Evaluation of Titanium Implants Placed into Simulated Extraction Sockets: A Study in Dogs

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The purpose of this study was to evaluate the effect of gap width on bone healing around implants placed into simulated extraction socket defects of varying widths in 10 mongrel dogs. All premolars were removed and the alveolar ridges were reduced to a width of 7 mm. Nine weeks later, a total of 80 implants, 10 mm long by 3.3 mm wide, were placed into osteotomy sites prepared to 3 different diameters in the coronal half, simulating extraction sockets. Three experimental sites, with gap sizes of 0.5 mm, 1.0 mm, and 1.4 mm, were created; the control sites had no gap. The depth of each defect was measured at the time of implant placement. All implants were stable at the time of placement. The dogs were euthanized 12 weeks after implant placement, and blocks containing the implants and adjacent bone were submitted for histologic evaluation. Clinically, all control and test sites healed, with complete bone fill in the defect. Percentages of bone-to-implant contact were measured histologically. As the gap widened, the amount of bone-to-implant contact decreased, and the point of the highest bone-to-implant contact shifted apically. These changes were statistically significant ($P < .001$). No statistically significant differences in bone-to-implant contact were found between the sites when the apical 4 mm of implants were compared. Within the limits of this study, the simulated extraction socket defects healed clinically, with complete bone fill, regardless of the initial gap size. However, the width of the gap at the time of implant placement had a significant impact on the histologic percentage and the height of bone-to-implant contact.
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Key words: gap, gap width, histomorphometry, immediate placement, implant, osseointegration

The use of titanium dental implants ad modum Brånemark to replace missing teeth has been shown to be predictable.[1] The placement of implants at the time of extraction has recently been advocated as a means of reducing the time needed for healing.[2] Excellent rates of survival with these immediately placed implants, ranging from 93.6% to 100%, have been reported in the literature.[3–6]

When implants are placed at the time of tooth extraction, there is often a gap between the walls of the extraction socket and the implant. This gap is usually widest in the coronal aspect of the socket. Various techniques and materials have been used to encourage bone growth within these sockets at the time of implant placement, including barrier membranes,[3,7–9] autogenous bone grafts,[4] demineralized or mineralized freeze-dried bone allografts (DFDBA and FDBA),[10–12] and hydroxyapatite (HA).[13,14] Most of these studies report complete bone fill of the gaps clinically. The question that remains unanswered is: does the newly formed bone truly osseointegrate with the implant surface?

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Several studies have been published to date in an effort to answer this question. In 1988, Carlsson et al[15] placed titanium rods of varying widths into the tibias of rabbits. After 6 and 12 weeks of healing, when the initial gap between bone and implant had been larger than 0.35 mm, histologic evaluation revealed no direct bone-to-implant contact in 10 of 13 implants. Knox et al[16] then compared the height and the percentage of direct bone-to-implant contact in simulated extraction sockets in dogs. Titanium grit-blasted press-fit implants, 3.25 mm long and varying in diameter from 3.25 to 7.25 mm, were placed into the osteotomy sites. The results indicated that gaps larger than 1 mm resulted in a smaller amount of direct bone-to-implant contact. In a recent study, Stentz et al[17,18] examined the healing of 3.75-mm-diameter titanium implants placed into 9.525-mm osteotomies in dogs. The gaps received expanded polytetraflouroethylene (e-PTFE) membranes alone or in combination with DFDBA. The researchers found no evidence of direct contact between bone and titanium implants in the area within the defect, regardless of the treatment rendered. The lack of statistical power and inaccurate simulation of the clinical situation lead to difficulties in the interpretation of these studies. The purpose of the present study was to evaluate the effect of gap width on bone healing around implants placed into simulated extraction socket defects of various widths when no additional materials or techniques are used to promote bone formation during healing.

Materials and Methods

Animal Model and Surgical Procedures. The study protocol was approved by the University of Washington Animal Care Committee. Ten adult mongrel dogs weighing 25 to 30 kg each were used. The dogs were given general anesthesia, and the first, second, third, and fourth premolars (P1, P2, P3, P4) were extracted from both sides of the mandible. At this time, the ridge height was reduced to achieve a uniform, 7-mm ridge width.

Nine weeks postextraction, the dogs were premedicated with amoxicillin 15 mg/kg and anesthetized with appropriate general anesthetic agents. The fields of surgery received block and infiltration anesthesia (2% xylocaine 1:100,000 epinephrine) (Astra, Westborough, MA). Crestal incisions were made extending from the canine to first molar. Full-thickness mucoperiosteal flaps were reflected, and the mental nerve was visualized. Implant sites were not randomized.

Table 1 summarizes the drilling sequence. Standard drilling procedures were used to prepare 4 osteotomy sites 2.7 mm wide and 10 mm long in the right and left mandible. Drilling was performed under a copious stream of sterile saline. In 9 of 10 dogs, sites were prepared from first molar to canine in the following order: control, site I, site II, and site III. In one dog, the order was reversed, ie, the control site was adjacent to the canines. Control sites (n = 20) received standard countersink preparations and 3.3-mm narrow-platform, self-tapping implants (Nobel Biocare, Westmont, IL).

In test sites, the coronal 6 mm was enlarged to various specified diameters using commercially available drills, as summarized in Table 1. Three different sizes were created for test sites. Site I (n = 20) was enlarged to 4.3 mm wide by 6 mm deep. Site II (n = 20) was enlarged to 5.25 mm wide by 6 mm deep, and site III (n = 20) was enlarged to 6 mm wide by 6 mm deep (Fig 1a).

Sixty commercially pure titanium implants 3.3 mm in diameter (Nobel Biocare) were placed into the test sites. All implants were stable at the time of placement (Fig 1b). The resulting gap between the bone and the implant for each control site was 0 mm. The gaps for the test sites were 0.5 mm, 1.0 mm, and 1.4 mm, for sites I, II, and III, respectively. At the mesial aspect of the implants, 2 clinical measurements were taken using calibrated 15-mm University of North Carolina periodontal probes (HuFriedy, Chicago, IL). The measurements were: *(1)* the distance from the top of the implant rim to the ridge crest (CR-RM); and *(2)* the distance from the ridge crest to the bottom of the defect (CR-BD) (Fig 2). In site I defects, the gap (0.5 mm) was too narrow to accommodate a probe between the implant and the bony wall; therefore, the depth of the osteotomy (6 mm) was used as the distance from the ridge crest to the bottom of the defect (CR-BD). Clinical photographs were taken of all sites. Cover screws were secured onto the top of the implants, and the flaps were coapted with 4-0 chromic gut using horizontal mattress and interrupted sutures (Johnson and Johnson, Sommerville, NJ). The dogs were given amoxicillin orally (15 mg/kg every 12 hours) for 7 days and buprenorphine (.02 mg/kg) as needed for pain as determined by their activity. The dogs were examined daily for the first postoperative week and once per week thereafter.

Twelve weeks after implant placement, the dogs were euthanized with an overdose of pentobarbital. Clinical photographs were taken of the specimens, and the bone blocks were defleshed. After the cover screws were removed, the implants were

Table 1 Size of Osteotomy and Drills

Site	Implant diameter (mm)	Osteotomy diameter (mm)	Size of gap (mm)	Drills used
Control	3.3	2.7	0	Drill kit,[1] 2.7 mm twist,[2] Counter sink[3]
Site I	3.3	4.3	0.5	Above plus 3 mm twist,[4] 3/4.3 mm pilot,[5] 4.3 mm twist drill[6]
Site II	3.3	5.25	0.975	Above plus 4.25/5.25 mm pilot,[7] 5.25 mm twist drill[8]
Site III	3.3	6.0	1.35	Above plus 5/6 mm pilot,[9] modified 5/6 mm pilot[10]

[1]SDIA 557 (Nobel Biocare), [2]SDIA 444 (Nobel Biocare), [3]SDIA 463 (Nobel Biocare), [4]SDIC 003 (Nobel Biocare), [5]SDIC291 (Nobel Biocare), [6]SDIA496 (Nobel Biocare), [7]DC600 (Implant Innovations, Palm Beach, Gardeus, FL), [8]DT528 (Implant Innovations), [9]PD600 (Implant Innovations), [10]PD600 (Implant Innovations) modified with tip removed to work as a 6-mm drill.

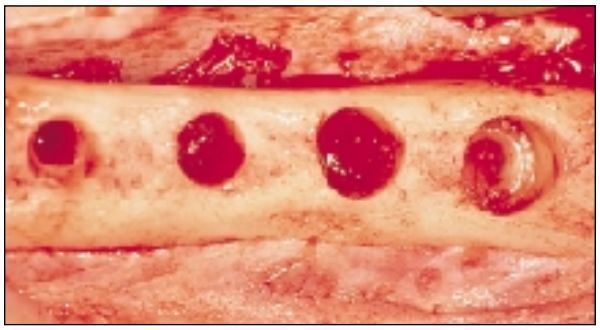


Fig 1a Prepared osteotomy sites. *Left to right:* control, site I, site II, site III. The diameter of the osteotomy in the coronal 6 mm is 2.7 mm, 4.3 mm, 5.25 mm, and 6 mm, respectively.

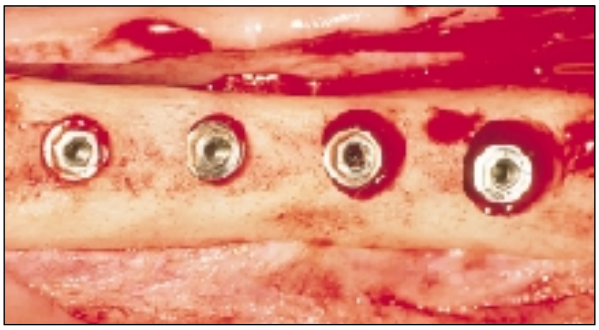


Fig 1b Four identical 3.3-mm-diameter titanium implants were placed into the osteotomy sites. The apical portion of the osteotomy enabled initial stability of the implants.

examined for stability by applying pressure apically and laterally with cotton pliers. Clinical measurements were repeated at the mesial aspect of each implant. Each block of bone containing an implant was reduced to approximately 8 mm wide by 12 mm long. The blocks were placed into neutral buffered formalin.

Histologic Processing. Blocks of specimens containing the implants were sent to the Hard Tissue Research Laboratory at the University of Oklahoma College of Dentistry. Each block was sectioned mesiodistally through the center of the implant. The sections were fixed in 10% neutral buffered formalin for an additional 24 hours; this was followed by dehydration in a graded series of alcohols for 9 days. Following dehydration, the specimens were infiltrated with a light-curing embedding resin (Technovit 7200 VLC, Kulzer, Wehrheim, Germany). Following 30 days of infiltration with constant shaking at normal atmospheric pressure, the specimens were embedded and polymerized by a 450 nm light, with the temperature of the specimens never exceeding 40°C. The specimens were then prepared by the cutting/grinding method of Donath.[19,20] The specimens were cut to a thickness of 150 µm on the Exakt cutting-grinding system (Exakt Apparatebau, Norderstedt, Germany) using a precision parallel control oscillating specimen mounting system. Three sections

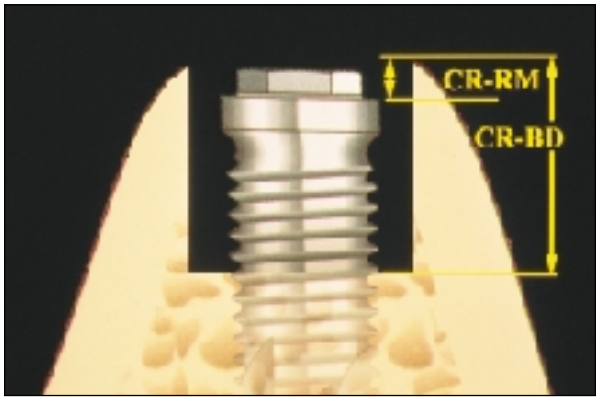


Fig 2 Two clinical measurements were taken at the mesial aspect of each implant: the ridge crest to the implant rim (CR-RM), and the ridge crest to the bottom of the defect (CR-BD). These measurements were taken at the time of implant placement and again at reentry.

Table 2 No. of Implants and Dogs

	Initial		Clinical evaluation		Histologic evaluation	
Site	No. of implants	No. of dogs	No. of implants retrieved	No. of dogs with retrieved implants	No. of implants integrated	No. of dogs with integrated implants
Control	20	10	20	10	18	9
Site I	20	10	20	10	20	10
Site II	20	10	20	10	20	10
Site III	20	10	19	10	12	8

were made of each implant. Each section was polished to a thickness of 50 µm using a series of polishing discs (800 to 2400 grit) on the Exakt microgrinding system, followed by a final polish with 0.3-µm alumina. The final slides were stained with Stevenel's blue and van Gieson's picric fuchsin.

Histomorphometric Measurements. Three mesiodistal sections from each block were available for evaluation. The section that was cut most perpendicular to the implant was selected for measurement. The coronal and apical 4 mm of each implant were examined separately to avoid possible bias. First, an opaque mask was laid over the apical part of the slide, leaving only the coronal 4 mm available for evaluation. A photomicrograph was taken at 2:1 magnification using a microscope fitted with a single-lens reflex camera (BX40 and SC35, Olympus America, Melville, NY). The opaque mask was then removed and placed coronally, exposing only the apical 4 mm of the implant. Photomicrographs were taken at the same magnification. The photographic slides were scanned at 600 dots per inch (dpi) using a slide scanner (Dimage Scan Dual, Minolta, Tokyo, Japan). The photographic slides were coded and evaluated by a blinded examiner, who took measurements using a microcomputer and a Windows-based software program (NIH Image for PC, Scion, Fredrick, MD). The measurements were made in pixels and converted to millimeters (136 pixels per millimeter). Two measurements were taken on each slide, which was masked to show only the coronal 4 mm of the implant. First, the length of the implant surface and the sum of bone-to-implant contact were calculated, and the percentage of bone-to-implant contact was determined. Second, the linear distance from the rim to the highest point of bone-to-implant contact was measured. Then the slide was masked to show only the apical 4 mm of the implant, and the percentage of bone-to-implant contact was determined. In the coronal 4 mm, both the mesial and distal sides of the implant were measured and averaged. In the apical 4 mm, the total surface of the implant, including the apex, was used for the measurement.

Reproducibility of Measurements. On 10 randomly selected samples, histomorphometric measurements were repeated after 2 weeks. All measurements of bone-to-implant contact, both in the coronal and apical 4 mm were within 5% of initial measurements, with the exception of 1 measurement, which differed by 6%. All measurements of the highest bone-to-implant contact were within 0.2 mm of the initial measurements. Eight of 10 measurements were exactly the same.

Statistical Analysis. The data were analyzed with statistical software (StatView Version 4.5 for Windows, Berkeley, CA) on an IBM-compatible microcomputer. For clinical measurements, analysis of variance (ANOVA) for block design was used to compare results between the sites. For histomorphometric measurements, a nonparametric Friedman rank test for block design was employed because of nonnormal distribution of the data. Post hoc multiple comparisons were done using Bonferroni method for significant ANOVA and Friedman rank tests. An alpha level of .05 was used to determine the statistical significance.

Results

There were no postoperative complications, and healing was uneventful. Of the 80 implants placed, 79 were successfully retrieved. One site III implant was missing. All retrieved implants were clinically immobile.

All implants, except the one that was not found at the time of sacrifice, were included in the analysis of clinical outcome. Upon histologic examination, 2 control group implants and 7 implants in site III were found to be completely encapsulated within connective tissue. These implants were not included in the histomorphometric analysis. When implants from both the left and right sides with the same gap

Table 3 Results Per Animal and Sites

	Clinical data (mm)							Histomorphometric data			
	Preoperatively			Postoperatively				Bone-implant contact (%)			
Animal	Ridge crest to rim of implant	Ridge crest to bottom of defect	Defect depth	Ridge crest to rim of implant	Ridge crest to bottom of defect	Residual defect	Defect fill	Coronal	Apical	Implant rim to bone (mm)	Remarks
Control											
#13767	0.8	0.8	0.0	0.5	0.5	0.0	0.0	27.9	32.9	1.0	
#13781	1.3	1.3	0.0	1.5	1.5	0.0	0.0	NA	NA	NA	A
#13782	1.0	1.0	0.0	0.8	0.8	0.0	0.0	57.1	36.0	0.0	
#13783	0.8	0.8	0.0	0.8	1.3	0.5	–0.5	39.9	49.0	0.8	
#13784	1.0	1.0	0.0	0.5	1.0	0.5	–0.5	40.2	31.5	0.9	
#13785	1.0	1.0	0.0	0.5	0.5	0.0	0.0	26.1	15.1	1.5	
#13787	0.8	0.8	0.0	1.0	1.8	0.8	–0.8	37.4	54.5	1.2	
#13788	2.0	2.0	0.0	1.8	2.3	0.5	–0.5	25.5	50.1	0.7	
#13789	1.0	1.0	0.0	1.0	2.0	1.0	–1.0	41.0	22.3	1.2	
#13790	1.5	1.5	0.0	1.5	2.3	0.8	–0.8	35.8	25.3	1.0	
Site I											
#13767	0.8	6.0	5.3	1.0	1.0	0.0	5.3	5.7	37.3	2.0	
#13781	1.3	6.0	4.8	1.5	1.5	0.0	4.8	21.6	20.1	1.1	
#13782	2.0	6.0	4.0	2.0	2.0	0.0	4.0	31.8	25.7	0.8	
#13783	1.0	6.0	5.0	1.5	1.5	0.0	5.0	45.6	39.9	0.7	
#13784	1.5	6.0	4.5	1.5	1.5	0.0	4.5	23.8	31.3	1.4	
#13785	1.5	6.0	4.5	1.0	1.0	0.0	4.5	19.0	8.7	1.3	
#13787	1.0	6.0	5.0	2.0	2.0	0.0	5.0	23.8	28.7	2.1	
#13788	1.5	6.0	4.5	1.5	2.0	0.5	4.0	3.7	31.1	3.1	
#13789	1.5	6.0	4.5	1.0	1.0	0.0	4.5	27.6	37.7	0.8	
#13790	1.5	6.0	4.5	1.3	1.5	0.3	4.3	25.8	34.1	1.5	
Site II											
#13767	2.5	7.5	5.0	2.0	2.0	0.0	5.0	6.3	16.1	2.6	
#13781	2.8	9.0	6.3	2.5	2.5	0.0	6.3	9.9	49.9	2.9	
#13782	2.5	7.5	5.0	2.0	2.0	0.0	5.0	22.4	10.8	0.9	
#13783	1.8	6.5	4.8	2.0	2.5	0.5	4.3	17.5	30.5	2.8	
#13784	2.5	7.0	4.5	2.8	2.8	0.0	4.5	14.3	13.3	2.3	
#13785	2.5	6.5	4.0	1.5	1.5	0.0	4.0	5.1	14.9	2.9	
#13787	1.5	6.5	5.0	1.5	2.5	1.0	4.0	14.2	30.3	2.5	
#13788	2.0	6.0	4.0	1.5	2.0	0.5	3.5	6.4	17.1	2.1	
#13789	2.0	7.0	5.0	0.8	1.3	0.5	4.5	14.2	27.8	1.4	
#13790	1.5	6.5	5.0	1.5	2.3	0.8	4.3	0.0	26.9	4.0	
Site III											
#13767	2.0	7.8	5.8	2.0	2.0	0.0	5.8	7.9	30.1	2.4	B
#13781	4.5	9.8	5.3	3.5	5.0	1.5	3.8	0.0	43.0	4.0	
#13782	1.8	7.5	5.8	1.5	1.5	0.0	5.8	NA	NA	NA	A
#13783	2.0	7.0	5.0	2.0	2.0	0.0	5.0	4.9	68.4	3.8	B
#13784	1.5	7.0	5.5	2.0	2.0	0.0	5.5	0.0	11.1	4.0	B
#13785	1.5	7.3	5.8	1.0	1.0	0.0	5.8	3.6	2.2	2.5	C
#13787	1.5	7.0	5.5	1.0	2.0	1.0	4.5	NA	NA	NA	A
#13788	2.5	6.5	4.0	1.5	1.8	0.3	3.8	2.9	7.2	2.0	
#13789	1.5	7.0	5.5	0.8	0.8	0.0	5.5	5.2	23.8	2.0	
#13790	2.0	6.0	4.0	1.0	1.0	0.0	4.0	0.0	27.5	4.0	

A = both implants not integrated; B = 1 implant not integrated; C = 1 implant missing at the time of retrieval.

size were encapsulated in fibrous tissue, no data were reported for that gap size from that animal. If 1 of the implants was available, that implant was used to represent the animal. This reduced the number of animals available for histomorphometric analysis to 9 for the control and 8 for site III (Table 2).

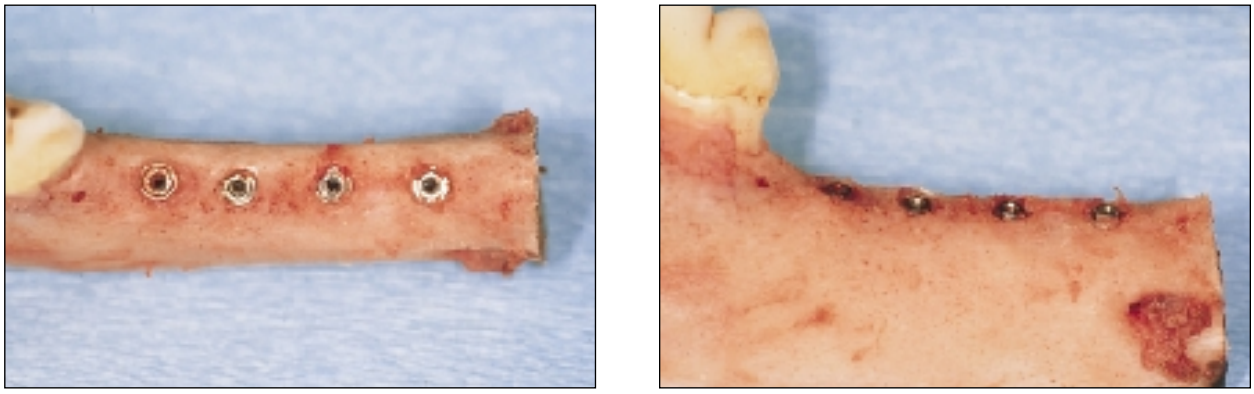
Both clinical and histomorphometric data are presented in Table 3.

Clinical Outcomes. The clinical outcomes for control and test sites are presented in Table 4. Most of the implants in the test sites healed with no signs of residual defect (Fig 3). Clinically, it was impossible to distinguish test sites from controls. The mean clinical bone fill for site I (0.5-mm gap), site II (1.0-mm gap), and site III (1.4-mm gap), were 4.6 ± 0.4 mm, 4.6 ± 0.8 mm, and

Table 4 Results of Clinical Measurements (mm)*

Site	Initial measurements			Final measurements			
	Ridge crest to rim of implant†	Rim of implant to bottom of defect	Depth of defect	Ridge crest to rim of implant	Rim of implant to bottom of defect	Residual defect‡	Bone fill
Control (n=10)	1.1 ± 0.4	1.1 ± 0.4	0.0 ± 0.0	1.0 ± 0.5	1.4 ± 0.7	0.4 ± 0.4	–0.4 ± 0.4
Site I (n=10)	1.4 ± 0.4	6.0 ± 0.0	4.7 ± 0.4	1.4 ± 0.4	1.5 ± 0.4	0.1 ± 0.2	4.6 ± 0.4
Site II (n=10)	2.2 ± 0.5	7.0 ± 0.9	4.9 ± 0.6	1.8 ± 0.6	2.1 ± 0.5	0.3 ± 0.4	4.5 ± 0.8
Site III (n=10)	2.1 ± 0.9	7.3 ± 0.3	5.2 ± 0.7	1.6 ± 0.8	1.9 ± 1.2	0.3 ± 0.5	4.9 ± 0.9

*Mean values and standard deviation.
†Significant difference between sites ($P < .001$; ANOVA); all pairwise differences were significant except control versus site I and site II versus site III ($P < .05$; Bonferroni).
‡No significant difference between any sites ($P = .22$; ANOVA).



Figs 3a and 3b Clinical photographs taken at the time of sacrifice after the cover screws were removed. *Left to right:* control, site I, site II, and site III implants. No residual defect can be observed clinically. All implants were stable when tested with cotton pliers.

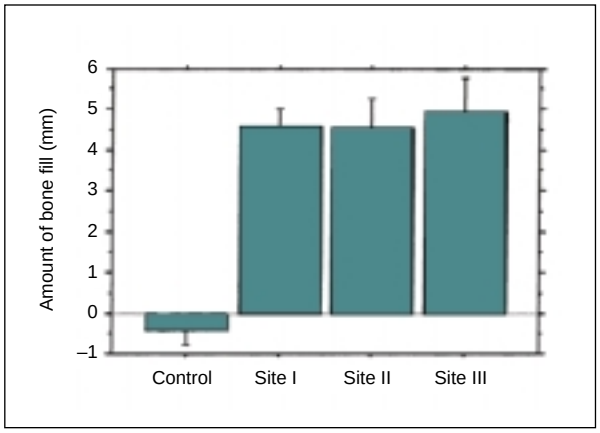


Fig 4 Graph indicating mean amount of clinical bone fill and standard deviation for all sites.

4.9 ± 0.9 mm, respectively (Fig 4). At the time of implant placement, there were significant differences among sites for the distance from the bone crest to the implant rim ($P < .001$). When residual defect depths were compared, no significant differences were found.

Histomorphometric Outcomes. Table 5 summarizes the results of the histomorphometric measurements. When the coronal 4 mm of the implants were examined, the control sites had the highest mean percentage of bone-to-implant contact (38.8%), followed by site I (22.9%), site II (11.0%), and site III (2.7%) (Fig 5). The differences were statistically significant ($P < .0001$). In the apical 4 mm of the implants, no statistical differences in percentage of bone-to-implant contact were found.

When the linear distance from the implant rim to the highest position of direct bone contact was measured, the control sites had the shortest dis-

Table 5 Results of Histomorphometric Measurements*

Site	Percentage of bone to implant contact (%)		Distance from rim to highest point of bone contact (mm)§
	Coronal 4 mm†	Apical 4 mm‡	
Control (n = 9)	38.8 ± 9.8	35.2 ± 13.6	0.9 ± 0.4
Site I (n = 10)	22.9 ± 12.0	29.5 ± 9.4	1.5 ± 0.8
Site II (n = 10)	11.0 ± 6.7	23.8 ± 11.8	2.4 ± 0.9
Site III (n = 8)	2.7 ± 2.9	26.7 ± 21.5	3.1 ± 0.9

*Mean values and standard deviation.
†Significant difference between sites ($P < .0001$; Friedman rank test); all pairwise differences were significant except site I versus site II and site II versus site III ($P < .05$; Bonferroni).
‡No significant difference ($P < .29$; Friedman rank test).
§Significant difference between sites ($P < .001$; Friedman rank test); all pairwise differences except control versus site I and site II versus site III ($P < .05$; Bonferroni).

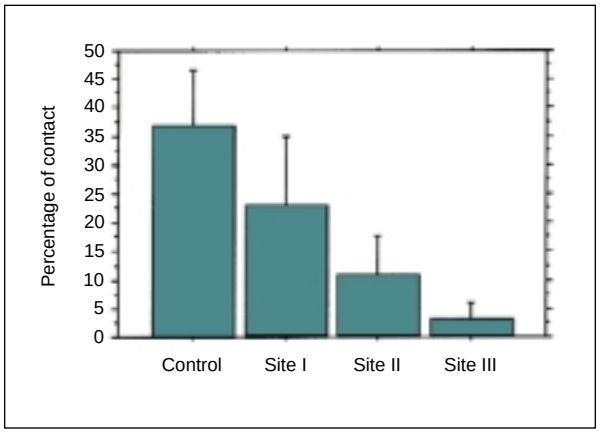


Fig 5 Graph indicating mean percentages (and standard deviation) of bone-to-implant contact in the coronal 4 mm of each group of implants.

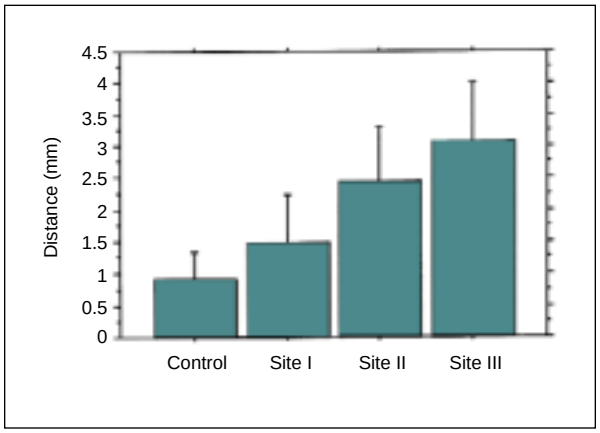


Fig 6 Graph indicating mean distance (and standard deviation) from the implant rim to the highest point of bone contact.

tance. This distance increased as the size of the gap increased (Fig 6), with statistically significant differences ($P < .001$).

Descriptive Histology. The control specimens generally had good bone-to-implant contact for the entire implant length (Fig 7). Enlarged marrow spaces (fatty and/or fibrous) were seen in many sections. In control specimens, bone-to-implant contact frequently extended to the implant rim. In many of the test sections, a space occupied by connective tissue was observed between the implant surface and bone. A bundle of connective tissue fibers running parallel to the implant surface separated the bone and the implant. Epithelial cells contacting the implants were not observed in any specimens. In 2 of the implants in the control and 7 in site III, the implants contacted the canine root. In all of these implants, fibrous tissue was observed encapsulating the implants (Fig 8). The formation of cementum on the titanium surface was not observed.

Discussion

The clinical outcomes of this study demonstrated that in most of the test sites, the defects filled completely with bone. At retrieval, all implants were also clinically immobile. In terms of residual defects, there were no differences between control and test sites. These results corroborate with reports related to bone fill and clinical success associated with implants placed at the time of tooth extraction.[2,4,21] Complete fill of the defect was achieved without the addition of any type of alloplast, allograft, autograft, or barrier membrane. The circumferential defect morphology may have allowed for formation of a more stabilized blood clot, which uneventfully filled with bone. As the gap distance increased, the implants were unintentionally submerged slightly further below the crest. The presence of a defect around the implant at the time of placement made it more difficult for the surgeon to control the depth of

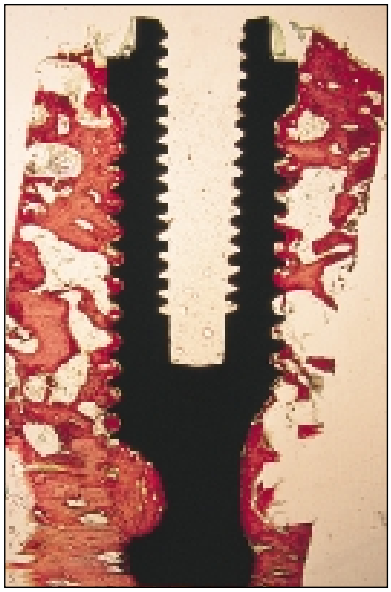


Fig 7 One of the control implants. Bone is in direct contact with the implant up to the rim. Note good bone-to-implant contact for the entire length of the implant.

Fig 8 Site III implant, which was placed in contact with the canine root *(right).* Note the complete fibrous encapsulation, without any direct bone-to-implant contact. No cementum is seen on the implant surface.

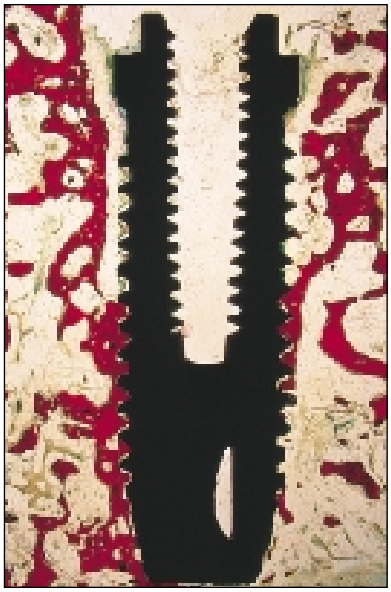


Fig 9 Site II implant. In the coronal portion, where the gap was created at the time of placement, connective tissue can be seen between the implant and bone. In the apical portion of the implant, good bone-to-implant contact is observed.

placement. Placing implants slightly below the ridge crest has been suggested as an appropriate procedure for implants placed at the time of extraction[3] and may have positively influenced the results in test sites.

At the time of retrieval, mobility could not be detected in any of the implants when they were tested with cotton pliers. However, 9 of 79 implants were not osseointegrated when examined histologically. The failure to detect implant mobility clinically at initial uncovering may be the result of the narrowness of the zone of connective tissue between the bone and the implants (Fig 8). Also, it might have been easier to detect mobility if healing abutments were connected. Adell et al[1] have reported that some implants, which seemed to be integrated at the time of second-stage surgery, developed mobility later. The nonintegrated implants in this study may belong to this category.

Histomorphometric measurements were made only in the coronal and apical 4 mm of the implants because in all specimens, the coronal and apical 4 mm were in only the defect or the host bone, respectively. The middle 2 mm were not used for measurement, since this portion of the implant was either in the defect or the host bone, depending on the specimen. By masking the apical or coronal portion during measurement, examiner bias was also minimized. In the coronal 4 mm, bone-to-implant contact ranged between 0 and 71.7%, with the highest mean percentage occurring in controls and the lowest in site III. Of the integrated implants, 1 (5%) in site I, 5 (25%) in site II, and 6 (50%) in site III were found to have absolutely no bone-to-implant contact in the coronal 4 mm (Fig 9). None of the 18 control implants had 0% contact in this area. In this model, the gap at the time of implant placement had a negative effect on bone-to-implant contact, confirming the findings by Carlsson et al,[15] who indicated that histologically, as the initial gap increases, the amount of bone-to-implant contact diminishes. Barzilay et al[22] reported similar percentages of bone-to-implant contact when immediate and control implants in monkeys were compared. In their study, 3.75-mm-diameter implants were placed into extraction sockets of lateral incisors, mesial root sockets of mandibular first molars, distal root sockets of mandibular first premolars, and the palatal root socket of maxillary first molars. This resulted in almost no initial gap between the implants and the host bone. The authors propose

that the present study model—with a defined gap—better represents the clinical situation of immediate implant placement. The lack of gap, as well as different experimental animal models and healing, may explain the differing results of this study and other studies. A recently published human case report[23] confirms this decrease in bone-to-implant contact as the initial gap widens.

The histologic evaluation of healing apparently conflicted with clinical findings. The controls healed with the smallest distance from the implant rim to the first contact of bone. As the initial gap widened, the first bone contact moved apically, with statistically significant differences related to the initial gap distance. Because the residual defect was narrow (Fig 9), it may be that the residual gaps were not possible to detect clinically. It is important to recognize that the clinical bone fill may not indicate true histologic integration of bone to implant. In the apical 4 mm of the implants, good bone-to-implant contact was observed, with no significant differences between control and test sites. Although the placement of implants was not randomized, the results indicate that in all areas, good bone-to-implant contact could be achieved regardless of the coronal gap.

Large marrow spaces were noted in many sections. The significance of this finding is unknown and may be related to the species model. When specimens were observed at higher magnification, no epithelial cells were found in any of the sections. In this model, primary closure of the wound apparently resulted in the exclusion of epithelium without the use of any additional devices.

One of the problems with this study is a lack of randomization in the position of implants. Initially, an attempt was made to randomize implant placement; however, when the implants were placed into wide defects created adjacent to the molars, initial stability was very difficult to achieve. This may have been the result of the presence of wide marrow spaces in the molar areas. As a result of this problem, 18 of 20 site III (1.4-mm gap) defects were created adjacent to the mandibular canines. In 9 sites, the implants were inadvertently placed into or very close to the canine roots. Histologic evaluation demonstrated that when the implants contacted the root surface, connective tissue always interposed between the implants and adjacent bone, resulting in lack of osseointegration (Fig 8). These findings differ somewhat from those reported by others,[24] who found cementum deposited onto titanium plasma-sprayed implant surfaces when the implants were placed in close approximation to root surfaces.

Conclusions

In this study, titanium implants were placed into simulated extraction socket defects of varying gap width (0 to 1.4 mm); they healed with complete clinical bone fill, and the initial gap width did not influence the stability of the implants at the time of retrieval. When healing was examined histologically in the coronal 4 mm of implant, however, the percentage of bone-to-implant contact diminished as the gap distance increased. Additionally, the highest point of bone-to-implant contact moved apically as the initial gap widened, but the coronal gap did not influence bone-to-implant contact in the apical 4 mm of any implant. Intimate contact between bone and implant at the time of placement seems to be an important factor in obtaining maximum bone-to-implant contact following healing. The clinical significance of these findings for long-term implant stability requires further investigation.

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