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Evaluation of an endosseous titanium implant with a sandblasted and acid-etched surface in the canine mandible: radiographic results

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Previous studies have demonstrated in short-term experiments that a sandblasted and acid-etched (SLA) titanium implant had a greater bone-to-implant contact than a titanium plasma-sprayed (TPS) implant in non-oral bone. In the present study, an SLA implant was compared radiographically to a TPS implant under unloaded and loaded conditions in the canine mandible for up to 15 months. 69 implants were placed in 6 foxhounds. Standardized radiographs were taken at baseline, preload, 3, 6, 9, and 12 months of loading. Loaded implants were restored with gold crowns similar to the natural dentition. Radiographic assessment of the bone response to the implants was carried out by measuring the distance between the implant shoulder and the most coronal bone-to-implant contact (DIB) and by evaluation of bone density changes using computer-assisted densitometric image analysis (CADIA). 5 different areas-of-interest (AOI) were defined coronally and apically along the implant. DIB measurements revealed that SLA implants had significantly less bone height loss (0.52 mm) than TPS implants (0.69 mm) at the preload evaluation ($p=0.0142$) as well as at 3 months of loading (0.73 mm/1.06 mm; $p=0.0337$). This difference was maintained between the implant types during the 1-year follow-up period. The same trend was also evident for CADIA measurements with SLA implants showing higher crestal bone density values when comparing preload to baseline data ($p=0.0890$) and 3 months to baseline data ($p=0.0912$). No measurable bone density changes were apparent in the apical areas of either implant. These results suggest that SLA implants are superior to TPS implants as measured radiographically in oral bone under unloaded and loaded conditions.

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Key words: loaded implants – titanium implants – sand-blasting technique – titanium acid-etched surface – titanium plasma-sprayed surface – digital subtraction radiography – image analysis

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Criteria for the predictable integration of endosseous dental implants date back to the late 1960s and early 1970s. Fundamental experimental studies, carried out by Brånemark et al. (1969), Schroeder et al. (1976, 1978, 1981) demonstrated that titanium implants regularly healed with direct bone-to-implant contacts, termed "osseointegration" or "functional ankylosis" respectively. Later, many clinical studies demonstrated that implant integration can be achieved and maintained on a long-term basis using submerged and nonsubmerged titanium dental implants (Brånemark et al. 1977, Adell et al. 1981, Babbush et al. 1986, Cox & Zarb 1987, Adell et al. 1990, Buser et al. 1990, 1991a, Ten Bruggenkate et al. 1990, Behneke et al. 1992, Schmitt & Zarb 1993; Laney et al. 1994, Mericske-Stern et al. 1994, Jemt & Lekholm 1995). Implants utilized in these clinical studies vary in many ways, including shape, size, surface characteristics, surgical placement, and restoration.

One characteristic of titanium implants that has received much attention in recent years is the texture and morphology of the finished surface. This is important, as the characteristics of the surface have a direct impact on the integration of the implant and provide the biological interface with the hard and soft tissues of the oral environment. Additionally, although often not mentioned in many papers on implant systems with submerged implants, the oral endosseous implant must penetrate the integument of the body with the oral tissues, providing a "biological seal" between the outside and inside of the body. Biologically, this "implantogingival junction" is normally formed by the supracrestal connective tissue and the oral epithelium (Schroeder et al. 1981, Buser et al. 1989, 1992, Berglundh et al. 1991, Listgarten et al. 1991, Cochran & Mahn 1992, Listgarten et al. 1992, Weber et al. 1996). Thus, integration of the implant includes integration of 3 tissues: epithelium, soft, and hard (bone) connective tissues. Data have now accumulated for over 10 years that clearly demonstrate that osseous integration of endosseous implants is directly affected by the surface characteristics of the implant. These studies have involved both in vitro experiments (Wennerberg et al. 1993, Martin et al. 1995, Martin et al. 1996, Schwartz et al. 1995), as well as in vivo studies (Claes et al. 1976, Kirsch & Donath 1984, Thomas & Cook 1985, Steinemann et al. 1986, Block et al. 1987, Carlsson et al. 1988, Wilke et al. 1990, Buser et al. 1991b, Gottlander et al. 1992, Weinlaender et al. 1992, Wennerberg et al. 1995). Thomas & Cook (1985), e.g., examined the variables that influenced the apposition of bone at the implant surface. Of 12 parameters studied, only surface characteristics had a significant effect on the integration of the implant. Rough surfaces resulted in the highest amount of bone-to-implant contact whereas smooth surfaces had more areas of soft tissue contact with the implant surface and less apposition to bone. As noted above, these findings have been repeated under various circumstances and in different types of bone and animal model systems with similar results, indicating that rough surfaced implants have more bone-to-implant contact compared to implants with a smooth surface.

The manufacturing of implants with a rough surface can be achieved in various ways. In many circumstances, these processes result in surface characteristics that, in addition to being rough, are also microporous. Very little information exists on the effect of roughness, versus microporosity, on the integration of endosseous implants. In a study by Buser et al. (1991b), cylindrical titanium implants with six different surface characteristics were placed in the metaphysis of the tibia and femur of miniature pigs and examined histomorphometrically after 3 and 6 weeks of healing. Results from this study and a similar study by Wilke et al. (1990) in sheep indicated that the extent of the bone-to-implant contact and the magnitude of removal torques were both positively correlated with an increasing roughness value of the implant surface. However, these studies were performed in non-oral long bones. In addition, the study by Buser et al. (1991b), and the majority of the studies performed on surface characteristics of implants, were short-term evaluations of implants without functional load.

Radiography is the only non-invasive method that can be used to evaluate the reaction of bone to an implant and to implant loading. With endosseous implants, 2 different assessments can be performed that evaluate distinct aspects of the bone-to-implant response. Conventionally, linear measurements are done to assess changes in crestal bone height (DIB) by measuring the distance between the implant shoulder and the most coronal bone-to-implant contact (Buser et al. 1990, Weber et al. 1992). Another method is the evaluation of bone density changes using the computer-assisted densitometric image analysis (CADIA) that was introduced by Brägger et al. (1988). CADIA is a convenient density change assessment method in which the exposure and film processing differences can be compensated for using the unchanged areas of the same images for the image density equalization (Brägger & Pasquali 1989, Brägger 1994).

The purpose of the present study was to compare titanium implants with a SLA and TPS surface in the canine mandible under unloaded and loaded conditions for up to 15 months. This paper presents the radiographic results utilizing the above mentioned methods with linear and density measurements based on longitudinal standardized radiography.

Materials and methods

Implant design and surfaces

2 different types of nonsubmerged cylindrical test implants with a hollow-screw design were made from grade-IV commercially pure titanium (Institut Straumann AG, Waldenburg/BL, Switzerland). The outer diameter was 4.1 mm, whereas the total length was 9 mm. The suprabony, smooth portion of each implant had a machined surface, whereas the infrabony portion was 6 mm in length and had either a TPS surface with typical roughness and porosity values of 30-50 μm (Fig. 1) or a sandblasted and HCl/H_2SO_4 acid-etched SLA surface with two levels of roughness, one being 20-40 μm peak to peak, and a superimposed second level at 2-4 μm peak to peak (Fig. 2.).

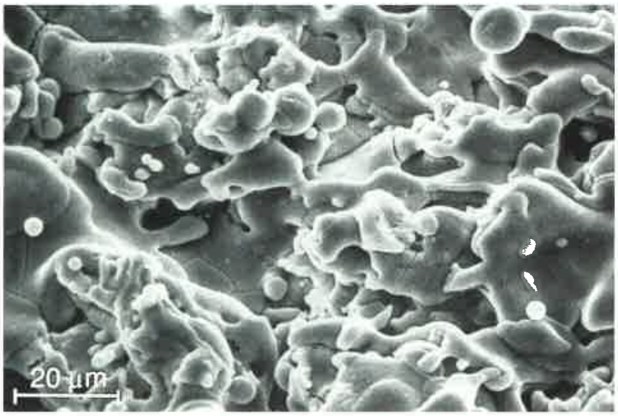

Fig. 1. Scanning electron micrograph of a TPS surface (bar=20 µm; original magnification × 1700).

Fig. 2. Scanning electron micrograph of a SLA surface (bar=20 µm; original magnification × 1700).

Study animals

6 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 30–35 kg. All animals were free of heart worms and were quarantined.

Surgical procedures – extraction

Tooth extractions were performed under general anaesthesia in an operating room using Pentothal® i.v. (Thiopenthal-Na solution 4%, 0.4 ml/kg bw. – Abbott Laboratories, North Chicago, IL, USA) as a premedication. The dogs were placed on a heating pad, intubated and inhalated with AErane® (Isoflurane 1.5-2% – Ohmeda Carbide Inc., Liberty Corner, NJ, USA) and monitored with an electrocardiogram during the surgery. After disinfection of the surgical site with Clinidine® (povidone-iodine solution 10%, titratable iodine 1% – Clinipad Co., Guilford, CT, USA), local anaesthetic (Lidocaine HCl 2% and epinephrine 1:100,000 – Henry Schein Inc., Port Washington, NY, USA) was administered by infiltration at the buccal aspect of the lower jaw. Crevicular incisions were made, and all four premolars (P_1-P_4) and the first molar (M_1) were carefully extracted. Prior to extraction, P_2-M_1 were sectioned to avoid tooth fracture. Adaptation of the wound margins was achieved with interrupted sutures. Finally the remaining teeth were scaled and cleaned.

The day of surgery, the dogs received 20 mg of the analgesic Nubain® s.c. *BID* (Nalbuphine 10 mg/ml – Astra Pharmaceutical Products Inc., Westborough, MA, USA). Three ml of the antibiotic Pen-B® was administered s.c. (Benzathine Penicillin 150,000 I.U. + Procaine Penicillin G 150,000 I.U. – Pfizer Inc., Lee's Summit, MO, USA) *SID* every 48 h for 7-10 days. For suture removal, after a period of 7-10 days, the animals were briefly anaesthetized utilizing a combination of xylazine, acepromazine, atropine and ketamine i.v. (1.1 ml/15 kg bw.).

Surgical procedures – implant placement

Endosseous, non-submerged titanium implants were inserted under the same conditions as the tooth extractions (sterility, operating room, anaesthesia) after a healing period of 3 mo (Fig. 3). A crestal incision was made maximizing keratinized gingiva 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 physiological saline. Measurements were made using a boley gauge to distribute 6 test implants on each side of the mandible. Implant osteotomy was performed

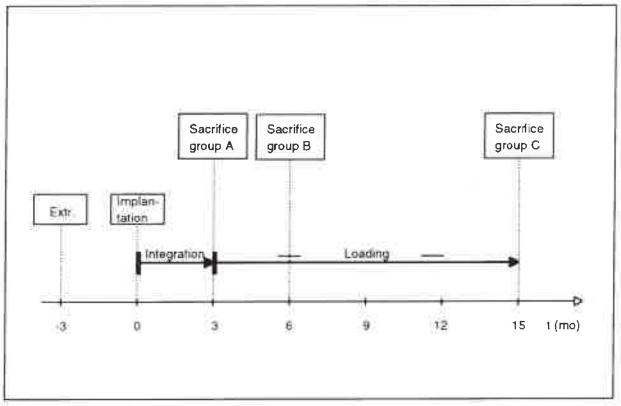

Fig. 3. Study design outlining three different groups of animals, A, B and C. Only animals in group B and C had restorations placed. Animals in group C had implants in place for 15 months with restorations for 12 months.

with torque reduction rotary instruments at 500 rpm using again chilled saline. According to a randomized starting selection, 3 of each kind of test implants were placed in an alternating manner per side and healing screws were placed on top of the implants. In this fashion, no implant type had a biased position in the arch. Due to anatomical limitations, three out of the possible 72 implants could not be placed, resulting in a total of 69 inserted implants. If necessary, periosteal relieving and contouring incisions were made on the buccal and lingual aspects to achieve tension-free wound closure, with a close adaptation of the mucosa to the transmucosal portion of the non-submerged implants. Horizontal mattress and interrupted sutures were placed. The day of surgery the dogs received 20 mg Nubain® s.c. *BID*. Three ml Pen-B® were administered s.c. *SID* every 48 h for 14 days. 100 mg of the antibiotic Gentocin® (Gentamicin 50 mg/ml – Schering-Plough Animal Health Corp., Kenilworth, NJ, USA) were given s.c. on day 1 *BID*, and the same dosage *SID* from days 2-10. To reduce swelling, the dogs received 2 ml of the antiinflammatory Dexaject® i.m. (Dexamethasone 2 mg/ml – Burns Veterinary Supply, Oakland, CA, USA) *SID* day 1 and day 4. Sutures were removed after 7-10 days as described above. A soft diet was utilized for the duration of the study.

Prosthetic reconstruction

4 out of the 6 dogs constituted the loaded implant groups, B and C (Fig. 3). 2 months after implant placement in these animals, individual impressions (President®, polyvinyl siloxane, Coltène/Whaledent Inc., Mahwah, NJ, USA) were made and screw-retained gold crowns fabricated (Fig. 4). To imitate the natural dentition of the dogs, the P_1 area had single crowns placed, whereas in the P_2-M_1 area, connected crowns on two implants were made. Octa abutments were placed in the implants and precise impressions were taken with standard ITI® components (International Team for Oral Implantology) including repositional transfer copings. Implant analogs were placed in the impressions and models made for fabrication of the restorations. Highly precise ITI® gold copings were incorporated into the wax-ups for the crowns and bridges. The restorations were inserted 3 months after implant placement (Fig. 3). At time of insertion, each bridge was carefully evaluated for passive fit by alternating occlusal screw tightening and evaluating movement of the restoration. In 7 bridges, where movements were detected, they were removed and sectioned on the models and placed as separate units to assure passivity of fit. Finally, the restorations were seated using 4 mm occlusal screws and adjusted in the mouth to assure that the crowns were either out of occlusion or had only light contact. Premolars are not in occlusion in the foxhound and the occlusion was maintained as naturally as possible by taking models of the dogs before extraction and duplicating each dog's occlusion. These models were additionally used to manufacture dog specific radiographic stents that allowed for standardized longitudinal radiography to be made and which also included a standardized radiographic step wedge (Fig. 5). Over time, most dogs exhibited wear patterns on the molar restorations as well as on some premolars.

Sacrifice

2 out of 6 dogs (group A) were sacrificed after a healing period of 3 months and constituted the unloaded implant group (Fig. 3). The other 4 dogs were sacrificed after loading, 2 of them after 3 months (group B) and 2 after 12 months of loading (group C). Euthanasia was performed with an overdose of Euthanasia-5® Solution i.v. (Pentobarbital sodium, 0.2 ml=65 mg/kg bw. – Henry Schein Inc., Port Washington, NY, USA). Mandibles were block-resected with an oscillating autopsy saw (Stryker Co., Kalamazoo, MI, USA) and the recovered segments with the implants were immersed in a solution of formaldehyde 4% combined with $CaCl_2$ 1% for histologic preparation and analysis (Schenk et al. 1984).

Radiographic evaluation – image acquisition

Baseline standardized periapical radiographs were taken either at the time of suture removal, 7-10 days after implant placement or within the first 3 weeks, while the dogs were under general anaesthesia. First follow-up radiographs were taken 3 months after implant placement, at the time of implant loading (preload data). Subsequently, the radiographic procedure was repeated after 3, 6, 9, and 12 months of loading (Fig. 3). A customized acrylic stent (Fig. 5) combined with a conventional film holding biteblock and a paralleling beam-aiming device was utilized (XCP® – Rinn Corp., Elgin, IL, USA). Thus, the X-ray beam projection did not noticeably change between two exposures of a pair of standardized X-rays in horizontal orientation as well as image distortion could be avoided due to film bending. A dental X-ray unit equipped with a 35 cm long-cone (Gendex® – Gendex Corp., Milwaukee, WI, USA) was used to expose the periapical intraoral radiographs (Ultra-speed® film, size 2, 31 × 41 mm – Eastman Kodak Co., Rochester, NY,

Fig. 4. This photograph demonstrates multi- and single-unit gold crowns (screw-retained) in situ in the P_1-M_1 area of the canine mandible. Bridges were sectioned if the restorations did not immediately go to place passively.

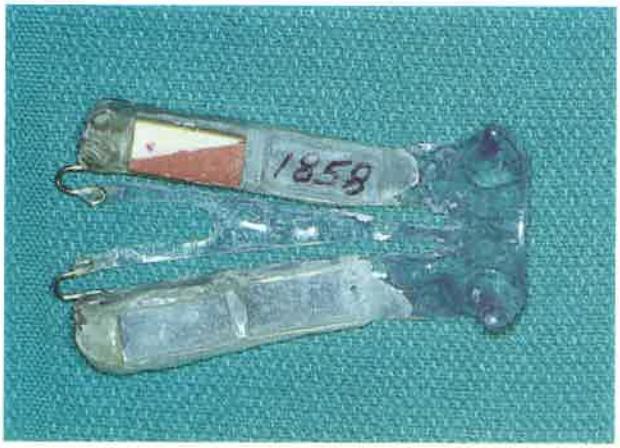

Fig. 5. Custom-made acrylic stent. An Ultra-speed® film size 2, horizontally mounted on a XCP® biteblock, could be inserted in a reproducible way in the existing slit of the stent. Note the acrylic reference step wedge for densitometric standardization.

USA). Exposure parameters were 70 kVp, 15 mA, and 1/4 s at a focus-to-film distance of 37 cm. The radiographs were processed with an automatic film processor (Dent-X 9000® - Dent-X Co., Elmsford, NY, USA) according to manufacturer's recommendations (Eastman Kodak Co., Rochester, NY, USA).

Radiographic evaluation – image capture and digitization

Radiographic image alignment and analysis was performed by one examiner experienced in computerized image analysis. This has been shown to increase the consistency and reliability of the measurements (Hausmann et al. 1989). In addition, the examiner was blind to the type of implant. The acquired radiographs were converted to 640 (H) X 480 (V) pixel digital images using a calibrated CCD video camera (CCD-72® – Dage-MTI Inc., Michigan City, IN, USA) and a Nikon 50 mm lens with an aperture of 8 (Nikon, Tokyo, Japan). The images were initially displayed on a 43 cm video monitor (Mitsubishi Diamond Scan®, model HC 3925ATK-Mitsubishi Electric Corp., Nagasaki, Japan), 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 'Crest/1' area (Fig. 6a), the most coronal bone-to-implant area, to pixel grey values of 120 to 200 for optimum visualization. The image was then digitized by a frame grabber board (VFG-100® – Imaging Technology Inc., Woburn, MA, USA) supported by a personal computer (Intel 80486 AT/bus® – Lane Systems, San Antonio, TX, USA). 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 (Panasonic Optical Disk Drive LF-7010® – Matsushita Electric Industrial Co., Osaka, Japan). The computer algorithms used in these analyses are part of a software package called 'computer assisted radiographic evaluation' – CARE (Dove et al. 1990).

Radiographic evaluation – crestal bone height (DIB)

To assess the loss of crestal bone height, the distance between the implant shoulder, serving as a reference point, and the most coronal bone-to-implant contact (DIB) was determined on the periapical radiographs at the mesial and distal aspect of each implant (Buser et al. 1990, Weber et al. 1992). The baseline and follow-up images were displayed simultaneously on the computer monitor with 8-fold magnification and the measurements were performed and registered to the accuracy of 0.1 mm. The loss of crestal bone height was calculated by subtracting the baseline DIB from the DIB values in the follow-up images. The mesial and distal bone loss was averaged and one value per implant was used in the analysis. 15 implants were measured a 2nd time at a separate appointment to obtain data for the calculation of the measurement error.

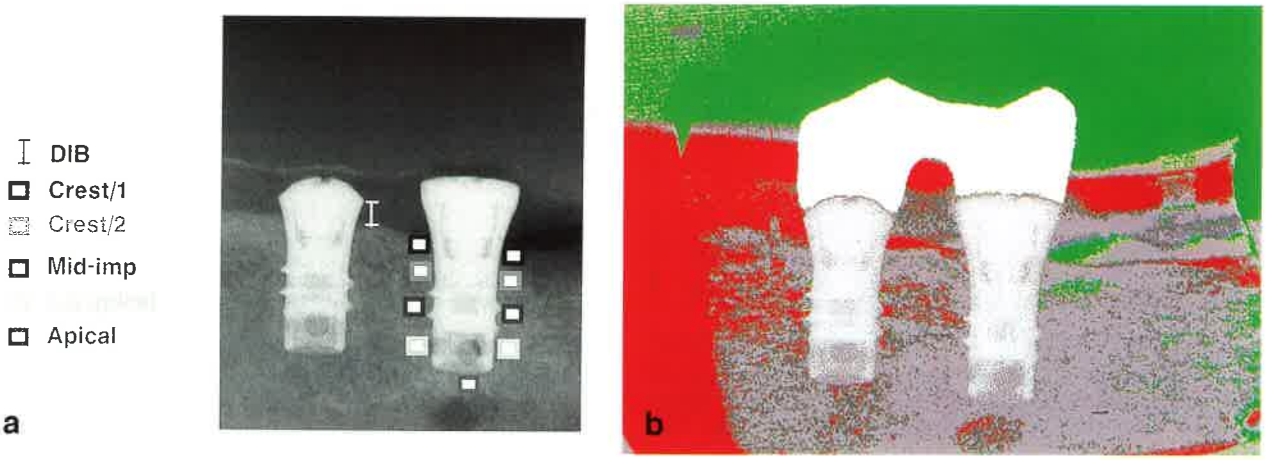

Fig. 6. (a) Baseline X-ray - left implant: vertical line indicates linear measurements for the evaluation of the distance between the implant shoulder and the most coronal bone-to-implant contact (DIB) - right implant: boxes defining areas-of-interest (AOI) at different levels for computer-assisted densitometric image analysis (CADIA). (b) Colour converted subtraction image, comparing 12 months of loading versus baseline. Typical remodeling changes are displayed. Red areas indicate regions of bone gain, green areas regions of bone loss. Note bone gain in the most coronal area of the bone crest. No changes were detected in more apical regions.

Radiographic evaluation – CADIA procedure

In the CADIA analysis, the baseline and follow-up images were displayed and manipulated on a high resolution VGA monitor (NEC Multisync 4FG® – NEC Corp., Tokyo, Japan). The differences in the overall distribution of grey values between the baseline and the follow-up radiographs, such as exposure, processing and contrast differences, were adjusted by a nonparametric histogram equalization algorithm described by Rüttimann et al. (1986). 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 the image density equalization, the radiographic images were subtracted from each other and the image noise, which is defined as the standard deviation of pixel grey values in the subtraction image, were measured in the subtraction image. Before the CADIA procedure was performed, a threshold value for the CADIA algorithm was set to be 2 × 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 Area-of-Interest (AOI) (Fig. 6a) on the image with a trackball driven mouse. The AOI were 16×16 pixel squares representing a measurement area of 1.0 mm^2. ‘Crest/1’ area described the most coronal bone-to-implant contact, whereas ‘crest/2’ area was located just apical to the ‘crest/1’ area. ‘Middle-implant’, ‘lateral-apical’ and ‘apical’areas served as the 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. 6b).

Statistical analysis

Descriptive statistics were calculated for the crestal bone height measurements and for the net-CADIA evaluation. Tests of analysis of variance with repeated measures were performed separately for crestal bone height measurements and for bone density changes to assess the effect of implant type and time interval on these variables while controlling for the effect of the dog variable.

Results

Clinical observations

Postoperative healing following implant placement was uneventful in all dogs. After 3 months of healing, all 69 implants demonstrated successful tissue integration with ankylotic implant stability and no signs of periimplant infection. No continuous periimplant radiolucencies were apparent on the radiographs. Therefore, all 48 implants of group B and C could be restored with single crowns or fixed partial dentures as described. After loading, all implants maintained ankylotic stability and revealed a complication-free follow-up period.

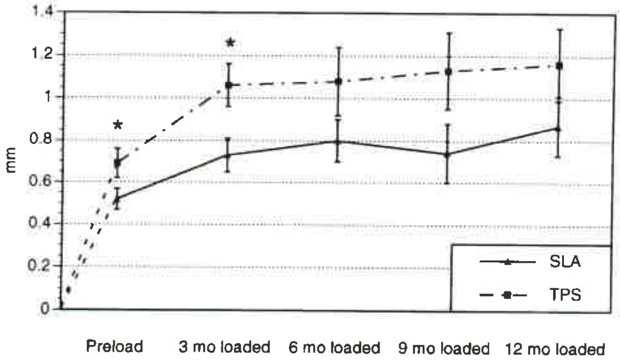

Fig. 7. Interaction line plot for average crestal bone loss (see DIB measurements): SLA versus TPS implants. Effect: implant * time; error bars: ±1 standard error(s). Note that TPS implants lost more bone than SLA implants only comparing preload to baseline (* $p=0.0142$) and 3 months of loading to baseline data (* $p=0.0337$) at a statistically significant level.

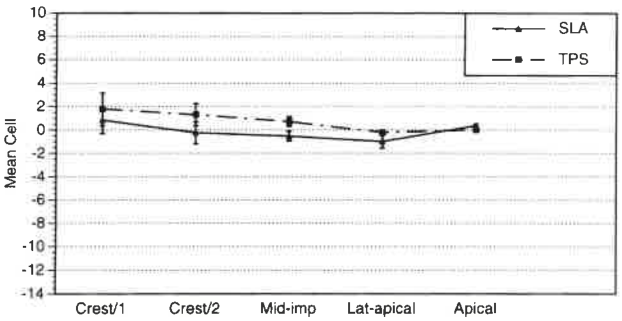

Fig. 8. Interaction line plot for net-CADIA: Preload versus baseline. Effect: implant * site; error bars: ±1 standard error(s). For Figs. 8-11, "mean cell" is the density change described as a net-CADIA value. Note little increase for crest/1 and crest/2 area, which is not significant compared to the remaining three AOI. No significant changes between SLA and TPS surfaces are apparent.

Radiographic evaluation – crestal bone height (DIB)

Out of the 69 implants placed, 2 were not adequately visualized on the radiographs leaving 67 implants for the crestal bone height analysis. The average loss of crestal bone is shown in Fig. 7 at each time point for both implant types. All the crestal bone loss occurred during the first 6 months after implant placement with 65% of bone loss before loading, and 35% in the first 3 mo of loading. No further bone loss was evident in the following 9 months of loading with either implant type. At preload evaluation and after 3 months of loading, the 2 types of implants significantly differ, i.e., at preload, the SLA mean bone loss compared to baseline was 0.52 mm, whereas the TPS mean bone loss measured 0.69 mm ($p=0.0142$). The evaluation at 3 months of loading revealed 0.73 mm of total crestal bone loss for SLA implants, and 1.06 mm for TPS implants ($p=0.0337$). In longer time intervals, there was no additional bone loss, and the difference between the SLA and TPS implants remained. However, the observed differences were not statistically significant.

Radiographic evaluation – bone density changes (CADIA)

For the assessment of bone density changes utilizing the CADIA method, 11 implants were not visible or acceptable for analysis due to radiographic film processing and projection alignment errors. Thus, 58 implants remained for density analysis. The mesial and distal surface measurements were averaged in each measurement level for each implant. The average change in bone density at different locations next to the implants, and the standard deviations (SD), are displayed in Table 2 and Fig. 8-11. The data are categorized by 2 implant types, 5 different bone levels, and 5 time intervals. The crest/1 area first gained density during the preload interval, but then lost statistically significant amounts of density during the early loading phase.

Table 1. Three-way ANOVA with repeated measures; the dependent variable is crestal bone height loss (DIB), and the independent variables are implant type, dog and time interval

Source	Degrees of freedom	Sum of squares	Mean square	*F*-value	*p*-value
implant	1	2.9749	2.9749	20.22	0.0001
dog	5	7.4060	1.4812	10.07	0.0001
implant * dog	5	1.2707	0.2541	1.73	0.1324
Within (implant * dog)	12	6.2662	0.5222	3.55	0.0001
time	4	2.2109	0.5527	3.76	0.0062
implant * time	4	0.1813	0.0453	0.31	0.8722
dog * time	6	0.3160	0.0527	0.36	0.9043
implant * dog * time	6	0.1832	0.0305	0.21	0.9740
error	138	20.3079	0.1472		
total	181	41.1172			

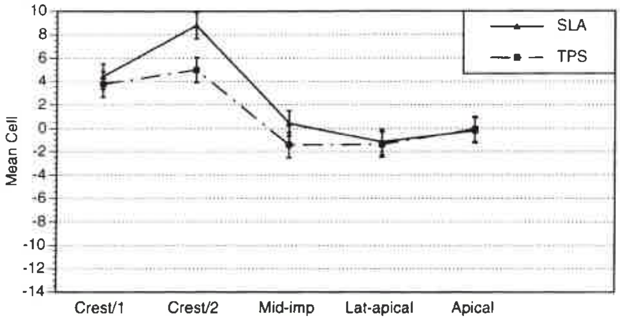

Fig. 9. Interaction line plot for net-CADIA: Three months loaded vs. baseline. Effect: Implant * Site; error bars: ±1 standard error(s). Note gain in bone density for Crest/1 and Crest/2 area at a significant level compared to the remaining three AOI. SLA implants show higher CADIA values when compared to TPS implants (*p*=0.0912).

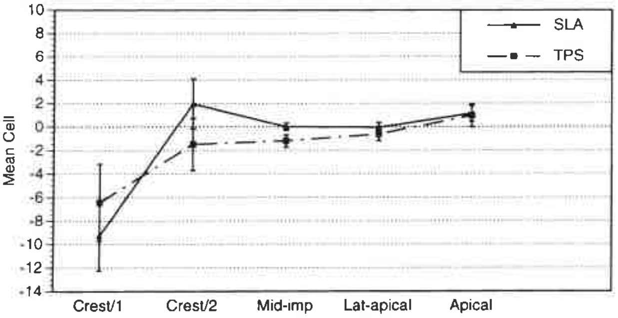

Fig. 10. Interaction line plot for net-CADIA: 6 months loaded vs. baseline. Effect: implant * site; error bars: 1 standard error(s). Due to remodeling, highly significant bone loss occurred in the crest/1 area compared to the remaining AOI-sites. No statistical changes occurred in the crest/2 area as well as when comparing SLA to TPS surfaces in general.

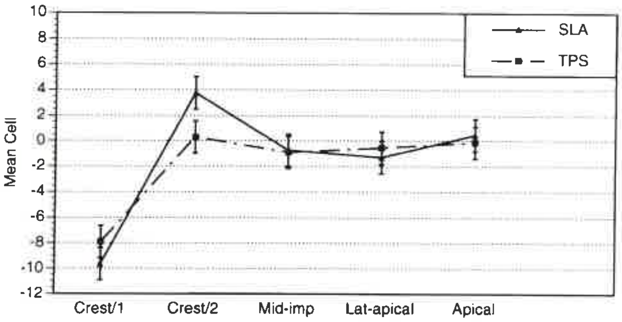

Fig. 11. Interaction line plot for net-CADIA: Twelve mo loaded vs. baseline. Effect: Implant * Site; error bars: ±1 standard error(s). Still, there is highly significant bone loss in the Crest/1 area compared to the remaining AOI-sites. Similar to 6 mo of loading, no statistical changes are obvious for the Crest/2 area as well as when comparing SLA to TPS surfaces in general.

The crest/2 area significantly gained density and retained the increase when compared to the original bone density at that site. The more apical bone areas (mid-imp, lat-apical, apical) did not change significantly in density during the 15-month follow-up period.

The three-way ANOVA revealed statistically significant differences between crest/1 and/or crest/2 respectively compared to the more apical AOI and between the measurement time intervals. The implant type was not statistically significant (*p*=0.1576), and none of the interactions of the independent variables were statistically significant. The bone adjacent to SLA type implants appeared to gain more density at the crest/2 area after loading than the TPS type implant, but the difference was not statistically significant (*p*=0.0912).

Discussion

In the present study, nonsubmerged titanium implants with the same macroscopic shape, but 2 different surfaces, a SLA and a TPS surface, were clinically and radiographically evaluated under unloaded and loaded conditions in the canine man-

Table 2. Bone density changes (net-CADIA) at five different bone levels next to implants, with two implant types, and five time intervals

AOI-site	Imp. type	Preload Mean, SD *n*=63	3 mo loading Mean, SD *n*=36	6 mo loading Mean, SD *n*=23	9 mo loading Mean, SD *n*=20	12 mo loading Mean, SD *n*=21
Crest/1	SLA	0.9 6.4	4.3 5.7	−9.3 9.7	−0.1 8.7	−9.7 8.4
	TPS	1.8 8.0	3.8 7.9	−6.5 11.3	−3.2 9.0	−7.9 13.1
Crest/2	SLA	−0.2 5.2	8.8 7.1	2.0 7.1	6.6 7.0	3.8 5.4
	TPS	1.3 5.4	5.0 8.9	−1.5 7.7	3.3 8.0	0.3 6.2
Mid-imp	SLA	−0.5 2.3	0.4 3.0	0.0 1.1	0.6 2.3	−0.8 2/1
	TPS	0.7 2.4	−1.4 2.0	−1.2 1.8	−0.8 5.4	−0.9 2.5
Lat-apical	SLA	−1.0 3.0	−1.2 2.5	−0.1 1.4	−0.6 1.5	−1.3 3.0
	TPS	−0.2 1.0	−1.4 2.6	−0.6 2.0	−1.6 3.2	−0.5 1.7
Apical	SLA	0.4 0.8	−0.2 1.7	1.1 2.2	−2.3 3.3	0.5 1.9
	TPS	0.0 0.6	−0.1 1.8	1.0 3.4	−0.9 2.5	−0.1 1.5

dible. All 69 inserted implants achieved and maintained successful tissue integration for up to 15 months following implant placement demonstrating ankylotic stability without clinical signs of periimplant infections. Therefore, the study confirmed the results of previous experimental investigations in which nonsubmerged titanium implants with a microporous TPS surface achieved osseointegration with high predictability (Gotfredsen et al. 1991, Buser et al. 1992, Weber et al. 1996).

The radiographic evaluation utilizing longitudinal standardized periapical radiography confirmed the clinical findings of implants with functional ankylosis since none of the 69 implants demonstrated a continuous periimplant radiolucency. The assessment of crestal bone loss showed significantly less bone loss for SLA implants at the preload and 3-month loading period when compared to the TPS implants. The observed difference between SLA and TPS implants can likely be attributed to differences in the surface characteristics, since the SLA surface has better osteoconductive properties when compared to the TPS surface. This was demonstrated in a histomorphometric study in miniature pigs by Buser et al. (1991b), in which SLA surfaces had significantly higher bone-to-implant contacts than TPS surfaces.

The evaluated crestal bone loss of 0.52 mm for SLA implants and 0.69 mm for TPS implants at the preload evaluation was probably caused by the surgical trauma, since the elevation of a mucoperiosteal flap compromises the vascular supply in the most crestal bone areas. Following initiation of functional loading, a further crestal bone loss after 3 months of 0.73 mm for SLA and 1.06 mm for TPS implants was observed. This bone loss is likely the result of remodeling patterns of the alveolar bone to the functional load. Subsequently, the bone levels stabilized. These results are comparable to results in humans with nonsubmerged implants. Buser et al. (1990) reported radiographic 1-year data on 100 implants with a TPS surface in partially edentulous patients with a mean crestal bone loss 12 months after implant placement of approximately 0.8 mm. In comparison, a radiographically detectable vertical bone loss of about 1.0 – 1.5 mm during the first year of loading for submerged titanium implants with a machined surface has been described in several publications (Adell et al. 1986, Albrektsson et al. 1986, Lekholm et al. 1986, Cox & Zarb 1987, Lindquist et al. 1988, Smith & Zarb 1989, Apse et al. 1991, Chaytor et al. 1991).

The bone healing and remodeling patterns were also assessed by the measurement of changes in peri-implant bone densities. The areas-of-interest (AOI) were chosen as close to the implant surface as possible to detect radiographic changes of bone density as a function of healing, remodeling, and/or loading. The 1 mm^2 measurement areas used in this investigation were positioned 0.1 mm away from the implants. Therefore, bone reaction to implant placement and implant loading were measured in the peri-implant bone area 0.1 mm to 1.1 mm away from the implant surface. Overall, no differences were found between the two tested implant types. During the first 3 months of healing, no differences were observed in the crest/1 area, probably due to the fact that radiographic changes were an average of the AOI total number of pixels. Thus, the slight resorption of up to 0.69 mm could not be detected by the CADIA measurements. Following initiation of functional loading, the crestal bone loss progressed to a lower level as discussed above, and both implant types showed a decrease in radiographic bone density in the crest/1 area close to the bone crest surface. In contrast, the crest/2 areas increased in density, and can be explained by the fact that a new cortical bone layer was formed at a lower, more apical level. AOI at more apical areas did not result in changes from baseline. As all the AOI were placed slightly away from the implant surface, changes in bone at the bone-to-implant interface would not be detected.

The observed radiographic data reflected the bone remodeling which occurred on the coronal aspect of the ridge. The radiographic density was decreased in the crest/1 area, while the crest/2 area increased in density. This was found around both types of implants and, in anterior and in posterior jaw locations. Because of this more universal finding it is thought that the observed remodeling reflects a physiological response of bone healing around the endosseous titanium implants. In most healed alveolar ridges, a layer of cortical bone overlies a more cancellous type bone.

The present radiographic data suggests that implant placement causes the most coronal cortical bone to remodel adjacent to the implant and form a new cortical bone layer at a lower, more apical level, as determined by increasing radiodensities at the crest/2 area and the loss of density in the crest/1 area. The reason for this remodeling is not yet known but may be related to the blood supply of the bone. Preparation of the bone for the implant and subsequent implant placement removes blood vessels that help provide nutrition to the surrounding bone. Loss of this blood supply by inserting the inert implant body may compromise the adjacent bone and cause remodeling to occur in a slightly more apical location, an area with greater blood supply from the endosseous marrow spaces. A second reason for this remodeling may be due to stresses which are placed on the bone immediately surrounding the implant. These stresses, likely resulting in microfractures in the bone, stimulate bone turnover and, without contiguous blood supply due to the implant body, may result in more apical remodeling.

The increase in crestal bone density that was evident during the first, preload time interval, is likely due to the fact that the baseline radiographs were exposed within three weeks after implant placement surgery. At that time, the crestal bone had already lost density because of the surgical trauma. During the following 3 months, part of the crestal bone density was regained and therefore, CADIA showed positive changes. No differences were found in the radiographic AOI located below the crest/1 and crest/2 area. This was true when comparing implant types or in unloaded or loaded implants. It is possible that changes were occurring in these areas but that radiographically these changes were not detected. Jeffcoat et al. (1991) showed that quantitative digital radiography can detect 8 mg bone loss, which represents about 5% to 10% of total bone at the site, with high accuracy. However, in this study, the selected 1 mm^2 measurement AOI are considerably larger than the area of bone change next to the implant. When the density changes occur only in a small area of the AOI it is unlikely to be detected due to the much larger number of pixels that do not change in the AOI.

In summary, the longitudinal radiographic analysis of 69 titanium implants with a SLA and TPS surface demonstrated that both implant types achieved and maintained successful tissue integration in the canine mandible with functional ankylosis for up to 15 months under unloaded and loaded conditions. Earlier healing periods indicated an advantage for SLA implants, since less crestal bone loss was observed for this implant surface, whereas the longer healing periods showed no differences between the two tested titanium surfaces. Therefore, this study confirmed encouraging results of previous studies in long bones (Wilke et al. 1990, Buser et al. 1991b) and supported the findings of several in vitro investigations (Martin et al. 1995, Martin et al. 1996, Schwartz et al. 1995). Furthermore, this study also shows the potential of the titanium SLA surface to become a valuable or even superior alternative to the 2 best documented titanium surfaces in implant dentistry, the machined and the TPS surface.

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Résumé

Lors d'expérimentations à court terme dans de l'os non-buccal un implant en titane dont la surface était décapé à la sableuse et mordançée par de l'acide (SLA) possédait un plus grand pourcentage de contact os-implant qu'un implant pulvérisé par du plasma de titane. Dans l'étude présente un implant SLA a été comparé radiographiquement à un TPS sous des conditions sans et avec charge dans la région canine inférieure pendant une période allant jusqu'à 15 mois. 69 implants ont été placés chez six chiens courants. Des radiographies standardisées ont été prises lors de l'examen initial, avant la charge, ainsi que 3, 6 et 12 mois après. Des implants chargés ont été restaurés avec des couronnes en or semblables à celles de la dentition naturelle. L'évaluation radiographique de la réponse osseuse aux implants a été faite en mesurant la distance séparant l'épaule de l'implant avec le contact le plus coronaire os-implant (DIB) et en évaluant les variations de densitée par ordinateur (CADIA). 5 zones d'intérêts différentes (AOI) ont été définiés en coronaire et en apical le long des implants. Des mesures DIB ont révélé que les implants SLA avaient significativement moins de perte osseuse (0.52 mm) que les TPS (0.69 mm) lors de l'examen avant charge (p=0.0142) aussi bien que 3 mois après charge (0.73 mm/1.06 mm; p=0.0337). Cette différence a été maintenue entre les types d'implants durant toute l'année du suivi. La même tendance a également été mise en évidence pour les mesures CADIA avec les implants SLA montrant des valeurs de densité osseuse crestale plus importantes lorsque les données avant charge et examen de départ étaient comparées (p=0.0890), ainsi que les données trois mois après et examen de départ (p=0.0912). Aucune variation mesurable de densité osseuse n'a été mise en évidence dans les zones apicales des deux implants. Ces résultats suggèrent que les implants SLA sont supérieurs aux TPS lorsqu'ils sont comparés radiographiquement dans l'os buccal, et ce sous conditions sans et avec charge.

Zusammenfassung

Frühere Studien haben gezeigt, dass in Kurzzeituntersuchungen die sandgestrahlten und säuregeätzten Implantate (SLA) bei nichtoralenm Knochen einen prozentual grösseren Knochen-Implantat-Kontakt aufweisen als die mit Titanplasma besprayten Implantate (TPS). In dieser Arbeit wurde im Unterkiefer ein SLA-Implantat mit einem TPS-Implantat unter belasteten und unbelasteten Verhältnissen während 15 Monaten radiologisch untersucht. Bei 6 Foxhunden wurden 69 Implantate eingesetzt. Bei Versuchsbeginn, unbelastet und 3, 6, 9 sowie 12 Monate nach Belastung wurden standartisierte Röntgen bilder aufgenommen. Die belasteten Implantate waren mit der natürlichen Bezahnung nachempfundenen Goldkronen restauriert. Die Parameter der röntgenologischen Knochenveränderungen als Reaktion auf die Implantate wurden definiert als Distanz zwischen Implantatschulter und dem koronalsten Knochen-Implantat-Kontakt (DIB). Zusätzlich erfolgte die Auswertung von Knochendichteveränderung mit der computerunterstützten Dichteanalyse der Röntgenbilder (CADIA). 5 verschiedene

Zonen von speziellem Interesse (AOI) wurden vorgängig koronal und apikal dem Implantat entlang definiert. Die DIB Messungen zeigten, dass SLA-Implantate einen signifikant geringeren Knochenhöheverlust (0.52 mm) als TPS-Implantate (0.69 mm) aufwiesen. Dies war vor der Belastung (p=0.0142) wie auch 3 Monate nach Belastung (0.73 mm/1.06 mm; p=0.0337). der Fall. Der Unterschied zwischen den Zwei Implantattypen blieb während der ganzjährigen Untersuchungsperiode bestehen. Derselbe Trend zeigte sich auch bei den CADIA Messungen, wo die SLA-Implantate eine höhere Dichte des crestalen Knochens zeigten. Die Werte der unbelasteten Situation verglichen mit den Ausgangswerten waren signifikant verschieden (p=0.912). In den apikalen Regionen waren bei keinem der Implantate messbare Knochendichteveränderungen feststellbar. Die Resultate lassen vermuten, dass SLA-Implantate den TPS-Implantaten überlegen sind, wenn sie im oralen Knochen röntgenologisch unter belasteten und unbelasteten Bedingungen verglichen werden.

Resumen

Estudios previos han demostrado en experimentos a corto plazo que un implante de titanio rociado con arena y grabado con ácido (SLA) tuvo un porcentaje mayor de contacto hueso a implante que un implante de titanio rociado con plasma (TPS) en un hueso no oral. En el presente estudio, un implante de SLA se comparó radiograficamente a un implante TPS bajo condiciones de descarga y carga en una mandíbula canina durante un máximo de 15 meses. Sesentinueve implantes se pusieron en seis Foxhounds. Se tomaron radiografías estandarizadas al inicio, en precarga, 3, 6, 9, y 12 meses tras la carga. Los implantes cargados se restauraron con coronas de oro parecidas a la dentición natural. La evaluación radiográfica de la respuesta del hueso a los implantes fue efectuada midiendo la distancia entre el hombro del implante y el punto más coronal del contacto hueso a implante (DIB) y por la evaluación de los cambios de densidad de hueso usando Análisis de Imagen Densitométrica Asistido por Ordenador (CADIA). Se definieron cinco áreas de interés (AOI) diferentes coronal y apicalmente a lo largo del implante.

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