Immediate and Early Loading of SLA ITI Single-Tooth Implants: An In Vivo Study

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Purpose: *The purpose of this investigation was to determine whether early and immediate loading of dental implants resulted in adverse consequences as determined clinically, radiographically, and histologically.* ***Materials and Methods:*** *In a canine model, 48 sand-blasted, large-grit, acid-etched (SLA) surfaced implants were placed at 4 different times before definitive restoration and loading. These times were 3 months (group A), 21 days (group B), 10 days (group C), and 2 days (immediately) (group D) before loading. Each implant was restored at the same time with a single gold screw-retained crown. Immediately after restoration all crowns were placed in function. Standardized periapical radiographs were made 1, 2, and 3 months after restoration. At the end of the study, block sections were obtained for histologic examination. Changes in crestal bone height on the mesial and distal aspects of each implant and the change in bone density of the coronal 3 mm of crestal bone were recorded. Primary, secondary, and total bone-to-implant contact; bone marrow–to-implant contact; and connective tissue–to-implant contact were evaluated histologically.* ***Results:*** *All implants were osseointegrated at the end of the study; no clinical failures of integration were noted. The changes in crestal bone heights for groups A, B, C, and D (means ± SE) were 0.02 ± 0.07 mm, 0.30 ± 0.08 mm, 0.15 ± 0.08 mm, and 0.35 ± 0.18 mm, respectively. Total bone-to-implant contact for the 4 groups was 69.1%, 71.3%, 74.6%, and 75.2%, respectively (*P > .57*).* ***Discussion:*** *Under the conditions of this study no statistically significant differences were noted between the 4 different loading protocols for any of the parameters recorded. This finding is consistent with other recent studies and case reports.* ***Conclusion:*** *The findings of this study indicate that early and immediate loading of single-unit SLA surfaced implants was possible in this model.* (More than 50 references.) INT J ORAL MAXILLOFAC IMPLANTS 2005;20:360–370

Key words: *bone density, bone-to-implant contact, canine teeth, computer-assisted densitometric image analysis, conventional loading, delayed loading, dental implants, histology, immediate loading*

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Current implant healing times are derived from the original work carried out by Brånemark and associates[1] during the initial and early stages of development of root-form endosseous dental implants. At that point, the conclusion that a long healing period was necessary was based on the scientific evidence available at the time[2–5] and on experience gained from research performed by the Gothenburg group.[1,6] It was believed that loads placed upon a healing implant would result in fibrous encapsulation of that implant. Supporting evidence for this concept was found in the orthopedic[7] and dental[4,5,8,9] scientific literature. A thorough review of the rationale prevalent at that time was recently published.[10,11]

A reanalysis of the original experimental design reported by Brånemark and associates[1,6] has questioned the necessity for a long implant healing period.[10] The Gothenburg data were obtained from

demanding clinical situations in which, with the wisdom of hindsight, various negative factors [10] may have acted synergistically to impede integration. Furthermore, other evidence found in orthopedic[12] and dental[13–18] scientific literature supports the concept that implants can be loaded early or immediately.

Exposure to a load early or immediately may not of itself be detrimental; it is the magnitude of the load, with the resulting movement at the bone-implant interface, that may affect osseointegration. Loads that produce "excessive" movement during the healing process may lead to fibrous encapsulation of the implant[4,5]; loads that do not may result in direct bone-to-implant contact.[19] To control loads placed upon dental implants and reduce micromotion at the bone-implant interface, various approaches have been tried.

One approach has been to rigidly splint implants together.[14,18] Another has been to incorporate macroretentive features into the implant design to achieve primary stability.[20,21] A third approach has been to control the load placed upon the healing bone-implant interface by reducing or eliminating the occlusal contact of the prosthesis supported.[13] Little distinction has been made in the scientific literature between these approaches or between degrees of implant loading.[4,5,13,18,22–24] Therefore, care should be taken when applying conclusions from one scenario to another. With these considerations in mind, a review of the current scientific literature on immediate and early loading of single-tooth implants shows that little data exist to justify these loading protocols.

Recently a healing time of 6 weeks for implants placed in good-quality bone has been recommended for sand-blasted, large-grit, acid-etched (SLA) implants.[25,26] This recommendation resulted from a better understanding of the bone-implant healing interface[27,28] and improved implant surface technology.[29–32]

It is reasonable to speculate that in controlled situations where implants with specific surface characteristics are lightly loaded, it may be possible to load unsplinted single-tooth implants early or immediately. The purpose of this investigation was to determine whether early and immediate loading of single tooth implants deleteriously affect these implants as compared to conventional loading.

MATERIALS AND METHODS

The research tool used to carry out this project was a prospective randomized controlled clinical study. Four lab-bred male American foxhounds were chosen as test subjects. The dogs were approximately 2 years of age at the beginning of the study and had a body weight of about 30 to 35 kg. The animal care protocol was approved by the Institutional Animal Care and Use Committee of the University of Texas Health Science Center at San Antonio (UTHSCSA).

All mandibular premolars and first molars were extracted, and the ridges were allowed to heal for 4 months. Groups of 3 implants were placed according to a random position table at 4 times prior to the restoration of the implants. All implants were restored at the same time with a single gold screw-retained crown. The restorations were placed in function immediately. Radiographs were made at 1, 2, and 3 months after restoration. The test subjects were sacrificed at 3 months postloading, and block sections of the mandibles were retrieved for histologic examination.

An 8-mm-long (placement depth), 4.1-mm-diameter, commercially available Straumann (Institut Straumann, Waldenburg, Switzerland) screw-type implant made from cold-worked, grade IV commercially pure titanium with a rough SLA surface was chosen for testing. The junction between the rough and smooth surfaces of the implant was placed at the level of the alveolar bone crest.

The protocols used for extraction of the teeth and surgical placement of implants used in this study have been described previously.[33] After a postextraction healing period of 4 months, the first group of 3 implants (group A) was placed in each subject. Further groups of 3 implants each were placed at 21 days (group B), 10 days (group C), and 2 days (group D) before restoration.

Octa abutments (Institut Straumann) were connected to implant groups A, B, and C at the time of group C surgery; Octa abutments were connected to group D implants at the time of their placement. All Octa abutments were torqued to 35 Ncm using an ITI torque driver (Straumann). Octa protective caps were utilized to cover the Octa abutments between abutment connection and crown placement.

Two mandibular master transfer implant impressions were made using custom trays for each subject. At the time of surgery C, an impression was made of the implants in groups A, B, and C; an impression of the group D implants was made at the time of surgery D. By making an impression of these implant groups at this time point, 12 days were available for fabrication of 75% of the crowns. Ten days later the final implants (group D) were placed. Transfer impression copings were screwed into place on each implant. Reprosil heavy-body polyvinyl siloxane impression material (Dentsply Caulk; Dentsply Friadent Ceramed, Lakewood, CO) was mixed using a hand-mixing gun and placed into the impression tray. An impression was also made of the opposing arch with the same impression material.

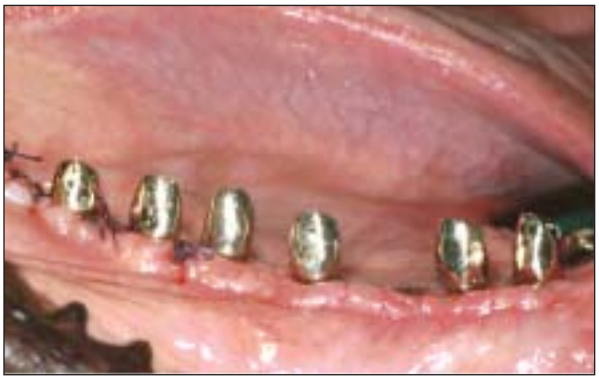

Fig 1 Implant crowns immediately postplacement. Sutures are present from the final implant surgery 2 days previously.

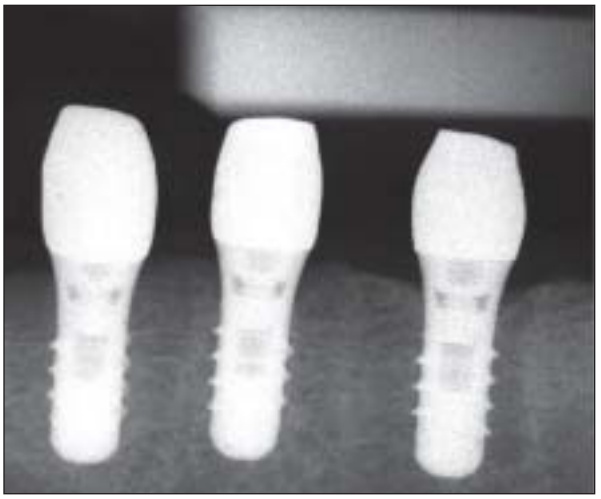

Fig 2 Example of a periapical radiograph made after 3 months of loading. Implants from groups A, D, and B *(left to right)* are shown.

The polyvinyl siloxane impressions were used to fabricate the implant master casts. All maxillary and mandibular impressions were poured using resin-reinforced dental stone (Resin Rock; Whip Mix, Louisville, Kentucky). Two master casts were made for each animal. One contained the group A, B, and C implant analogs and the other the group D implant analogs.

A gold waxing cylinder (Institut Straumann) was secured upon each analog with a waxing screw, and the crowns were waxed to full contour. The anatomic forms of all the crowns were similar with respect to height and width. On completion of the waxup, the crowns were cast in type IV gold (Type IV Extra Hard; Jelenko, Armonk, NY). Each crown was refined, polished to a high luster, and sterilized prior to placement.

Forty-eight hours after placement of the final group of implants, all crowns were seated (Fig 1). The crowns were screw retained with a torque of 15 N. All crowns were placed out of occlusion with the opposing dentition. This was verified by visual inspection and by utilization of articulating paper (Bausch Occlusionspapier, 40 µm; Bausch, Köln, Germany).

Radiographs

Acrylic resin templates were fabricated that ensured that the x-ray tube was repeatedly placed at the same angle and distance from the film for each implant.[33] Radiographs were made at 1, 2, and 3 months after implant loading (Fig 2). For radiographic measurements, 1 month postloading was chosen as the baseline to ensure that the periimplant bone around the group D implants had stabilized after implant surgery and that any changes seen in this group resulted from the experimental loading protocol and not from normal postplacement bony remodeling.

The exposure parameters were 70 kilovolts (peak), 15 mA, and 90 degrees to the long axis of the implant at a focus-to-film distance of 37 mm. The radiographs were digitized to 640 × 480-pixel 8-bit digital images using a calibrated video camera and a 50-mm lens with an aperture of 8.[33] The pixel size in the image was 62.5 µm × 62.5 µm.

Crestal Bone Height

To measure changes in crestal bone height 2 easily locatable reference points were chosen: the most mesial and distal points of the implant-crown interface. The most coronal bone-to-implant contact points on the mesial and distal aspect of each implant[34] were then located on the digitized radiograph, which was displayed on a high-resolution video graphics array (VGA) monitor. The distance between the reference points and the first bone-to-implant contact on each aspect of the implant (the DIB) could then be measured by the computer program (CARE; UTHSCSA, San Antonio, TX). The change in crestal bone height was calculated mesially and distally by comparing the measurements made using the 2- and 3-month radiographs to the baseline (1-month) values. The SLA implant used in the study had a coronal flare design; the values obtained by measuring from the reference point to the first point of bone-to-implant contact did not represent the true vertical crestal bone height. The true height was obtained using the Pythagorean theorem, which

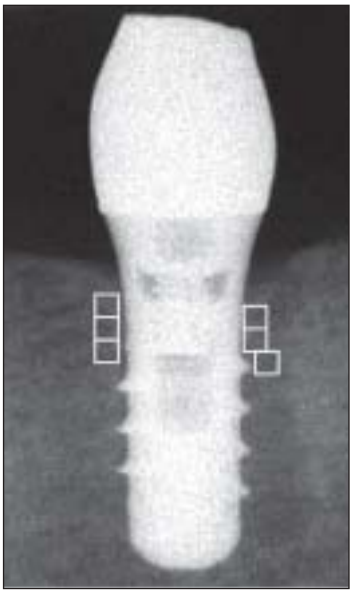

Fig 3 Radiographic detail of a single implant demonstrating the positions of the 3 AOIs (crestal, middle, and bottom) on the mesial and distal aspects of the implant.

states that in a right angle triangle the square root of the hypotenuse is equal to the sum of the square roots of the 2 opposing sides.[35] The formula used was

$$\text{Vertical height} = \sqrt{(\text{Diagonal distance}^2 - 0.65^2)}$$

where the diagonal distance was obtained from the radiographs and 0.65 was a known dimension of the implant.

Crestal Bone Density Change

Baseline and follow-up radiographic images were subjected to computer-assisted densitometric image analysis (CADIA).[33] Starting at the first bone-to-implant contact, areas of interest (AOIs) were created on the mesial and distal aspects of each implant. An AOI was a 16-pixel square representing a 7×9 mm^2 area of bone. There were 3 AOIs on either side of the implant. An additional AOI was located in an area of the radiograph that was deemed to have been stable over the course of the study (designated "the static area"). The most coronal AOI was designated the "crestal" AOI; below the crestal AOI was the middle AOI, followed by the bottom AOI (Fig 3).

The CADIA values quantified the changes in pixels from baseline to 2 months, baseline to 3 months, and 2 months to 3 months. The changes in pixels represented change in bone density of the area examined. Once values for the 6 sites around the implant were obtained, they were compared to the static area. A ratio of change for each of the AOIs compared to the static area was then derived.

The CADIA software algorithm used to analyze the data was set to 0. The changes in bone density detected around the implant were adjusted by obtaining the ratio of the CADIA value to the static value, with 0.5 used when the static value was 0 (eg, a change of 0.0% to 0.9% was recorded as 0). However, a perfect value of 0 (no change in density) is highly unlikely, and since 0 cannot be used to calculate the implant AOI to static AOI ratio, a value of 0.5 halfway between 0 and 1 was used instead. The values obtained reflect the peri-implant change relative to the static area.

Histologic Analysis

Three months after abutment connection, all subjects were sacrificed and block samples (Fig 4) were obtained for histologic preparation and analysis.[36] The percentage of primary, secondary, and total bone-to-implant contact and the percentage of bone marrow– and connective tissue–to-implant contact were recorded histologically in 1 to 3 sections per implant on both the mesial and distal aspects. Values obtained from implants with multiple sections were averaged to ensure a single set of histologic data for each implant before statistical analysis.

Statistical Analysis

One of each of the 4 groups of implants was placed on each side of the dog mandible. As there was room for 2 additional implants per side, 1 implant from each of 2 randomly selected groups was placed per side. Twelve implants from each of the 4 groups of implants were used. To ensure that position in the arch did not influence the results, the sequence of placement was randomized for the left and right sides of the mandible in each dog. Because the goal of the study was to detect differences between implant group loading protocols, a power analysis was used to confirm that a sample size of 48 implants was sufficient to identify clinically significant implant group differences using analysis of variance (ANOVA) at the .01 level with a power of 80%. Four dogs, each with 12 implants placed, were used in the study.

SAS statistical software (SAS Institute, Cary, NC) was used to analyze the data. The DIB and CADIA values were approximately normally distributed, so parametric tests were performed.

A paired Student *t* test was performed to determine whether mesial DIB and distal DIB differed significantly. This test was also performed in regard to mesial and distal CADIA measurements. Because of anatomic limitations, CADIA changes could not be

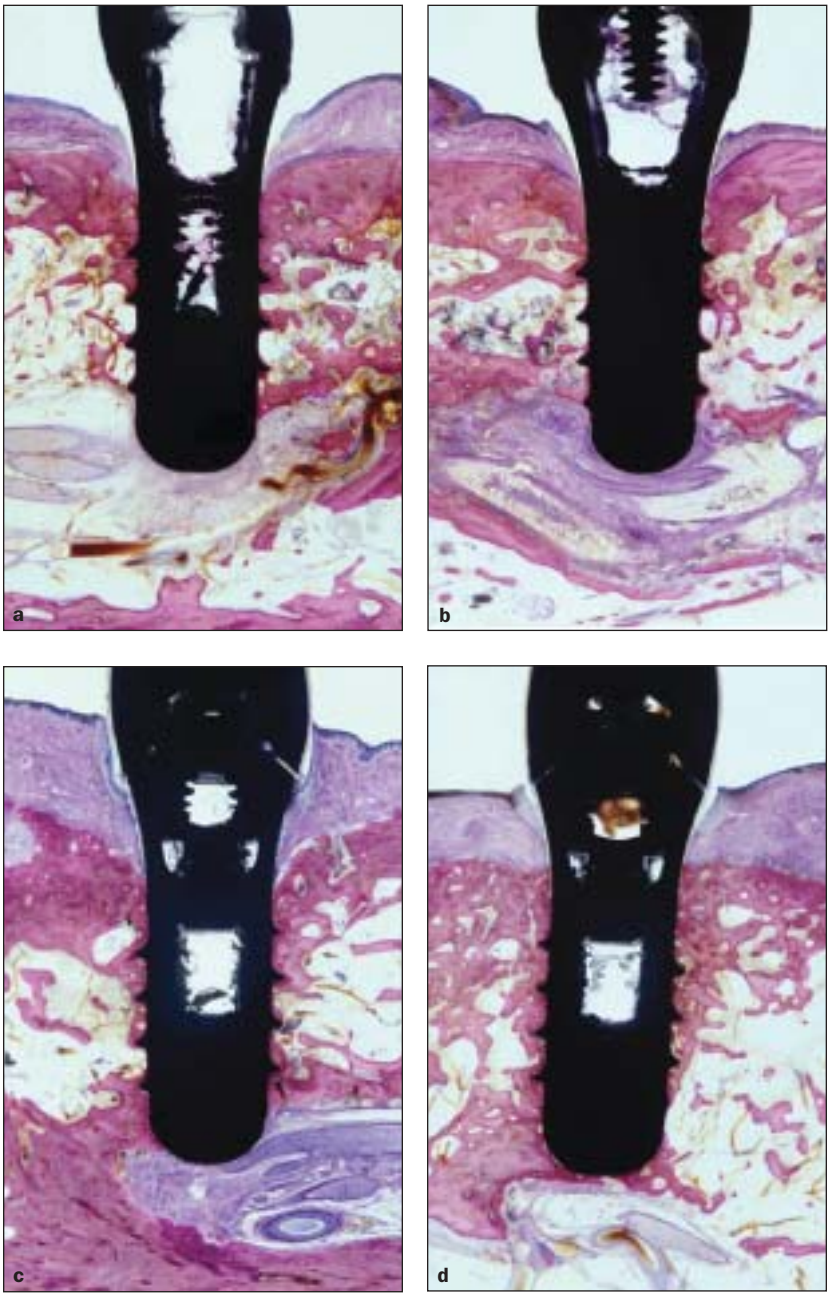

Fig 4 Representative sample of histologic cross sections of implants from *(a)* group A (3 months), *(b)* group B (21 days), *(c)* group C (10 days), and *(d)* group D (2 days) after 3 months of loading.

calculated for both the mesial and distal aspects for 10% of the implants. If data was available for both aspects, the 2 values were averaged; otherwise, the single CADIA change value was used. This was done separately for the crestal, middle, and bottom AOIs.

Primary, secondary, and total bone-to-implant contact; bone marrow–to-implant contact; and connective tissue–to-implant contact were calculated as percentages for 1 to 3 histologic sections for each implant. Averages were obtained for each measure, resulting in a single set of measures for each implant.

Each measure was then analyzed using a mixed-model ANOVA to check whether implant groups differed in a consistent fashion for each dog. The mixed-model ANOVA tested the main effect of implant groups, with all results adjusted for any dog effect. If any of the F tests were significant ($P < .05$), then relevant pairwise comparisons, using unpaired Student *t* tests adjusted for any dog effect, were performed to identify differences across implant groups A through D.

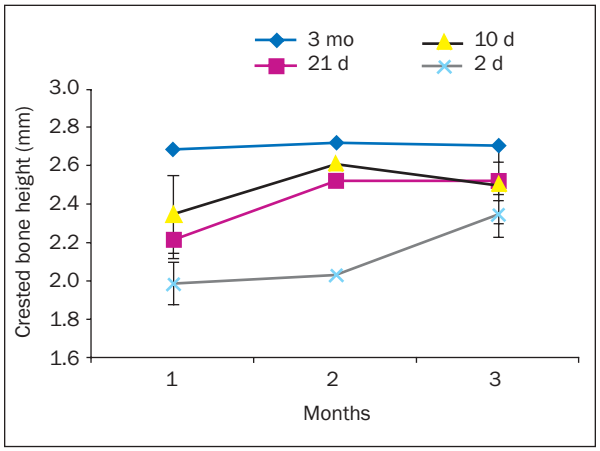

Fig 5 Combined mesial and distal crested bone heights measured vertically from the first point of bone-to-implant contact to the implant-crown margin for groups A (3 months), B (21 days), C (10 days), and D (2 days).

RESULTS

Clinical

At the conclusion of the study all tissues appeared clinically normal, with an absence of inflammation or suppuration. The gingiva, which was generally pink in color, was not edematous and did not appear swollen. Radiographic examination did not indicate any peri-implant radiolucencies, and the bone appeared to be in direct contact with all implants. All implants appeared to be integrated and were clinically stable (ie, no mobility detected) after the 3-month loading period. The clinical survival rate for implants placed was therefore 100%.

Radiographic

The average crestal bone heights on the mesial aspect of the implants for groups A, B, C, and D after 1 month of loading (baseline) were 2.6 mm, 2.1 mm, 2.3 mm, and 2.0 mm, respectively. After 2 months, the crestal bone heights were 2.7 mm, 2.5 mm, 2.6 mm and 2.0 mm, respectively and by 3 months, they were 2.5 mm, 2.5 mm, 2.5 mm, and 2.3 mm, respectively. ANOVA revealed a difference in crestal bone heights ($P = .085$) between groups A and D at 2 months.

Crestal bone height measurements for groups A, B, C, and D on the distal aspect of each implant were 2.7 mm, 2.3 mm, 2.3 mm, and 1.9 mm, respectively, at 1 month (baseline); 2.7 mm, 2.5 mm, 2.6 mm, and 2.0 mm, respectively, at 2 months; and 2.8 mm, 2.5 mm, 2.5 mm, and 2.3 mm, respectively, at 3 months. Using ANOVA, a statistically significant difference was detected between groups at A and D at 1 month ($P < .015$). However, no statistically significant differences were detected for the remaining sites at any point in time.

When mesial and distal values were combined (Fig 5), the mean crestal bone heights at 1 month (baseline) for groups A, B, C, and D were 2.7 mm, 2.2 mm, 2.3 mm, and 2.0 mm, respectively. After 2 months of loading, the values were 2.7 mm, 2.5 mm, 2.6 mm, and 2.0 mm, respectively, and by 3 months, the heights were 2.7 mm, 2.5 mm, 2.5 mm, and 2.3 mm, respectively. ANOVA of radiographic crestal bone heights revealed significant differences at 1 month ($P < .04$) and 2 months ($P < .05$) after loading between groups A to C and group D. At 3 months, there were no significant differences in crestal bone height between any of the groups.

Statistical analysis of the change in mesial crestal bone heights revealed significant differences from baseline to 2 months for all 4 groups ($P = .058$). The greatest difference was between groups B and D from baseline to 2 months ($P < .05$). Statistically significant differences were also noted between groups A and D from 2 months to 3 months postloading ($P < .045$). No other statistically significant differences were detected for the change in bone height on the mesial aspect of the implants.

On the distal aspect of the implants, significant differences in bone height were detected between groups A, B, C, and D from baseline to 2 months postloading ($P < .05$). A statistically significant difference was detected between groups C and D from 2 months to 3 months postloading ($P < .045$). No other statistically significantly differences were detected for the change in bone height on the distal aspect of the implants.

The changes in crestal bone heights for groups A, B, C, and D (means ± SE) were 0.02 ± 0.07 mm, 0.30 ± 0.08 mm, 0.15 ± 0.08 mm, and 0.35 ± 0.18 mm respectively. When mesial and distal changes were

Table 1 Change in Crestal Bone Height in mm Between the 4 Groups For the Combined Mesial and Distal Aspects of Each Implant

	Change from 1 to 2 mo postloading		Change from 1 to 3 mo postloading		Change from 2 to 3 mo postloading	
Group	Mean	SE	Mean	SE	Mean	SE
A	0.03	0.09	0.02	0.07	−0.02	0.05
B	0.30	0.06	0.30	0.08	0.00	0.07
C	0.26	0.07	0.15	0.08	−0.10	0.06
D	0.04	0.08	0.35	0.18	0.31	0.17

Table 2 Ratio of CADIA of Static Area to CADIA of the AOIs

Group	TIme implants loaded (mo)	No. of implants	CADIA ratio Mean	CADIA ratio SE
Crestal				
A	2	11	−4.02	2.51
	3	11	−0.79	1.36
B	2	12	1.06	1.90
	3	12	0.69	1.95
C	2	12	−0.20	1.23
	3	12	3.48	2.39
D	2	12	−1.62	1.50
	3	12	−3.88	4.28
Middle				
A	2	11	−1.84	1.39
	3	11	1.87	1.66
B	2	12	1.47	1.30
	3	12	1.06	2.20
C	2	12	3.44	0.90
	3	12	3.56	2.19
D	2	12	0.81	0.92
	3	12	1.09	1.23
Bottom				
A	2	11	−0.33	0.47
	3	11	1.35	0.74
B	2	12	0.92	1.64
	3	12	−0.28	3.17
C	2	12	4.07	1.48
	3	12	1.72	1.34
D	2	12	2.04	1.42
	3	12	1.55	1.83

Mesial and distal values for the AOIs were combined. The static area was chosen because it was uninvolved in the surgical procedure and reflected normal bone density variations. The AOIs were selected because they were the areas most likely to be affected by the loading conditions. The mean CADIA ratios reflect the density changes that occurred in the bone around the implants; a positive value indicates that the change was greater than the change that occurred as part of normal bone physiology; a negative value indicates that the change was less than the change that occurred as part of normal bone physiology.

combined (Table 1), the analysis revealed no statistically significant differences for the change in bone height of the combined mesial and distal bone changes.

A statistical analysis of the radiographic density (Table 2) revealed that, except for the middle AOI for change from baseline to 2 months postloading ($P < .025$), none of the mixed-model ANOVAs comparing implant groups within AOI levels revealed significant differences ($P < .15$). ANOVAs comparing AOI levels within implant groups also failed to reveal significant differences ($P < .10$), except for group C for change from baseline to 2 months postloading ($P < .03$). The only occasions when CADIA was significantly different from 0 (indicating a change in bone density from baseline) were for group C (loaded after 21 days) at 1 month from baseline for the middle ($P < .02$) and bottom ($P < .01$) AOIs. As a result, group C differed significantly ($P < .015$) from groups A and D for the

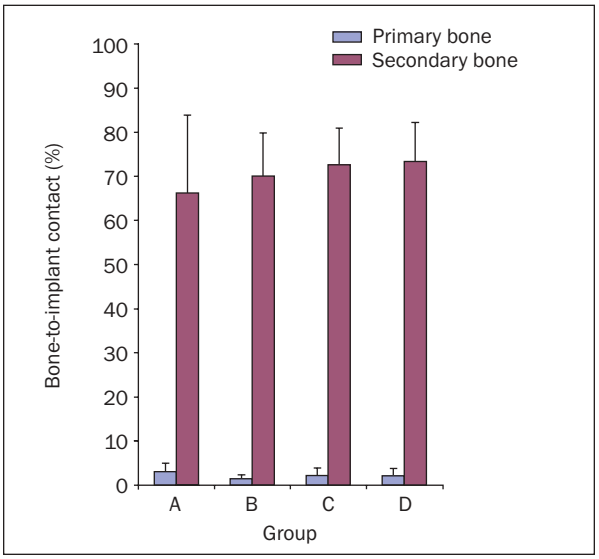

Fig 6 Total bone-to-implant contact comprised of primary and secondary bone for groups A (3 months), B (21 days), C (10 days), and D (2 days). Bars indicate SE.

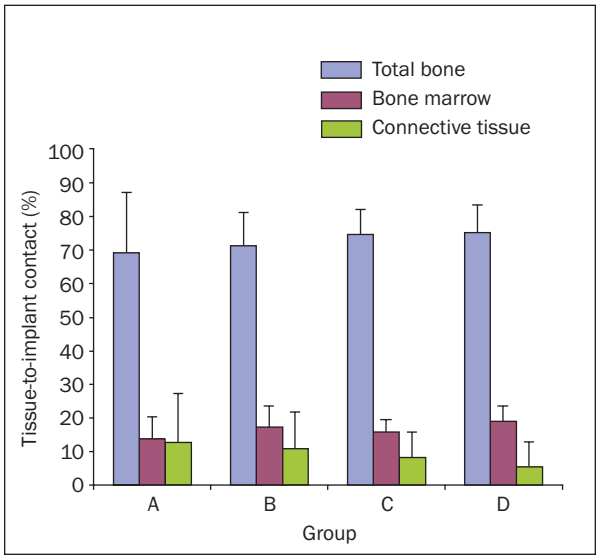

Fig 7 Total tissue-to-implant contact comprised of contact between tissue and primary and secondary bone, bone marrow, and connective tissue for groups A (3 months), B (21 days), C (10 days), and D (2 days). Bars indicate SE.

middle AOI at 1 month from baseline (2 months postloading). Also for group C for the same time period, CADIA values for the crestal and bottom AOIs differed significantly ($P < .04$).

Histologic

The values obtained for groups A, B, C, and D for the percentage of primary bone-to-implant contact, which reflect the amount of original native bone in contact with the bone-implant interface, were 2.9%, 1.3%, 2.1%, and 2.0%, respectively (Fig 6). Secondary bone-to-implant contact percentages, illustrating the amount of new bone formed since implant placement, were 66.2%, 70.0%, 72.5%, and 73.2%, respectively (Fig 6). Total bone-to-implant contact values, which are obtained by combining primary and secondary values, were 69.1%, 71.3%, 74.6%, and 75.2%, respectively (Fig 6). Percentage bone marrow–to-implant and connective tissue–to-implant contact values were also recorded for groups A, B, C, and D (Fig 7). These were 14.0%, 17.3%, 16.0%, and 19.2%, respectively, for bone marrow and 12.8%, 11.0%, 8.2%, and 5.5%, respectively, for connective tissue.

Using a mixed-model ANOVA, marginally significant ($P = .076$) differences were revealed for percentage bone marrow contact between groups D (mean ± SE 19.16% ± 35%) and A (13.98% ± 2.02%). There were no significant differences between groups for primary bone-to-implant contact ($P > .18$) , secondary bone-to-implant contact ($P > .50$), total bone-to-implant contact ($P > .57$), and connective tissue–to-implant contact ($P > .30$).

DISCUSSION

The relationship between canine and human bone physiology is important for interpreting the results from this study. Differences in the Σ value, the rate of bone turnover, have been observed between the 2 species. This value has been determined to be lower for dogs (3 months) than for humans (6 months).[37] For this reason, it was decided to sacrifice the test subjects at 3 months. If sacrifice had occurred at 6 months, it is possible that any histological differences in the peri-implant bone that existed would have been masked by the greater rate of bone turnover in the canine.

A further criticism of the canine model is that the "hingelike" canine masticatory apparatus is unable to accurately replicate the range of motion of the human masticatory system.[38–40] However, the ability to make excursive mandibular movements is not significant, as implant occlusal schemes are usually designed to place compressive axial loads only upon the implant restoration[41–43] and to avoid excursive contacts.[44] The issue of human versus canine mandibular movement is moot, as occlusal schemes in both systems can be designed to load implants in a similar fashion.

A 100% survival rate may be considered high compared to longer-term human studies.[45] However, similar high rates have been reported for early and immediate single-tooth implants in previous studies.[46,47] No difference in the survival rate was noted in the current study between the 4 implant

groups. All implants in all groups were immobile, with healthy peri-implant tissue. In light of earlier studies,[10,11] the similarity in survival rates between the groups should not be surprising.

Radiographic peri-implant bone was assessed by 2 techniques: *(1)* measurement of crestal bone height and *(2)* CADIA of crestal bone density changes. Stability in the crestal area is indicative of implant health.[48,49] For 1-stage implant systems, stability occurs after an initial period of postplacement remodeling of the osseous crest, with the final crestal bone height being determined by the position of the rough-smooth interface.[33] In the canine model, this period of remodeling takes approximately 1 month to occur.[33] For this reason, the baseline for radiographic analysis was determined to be 1 month after restoration. No statistically significant differences were seen between groups A, B, C, and D with respect to change in crestal bone height, suggesting that the early and immediate loading protocols did not differentially affect the peri-implant crestal bone. This finding is in agreement with a similar previous study.[13]

Differences in the actual crestal bone heights can be noted between the 4 groups (Fig 5). These differences were greatest at the start of the study and decreased over the 3-month loading period. The greatest differences were seen between group A and group D implants. Two plausible explanations exist for this finding. The first is that a period of remodeling occurs in the crestal bone after placement of a single-stage implant for approximately 1 month after placement in the canine.[33] For group A, the remodeling period may have ended before the first crestal bone height readings were made, while the other groups were in various stages of this process. This explanation may account for the differences seen for the values recorded at 1 month postplacement and possibly those recorded at 2 months postplacement. However, if crestal bone remodeling takes 1 month in the canine, this explanation does not account for the difference in crestal bone heights seen after 3 months. Nor does it explain why the conventionally loaded implants had more apical bone height than the early and immediately loaded groups. A possible explanation for this difference may lie in the experimental model. The surgical placement of each group of implants resulted in the exposure of the previously placed groups. Although efforts were made to avoid exposure of the implant groups placed earlier, the requirement to place each group randomly ensured that these efforts were not always successful. Flap reflection and subsequent exposure of bone have been demonstrated to result in crestal bone loss.[50]

CADIA offers a highly sensitive evaluation of the peri-implant osseous tissues.[51] Decreases in bone density are indicative of demineralization of bone, which in turn indicates a loss of bone mass. The most likely location for bone density changes to occur around an implant is in the crestal area[52]; crestal bone density changes have been used as a predictor for future crestal bone height changes and for implant failure.[52] For this reason 3 crestally located AOIs on either side of the implant were chosen. These evaluated the coronal 3 mm of bone-to-implant contact. The CADIA values revealed no statistically significant differences ($P > .15$) in the crestal, middle, and bottom bone densities in the AOIs between the 4 groups. The only occasions when CADIA was significantly different were for group C at 2 months of loading for the middle ($P < .02$) and bottom ($P < .01$) AOI levels. At the conclusion of the study, no difference was found between these AOIs and the rest of the AOIs examined. This suggests that no differences existed in the peri-implant bone density based upon when the implants were loaded after placement.

Primary bone-to-implant contact represents the original bone that contacted the implant at the time of placement and is replaced during the remodeling process. It provides a useful function by contributing to initial implant stability. In this study, the percentage values for primary bone-to-implant contact, measured after 3 months of healing, were 2.9%, 1.3%, 2.1%, and 2.0% for groups A, B, C, and D, respectively (Fig 6). These values were not significantly different and reflect the resorption of primary bone that occurs as the bone heals around the implant.[32,53] The loading protocol did not appear to influence the peri-implant remodeling process.

Secondary bone-to-implant contact values represent the new bone that forms around the implant after placement.[32,53] Total bone-to-implant contact represents the combination of the primary and secondary values. For conventionally loaded implants, total bone-to-implant contact values of between 56% and 85% have been reported[54] and have been shown to be greater for rough-surfaced implants compared to machined-surfaced ones.[55,56] Cochran and colleagues reported total bone-to-implant contact values for 2 roughened surfaces of 78% and 68% after 3 months of loading.[32] A case report of immediately loaded implants retrieved from humans reported total bone-to-implant values of 60% to 80%.[15] In the current investigation, total bone-to-implant contact values of 69.1%, 71.3%, 74.6%, and 75.2% were obtained for groups A, B, C, and D, respectively (Fig 7). The group A figures are similar to values obtained in other canine studies with rough-surfaced implants[32,55] and to values obtained in a long-term human study.[54] The results for groups B, C,

and D are similar to the results of other immediate and early loading studies in animal models.[20,21]

Radiographic evaluation provides a convenient and noninvasive alternative method for evaluation of osseointegration. Hermann and colleagues[57] demonstrated that radiographic and histologic measurement could be made with a high degree of precision (0.01 mm) and could be accurately correlated (r = 0.99, $P < .001$). In this study no statistically significant differences between the 4 implant groups were detected radiographically. This result was later confirmed by histologic evaluation of the bone-implant interface and reinforces an earlier study that suggested that loading protocol does not influence the peri-implant bone.[31] Radiographic evaluation was predictive of the histologic results for early and immediately loaded implants, further demonstrating the correlation between radiographic and histologic evaluations.

SUMMARY

This in vivo study examined the effects of immediate and early loading on SLA-surfaced implants in a dog model. The results indicated that no statistically significant differences existed between conventionally loaded, early loaded, and immediately loaded implants in this group of 4 dogs. The data are consistent with the hypothesis that immediate and early loading of single-tooth dental implants is possible. Although numerous case reports have described successful early and immediately loaded implants, this may be the first prospective study that presents and relates clinical, radiographic, and histologic data.

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