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The biocompatibility of SLA-treated titanium implants

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Abstract
The titanium implant surface was sandblasted with large grits and acid etched (SLA) to increase the implant surface for osseointegration. The topography of the titanium surface was investigated with scanning electron microscopy (SEM) and a profilometer. The SLA implant demonstrated uniform small micro pits (1–2 μm in diameter). The values of average roughness (R_a) and maximum height (R_t) were 1.19 μm and 10.53 μm respectively after sandblasting and the acid-etching treatment. In the cell–surface interaction study, the human osteoblast cells grew well *in vitro*. The *in vivo* evaluation of the SLA implant placed in rabbit tibia showed good bone-to-implant contact (BIC) with a mean value of 29% in total length of the implant. In the short-term clinical study, SLA implants demonstrated good clinical performance, maintaining good crestal bone height.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Commercially pure titanium (CP-Ti) and titanium alloys are frequently used as dental and orthopedic implant materials because of their excellent mechanical strength, chemical stability and biocompatibility [1]. The biocompatibility of titanium is closely related to the surface properties such as surface roughness, surface topography and surface chemistry [2]. The most widely used commercial techniques for the surface treatment are sandblasting and acid etching (SLA), and plasma spray coating of hydroxyapatite [3–7]. Electron beam evaporation of calcium phosphate is another recent development [8, 9].

Air-particle abrasion with TiO_2 and Al_2O_3 particles can increase the roughness and irregularity of the surface. Recently, resorbable blast media (RBM) such as hydroxyapatite and calcium phosphate have been commercially used for Swissplus® and Restore®. Wennerberg reported that the optimal size of blasting media is 75 μm for alumina particle *in vivo* study [10]. Acid etching is also a useful technique to modify the Ti surface. It can create regular micro pits in the range of micron to sub-micron size. OSSEOTITE® is a typical example of the double acid-etching method applied on the machined surface [11]. The SLA technique combines the advantages of both sandblasting and acid-etching methods to obtain macro-roughness and micro pits. Straumann's implant surface became the gold standard for the SLA technique; 250–500 μm alumina particles were used as blasting media, followed by acid etching in HCl/H_2SO_4 solution. It resulted in an average roughness value (R_a) of 1.5 μm [6].

Since there is a lack of systematic studies on the SLA implant surface, the aim of this study is to investigate the efficacy of the newly developed SLA surface treatment technique. It was conducted through an *in vitro* cell–surface

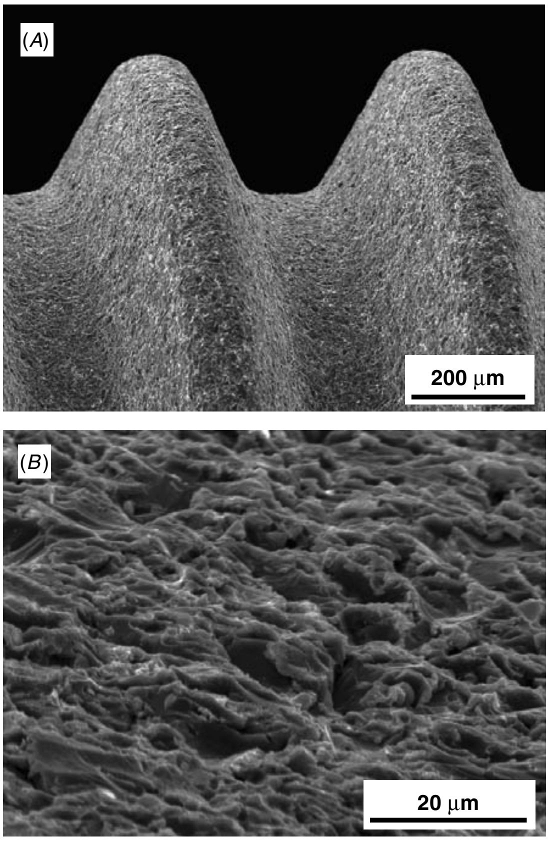

Figure 1. SEM topography of sandblasted Ti implant.

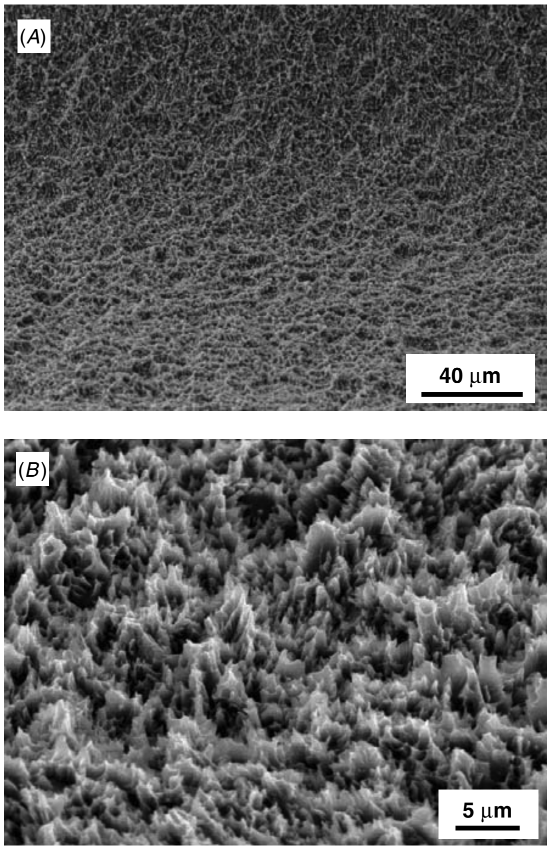

Figure 2. SEM topography of SLA surface.

interaction experiment, animal tests and a clinical evaluation of the alveolar crestal bone loss in humans.

2. Materials and methods

2.1. Surface characterization

Ti specimens (grade IV) were treated by sandblasting using alumina particles and washed in an ultrasonic ultra-pure water bath and dried. The sandblasted Ti specimens were further etched by warm hydrochloric acid, and rinsed and cleaned by the ultrasonicating method in ultra-pure water, and dried. The surface morphology was investigated using scanning electron microscopy (SEM; VEGA II LSH, TESCAN, Brno, Czech Republic). The treated surface was analyzed with an energy-dispersive spectroscope (EDS) incorporated in the SEM. The surface roughness was measured using a contact profilometer (SURFPAK-SV, Mitutoyo, Hiroshima, Japan). Two parameters, the average roughness (R_a) and the maximum peak-to-valley height of the surface (R_t), were used to characterize the roughness.

2.2. Biological evaluation

The biological behavior of the specimens was evaluated through the *in vitro* cell–surface interaction and *in vivo* animal tests with rabbits.

2.2.1. Cell–surface interaction. The morphology of the cells after seven-day culture was observed with the SEM after fixation with 2.5% glutaraldehyde, dehydration with graded ethanols (70, 90 and 100%), and critical point drying using CO_2.

2.2.2. Animal study. The animal tests were carried out using screw-shaped Ti implants with dimensions of 4.0 mm in length, 3.4 mm in diameter and 0.75 mm in pitch height. The implants were sandblasted and then acid etched. New Zealand white rabbits (male), weighing 3.0–3.5 kg and aged from 9 to 10 months, were used for the tests. After general anesthesia, implants were placed in each proximal tibial metaphysis. After a healing period of four weeks, the rabbits were sacrificed and bone blocks were obtained with a diamond saw. The block specimens with implants were immersed in formalin solution. After dehydration, the specimens were cut into undecalcified sections of ~400 μm in thickness. The sections were glued to a slide glass and ground to a final thickness of 15 μm, and stained with H&E. The histological morphology was observed using optical microscopy and the contact ratio of bone to implant (BIC) was calculated.

2.3. Clinical study

In the period from October 2004 to October 2005, a total of 52 patients (19 men, 33 women) were included in the

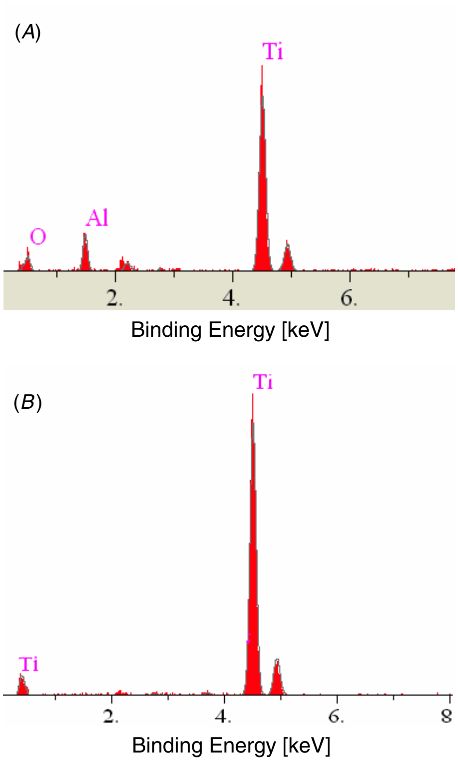

Figure 3. Energy-dispersive x-ray spectroscopy of (*A*) the sandblasted only and (*B*) the sandblasted and acid-etched surface (SLA).

study at Yonsei University, Korea. A total of 164 SLA implants (Dentium Co. Ltd, Suwon, Korea) were surgically placed following manufacturer's guidelines. The diameter of implants was in the range from 3.4 mm to 4.8 mm and the length was in the range of 8–14 mm. The marginal bone loss around implants was measured from radiographs taken with a standardized guiding device. The average evaluation period was 15.2 months.

3. Results

3.1. Surface characterization

The surface morphologies of the sandblasted Ti implant are shown in figure 1. After sandblasting, the surface became rough and irregular, and small holes were observed under high magnification (figure 1(*B*)). Further, the acid-etching treatment developed more uniform small micro pits (1–2 μm in diameter) on the sandblasted surface as shown in figures 2(*A*) and (*B*). The sharp edge of each peak was clearly observed. The aluminum element was detected on the sandblasted surface as shown in figure 3(*A*). However, traces of aluminum were not detected on the SLA surface under energy-dispersive x-ray spectroscopy (EDS) analysis (figure 3(*B*)).

Table 1 compares the roughness values of specimens subjected to sandblasting only with the samples treated with the SLA technique. The values of average roughness (R_a) and maximum height (R_t) of the sandblasted samples were 1.35 and 12.3 μm, respectively. However, the values of both R_a and R_t were decreased to 1.19 μm and 10.53 μm respectively after the subsequent acid-etching treatment.

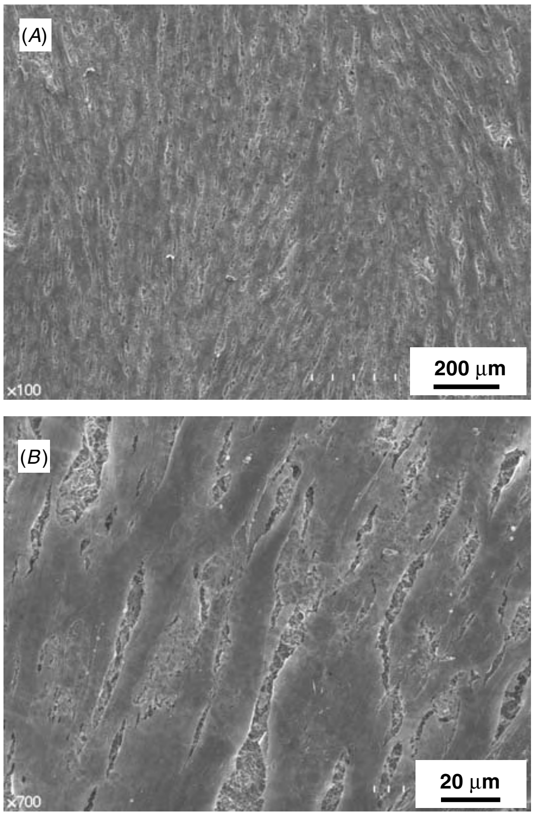

Figure 4. SEM image of human osteoblasts on the SLA surface after seven days of incubation at different magnification. (*A*) ×100, (*B*) ×700.

Table 1. Roughness values of sandblasted only and SLA surface.

	R_a (μm)	R_t (μm)
Sandblasting	1.35 ± 0.02	12.30 ± 1.36
SLA	1.19 ± 0.04	10.53 ± 0.72

3.2. Biological evaluation

Figure 4 shows the morphologies of human osteoblast cells grown on the SLA surface after seven days of incubation, and indicates that cells were adhered and spread well over the surface. The *in vivo* evaluation of the animal testing was performed by measuring the percentage of bone-to-implant contact (BIC). The mean value was 29% in the total length of the implant surface. Figure 5 depicts the histological image of new bone formation over the implant surface. Moreover, the bone grew down along the implant surface from the cortical bone to the apex as shown in figure 6.

3.3. Clinical study

The average marginal bone loss of 164 implants was 0.28 mm over an average observation period of 15.2 months. The

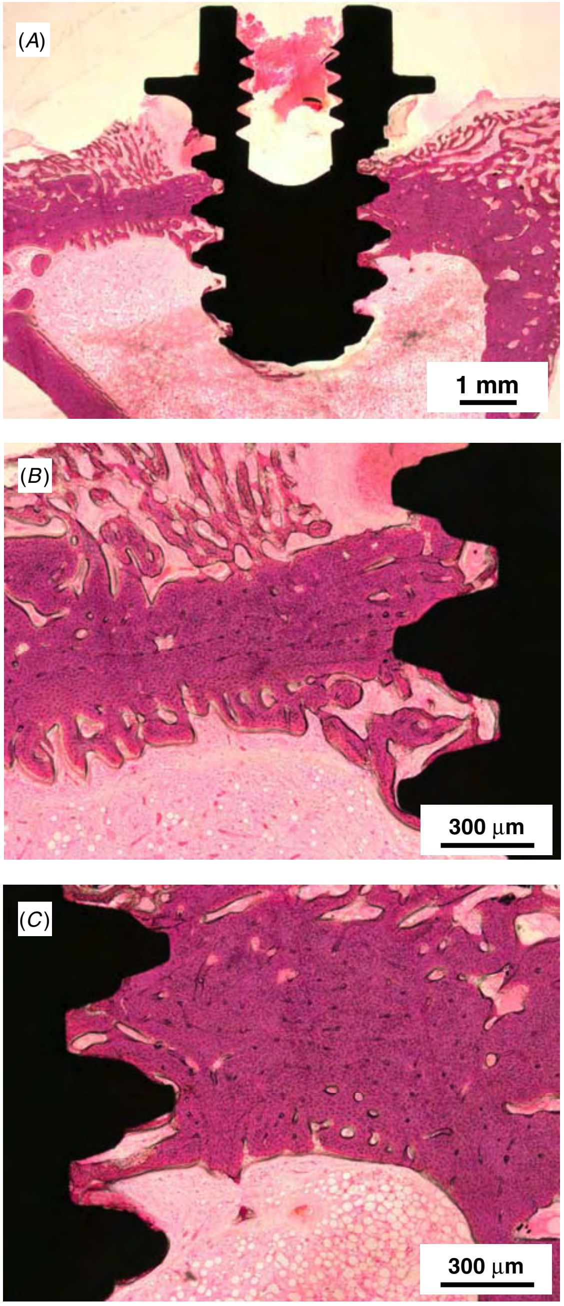

Figure 5. Histological image of new bone apposition over the implant surface at four weeks.

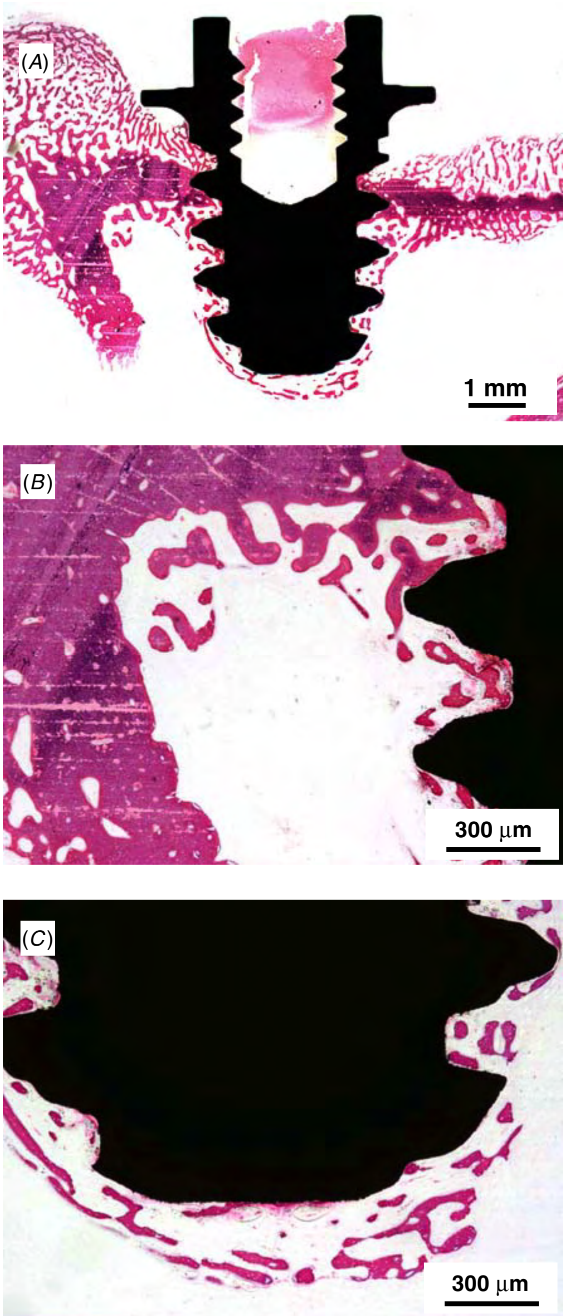

Figure 6. Bone formation along the SLA surface from the cortical bone to the apex.

maximum marginal bone loss out of the total 164 implants was less than 1 mm. Figure 7 shows two cases which did not lose marginal bone after one year of loading. Two of the implants, placed in a narrow crestal bone, were removed due to bone resorption.

4. Discussion

The purpose of this study was to characterize the SLA implant surface systematically. The sandblasting procedure left the macro-roughness value of the Ti-implant surface within the optimal range of 1.0–2.0 μm [12]. It was followed by the acid-etching treatment, which produced smaller pits at the sub-micron to micron level. The size of the pits depended on the treatment methods. Acid etching also cleaned the Ti-implant surface of the remaining air-abrasive particles (figure 3).

The surface properties of macro-roughness, micro pits and cleanness of the Ti implant are very important for the osseointegration [10]. The roughness value is dependent upon sandblasting factors such as blasting material, particle

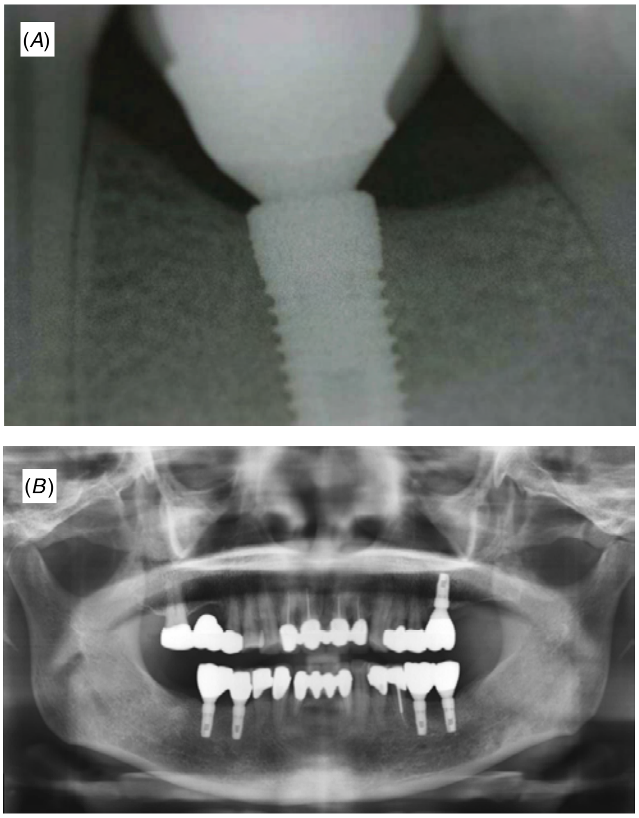

Figure 7. Clinical radiography after one year of loading. (*A*) Single case and (*B*) multiple cases.

size, blasting pressure, etc. After acid etching, the surface morphology (figure 2) has undergone a complete change from figure 1. The micro pits and sharp peaks formed on the SLA surface increased the surface area, and benefited osteoblast proliferation and bone formation [3–6].

The Ti-implant surface treated with the newly developed SLA procedure showed good biological properties. The human osteoblast cells grew very well on the SLA surface, indicating that it provided a favorable surface for cell attachment and proliferation. In the animal study, new bone formed around nearly the entire cortical bone of the tibia (figure 5). Furthermore, the bone formation continued along the implant surface to the portion of hollowed tibia bone, and to the apex of the implant (bone marrow region, figure 6). This indicated that the SLA surface had good biocompatibility and bone forming ability. The surface topography of the SLA implant in this study demonstrated a slightly higher sharpness and a lower roughness value than the Straumnn's SLA implant [6].

Based on the short-term clinical results, the SLA implants used in this study showed an excellent survival rate regardless of bone quality and quantity. A total of 164 implants (19 anterior, 145 posterior) were surgically placed in 52 patients. Seventy five implants were located in the maxilla and 89 implants in the mandible. In regard to marginal bone loss of the implants over a period of 15.2 months, the average value was 0.28 mm, significantly lower than average values reported in the literature [13–23].

5. Conclusions

The surface treated by sandblasting and then acid etching (SLA) had beneficial effects on the biocompatibility and bone formation around the Ti implant. Although there was a slight decrease in the roughness value after the acid-etching treatment following sandblasting, it developed more uniform small micro pits (1–2 μm in diameter) and sharp-edged peaks on the sandblasted surface.

The SLA surface showed good biocompatibility with both *in vitro* cell response and *in vivo* animal study. Based on the short-term clinical results, the SLA implant used in this study showed an excellent survival rate (98.7%) with an average marginal bone loss of 0.28 mm over a period of 15.2 months. A long-term clinical study is required in future work.

Acknowledgments

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References

[1] Brunette D M, Tengvall P, Textor M and Thomsen P 2001 *Titanium in Medicine* (Berlin: Springer)
[2] Boyan B D, Hummert T W, Dean D D and Schwartz Z 1996 *Biomaterials* **17** 137
[3] Li D, Ferguson S J, Beutler T, Cochran D L, Sittig C, Hirt H P and Buser D 2002 *J. Biomed. Mater. Res.* **60** 325
[4] Buser D, Broggini N, Wieland M, Schenk R K, Denzer A J, Cochran D L, Hoffmann B, Lusi A and Steinemann S G 2004 *J. Dent. Res.* **83** 529
[5] Buser D, Nydegger T, Oxland T, Cochran D L, Schenk R K, Hirt H P, Snétivy D and Nolte L P 1999 *J. Biomed. Mater. Res.* **45** 75
[6] Szmukler-Moncler S, Perrin D, Ahossi V, Magnin G and Bernard J P 2004 *J. Biomed. Mater. Res. Part B: Appl. Biomater.* **68B** 149
[7] de Groot K, Geesink R, Klein C P A T and Serekian P 1987 *J. Biomed. Mater. Res.* **21** 1375
[8] Lee I-S, Kim D-H, Kim H-E, Jung Y-C and Han C-H 2002 *Biomaterials* **23** 609
[9] Lee I-S, Zhao B-H, Lee G-H, Choi S-H and Chung S-M 2007 *Surf. Coat. Technol.* **201** 5132
[10] Wennerberg A 1998 *Int. J. Mach. Tools Manuf.* **38** 657
[11] Park J Y and Davies J E 2000 *Clin. Oral Implants Res.* **11** 530
[12] Wennerberg A and Albrektsson T 2006 *Appl. Osseointegrat. Res.* **5** 40
[13] Palmer R M, Smith B J, Palmer P J and Floyd P D 1997 *Clin. Oral Implants Res.* **8** 173
[14] Quirynem M, Naert I and van Steenberghe D 1992 *Clin. Oral Implants Res.* **3** 104
[15] Sennerby L, Rocci A, Becker W, Jonsson L, Johansson L A and Albrektsson T 2008 *Clin. Oral Implants Res.* **19** 219
[16] Turkyilmaz I, Sennerby L, Tumer C, Yenigul M and Avci M 2006 *Clin. Oral Implants Res.* **17** 501
[17] Zarone F, Sorrentino R, Vaccaro F and Russo S 2006 *Clin. Oral Implants Res.* **17** 94

[18] Renouard F and Nisand D 2005 *Clin. Implant Dent. Relat. Res.* **7** S104
[19] Maló P, Rangert B and Nobre M 2005 *Clin. Implant Dent. Relat. Res.* **7** S88
[20] Glauser R, Ruhstaller P, Windisch S, Zembic A, Lundgren A, Gottlow J and Hämmerle C H 2005 *Clin. Implant Dent. Relat. Res.* **7** S52
[21] Testori T, Meltzer A, Fabbro M D, Zuffetti F, Troiano M, Francetti L and Weintein R L 2004 *Clin. Oral Implants Res.* **15** 278
[22] Proussaefs P and Lozada J 2004 *J. Prosthet. Dent.* **91** 228
[23] Makkonen T A, Holmberg S, Niemi L, Olsson C, Tammisalo T and Peltola J 1997 *Clin. Oral Implants Res.* **8** 469