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Osseointegration of dental implants installed without mechanical engagement: a histometric analysis in dogs

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Abstract

Objectives: The purpose of this study was to elucidate the healing pattern of sand-blasted, large grid, acid-etched (SLA)-surfaced implants at two healing periods in a model that represents loosened implants (LIs) installed without mechanical engagement.

Material and methods: Five mongrel dogs were used, in which 20 dental implants were prepared. The implants were divided into two groups according to the absence or presence of initial mechanical engagement: LIs and control, respectively. An oversized drill was used to prepare the implant area for the LI group. The implants were allowed to heal for 4 or 8 weeks. After the healing period, the experimental animals were sacrificed and block sections were obtained for histological analysis and histometric measurements.

Results: All implants were in intimate contact with the host bone and were without any inflammation after both 4 and 8 weeks of healing. While the mean amount of bone-to-implant contact (BIC) was constant in the control group, it tended to increase in the LI group with increasing healing period. However, neither BIC nor bone density differed significantly between the groups or with the healing period.

Conclusion: From the results of the study, it can be conjectured that the submerged and unloaded SLA-surfaced implants could result in successful osseointegration, even if the mechanical engagement was not obtained at placement of the implants.

Implant stability can be classed as either primary or secondary stability. Primary stability is defined as the stability achieved by mechanical engagement at placement of dental implants, where there is no biological union. In general, the diameter of the final drill used to prepare the implant site is slightly smaller than that of the corresponding fixture. Partial engagement of the thread into the bone produces a "press fit," which secures the wound against external loading in the initial recovery stage, until biological osseointegration is established.

The level of primary stability is associated with the condition of the host bone bed, the thread design of the implant, and the surgical techniques used (Meredith 1998). The presence of more cortical bone in the bone bed will improve the primary stability. Primary stability might also be achieved by using a self-tapping, double-thread, tapered implant fixture with appropriate thread dimensions,

even in cases of poor bone quality. Several techniques can be used to enhance bone quality, such as bone compaction by an osteotome, undersized drilling, and implant installation without pretapping, instead of standard drilling protocols (Martinez et al. 2001). Nevertheless, clinical situations are often encountered in which it is not possible to obtain mechanical engagement. In particular, poor bone quantity and quality can compromise the stability of the implant. A widened drilling socket produced by inconsistent drilling may also be responsible for rotationally loosened implants (LIs).

The importance of primary stability has been emphasized since the introduction of the concept of immediate loading (Adell et al. 1981; Sennerby et al. 1992; Meredith 1998; Szmukler-Moncler et al. 2000). However, how much mechanical engagement is required for optimal bone healing around implants has yet to be determined, and the

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effect of rigid mechanical engagement on osseointegration is controversial. Overcompression of bone may result in hyalinization of the surrounding bone during the early healing stages, which may in turn result in a delayed overall healing time for osseointegration (Ueda et al. 1991).

The vital importance of rigid primary stability of the implant to successful and predictable osseointegration has been questioned. This might be true for machined-surfaced implants, but whether this is also true for sand-blasted, large grid, acid-etched (SLA)-surfaced implants is yet unclear. In unloaded and submerged situations, the fate of the implant installed without mechanical engagement by oversized drilling has not been determined.

Several rabbit experiments evaluating rotationally mobile implants revealed favorable outcomes (Ivanoff et al. 1996; Fernandes Ede et al. 2007; Blanco et al. 2011). However, these studies have been performed at the rabbit long bone. The results cannot be applied to human clinical situations due to significant differences in the metabolism of bone healing and micro/macrostructure of bone between the two species (Roberts & Breznak 1994; Wang et al. 1998; Pearce et al. 2007). Thus, outcomes from experiments on alveolar bone in dogs would be more clinically relevant to humans.

The appropriate healing time is also important for successful osseointegration. Some studies have investigated the relationship between the initial and final stability of implants relative to healing time (Bischof et al. 2004; Nedir et al. 2004). It was found that implants with or without mechanical engagement reached a similar level of stability after the appropriate healing time. If final osseointegration of the loosened implant (LI) is achieved after a certain period of healing, the minimal healing time required for the implant to be able to bear the occlusal load should be determined.

The purpose of this study was to elucidate the healing pattern of SLA-surfaced implants at two healing periods in a model that represents LIs installed without mechanical engagement.

Material and methods

Experimental animals

Five male mongrel dogs, 18–24 months old and weighing about 30 kg, were used. All of the dogs had intact dentition and a healthy periodontium. Animal selection, management, and preparation, and the surgical proto-

cols followed routine procedures approved by the Animal Care and Use Committee, Yonsei Medical Center, Seoul, Korea.

Experimental design

The bone sites were prepared and a total of 20 SLA-surfaced implants (Implantium, Dentium, Seoul, Korea) were placed. Implants were divided into two groups according to the absence or presence of initial mechanical engagement: LI and control, respectively (Fig. 1). The implants were allowed to heal for either 4 or 8 weeks.

Surgical procedures

All surgical operations were performed under general anesthesia. The dogs received a pre-anesthetic intravenous injection of atropine (0.05 mg/kg; Kwangmyung Pharmaceutical, Seoul, Korea) and an intramuscular injection of xylazine (2 mg/kg; Rompun, Bayer Korea, Seoul, Korea) and ketamine hydrochloride (10 mg/kg; Ketalar, Yuhan, Seoul, Korea). Inhalation anesthesia was administered using 2% enflurane (Gerolan, Choongwae Pharmaceutical, Seoul, Korea). Infiltration anesthesia was administered using lidocaine (2% lidocaine hydrochloride–epinephrine 1 : 100,000; Kwangmyung Pharmaceutical). Following the extraction of all mandibular premolars and the first molar, the edentulous alveolar ridges were allowed to heal for 8 weeks. For the 8-week implant healing group, a midcrestal incision and full-thickness mucoperiosteal flap was made in the left side of the mandible. Implant osteotomy was prepared with a final drill bit that was the same size as the fixture (3.4 mm in diameter and 10 mm in length) for the LI group. The fixtures were placed manually using the fixture adaptor without mechanical engagement, and rotational and vertical mobility was confirmed by digitally applied force to the fixture adaptor which was connected to the implant. The fixture adaptor was carefully removed after the insertion of fixture. Conventional standard drilling procedures and implant placements were performed in the control group, for which the final drill bit had a diameter of 2.85 mm; the fixture sizes of the control group were the same as for the LI group. Initial mechanical engagement with the insertion torque exceeded 30 NCm was obtained. SLA-surfaced implants were placed in all cases. The flaps were sutured with a 4–0 resorbable suture material (Monosyn 4.0 Glyconate Monofilament, B. Braun, Tuttlingen, Germany), and the implants were submerged during the entire experimental period. The sutures were removed after 10 days.



Fig. 1. Schematic illustrations of the experimental design.

After 4 weeks of healing, the same procedure was repeated on the right side of the mandible. The sacrifice of all the animals was executed by anesthesia drug overdose 4 weeks after the previous procedure (i.e., 8 and 4 weeks after implanting on the left and right sides, respectively). Block sections that included segments of the implants were dissected for histological analysis.

Specimen preparation

The block sections were fixed in 10% neutral buffered formalin for 10 days. They were then dehydrated in ethanol, embedded in methacrylate, and sectioned in the buccolingual plane using a diamond saw (Exakt, Apparatebau, Norderstedt, Germany). From each implant site, the central section was reduced to a final thickness of about 20 μ m. The sections were stained with hematoxylin-eosin. Histological analysis was performed using a stereomicroscope (MZFLIII, Leica, Wetzlar, Germany) and microscope (DM-LB, Leica). After conventional microscopic examination, histometric measurements were made using an automated image-analysis system (Image-Pro Plus, Media Cybernetics, Silver Spring, MD, USA). The following parameters were measured:

- Bone-to-implant contact (BIC) within the six most coronal threads at the lingual

side of the implant, defined as the percentage of the implant zone that is in direct contact with the bone over the total length of the implant.

- Bone density (BD) within the six most coronal threads at the lingual side of the implant, defined as the percentage of bone area over the total area between the imaginary line connecting the top of the thread and the fixture lines.

Statistical analysis

In this study, descriptive data analysis was performed. The measured data are presented as mean ± SD value.

Results

Clinical findings

Surgical wound healing was uneventful during the experimental period, with no complications including wound dehiscence, severe swelling, or bleeding being observed. All implants were well maintained during the postoperative periods.

Histological findings

Light microscopic examination of all the implants demonstrated no sign of inflammation. No intervening fibrous tissue layer between any implant and the surrounding bone was observed. Most of the implant surface was in intimate contact with the host bone.

After 4 weeks of healing

In the LI group, a reversal line demarcating the drilled margin was present away from the tip of the implant thread, and the space was filled with newly formed, woven bone (Fig. 2). The coronal part of the implant was surrounded by dense cortical bone with a high BIC, while no difference in the BIC between the tip surface and the inner surface of the thread was found in the LI group. In the control group, several voids were found at the thread tip engaged to the cortical bone (Fig. 3). The apical part of the implant was present in a marrow compartment containing adipocytes, vessels, collagen fibers, and some mononuclear leukocytes, and a narrow rim of bone was apparently apposed along the implant surface (Fig. 2b). There was no notable difference between the groups at this point in the healing process.

After 8 weeks of healing

The general histological features of the LI group were similar to those of the control

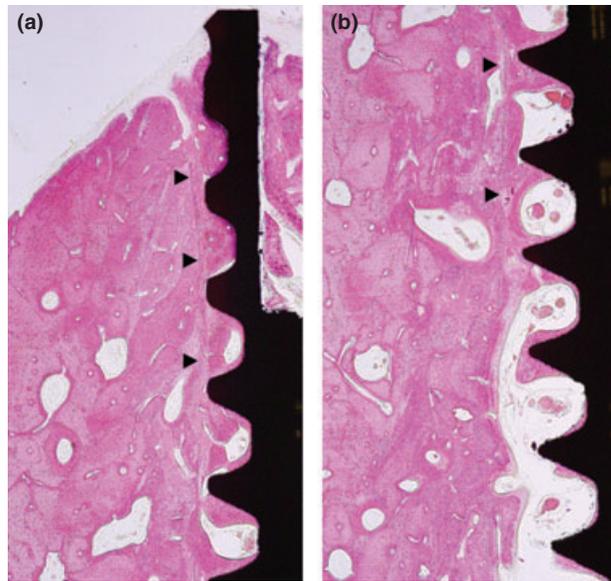


Fig. 2. Histological photomicrographs from the loosened implant (LI) group after 4 weeks of healing. (a) Coronal part of the implant (original magnification ×40). (b) Apical part of the implant (original magnification ×40). Arrow-head = reversal line demarcating the drilled margin.

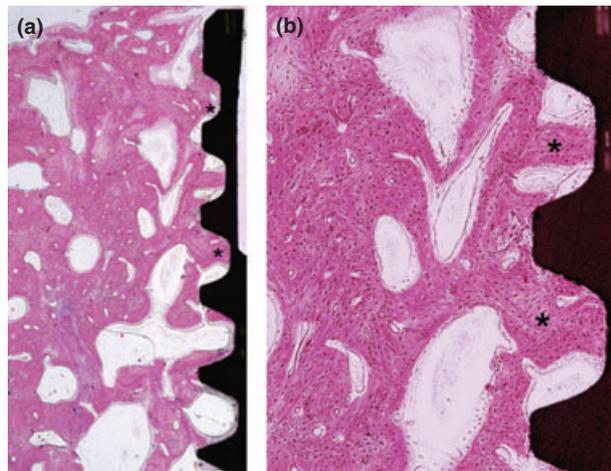


Fig. 3. Histological photomicrographs from the control group after 4 weeks of healing. (a) Coronal part of the implant (original magnification ×40). (b) Highly magnified view of the coronal part (original magnification ×100). Star = newly formed woven bone.

group (Figs 4a and 5a). The borderline of the original drilling socket, which was apparent after 4 weeks of healing, was less clear after 8 weeks in both the LI and control groups (Fig. 5a). The woven bone within the thread was partly replaced by mature lamellar bone in the 8-week groups. Many primary osteons were observed around the implants (Figs 4b and 5b).

Histometric analysis

The results of histometrical analysis of all 20 implants (N = 5) are presented in Table 1. While the mean BIC was constant in the control group, in the LI group it tended to increase with the healing time. The BD was

lower after 4 weeks than after 8 weeks of healing in both the LI and control groups.

Discussion

Oversized drilling sockets were prepared to exclude the effect of mechanical engagement during the healing process of implants in the present study. The rotationally and vertically LIs were submerged, allowing undisturbed healing. The results revealed that SLA-surfaced implant installed with no mechanical engagement could achieve successful osseointegration that was comparable with the control condition after both 4 and 8 weeks of

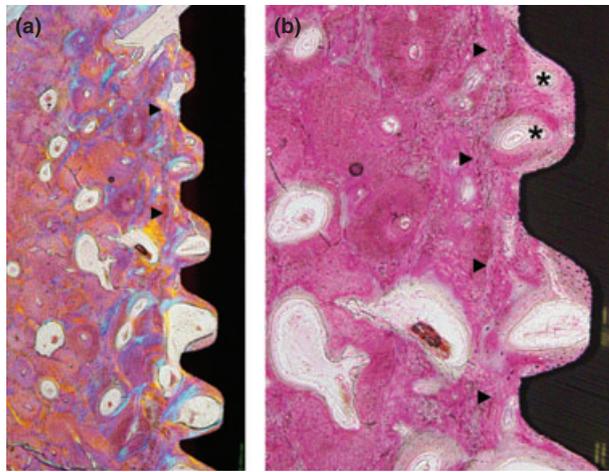


Fig. 4. Histological photomicrographs from the LI group after 8 weeks of healing. (a) Polarized photomicrograph at the coronal part of the implant (original magnification $\times 40$). (b) Highly magnified view of the coronal part (original magnification $\times 100$). Arrowhead = reversal line demarcating the drilled margin; star = primary osteon.

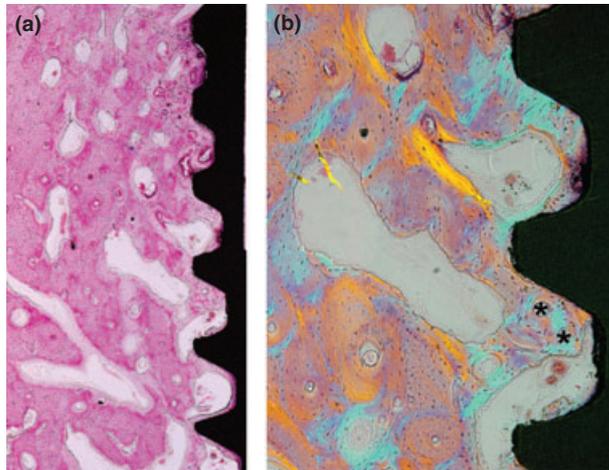


Fig. 5. Histological photomicrographs from the control group after 8 weeks of healing. (a) Coronal part of the implant (original magnification $\times 40$). (b) Polarized photomicrograph of the coronal part (original magnification $\times 100$). Arrowhead = reversal line demarcating the drilled margin; star = primary osteon.

Table 1. Histometric results for bone-to-implant contact (BIC) and bone density (BD) in the loosened implant (LI) and control groups after 4 and 8 weeks of healing

	BIC		BD	
	LI	Control	LI	Control
4 weeks	67.94 \pm 18.49	76.13 \pm 7.98	64.87 \pm 14.90	62.29 \pm 14.76
8 weeks	75.51 \pm 18.07	74.34 \pm 29.81	46.94 \pm 10.09	54.90 \pm 23.09

Data are percentages (mean \pm SD values; N = 5).

healing. The implant with mechanical engagement already exhibited a higher mean BIC value in the early phase, and maintained this BIC throughout the experimental period. On the other hand, the mean BIC value in the LI group appeared to increase gradually from 4 to 8 weeks of healing. It can be assumed that osseointegration would be obtained differently when there is no initial

mechanical engagement. The result could be extrapolated that osseointegration in LI group is made totally with the newly formed bone from the bone adjacent to implant surface. It was observed that osseointegration was still going on even at 8 weeks. Furthermore, the similar levels of BIC were acquired in both groups in 8 weeks and this period of time could be expected to be shortened by the

development of the surface modification of implant. It could be explained that compromised initial mechanical engagement was compensated by rapid biological response which is obtained by direct osseointegration at bone-implant interface during healing (Meredith et al. 1997).

Poor primary stability has been considered as one of the major causes of implant failure in machined-surfaced implants (Romanos 2004). Micromotion at the bone-implant interface may affect the bone healing process and result in fibrous encapsulation (Soballe et al. 1992; Lioubavina-Hack et al. 2006). However, SLA surfaces accelerate osseointegration and facilitate appositional bone growth at the void between the drilled socket and the body of the implant. Recent advances in surface treatment have been found to promote BIC, even where the quality of the bone is poor, making earlier loading possible (Gottfredsen et al. 1995; Wennerberg et al. 1997; Lazzara et al. 1999). In other words, optimal surface treatment produces higher and faster osseointegration.

The apical portion of the implant is placed in the medullar space, where there is little mineralized substance. Since bony contact with the apical part is very small compared to that with the coronal part, healing might be less influenced by the use of the oversized drilling protocol. In the present study, the histological features of the apical part were similar in the groups. Thus, only coronal and lingual side of implant was investigated to exclude the buccal side where various level of bone loss can occur, and to exclude the apical area where various amount of trabecular bone exists. Davies reported that de novo bone formation can occur directly on an implant with an SLA surface by contact osteogenesis (Davies 1998). In the present study, the apical part of the implant was covered by a thin bony rim projecting into the medullar space, which can be elicited by contact osteogenesis.

The main difference was seen at the coronal cortical portion, which is composed mainly of dense mineralized bone. The control group was installed using a “press fit” method, which means that the triangular thread tip is partly engaged with the dense bone via mechanical compression. However, excessive compression forces might be detrimental to bone healing (Duyck et al. 2010; Padmanabhan & Gupta 2010). It has been reported that BIC is higher in rotationally mobile implants than in those with good mechanical engagement (Fugazzotto et al. 1993; Ivanoff et al. 1996). Duyck et al. (2010)

also showed that implants with a high insertion torque were associated with greater marginal bone loss, thereby compromising implant success.

In the present study, resorption voids were observed at the thread tip area in the cortical part of the implant in the control group, while there were no such voids in the LI group. It has been reported that bone resorption can initially take place at compressed areas before new bone is formed (Berglundh et al. 2003; Slaets et al. 2006). In noncontact areas, bone can be formed immediately without a resorption process, thereby allowing faster osseointegration.

The submerged and unloaded implant model was used in this study. This would

prevent the LI group from micro and macro movement during initial healing period, as they were not loaded postoperatively. The importance of an initial postsurgical healing without loading stress in the unstable implants has been demonstrated by the previous reports (Uthoff 1973; Ivanoff et al. 1996). In the present study, a torque rigid enough to tighten the abutment for loading could not be applied to the screw due to the rotational and vertical movement of implants in the LI group.

There are a few limitations in the present study. The sample size is quite small to show the statistical power. Further comparative studies with larger sample size should be

conducted so as to increase the scientific and statistical power.

From the results of the study, it can be conjectured that the submerged and unloaded SLA-surfaced implants could result in successful osseointegration, even if the mechanical engagement was not obtained at placement of the implants.

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