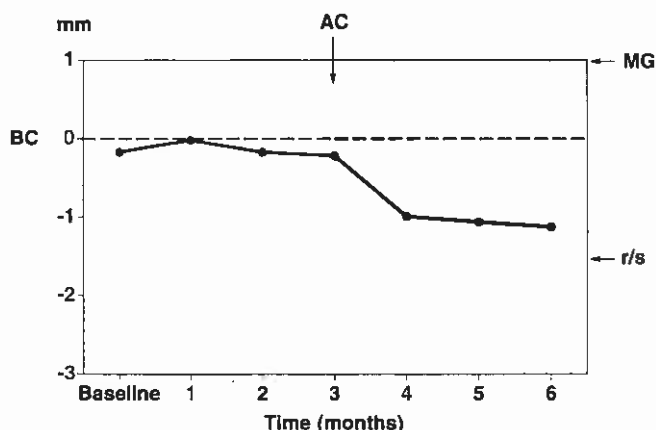


Figure 11. Line graph explaining crestal bone changes over time (continuous line) for 2-part, submerged type E implants. Note original bone crest level (BC; dashed line), level of the microgap (MG), level of the rough/smooth implant interface (r/s) at the beginning of the study, as well as the time point of abutment connection (AC). Differences comparing the time points before and after abutment connection were statistically significant ($P < 0.0001$).

connected, the alveolar change (and time for change) was identical between these two implants. No significant changes occurred in the bone crest level during the submerged healing phase (first 3 months after implant placement) of types D through F implants. The changes in alveolar crest location in all 2-part implants (types C through F) occurred within the first 4 weeks after abutments were in place whether the abutment was placed at the time of surgery (type C) or after 3 months of healing (types D through F). Changes in the bone crest level around all 2-part implants were statistically significant ($P < 0.0001$) compared to the baseline (type C) and also to the first 3 months of healing (types D through F).

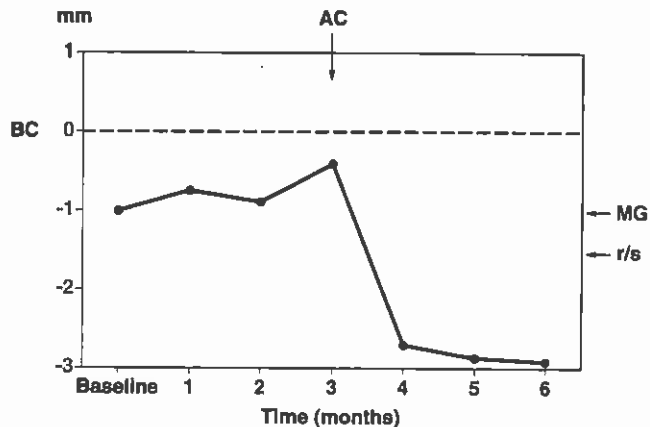


Figure 12. Line graph showing crestal bone changes over time (continuous line) for 2-part, submerged type F implants. Note original bone crest level (BC; dashed line), level of the microgap (MG), level of the rough/smooth implant interface (r/s) at the beginning of the study, as well as the time point of abutment connection (AC). Differences comparing the time points before and after abutment connection were statistically significant ($P < 0.0001$).

Bone density changes (CADIA). Bone density changes around the implants were evaluated in discrete areas-of-interest (AOI) using computer-assisted densitometric image analysis (CADIA). Three AOI were analyzed with one area in the crestal region, another area apical to the crestal area, and the third area more apically located (Fig. 4). In general, changes in density of the AOI (Table 1) of the Crest region reflected the linear changes of the bone crest level (DIB measurements) of the implants. In type A implants, there were minimal changes in Crest and Lat-ap areas with a marginal increase in density in the Mid-imp AOI. In the other 1-part, nonsubmerged implant (type B), where the rough/smooth implant interface was 1.5 mm more apical than the type A implant, the crestal density significantly decreased over time. After 2 months, this density was significantly less than baseline except at 5 months. The Mid-imp AOI was marginally denser over time and the Lat-ap AOI remained relatively constant. In the 2-part, nonsubmerged type C implant with a microgap at the alveolar crest, the density of the Crest AOI was the least of the nonsubmerged implants and was significantly less at all time points compared to baseline. The Mid-imp and Lat-ap AOI showed marginal density increases after 3 months (Fig. 5).

In the case of submerged, 2-part implants (types D through F), density changes in the Crest and Mid-imp AOI were similar to the changes observed for the 2-part, nonsubmerged type C implants except that the significant changes were observed after abutment connection following 3 months of healing. No significant changes were found in the Lat-ap AOI either when the implants were submerged in the first 3 months or when they were uncovered for the second 3 months. Also, no significant changes occurred in the Crest AOI for the first 3 months

Table 1. Bone Density Changes at 3 Different Bone Levels (AOI) Next to Implants at 6 Time Intervals (net CADIA results) (Mean \pm Standard Deviation)

Bone Level	Month					
	1	2	3	4	5	6
Type A—1-Part, Nonsubmerged						
Crest	-1.39 \pm 2.88	-2.00 \pm 3.75	-2.06 \pm 5.15	-2.17 \pm 5.18	-1.44 \pm 4.78	-1.56 \pm 4.88
Mid-imp	0.06 \pm 1.33	0.11 \pm 1.69	0.56 \pm 1.31	1.61 \pm 4.61	2.67 \pm 3.87	2.22 \pm 3.76
Lat-ap	0.44 \pm 0.68	0.33 \pm 0.87	0.72 \pm 1.09	-0.11 \pm 1.78	0.28 \pm 1.15	0.89 \pm 1.90
Type B—1-Part, Nonsubmerged						
Crest	-2.20 \pm 7.75	-5.30 \pm 10.37	-3.25* \pm 3.26	-6.50* \pm 6.21	-4.25 \pm 7.53	-4.50* \pm 4.45
Mid-imp	0.30 \pm 1.44	0.70 \pm 1.80	0.50 \pm 1.11	0.95 \pm 2.52	1.40 \pm 2.56	1.95 \pm 2.72
Lat-ap	0.70 \pm 1.51	0.70 \pm 1.30	0.60 \pm 1.43	0.05 \pm 1.61	0.40 \pm 2.94	-0.30 \pm 1.99
Type C—2-Part, Nonsubmerged						
Crest	-10.95* \pm 10.49	-12.25* \pm 11.35	-9.95* \pm 6.81	-13.45* \pm 13.16	-9.75* \pm 6.49	-9.30* \pm 6.31
Mid-imp	0.45 \pm 2.19	1.75 \pm 3.76	2.95 \pm 4.46	2.85* \pm 3.48	3.15 \pm 5.27	3.90* \pm 5.25
Lat-ap	0.25 \pm 0.68	0.55 \pm 1.32	0.80 \pm 0.98	0.65 \pm 0.97	1.50 \pm 1.97	1.00 \pm 1.89
Type D—2-Part, Submerged						
Crest	-0.19 \pm 1.81	0.45 \pm 3.22	1.35 \pm 3.56	-9.80* \pm 6.98	-9.00* \pm 8.63	-7.90* \pm 7.90
Mid-imp	0.00 \pm 1.17	0.35 \pm 0.71	0.35* \pm 0.47	1.30* \pm 1.62	1.10 \pm 2.00	1.40 \pm 2.09
Lat-ap	0.19 \pm 0.26	0.05 \pm 1.32	0.00 \pm 0.47	0.25 \pm 0.64	0.00 \pm 0.24	0.05 \pm 0.28
Type E—2-Part, Submerged						
Crest	-0.83 \pm 3.39	2.20 \pm 3.02	1.10 \pm 2.45	-6.05* \pm 3.44	-6.50* \pm 6.60	-10.00* \pm 8.74
Mid-imp	0.28 \pm 0.67	1.30 \pm 2.14	1.25 \pm 2.75	3.35* \pm 3.80	2.35* \pm 2.76	2.20 \pm 3.47
Lat-ap	-0.06 \pm 0.39	-0.20 \pm 1.69	-0.30 \pm 1.32	-0.45 \pm 1.28	-0.35 \pm 1.06	0.25 \pm 0.76
Type F—2-Part Submerged						
Crest	-0.11 \pm 1.14	0.30 \pm 0.68	-0.20 \pm 1.75	-6.60* \pm 6.98	-8.25* \pm 8.59	-10.70* \pm 8.72
Mid-imp	0.11 \pm 0.33	0.70* \pm 0.72	0.90 \pm 1.31	2.30* \pm 2.73	2.25* \pm 3.10	3.30* \pm 2.82
Lat-ap	0.17 \pm 0.50	0.40 \pm 0.70	0.05 \pm 1.26	0.15 \pm 0.24	0.20 \pm 0.75	0.15 \pm 0.47

*Statistically significant compared to baseline at $P < 0.05$.*Statistically significant compared to baseline at $P < 0.01$.

of submerged healing. Once uncovered, types D through F crestal AOI density was significantly decreased relative to baseline and the first 3 months of submerged healing. In addition, the density of the Mid-imp AOI was increased for the 3 implant types D through F relative to the first 3 months of submerged healing.

DISCUSSION

This study has evaluated the radiographic changes in bone associated with nonsubmerged and submerged titanium implants placed side-by-side in the canine mandible. A total of 59 implants comprised of 3 different types of

nonsubmerged and 3 different types of submerged implants were evaluated. The difference among the different types of implants was a varying level of the rough/smooth implant interface in 1-part, nonsubmerged implants and the location of the microgap in 2-part, either nonsubmerged or submerged types of implants. All implants were cylindrical screws with a machined coronal portion and a sandblasted and acid-etched apical portion (SLA). All 59 implants were well integrated in bone for the duration of the study as evaluated by clinical and radiographic criteria. No increased mobility was detected on follow-up examinations of the nonsubmerged implants

when abutments were placed on submerged implants and during follow-up evaluations of submerged implants after the abutments were placed. Additionally, no periapical radiolucencies were detected on any of the radiographs taken throughout the course of the study. Clinical healing occurred without complications but with interesting, different patterns of peri-implant inflammation in the presence of mechanical and chemical plaque control 3 times per week. All the 1-part implants healed with no or minimal clinical signs of inflammation, while all 2-part implants exhibited moderate to severe levels of peri-implant inflammation (data in preparation with histological findings).

The data demonstrate that the rough/smooth implant interface in 1-part, nonsubmerged implants and its relationship to the alveolar crest influence the radiographic level of the first bone-to-implant contact. In addition, the gap between implant and abutment and its location in relationship to the alveolar crest, whether placed in a non-submerged or submerged approach, also had a profound influence on the alveolar bone surrounding the 2-part, nonsubmerged or submerged implants. The radiographic changes observed around each type of implant were consistent no matter where in the half arch the implant was placed, whether the implant was inserted on the right or left side of the dog's arch, or in which of the 5 dogs the implants were placed. In addition, the implants had similar overall shape and surface characteristics. These results indicate that the radiographic changes are due to the location of the rough/smooth implant interface in 1-part implants, and the location of the microgap in 2-part implants. This study thus demonstrates for the first time that a gap between an implant and abutment has a direct effect on bone loss regardless of whether the 2 parts are connected at the time of implant placement (type C in this study) or at abutment connection after initial submerging and integration of the implant (types D through F).

Interestingly, the alveolar changes observed around each implant type occurred rapidly, within the first 4 weeks after implant placement of nonsubmerged implants (types A through C), and after abutment connection of submerged implants (types D through F). Type B and type C implants are both nonsubmerged implants and only different from each other by type B being a 1-part implant, whereas type C is a 2-part implant. However, changes detected at type B and C implants occurred over the same period of time. Another interesting result is that changes around type C and D implants (type D being identical to type C but placed in a submerged technique) were identical in morphology and timing. These observations suggest that the mechanism causing these changes in the crestal alveolar bone around these different implant types is similar.

The exact mechanism responsible for the induced marginal bone changes is not known. Several possibilities

could account for these findings. One mechanism may involve bacterial colonization of the microgap and implant components. Evidence has been published which demonstrates the presence of bacteria in these areas under certain conditions.^{31,32} One possibility is that the epithelium migrates beyond the bacteria and the microgap in an attempt to isolate the infection. This epithelial proliferation and subsequent physiological response to establish a biologic width could be responsible for the approximately 2 mm of distance observed apical to the microgap. A second possibility to describe the noticed radiological changes could involve micromovements of the abutment. In this case, the epithelium could attach to the stable implant rather than to the abutment. Under these circumstances, a biologic width could form apical to the microgap and account for the 2 mm distance between the microgap and alveolar bone. A third possibility for the detected radiological changes has been suggested by Cochran et al.⁴⁷ and involves an interruption of the blood supply when implants and abutments are placed transmucosally. Evidence of this is supported by the fact that new bone appears to have grown over the top of type F implants as time after placement increased (Fig. 12). When the submerged implants were uncovered, however, at abutment connection, the blood supply in the periosteum and soft connective tissues was interrupted and the osseous changes were observed within the subsequent 4-week period.

No significant radiographic bone changes were detected around type A implants over the course of the study. This was a 1-part, nonsubmerged implant with the rough/smooth interface placed at the original bone crest level at the time of implant placement. Thus, the rough surface was placed in bone and the smoother machined surface in soft tissues. Abundant evidence demonstrates that implants with a rough surface achieve a more rapid and greater degree of bone apposition than do more smooth implant surfaces.⁴⁷⁻⁵¹ Clinically, however, the most important finding in this study was that no significant osseous changes were found around the 1-part, nonsubmerged implants (type A) and that this implant resulted in the optimal healing response (i.e., no crestal bone loss) of all 6 implant types examined.

In comparison to type A implants, type B implants resulted in bone loss to the level of the rough/smooth implant interface. This bone loss was approximately 1.7 mm in the first 4 weeks after placement. This finding is consistent with previous publications that demonstrate that titanium implant surfaces with a rough surface are more osteophilic than implant surfaces with a smoother surface (see above). Thus, the more pronounced bone loss is most likely caused by the difference in implant surface and confirms the findings in earlier studies.^{27,41}

The type C implant is interesting due to the clinical cases where the surgeon places an abutment on the implant

at the time of implant placement using a nonsubmerged approach, but still utilizes a 2-part implant system. The placement is carried out with the assumption that this results in a similar healing as found around 1-part, nonsubmerged implants. The results show, however, that of the 3 types of nonsubmerged implants placed, this situation resulted, by far, in the greatest amount of bone loss. Clearly, having a microgap placed at the alveolar crest caused the largest amount of radiographic bone loss of the 3 nonsubmerged implant types. Additionally, the bone loss induced around this type of implant appeared independent of the rough/smooth implant interface in contrast to the 1-part, nonsubmerged implant types A and B.

In all cases of submerged implants, no crestal changes were found during the initial healing period (first 3 months after implant placement) when the implants were covered with soft tissues. However, once a gap was created with the addition of the abutments, bone resorption occurred rapidly. In the case of the type D implant, the bone loss pattern was identical to the type C implant except that the changes occurred after abutment connection. This result indicates that the bone loss was not dependent on whether the implant was placed in a nonsubmerged or a submerged technique; rather, the bone loss was dependent on the microgap. It is likely that the approximately 2 mm of bone loss observed below a microgap is necessary to re-establish a biologic width with epithelium migrating below the microgap as was shown by Weber et al.²⁴ and discussed by Cochran et al.⁴⁰

The location of the microgap determined the amount of bone loss as shown by implant types E and F. The same linear distance, approximately 2.0 mm, was found between the microgap and the osseous crest around these 2 implant types as was found around types C and D, the other 2-part implants. These findings suggest that the observed bone changes were the result of a physiological response to the microgap and is consistent with the proposal by Cochran et al.⁴⁰ that a biologic width also exists around nonsubmerged implants formed by the implantogingival junction similar to that around teeth created by the dentogingival junction.⁵² This similarity to the biologic width found around teeth⁵³ has been confirmed histologically around unloaded and loaded 1-part, nonsubmerged titanium implants.⁴⁰

The results obtained around the submerged implants in this study also provide an explanation for the observation that submerged implants lose approximately 1.5 mm of bone over the first year of function.^{33,34} Suggested explanations in the past have centered on countersinking procedures and stress placed on the bone by the restoration. The data in this study, where no restorations were placed, demonstrate clearly that bone loss occurs as a result of creating a microgap between implant and components and consistent with the creation of a biological width. These data additionally confirm the suggestion by Cochran et

al.⁴⁰ that this evaluation criterion for the success of an implant is only valid for submerged implants where a microgap is subsequently formed after abutment and/or restoration connection.

CONCLUSION

The results of this side-by-side comparison of nonsubmerged and submerged endosseous titanium implants in the canine mandible demonstrate that the creation of a microgap between the implant and an abutment results in bone loss around the implant. This bone loss occurs even if the microgap is placed 1 mm coronal to the alveolar crest. Furthermore, the alveolar changes occur rapidly and then stabilize. These findings have significant clinical implications for the way in which implants are manufactured and placed in the patient's bone and soft tissues. In addition, these findings are consistent with previous work^{40,53} that indicates that a biologic width is established by the implantogingival junction similar to the dimensions found around teeth by the dentogingival junction.^{42,52} The results reveal that a 1-part, nonsubmerged implant with a rough osteophilic surface for hard tissue integration and a smooth surface for soft tissue integration results in the best tissue response of the 6 implant types (1- or 2-parts, nonsubmerged or submerged) examined.

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