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Hard-tissue alterations following immediate implant placement in extraction sites

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Abstract

Background: The marginal gap that may occur following implant installation in an extraction socket may be resolved by hard-tissue fill during healing.

Objective: To study dimensional alterations of hard tissues that occur following tooth extraction and immediate placement of implants.

Material and methods: Eighteen subjects with a total of 21 teeth scheduled for extraction were included. Following flap elevation and the removal of a tooth and implant installation, clinical measurements were made to characterize the dimension of the surrounding bone walls, as well as the marginal defect. No membranes or filler material was used. The flaps were subsequently replaced and secured with sutures in such a way that the healing cap of the implant was exposed to the oral environment. After 4 months of healing a re-entry procedure was performed and the clinical measurements were repeated.

Results: Fifty-two marginal defects exceeding 3 mm were present at baseline: 21 at buccal, 17 at lingual/palatal, and 14 at approximal surfaces. At the re-entry eight defects exceeding 3.0 mm remained. During the 4 months of healing, the bone walls of the extraction underwent marked change. The horizontal resorption of the buccal bone dimension amounted to about 56%. The corresponding resorption of the lingual/palatal bone was 30%. The vertical bone crest resorption amounted to 0.3 ± 0.6 mm (buccal), 0.6 ± 1.0 mm (lingual/palatal), 0.2 ± 0.7 mm (mesial), and 0.5 ± 0.9 mm (distal).

Conclusion: The marginal gap that occurred between the metal rod and the bone tissue following implant installation in an extraction socket may predictably heal with new bone formation and defect resolution. The current results further documented that marginal gaps in buccal and palatal/lingual locations were resolved through new bone formation from the inside of the defects and substantial bone resorption from the outside of the ridge.

Key words: bone defect; ridge resorption; socket

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The installation of implants in extraction sockets was advocated as a means to (i) reduce the number of surgical procedures; (ii) to preserve the dimensions of the alveolar ridge; and (iii) to reduce the interval between the removal of the tooth and the insertion of the implant supported restoration (for review see Schwartz-Arad & Chaushu 1997, Mayfield 1999). In most of the studies referred to in the reviews, bone substitutes were used to fill the marginal void between the implant and the bone, and barrier membranes were placed to protect the site during healing.

In a recent study including 48 patients, Paolantonio et al. (2001) installed implants either in sites with healed bone (control sites) or in fresh extraction sockets (test sites). In the extraction sites, a gap ($\leqslant 2$ mm) consistently occurred between the bone walls and the implant surface, while at the control sites the cortical bone was in direct contact with the implant. No membranes or filler materials were used at the surgical sites, which during healing were covered by soft tissue. From each patient, two implants with surrounding bone, one test and one control, were surgically retrieved after 12 months of healing and processed for histological examination. It was reported that the degree of bone to implant contact in all specimens was high, between 62% and 71%, and did

not differ between test and control sites. In a case series, Wilson et al. (2003) presented data from observations made in sections from biopsies obtained from five patients and seven implants (ITI® Dental Implant System, Institute Straumann AG, Waldenburg, Switzerland) with a Sand-blasted, Large-grit, Acid-etched (SLA)-surface topography that were placed in fresh extraction sockets. The sites were following implant installation covered with a connective tissue membrane and primary closure of soft-tissue flaps was achieved in each case. It was reported that osseointegration could occur to such implants also when following implant installation has a marginal gap >4 mm.

In a series of clinical studies (e.g. Cochran & Douglas 1993, Brägger et al. 1996, Lang et al. 1994, Hämmerle et al. 1998, Cornelini et al. in press), it was demonstrated that substantial hard-tissue fill could also occur in marginal defects around implants in fresh extraction sites if during healing they were not submerged under the ridge mucosa but protected with a barrier membrane.

Observations made in clinical studies and animal experiments have further documented that following tooth extraction, the socket as well as the surrounding bone tissue will undergo substantial modeling, remodeling and resorption. Thus, the socket will heal with woven bone formation, the establishment of a cortical ridge and replacement of woven bone with lamellar bone and marrow (e.g. Amler 1969, Cardaropoli et al. 2003). The buccal and palatal portion of the ridge will, following tooth removal, suffer minor vertical but major horizontal tissue loss (Johnson 1967, 1969a, b, Pietrokovski & Massler 1967, Schropp et al. 2003).

The aim of the present investigation was to study dimensional alterations of hard tissues that occur following tooth extraction and immediate placement of implants.

Material and Methods

Eighteen healthy subjects (nine female and nine male; mean age, 49.1 years; range, 21–81) providing 21 extraction sockets were included in the study. Prior to the start of the trial, the patients gave their informed consent. The subject sample consisted of patients the treatment of whom called for extraction of either incisors, canines or premolars, and restoration by means of implants. The reasons for tooth extraction were endodontic and caries lesions combined with root or crown fractures. No tooth was removed because of advanced periodontal disease.

The removal of the tooth was performed under local anesthesia. Full-thickness mucosal flaps were raised and the tooth was carefully luxated with the use of small elevators. The extraction of the mobilized tooth was made with forceps and thus, a minimum amount of mechanical trauma was applied to the surrounding bone. The periodontal ligament attached to the bone in the socket wall was left undisturbed.

The apical portion of the socket was carefully prepared using a conventional drill set for the implants to be used (Institute Straumann, Waldenburg, Switzerland). A solid screw ITI® implant with an SLA-modified surface (Straumann AG, Waldenburg, Switzerland) was installed. The vertical distance between the implant shoulder and the marginal level of the SLA portion was 2.8 mm in the type of implant used. All implants installed had a diameter of 4.1 mm and a length that varied between 8 and 12 mm, depending on the depth of the socket. The implant was generally positioned so that the marginal level of the SLA portion was placed apical of the marginal level of buccal and lingual/palatal wall of the socket (Fig. 1a, b).

After implant installation, the defect that occurred between the bone walls of the extraction socket and the implant surface was characterized and the following landmarks were identified (Fig. 2): S = rim of the implant shoulder, C = top of the bone crest, OC = outer border the bone crest, D = base of the defect.

Clinical measurements were performed at the time of implant installation with the use of caliper instruments (Castroviejo measuring instrument, Iwanson caliper, Bontempi snc, S. Giovanni in Marignano RN, Italy). The mesial–distal and buccal–lingual dimensions of the socket were assessed and the thickness of the buccal and lingual/palatal bone walls, at a position of about 1 mm apical of the bone crest, was measured prior to implant installation.

Following implant installation (i) the vertical distance between the implant shoulder (S) and the bone crest (C), (ii) the width of the gap between the implant surface and the inner side of the bone wall (G) and (iii) the horizontal distance between the implant surface and the outer side of the bone crest (OC) were assessed (Fig. 2).

The distance between S and the base of the defect (D) was measured using a periodontal probe (William, Hu-Friedy, Chicago, IL, USA).

An SCS closure screw (Institute Straumann, Waldenburg, Switzerland) was attached to the implant. The flaps were replaced and secured with sutures. All implants were semi-submerged but all parts of the defects were covered by mucosal tissue (Fig. 1c). The closure screw was always exposed to the oral environment.

After 4 months of healing (Fig. 1d), the soft-tissue exhibited no signs of inflammation and a surgical re-entry procedure was performed. Full-thickness flaps were elevated to allow the access to marginal portions of the implant sites (Figs 1e, f) and the following clinical measurements were performed: the distance between S and the most coronal contact between bone and implant (D); the width of the remaining gap between the implant surface and the inner side of the bone wall (G); the horizontal distance between the implant surface and the outer side of the bone crest (OC); the vertical distance between the implant shoulder (S) and the bone crest (C) (Fig. 2).

The SCS closure screw was removed and a healing cap was connected to the implant. The flaps were adapted and secured with sutures around the implant-healing cap unit.

Results

Some overall alterations that occurred in the extraction sites during the 4 months of healing are illustrated in Figs 1, 3–5. In most sites the marginal defects were completely resolved and the ''horizontal'' dimensions of the buccal and lingual/palatal bone walls, markedly reduced.

Defects

Baseline measurements

The mesial–distal mean width of the marginal aspect of the sockets was 5.3 $\pm$ 1.2 (SD) mm (range 4.0–8.0 mm), and the buccal–lingual mean width was 7.3 $\pm$ 1.1 mm (range 5.5–9.0 mm; Table 1).

Following implant installation, considering four aspects at each implant, a

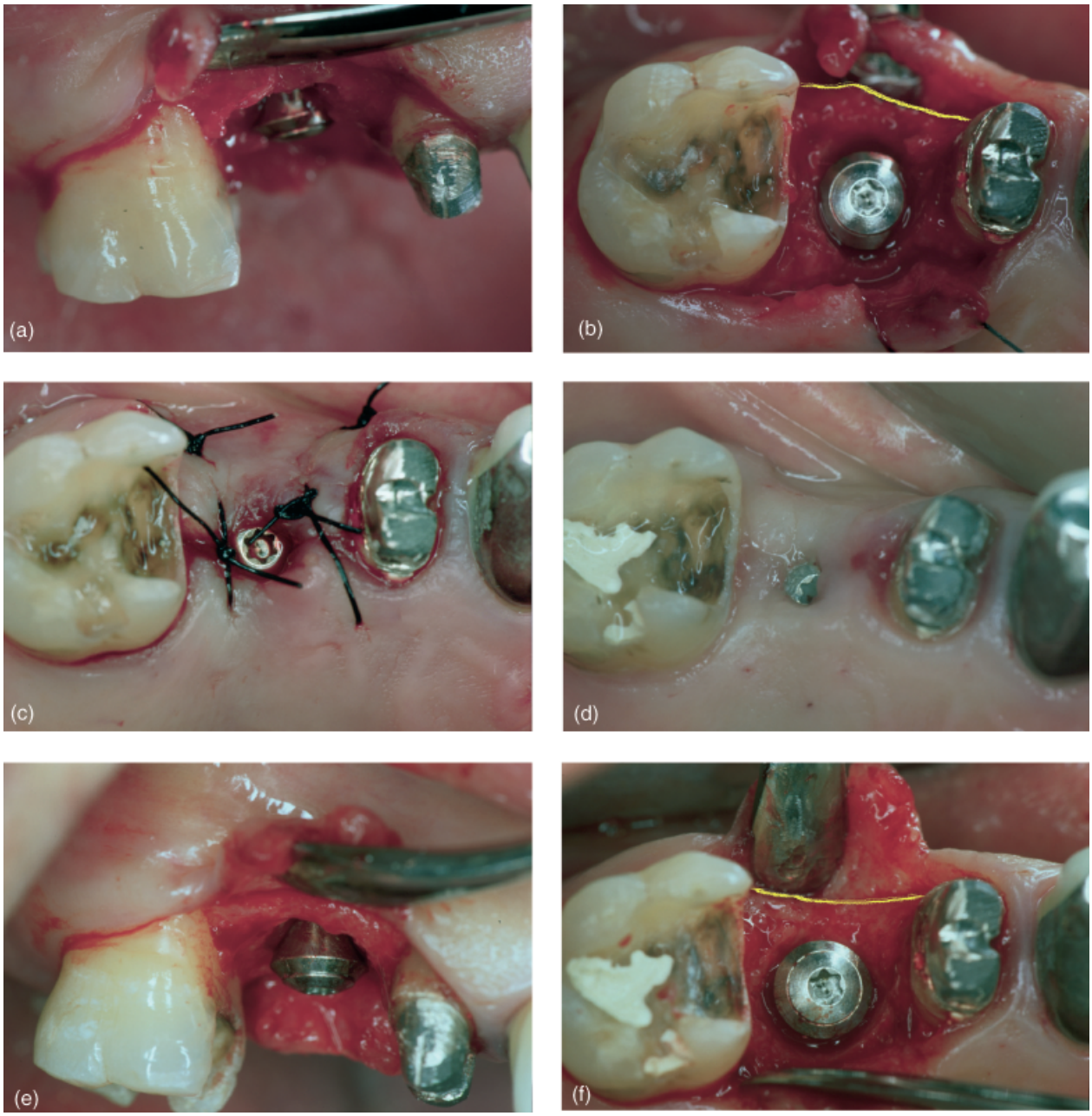

Fig. 1. Clinical photographs describing the implant site of patient L. C. immediately after implant installation: (a) buccal view and (b) occlusal view, (c) follow flap closure with sutures and (d) after 4 months of healing. During the 4-month interval, the marginal bone crest at the buccal surface exhibited minor signs of ''vertical'' resorption ((e) to be compared with (a)) and the buccal bone wall (yellow lines) was markedly reduced in width ((f) to be compared with (b)).

total of 52 marginal defects were identified that had the distance S–D exceeding 3 mm. Twenty-one of these defects were located at the buccal aspect of the implants, 17 at the lingual aspect, and 14 at approximal (mesial and distal) aspects (Table 2).

Buccal defects. Distance S–D: The mean distance S–D at the buccal aspect was 8.2 ± 2.1 mm (range: 5.0–11.5 mm; Table 2).

Gap: The mean width of the defect at the buccal aspect was 2.0 ± 0.7 mm and ranged between 1.0 mm (four sites) and 3.0 mm (five sites, Table 3).

Lingual/palatal defects. Distance S–D: The mean distance S–D at the lingual/palatal aspects was 5.6 ± 3.1 mm (range 0.0–12.0 mm).

Gap: The mean width at the lingual/palatal sites was 1.5 ± 0.9 mm and ranged between 0.0 mm (one site) and 3.0 mm (three sites).

Approximal defects. Distance S–D: The mean distance S–D at the mesial aspects was 3.0 ± 3.7 mm and at the distal aspects 2.1 ± 2.7 mm (overall range 0.0–10.0 mm).

Gap: The mean width was 0.7 ± 0.8 mm at the mesial aspect and 0.6 ± 0.7 mm at the distal aspect. The

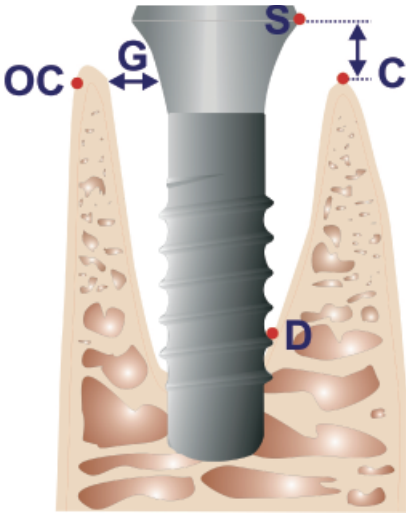

Fig. 2. Schematic drawing illustrating the landmarks used for the clinical measurements. S, shoulder of the implant; C, coronal margin of bone crest; OC, outer surface of the bone crest; D, base of the defect; G, gap between the implant surface and the inner side of the bone wall.

overall range was 0.0 (19 sites)–3.0 mm (one site).

Re-entry measurements

Buccal defects. Distance S–D: The mean distance S–D at the buccal aspects was 2.7 ± 1.4 mm (range 0.0–7.0 mm; Table 2). In three sites, the remaining S–D distance exceeded 3 mm.

Gap: The mean width at the buccal aspects was 0.4 ± 0.5 mm and ranged between 0.0 mm (10 sites) and 1.5 mm (one site, Table 3).

Lingual/palatal defects. Distance S–D: The mean distance S–D at the lingual/palatal aspects was 2.1 ± 1.1 mm (range 0.0–4.0 mm). In two sites, the remaining S–D distance exceeded 3 mm.

Gap: The mean width at the lingual/palatal sites was 0.4 ± 0.4 mm and ranged between 0.0 mm (nine site) and 1.0 mm (six sites).

Approximal defects. Distance S–D: The mean distance S–D at the mesial aspects was 1.4 ± 1.3 mm and at the distal aspects was 1.8 ± 1.3 mm. The overall range was between 0.0 and 3.5 mm. In three sites, the remaining S–D distance exceeded 3.0 mm.

Gap: The mean width was 0.5 ± 0.5 mm both at the mesial and the distal aspects and varied overall between 0.0 mm (18 sites) and 2.0 mm (one site).

Dimensions of bone walls

The thickness of the buccal and lingual/palatal bone plate

The width of the bone wall of the extraction socket was 1.4 ± 0.4 mm buccally and 1.6 ± 0.6 mm lingually (Table 4). The distance between the implant surface and the outer surface of the buccal bone plate (Table 5) was, at the time of installation, on the average

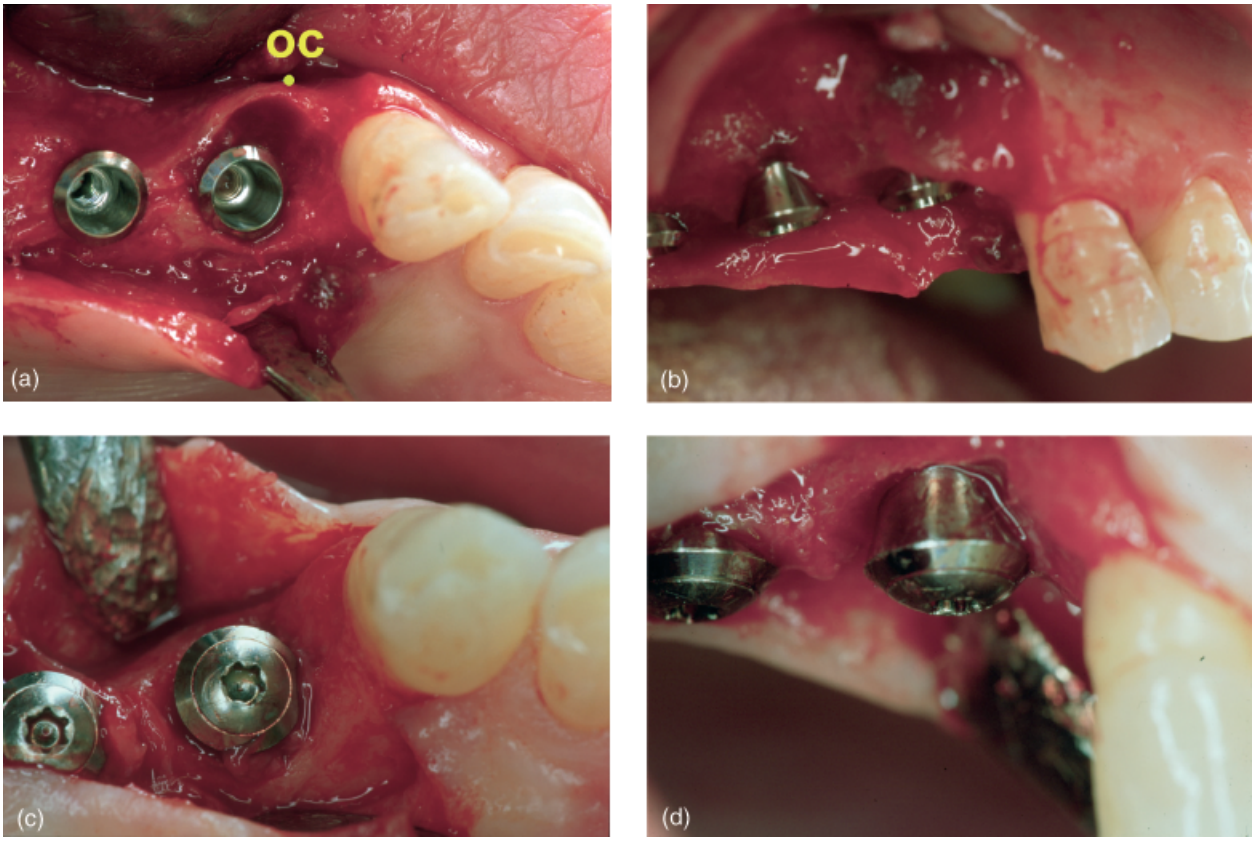

Fig. 3. *Case T. M.*: The implant was placed in the palatal socket of the extracted tooth 14 ((a) occlusal view). Note the long distance between the outer surface of the buccal bone wall (OC) and the implant. (b) (buccal view) illustrates that the buccal bone margin is at about the same ''vertical'' level as the implant shoulder. The large horizontal dimension of the socket (9 mm bucco-lingually and 7 mm disto-mesial) allowed probing the defect at the buccal, mesial and lingual aspects. The implant in position 15 was placed in the same surgical procedure but in a healed ridge. After 4 months of healing ((c) occlusal view) there has been a marked remodeling of the buccal bone tissue and a substantial reduction of the height of the marginal bone crest (d).

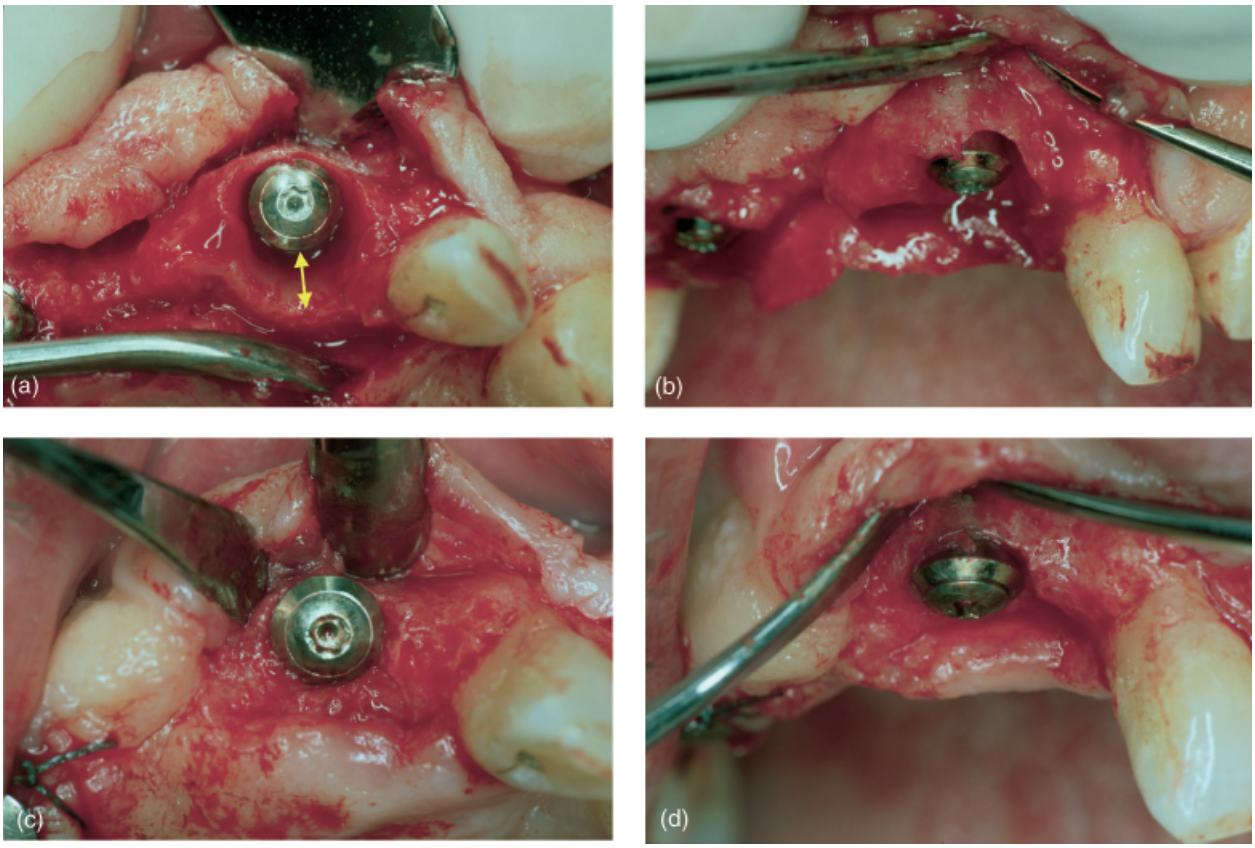

Fig. 4. Case E. M. C.: The implant was installed in the extraction socket in position 21 ((a) occlusal view; (b) buccal view). Note the wide palatal defect (arrow). After 4 months, the defect was resolved (c, d).

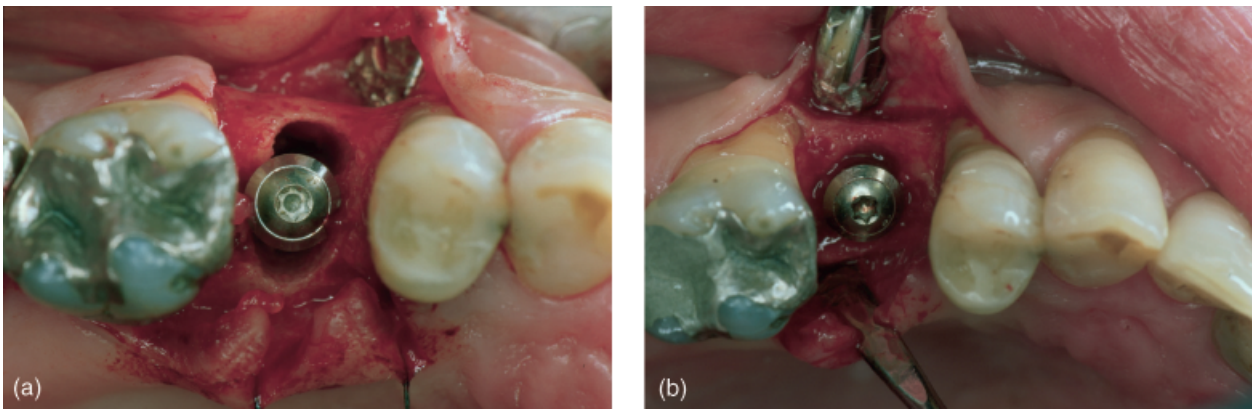

Fig. 5. Case B. M.: (a) A clinical photograph that illustrates an implant that was placed in the socket immediately after the extraction of tooth 15 (occlusal view). Note the wide marginal gaps that are present at the buccal and palatal surfaces of the extraction site. (b) After 4 months of healing, the marginal defect was reduced, but the depth at the buccal aspect was not completely resolved.

3.4 ± 0.7 mm. The corresponding dimension on the lingual/palatal surface of the implants was 3.0 ± 1.2 mm. At re-entry these distances at the buccal and lingual/palatal aspects were 1.5 ± 0.9 and 2.2 ± 0.9 mm, respectively. This means that the horizontal resorption of the bone crest at the buccal site (point OC towards the implant surface) amounted at least to 1.9 ± 0.9 mm while at the lingual/palatal surface the corresponding reduction was 0.9 ± 0.6 mm.

The vertical distance between the shoulder (S) of the implant and the bone crest (C)

The mean values of the S–C (Table 6) distances measured at baseline were 1.6 ± 0.9 mm (buccal), 0.6 ± 0.9 mm (lingual/palatal), − 0.3 ± 0.8 mm (mesial), and − 0.1 ± 0.9 mm (distal). At re-entry the corresponding dimensions were 2.0 ± 0.8 mm (buccal), 1.2 ± 0.8 mm (palatal/lingual), − 0.1 ± 0.6 mm (mesial), and 0.4 ± 0.9 mm (distal). This means that the vertical resorption of the bone walls around the implants amounted to 0.3 ± 0.6 mm (buccal), 0.6 ± 1.0 mm (lingual/palatal), 0.2 ± 0.7 mm (mesial), and 0.5 ± 0.9 mm (distal).

Table 1. Tooth position and marginal width (mm) of the extraction socket in mesio-distal (MD) and bucco-lingual (BL) directions

	Tooth	MD	BL
M. B.	34	5.0	5.5
M. T.	44	8.0	6.0
I. O.	14	4.0	8.0
T. M.	14	7.0	9.0
R. M.	24	5.0	7.0
A. V.	24	4.0	9.0
M. F.	14	4.0	8.0
P. F.	23	5.0	7.0
M. C. G.	15	6.0	7.0
B. M.	15	6.0	8.5
R. R.	24	4.0	8.5
I. B.	44	4.0	6.0
L. B.	14	5.0	9.0
L. C.	15	4.5	7.0
L. D. P. 1	13	4.5	7.0
L. D. P. 2	24	5.0	8.0
G. C.	15	6.0	7.5
F. A. 1	43	7.0	7.0
F. A. 2	44	5.0	6.0
E. M. C. 1	21	7.5	6.5
E. M. C. 2	12	5.5	6.5
mean		5.3	7.3
SD		1.2	1.1

Mean values and standard deviation (SD).

Table 2. Measurements of the distance (mm) from the shoulder (S; Fig. 2) of the implant to the base of the defect (D) immediately following implant installation and at re-entry after 4 months

	Installation				Re-entry				Difference			
	M	B	D	L	M	B	D	L	M	B	D	L
M. B.	0.0	6.0	1.0	4.0	1.0	3.0	3.0	2.5	− 1.0	3.0	− 2.0	1.5
M. T.	9.0	7.0	6.0	0.0	3.0	3.0	3.5	2.0	6.0	4.0	2.5	− 2.0
I. O.	0.0	6.0	0.0	4.0	0.0	3.0	3.0	1.0	0.0	3.0	− 3.0	3.0
T. M.	8.0	8.0	3.0	6.0	0.0	3.0	3.0	3.0	8.0	5.0	0.0	3.0
R. M.	0.0	8.0	0.0	6.0	2.0	3.0	1.5	2.5	− 2.0	5.0	− 1.5	3.5
A. V.	1.0	8.5	0.0	8.0	2.0	2.5	2.5	2.5	− 1.0	6.0	− 2.5	5.5
M. F.	9.0	10.0	0.0	12.0	2.5	3.5	2.5	3.0	6.5	6.5	− 2.5	9.0
P. F.	5.0	11.0	0.0	0.0	0.0	0.0	0.0	2.0	5.0	11.0	0.0	− 2.0
M. C. G.	3.0	8.0	4.0	4.0	0.0	2.0	0.0	2.0	3.0	6.0	4.0	2.0
B. M.	0.0	11.5	5.0	7.0	3.0	7.0	3.0	4.0	− 3.0	4.5	2.0	3.0
R. R.	2.0	9.0	0.0	8.0	3.5	4.0	3.5	3.5	− 1.5	5.0	− 3.5	4.5
I. B.	0.0	5.5	0.0	5.5	1.5	2.0	1.0	2.0	− 1.5	3.5	− 1.0	3.5
L. B.	0.0	8.0	0.0	8.0	1.0	3.0	0.0	3.0	− 1.0	5.0	0.0	5.0
L. C.	2.0	6.0	3.0	11.0	3.0	3.0	3.0	3.0	− 1.0	3.0	0.0	8.0
L. D. P. 1	0.0	10.5	0.0	5.5	0.0	1.5	0.0	1.5	0.0	9.0	0.0	4.0
L. D. P. 2	0.0	8.0	0.0	3.0	0.0	2.5	0.0	0.0	0.0	5.5	0.0	3.0
G. C.	9.0	10.0	9.0	8.0	3.0	3.0	3.0	3.0	6.0	7.0	6.0	5.0
F. A. 1	5.0	5.0	4.0	6.0	1.0	1.0	1.0	0.0	4.0	4.0	3.0	6.0
F. A. 2	1.0	5.0	0.0	0.5	1.0	3.0	1.0	1.0	0.0	2.0	− 1.0	− 0.5
E. M. C. 1	10.0	10.0	5.0	5.0	0.0	1.0	0.5	1.0	10.0	9.0	4.5	4.0
E. M. C. 2	0.0	11.5	5.0	6.0	2.5	2.5	2.5	2.5	− 2.5	9.0	2.5	3.5
mean	3.0	8.2	2.1	5.6	1.4	2.7	1.8	2.1	1.6	5.5	0.4	3.5
SD	3.7	2.1	2.7	3.1	1.3	1.4	1.3	1.1	3.8	2.3	2.6	2.7

Mean values and standard deviation (SD).

Table 3. Measurements describing the width (mm; G; Fig. 2) of the horizontal marginal defects at the mesial (M), buccal (B), distal (D) and lingual/palatal (L) surfaces at the time of implant installation and at re-entry after 4 months of healing of each subject

	Installation				Re-entry				Difference			
	M	B	D	L	M	B	D	L	M	B	D	L
M. B.	0.5	1.5	0.5	1.0	0.0	0.0	0.0	0.0	0.5	1.5	0.5	1.0
M. T.	3.0	1.5	2.0	0.5	1.0	0.0	0.0	0.0	2.0	1.5	2.0	0.5
I. O.	0.0	3.0	0.0	1.0	0.0	0.5	1.0	0.0	0.0	2.5	− 1.0	1.0
T. M.	1.5	3.0	1.0	1.0	0.0	0.0	1.0	0.5	1.5	3.0	0.0	0.5
R. M.	0.0	3.0	0.0	2.5	1.0	0.0	0.0	0.0	− 1.0	3.0	0.0	2.5
A. V.	0.5	3.0	0.0	2.0	0.5	0.5	0.5	0.5	0.0	2.5	− 0.5	1.5
M. F.	1.0	2.0	0.0	3.0	1.0	1.0	1.0	1.0	0.0	1.0	− 1.0	2.0
P. F.	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0
M. C. G.	1.0	1.0	2.0	1.0	0.0	0.5	0.0	1.0	1.0	0.5	2.0	0.0
B. M.	0.0	2.5	1.0	2.0	1.0	1.5	2.0	1.0	− 1.0	1.0	− 1.0	1.0
R. R.	1.0	3.0	0.0	1.5	1.5	1.0	0.5	0.5	− 0.5	2.0	− 0.5	1.0
I. B.	0.0	1.0	0.0	1.5	0.5	0.0	0.5	0.5	− 0.5	1.0	− 0.5	1.0
L. B.	0.0	2.0	0.0	3.0	0.5	0.5	0.0	1.0	− 0.5	1.5	0.0	2.0
L. C.	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	0.5
L. D. P. 1	0.0	1.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	1.0
L. D. P. 2	0.0	2.0	0.0	1.0	0.0	0.5	0.0	0.0	0.0	1.5	0.0	1.0
G. C.	2.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0
F. A. 1	1.0	1.5	1.0	1.5	0.5	0.0	0.5	0.5	0.5	1.5	0.5	1.0
F. A. 2	0.5	1.0	0.0	0.5	0.0	0.0	0.0	0.0	0.5	1.0	0.0	0.5
E. M. C. 1	1.5	1.0	1.5	3.0	0.0	0.0	0.5	0.0	1.5	1.0	1.0	3.0
E. M. C. 2	0.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5	− 0.5	1.0	0.5	0.5
mean	0.7	2.0	0.6	1.5	0.5	0.4	0.5	0.4	0.3	1.5	0.1	1.1
SD	0.8	0.7	0.7	0.9	0.5	0.5	0.5	0.4	0.8	0.7	0.8	0.8

Mean values and standard deviation (SD).

Discussion

The present clinical study demonstrated that a marginal gap that occurs between the metal rod and the bone tissue following implant installation in an extraction socket may predictably heal with new bone formation and defect resolution. The current results further documented that wide and deep marginal gaps in buccal and palatal/lingual locations could be resolved through new bone formation from the inside of the defects and bone resorption from the outside of the ridge.

The finding that localized marginal defects that occur following implant placement in extraction sockets may heal without the use of space maintaining barrier membranes or filler material confirms findings made in previous studies in man (e.g. Paolantonio et al. 2001, Covani et al. 2003) and experimental animals (e.g. Fiorellini et al. 1998). There are reasons to suggest that the hard-tissue formation was the result of proper clot maturation in the protected environment that was established in the confined defect lateral of the implant. Thus, Botticelli et al. (2004) reported from experiments in dogs that mechanically produced defects of varying dimension (1.25–2.25 mm in width and 5 mm in depth) in the marginal portion of implant sites following 4 months of healing were consistently filled with newly formed bone. The current findings, however, demonstrated

Table 4. Measurements describing the thickness of the buccal (B) and lingual/palatal (L) bone walls. The assessments were made immediately prior to implant installation

	Installation	
	B	L
M. B.	1.0	1.0
M. T.	2.0	1.0
I. O.	0.5	1.0
T. M.	1.0	1.0
R. M.	1.0	1.0
A. V.	1.0	1.5
M. F.	2.0	2.0
P. F.	2.0	1.0
M. C. G.	2.0	2.0
B. M.	1.5	1.5
R. R.	1.0	1.5
I. B.	1.5	1.5
L. B.	1.5	2.0
L. C.	2.0	1.5
L. D. P. 1	1.0	1.0
L. D. P. 2	1.5	2.0
G. C.	1.5	1.5
F. A. 1	1.5	3.0
F. A. 2	1.5	3.0
E. M. C. 1	1.0	2.0
E. M. C. 2	1.5	1.0
mean	1.4	1.6
SD	0.4	0.6

Mean values and standard deviations (SD).

Table 5. Measurements of the distance between the implant surface and the outer surface of the buccal (B) and lingual/palatal (L) bone wall (OC; Fig. 2) at the time of implant installation and at re-entry after 4 months

	Installation		Re-entry		Difference	
	B	L	B	L	B	L
M. B.	2.5	2.0	1.0	1.5	− 1.5	− 0.5
M. T.	3.5	1.5	0.5	1.0	− 3.0	− 0.5
I. O.	3.5	2.0	1.5	1.0	− 2.0	− 1.0
T. M.	4.0	2.0	1.0	1.5	− 3.0	− 0.5
R. M.	4.0	3.5	0.5	2.0	− 3.5	− 1.5
A. V.	4.0	3.5	2.0	2.5	− 2.0	− 1.0
M. F.	4.0	5.0	2.0	3.0	− 2.0	− 2.0
P. F.	4.0	1.0	0.5	0.5	− 3.5	− 0.5
M. C. G.	3.0	3.0	2.5	3.0	− 0.5	0.0
B. M.	4.0	3.5	3.0	2.5	− 1.0	− 1.0
R. R.	4.0	3.0	3.0	2.5	− 1.0	− 0.5
I. B.	2.5	3.0	0.5	1.5	− 2.0	− 1.5
L. B.	3.5	5.0	1.5	4.0	− 2.0	− 1.0
L. C.	4.0	2.5	3.0	2.5	− 1.0	0.0
L. D. P. 1	2.5	2.0	0.5	1.0	− 2.0	− 1.0
L. D. P. 2	3.5	3.0	1.5	2.0	− 2.0	− 1.0
G. C.	3.5	3.5	3.0	3.0	− 0.5	− 0.5
F. A. 1	3.0	4.5	1.0	3.5	− 2.0	− 1.0
F. A. 2	2.5	3.5	1.0	3.0	− 1.5	− 0.5
E. M. C. 1	2.0	5.0	0.5	2.5	− 1.5	− 2.5
E. M. C. 2	3.0	2.0	1.5	1.5	− 1.5	− 0.5
mean	3.4	3.0	1.5	2.2	− 1.9	− 0.9
SD	0.7	1.2	0.9	0.9	0.9	0.6

Mean values and standard deviations (SD).

Table 6. Measurements describing the ''vertical'' distance between the shoulder of the implant (S; Fig. 2) and the marginal bone crest (C; Fig. 2) at the time of implant installation and at re-entry after 4 months

	Installation				Re-entry				Difference			
	M	B	D	L	M	B	D	L	M	B	D	L
M. B.	0.0	4.0	1.5	2.0	1.0	3.0	2.5	2.5	− 1.0	1.0	− 1.0	− 0.5
M. T.	− 1.0	3.0	1.0	0.0	0.0	3.0	3.0	2.0	− 1.0	0.0	− 2.0	− 2.0
I. O.	− 1.0	0.0	− 1.0	0.0	− 1.0	1.5	0.0	1.0	0.0	− 1.5	− 1.0	− 1.0
T. M.	− 1.0	1.0	1.0	0.0	0.0	2.5	0.0	0.0	− 1.0	− 1.5	1.0	0.0
R. M.	0.0	4.0	0.0	0.0	− 1.0	3.0	0.0	2.5	1.0	1.0	0.0	− 2.5
A. V.	0.0	1.5	0.5	1.0	0.0	2.0	1.0	2.0	0.0	− 0.5	− 0.5	− 1.0
M. F.	0.0	2.0	0.0	2.0	0.5	3.0	1.0	2.0	− 0.5	− 1.0	− 1.0	0.0
P. F.	0.5	0.0	0.0	0.0	− 1.0	0.0	0.0	2.0	1.5	0.0	0.0	− 2.0
M. C. G.	− 1.0	1.0	− 1.0	1.0	− 1.0	1.0	− 1.0	0.0	0.0	0.0	0.0	1.0
B. M.	0.0	2.0	0.0	0.0	0.0	3.0	1.0	1.0	0.0	− 1.0	− 1.0	− 1.0
R. R.	1.0	2.5	1.5	1.5	0.5	2.5	0.0	1.5	0.5	0.0	1.5	0.0
I. B.	0.0	1.0	0.0	1.5	0.0	2.0	0.0	1.5	0.0	− 1.0	0.0	0.0
L. B.	− 2.0	1.0	− 0.5	0.0	− 1.0	1.0	− 1.0	0.0	− 1.0	0.0	0.5	0.0
L. C.	0.5	1.5	0.0	0.0	0.0	2.0	1.0	0.5	0.5	− 0.5	− 1.0	− 0.5
L. D. P. 1	0.0	2.0	0.0	1.5	0.0	1.5	0.0	1.5	0.0	0.5	0.0	0.0
L. D. P. 2	0.0	1.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	− 1.0	0.0	2.0
G. C.	0.0	1.0	0.0	1.0	0.0	1.5	1.0	1.5	0.0	− 0.5	− 1.0	− 0.5
F. A. 1	− 2.0	1.0	− 3.0	− 1.0	− 1.0	1.0	− 1.0	0.0	− 1.0	0.0	− 2.0	− 1.0
F. A. 2	0.0	2.5	0.0	0.0	1.0	3.0	1.0	1.0	− 1.0	− 0.5	− 1.0	− 1.0
E. M. C. 1	− 1.0	1.0	− 1.5	− 1.0	0.0	1.0	− 0.5	1.0	− 1.0	0.0	− 1.0	− 2.0
E. M. C. 2	0.5	1.0	0.0	1.0	0.5	1.5	0.5	1.5	0.0	− 0.5	− 0.5	− 0.5
mean	− 0.3	1.6	− 0.1	0.6	− 0.1	2.0	0.4	1.2	− 0.2	− 0.3	− 0.5	− 0.6
SD	0.8	0.9	0.9	0.9	0.6	0.8	0.9	0.8	0.7	0.6	0.9	1.0

Mean values and standard deviations (SD).

that even wider defects exhibited features of bone fill that was similar to that obtained in more narrow gaps. Thus, eight out of nine defects that at implant installation were $\geqslant 3$ mm wide were at the re-entry procedure after 4 months found to be completely resolved. This is also in agreement with findings from Wilson et al. (2003) who demonstrated, in a human study, that gaps greater than 4 mm around implants with an SLA surface could heal.

Clinical examinations may not disclose whether the newly formed bone in the defect had ''integrated'' with the exposed portion of the implant. Thus, in experiments presented by, e.g. Akimoto et al. (1999), marginal bone defects resulted in clinical complete bone fill while the histological examination of biopsies obtained from the ''healed'' sites disclosed the presence of connective tissue between the implant and the newly formed bone. Thus, it may be argued that even if most defects in the current study were resolved, the question whether they healed with osseointegration is still open. In this context, it must be realized that in the current subject sample, implants with an SLA surface modification were consistently used. Findings by, e.g. Botticelli et al. (in press) from animal experiments disclosed that while defects lateral to implants with an SLA surface healed

with proper osseointegration, the healing of similar defects adjacent implants with turned surface configurations healed with the formation of a connective tissue capsule that separated the implant from the newly formed bone. In the publications referred to, it was suggested that the rough SLA surface provided optimal conditions for coagulum stability and maturation, i.e. features essential to the formation of new bone tissue. The validity of this assumption was confirmed by findings from a study presented by Persson et al. (2001). Experimental peri-implantitis was induced around implants with either a turned or roughened (SLA) surface by the use of a technique that included ligature placement and plaque accumulation (Lindhe et al. 1992). The lesions were subsequently treated with curettage of the marginal defect and careful debridement of the implant surfaces. It was observed that during healing there was at both types of implants substantial hard tissue fill of the defect while re-osseointegration to the previously exposed and contaminated surfaces took place only at implants with an SLA surface topography.

In the present clinical study, a ''non-submerged'' surgical protocol that allowed the abutment portion of the implant to be exposed to the oral cavity during the early phase of healing was used. Studies by Abrahamsson et al. (1999) demonstrated that tissue healing that followed submerged (two-stage) and non-submerged (one-stage) implant installation techniques had many features in common. Thus, irrespective of surgical protocol, a soft tissue formed around the implant that contained one epithelial and one connective tissue component that provided a proper barrier between the bone tissue and the oral cavity. Further, both one-stage and two-stage protocols ensured hard tissue healing with high degree of osseointegration. The clinical measurements made in the re-entry procedure in the present study evidently confirmed the experimental evidence by documenting close to ideal healing of the defects that were present following the insertion of the implants.

The clinical protocol used in the present clinical trial called for re-entry after 4 months of healing. This decision was based on findings made in experiments in dogs (Botticelli et al. 2003a, b). It was reported that hard-tissue formation in marginal defects that were $\geqslant 1.25$ mm wide was complete after 4 months of healing. It may be argued that soft- and hard-tissue healing occurs faster in dogs than in man. Hence, it is possible that the four remaining defects in the present sample that were not filled with bone – after 4 months – may also have been resolved if the healing period had been extended. In this regard, it should be noted that the current subject sample will be monitored for at least 5 years after the installation of the prosthetic devices and that data from this more extended observation interval will be reported in a subsequent publication.

In the present study, the distance between the implant and the outer surface of the buccal or lingual/palatal bone wall was determined at surgery and at re-entry following 4 months of healing. At surgery this dimension was found to be 3.4 mm (buccal) and 3.0 mm (lingual/palatal). At re-entry, the dimensions at the corresponding sites were 1.5 and 2.2 mm, respectively. In other words during the 4-month interval following tooth extraction, the buccal bone dimension had undergone ''horizontal'' resorption that amounted to about 56%. The corresponding reduction of the lingual/palatal bone wall was 30%. The finding that following tooth extraction resorption of the buccal and lingual/palatal bone walls occurs is in agreement with findings by, e.g. Pietrokovski & Massler (1967) and Schropp et al. (2003). Pietrokovski & Massler (1967) used stents from 149 subjects and measured the bucco-lingual/palatal width of an extraction site and compared this dimension to that of a contralateral tooth site. They observed that both the buccal and lingual/palatal walls underwent marked resorption following tooth extraction, but that the reduction on the buccal side was more pronounced than on the lingual/palatal side. Schropp et al. (2003) studied bone healing and soft-tissue contour changes following single-tooth extraction. They removed one premolar or molar tooth in 46 patients and monitored alterations of the alveolar ridge that had occurred after 3, 6, and 12 months of healing. The authors reported that while there was only a minor reduction of the vertical dimension of the ridge, the width of the ridge underwent marked change. Thus, ''with regard to the width of the ridge, a reduction of approximately 50% was found'' after 12 months ''of which 2/3 occurred during the first 3 months of healing''. In this context, it must be realized that although a marked resorption of the buccal and lingual/palatal bone wall occurred during the 4 months of healing in the present study, at no site was the SLA-modified surface of the implant devoid of bone coverage.

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