An Experimental Comparison of Two Different Clinically Used Implant Designs and Surfaces

Jan Gottlow, DDS, PhD;* Sargon Barkamo, DDS;† Lars Sennerby, DDS, PhD‡

ABSTRACT

Background: Various designs of dental implants representing different geometries and surface technologies are commercially available and clinically used in patients. However, data with regard to bone tissue responses and stability for comparison of their biologic performances are rare.

Purpose: The aim of the present experimental investigation was to compare the bone tissue responses and implant stability between two commonly used dental implants representing different geometries and surface characteristics.

Materials and Methods: A total of 90 dental implants (4.3 mm in diameter, 10 mm long) with an oxidized surface (Replace Select Tapered, TiUnite, Nobel Biocare AB, Gothenburg, Sweden) (OX) and 90 implants (4.1 mm in diameter, 10 mm total length) with a hydrophilic sand-blasted and acid etched surface (Standard Plus, SLActive, Institut Straumann AG, Basel, Switzerland) (HSBA) were placed in the distal femur ($n = 1$) and tibia ($n = 2$) of 30 rabbits. The implants were analyzed with implant stability quotient (ISQ) measurements, removal torque (RTQ) and histomorphometry (bone–implant contact, BIC) after 10 days, 3, and 6 weeks. Moreover, RTQ values were corrected for differences in surface area by calculating the shear strength for each implant.

Results: RTQ and ISQ measurements showed an increase with time for both implant types. A significantly higher RTQ value was observed for the HSBA implant at 3 weeks ($p = .05$). A lower ISQ value was seen for HSBA than for OX implants at placement in the tibia ($p < 0.001$). HSBA implants showed higher shear strength values than OX implants after 3 weeks ($p < .001$), and 6 weeks ($p < .01$). The morphometric measurements showed significantly higher BIC for HSBA implants after 10 days ($p < .01$), similar values after 3 weeks and significantly higher BIC for OX implants after 6 weeks ($p < .001$).

Conclusions: Both HSBA and OX implants were well integrated in bone and showed firm and increased stability from placement to after 6 weeks of healing. The HSBA implant showed more BIC after 10 days and the OX implant more BIC after 6 weeks of healing. The HSBA implant showed significantly higher shear strength after 3 and 6 weeks and higher RTQ values after 3 weeks than the OX implant. The results may be due to differences in surface roughness and hydrophilic properties.

KEY WORDS: anodic oxidation, dental implant, histology, hydrophilicity, removal torque, resonance frequency analysis, titanium

INTRODUCTION

Various designs of dental implants representing different geometries and surface technologies are used in patients on a daily basis. The vast majority of implants are solid parallel-walled or tapered screws with threads and with some kind of surface modification.[1] Different technologies, including grit-blasting, acid-etching, anodic oxidation, coating, or combinations of techniques have been used to change the surface topography in an attempt to improve implant fixation with bone. The most recent generation of dental implant surfaces have been modified by chemical/physical treatments and nanotechnology in order to further improve the bone integration process.[2] Previous work has shown that the macro-design may influence the primary stability of the implant after surgical placement, at least in low-density bone.[3] Studies have also demonstrated different

*Researcher, Department of Biomaterials, Institute for Surgical Sciences, Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden; †research student, Department of Biomaterials, Institute for Surgical Sciences, Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden; ‡professor, Department of Oral & Maxillofacial Surgery, Institute for Odontology, Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden

Reprint requests: Dr. Jan Gottlow, Department of Biomaterials, Gothenburg University, PO Box 412, SE 405 30 Gothenburg, Sweden; e-mail: jan.gottlow@telia.com

DOI 10.1111/j.1708-8208.2012.00439.x

pathways of implant integration depending on surface characteristics. It is generally anticipated that minimally rough, "as machined", surfaces are integrated by distance osteogenesis, meaning that newly formed bone approaches the implant surface with time, whilst moderately rough surfaces often show contact osteogenesis, that is, bone formation by newly differentiated osteoblasts directly to the surface.[4,5]

Nobel Biocare Replace Select and Straumann implants are widely used for prosthetic reconstruction of the edentulous patient. They represent two different geometries and surface technologies, as the former implant is a tapered screw with an oxidized surface and the latter is cylindrical with a few threads and a chemically treated sand-blasted and acid etched (SLActive) surface, which is hydrophilic. Experimental studies have shown stronger bone responses to oxidized surfaces than to machined implants.[6–8] Similarly, in vitro and in vivo work have shown biological advantages with the hydrophilic SLActive surface as compared with non-hydrophilic control surfaces.[9–13] Clinical follow-up studies have reported good short-term clinical outcomes for both implant types.[14–18] However, to the knowledge of the present authors, no thorough comparisons of the two implants have been made with regard to bone tissue responses and implant stability.

The aim of the present animal study was to compare the bone tissue responses and implant stability of two principally different implant designs and surfaces after 10 days, 3 and 6 weeks of healing.

MATERIALS AND METHODS

Animals and anesthesia

The ethics committee for animal research at Malmö University, Sweden approved the study. A total of 30 adult loop-eared rabbits of both sexes weighing from 4 to 5.5 kg were used in the study. The animals were kept in double cages and were fed *ad libitum* with water and standard laboratory animal diet. General anesthesia was induced via intravenous injections of ketamin (Ketalar Vet, Pfizer AB, Sollentuna, Sweden, 50 mg/mL, 0.35 mL/kgbw) and metetomidin (Dormitor Vet, Orion Pharma, Espoo, Finland, 1 mg/mL, 0.15 mL/kgbw). Local anesthesia was induced with 1 mL of lidocain/epinephrine solution per site (Xylocain Dental adrenalin 20 mg/mL + 12.5 mg/mL, Astra AB, Södertälje, Sweden). Postoperatively, the animals were given analgetics (buprenorfin, Temgesic, Schering-Plough AB, Stockholm, Sweden, 0.3 mg/mL, 0.3 mL/animal) and antibiotics (streptomycin/bensylpenicillin, Streptocillin vet, Boehringer Ingelheim Vetmedica, Malmö, Sweden, 250 mg/mL + 200 mg/mL, 1 mL/animal) for 3 days.

Implants

A total of 90 dental implants (4.3 mm in diameter, 10 mm long including the machined surfaced neck/collar) with an oxidized surface (Replace Select Tapered, TiUnite, Nobel Biocare AB, Gothenburg, Sweden; OX) and 90 implants (4.1 mm in diameter, 10 mm long including the machined surfaced neck/collar) with a hydrophilic sand-blasted and acid etched surface (Standard Plus, SLActive, Institute Straumann AG, Basel, Switzerland; HSBA) were used in the study (Figure 1A and B).

Surgery and experimental protocol

Surgery was made under sterile conditions. The tibial methaphysis and the distal femoral condyle of both legs were used as experimental sites and assigned to test and control implants using a rotational scheme. The sites were exposed via a 3-cm-long incision through skin and underlying fascia and periosteum. For each side, three implant sites were prepared according to the guidelines from the manufacturers, one in the femoral condyle and

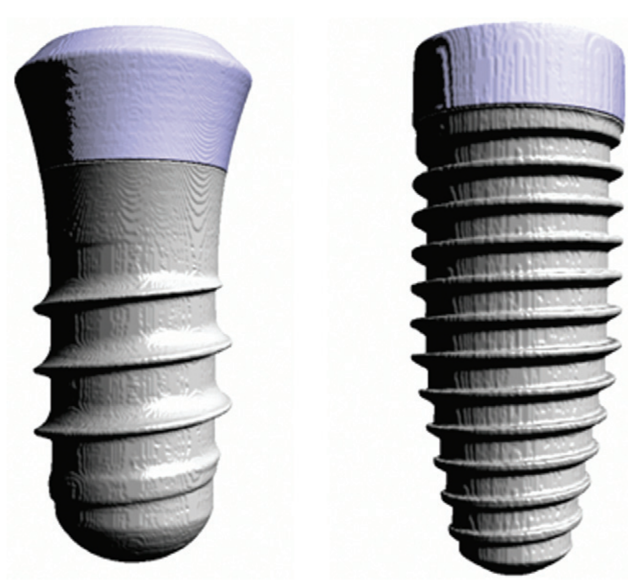

Figure 1 Implants used in the study. *A*, Straumann SLActive implant (HBSA). *B*, Nobel Biocare Replace Select implant with TiUnite surface (OX).

two in the tibial metaphysis. No countersinking was performed. The implants were inserted by motor (set torque of 30 Ncm and a maximal speed of 35 rpm during irrigation with sterile saline solution. The machined surfaced neck/collar of the implants were positioned supracrestally. All implants were subjected to ISQ measurements using specially designed Smartpegs™ and a Mentor™ instrument (Osstell AB, Göteborg, Sweden). Measurements were made perpendicular and parallel to the tibia. Thus, two measurements were registered for each implant. Cover screws where applied to the implants. The wounds were sutured with resorbable sutures in separate layers.

Termination of the experiment

Three groups of 10 animals were sacrificed after 10 days, 3 weeks, and 6 weeks by an overdose of pentobarbital (Pentobarbitalnatrium, Apoteket AB; Stockholm, Sweden, 60 mg/mL).

The implant sites were immediately excised and all implants were subjected to ISQ measurements. The proximal implant in each tibia was then subjected to a removal torque (RTQ) test using a specially designed rig consisting of an electrical torque transducer and a torsion rod. The rod was connected to the implants after connection of fixture mounts (control) or an implant driver (test). An electric motor ramped the torque to a maximum value, which was registered and stored by a microprocessor. At the point of interfacial failure between the bone and the implant, the peak force dropped and a slight rotational movement of the implants was observed. Mean ISQ and RTQ values were calculated for each implant type and time point.

The implants and surrounding bone tissue were fixated by immersion in 4% buffered formaldehyde for production of histological ground sections.

Normalization of removal torque values by implant design

One implant of each design was subjected to a micro-CT procedure in order to provide with a 3D model, wherein the total surface area of the implant submerged in bone and the mean distance between the implant axis and the implant surface (mean radius) could be calculated (Scanco μCT 40, Bruettisellen, Switzerland). Surface area of 107 mm^2 for HSBA and 158 mm^2 for OX implants and a mean radius of 1.95 mm for HSBA and 1.85 mm for OX were revealed.

Each RTQ value (Ncm) was divided with the mean radius. The resulting shear force values (N) were normalized over the calculated surface area of the specific implant and displayed as shear strength values (N/mm^2).

Histology

The fixated bone–implant biopsies were dehydrated in a graded series of alcohol and then embedded in a light-curing plastic resin (Technovit 7200 VCL, Kulzer, Friedrichsdorf, Germany). The plastic blocks were sectioned using a sawing and grinding technique (Exact Apparatebau, Norderstedt, Germany). One cross-section per biopsy was taken perpendicular to the long axis of the tibia (Figure 2) and femur (Figure 3) and stained with toluidine blue and 1% pyronin-G.

Computer-assisted histometric measurements were obtained using a semi-automated image analysis system

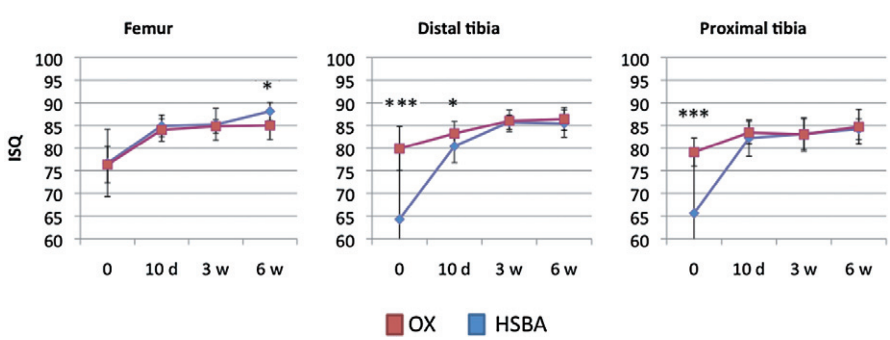

Figure 2 Graphs showing results from ISQ measurements (±S.D) at placement, 10 days, 3 and 6 weeks for HSBA and OX implants placed in femoral and in distal and proximal tibial sites. *** $p < .001$, * $p < .05$.

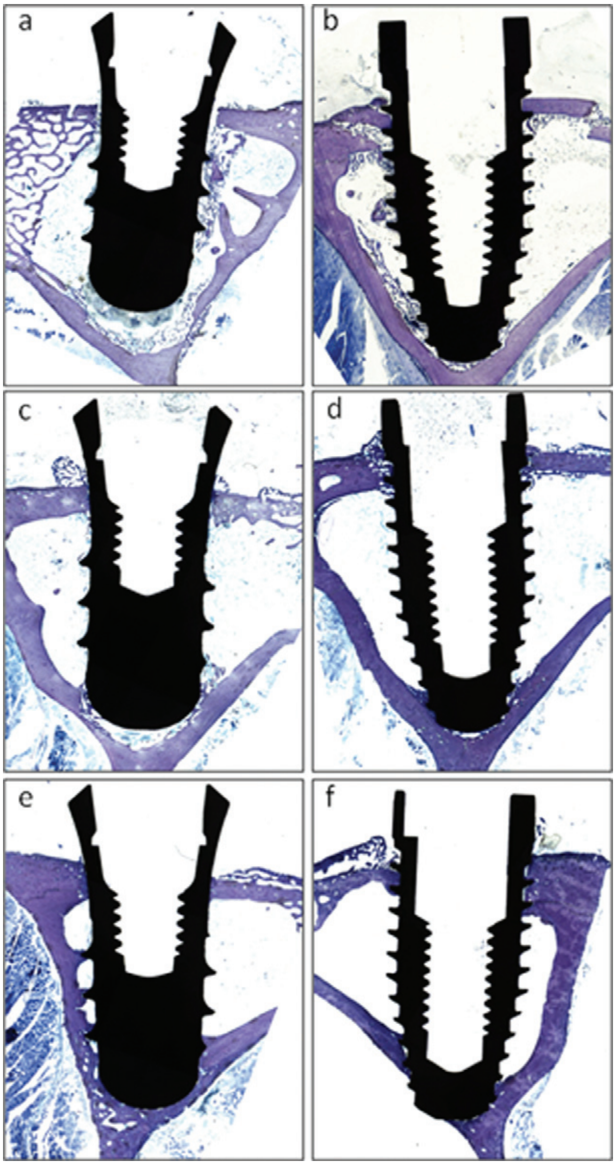

Figure 3 Light micrographs of HBSA and OX implants in the tibia after 10 days (A and B), 3 weeks (C and D), and after 6 weeks (E and F).

(VisioMorph – Visiopharm Integrator System®, Visiopharm, Hørsholm, Denmark), coupled with a video camera (Nikon Digital Sight DS-5Mc) mounted on a light microscope (Nikon Eclipse 90i). Digital pictures of all 180 implants were taken with 10× magnification. The contour of the implants was defined automatically. All pictures were checked one by one for successful segmentation and corrected when necessary. The lengths of the implant/bone and the implant/non-bone interface were measured by the software in order to calculate a bone–implant contact (BIC) ratio in percent. All data were automatically saved in a spreadsheet. The examiner was masked relative to the temporal aspect of the study.

Statistical analyses

Comparisons between implant types by endpoint were performed using the Wilcoxon signed-rank test, a non-parametric test for paired data.

Multiple regression mixed models were used to determine the effect of implant type on the different outcomes, adjusting for factors side, position and endpoint. Mixed-model regression provides the required covariance structures to correct for additional sources of variability and correlation such as repeated measurements in the same experimental unit or experimental units in which the data are grouped into clusters. The calculated effect sizes were adjusted for multiple comparisons using Dunnett-Hsu's correction. All analyses were performed using SAS, release 9.2 (SAS Institute Inc., Cary, NC, USA). p values < 0.05 were considered significant.

RESULTS

ISQ measurements

The ISQ measurements showed an increase of stability for both implant types from placement to 6 weeks (Figure 2). The HSBA implants in the proximal and in the distal tibia sites showed a lower primary stability than the corresponding OX implants ($p < .001$). The HSBA implants had a lower ISQ value after 10 days in the distal tibia ($p < .05$). At 6 weeks, the HSBA implants in the femur were more stable than OX implants ($p < .05$).

Histology

The histological examination revealed bone formation directly on the surface of both implant types (Figures 3A–F and 4A–F). The morphometric measurements showed significant more BICs for HSBA implants after 10 days ($p < .01$), similar values after 3 weeks and significant more BIC for OX implants after 6 weeks ($p < .001$; Table 1).

Removal torque

Removal torque measurements showed an increase with time for both implant types and a significant difference ($p = .05$) at 3 weeks in favor of the HSBA implant (Figure 5). The values were 30.9 and 29.1

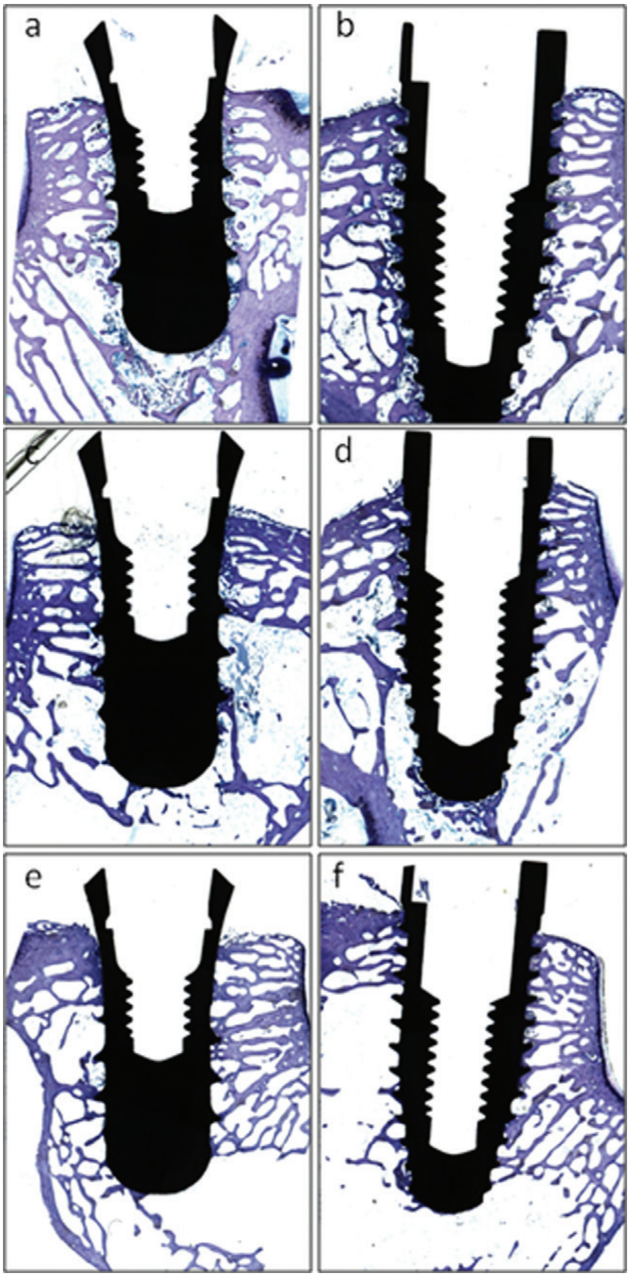

Figure 4 Light micrographs of HBSA and OX implants in the femur after 10 days (A and B), 3 weeks (C and D), and after 6 weeks (E and F).

(95% CI 7.8) Ncm, respectively, after 10 days, 75.6 and 94.7 (95% CI 14.4) Ncm after 3 weeks, and 93.7 and 102.5 (95% CI 18.6) Ncm after 6 weeks for OX and HSBA implants, respectively.

Normalization of removal torque values by implant design

Shear strength values, displayed as shear force normalized by implant area, showed significant higher values for HSBA implants at 3 weeks ($p < .001$): 4.54 versus 2.55 (95% CI 0.57) N/mm^2 and 6 weeks ($p < .01$) 4.91 versus 3.20 (95% CI 0.76) N/mm^2. No significant difference was observed after 10 days HSBA 1.39 and OX 1.06 (95% CI 0.35) N/mm^2 (Figure 6).

DISCUSSION

The present experimental study was designed to histologically and biomechanically compare two commonly used dental titanium implants. This may seem problematic from a scientific point of view, since many variables are different when comparing the two implant types. Thus, the effect of one factor only, such as a surface property (roughness, hydrophilicity etc) or implant design (diameter, thread pitch etc), could not be isolated and compared when using the present experimental design. However, in light of the many controlled experimental studies on different implant surfaces and designs that have been published so far,[1,2,4,6–13] the purpose of the present study was instead to compare the two implants when used as in the clinical setting. If assuming that resistance to reverse torque and lateral stability are determinants of successful clinical function, then the actual removal torque and ISQ values ought to be relevant for comparison irrespective of the contribution of each isolated factor. Moreover, in strictly controlled experimental situations, it may also be difficult to

TABLE 1 Results from Histomorphometric Measurements. Relationship between Measured Outcomes (BIC) and Implant Type with Mean Values Adjusted for the Effect of Animal, Side, and Implant Position ($N = 60$). Significant Differences Marked with (*)

Measure Outcome	Endpoint	Implant Type	Adjusted mean (95%CI)	Dunnett-Hsu p Value
BIC (%)	10 days	HSBA	63.1 (58.7 to 67.5)	0.002*
		OX	53.1 (48.7 to 57.5)	
	3 weeks	HSBA	45.5 (41.8 to 49.1)	0.937
		OX	45.7 (42.0 to 49.3)	
	6 weeks	HSBA	33.9 (30.3 to 37.6)	<0.001*
		OX	44.4 (40.8 to 48.1)	

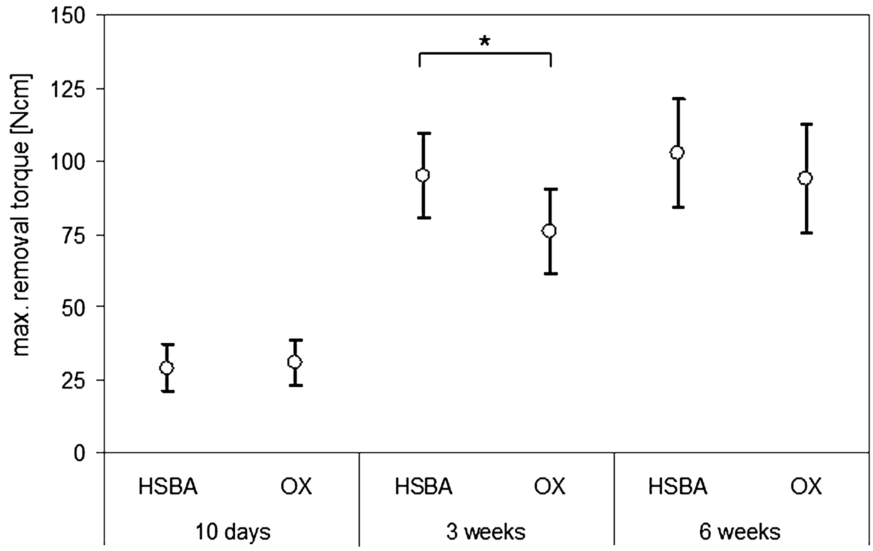

Figure 5 Removal torque values (RTV) displayed as mean values adjusted for the effect of animal, side, and position (multivariate analysis). Error bars: 95% confident interval. Significance levels * $p = .05$ (Dunnett-Hsu).

change one parameter at the time, since, for instance, chemical surface treatment may alter surface topography.[19]

The histological examination revealed bone formation directly on the surface of both implant types, that is, contact osteogenesis.[4,5] The morphometric measurements showed some differences, possibly attributed to the different topographies and/or chemical/physical properties. For instance, more BICs were found for HSBA implants after 10 days, which is in line with previous experimental studies using a non-hydrophilic implants as control.[9–11,13] The findings may be explained by the hydrophilicity and the ability of attracting and binding blood to the surface at an early stage. It has been speculated that contact osteogenesis can be explained by the formation of a stable blood clot at the tissue-implant interface and that the fibrin network serves as a scaffold for migration of osteopotent cells to the interface.[4,5] It is also likely that the possible effect of hydrophilicity is seen during the early healing period but not at later

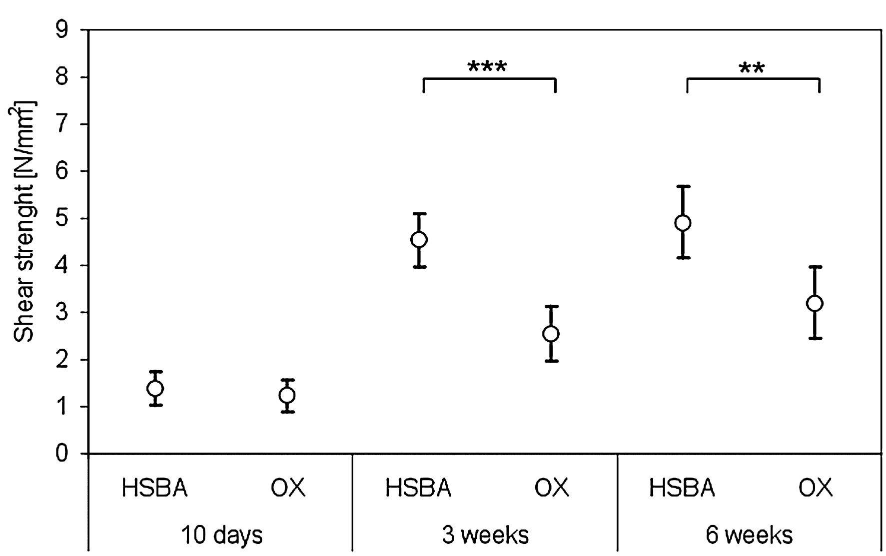

Figure 6 Shear strength values displayed as shear force normalized by surface area. Mean values adjusted for the effect of animal, side, and position (multivariate analysis). Error bars: 95% confident interval. Significance levels ** $p < .01$, *** $p < .001$ (Dunnett-Hsu).

stages, which may explain why similar BICs were seen after 3 weeks. Significantly more BICs were seen for OX implants after 6 weeks and it is possible that this was due to other surface characteristics. For instance, anodic oxidation results in thickening of the native oxide layer and a porous surface structure.[20] However, the outcome of the integration process is multifactorial and other explanation models do apply, for instance, difference in surface topography as will be discussed below. It should also be noted that the microscopic BIC measurements are made at the 0.1–0.01 mm level, thus not taking into account the surface topography and surface area at the micron- and nanolevel.

RTQ measurements showed an increase with time for both implant types and a significant difference ($p = .05$) at 3 weeks in favor of the HSBA implant. Previous work has shown a correlation between implant diameter and RTQ measurements when using the same surface and time of healing.[21] The surface area of the OX implant was about 50% larger than the HSBA implant, as assessed in a 3D modeling software. In an attempt to normalize the RTQ data, a shear strength value was therefore calculated for each implant based on diameter and length. In this way, the RTQ (Ncm) needed to rupture the bone-implant interface was broken down to force per area unit (N/mm^2). This revealed significantly higher shear strengths and, therefore, stronger fixation of the HSBA than of the OX implant after 3 and 6 weeks. Apart from surface area, the BIC has also been shown to influence the RTQ value.[22] In the present study, the HSBA implant showed higher shear strength irrespective of similar or less BICs than the OX implant at 3 and 6 weeks. A third factor that influences the RTQ value is the surface roughness.[1] Previous papers on the previous non-hydrophilic SBA and the present oxidized surface have presented Sa values of about 1.5 μm and 1.1–1.35 μm, respectively,[23] indicating that the former implant has a higher surface roughness. A recent paper claims that the HSBA has a Sa value of 1.78 μm.[19] This indicates that the HSBA surface is rougher than the OX surface and thereby offers a stronger interlock of the newly formed bone at the interface, which, in turn, may explain differences in shear strength. However, as pointed out before, with the present experimental design, no single factor can be isolated to alone explain the differences.

Implant stability is determined by the mechanical properties of the bone tissue at the implant site and how well the implant is engaged with the bone tissue.[24] Bone density depends on the composition of the bone at the implant site, that is, the ratio of cortical and cancellous bone and is influenced by healing as a corticalization of cancellous bone occurs with time. The fixation of the implant is influenced by the surgical technique, the design of the implant and of the bone tissue responses to the implant. Bone healing results in bone formation that reinforces the interface zone, as well as forms bridges and a direct contact between the implant surface and the surrounding bone. The use of insertion and removal torque, ISQ measurements, and histology allow for examination of the previously mentioned various aspects of implant stability and integration. ISQ assessments measure the lateral stability of an implant, while application of shear forces with the removal torque test measures the strength of the interface.[24]The outcome of the two tests does not necessarily correlate with each other. For instance, a newly placed implant can show a high ISQ value but may be easily removed when applying reverse torque, since bone has not yet been formed and interlocked with the implant surface. In the present study, the HSBA implants showed a lower primary lateral stability, which confirmed the subjective feeling during surgery. The morphology of the site, with a thin cortical bone, and the absence of threads on the most coronal part of the HSBA implant, explain the low primary stability. In spite of this, implant stability was recovered after 10 days, probably as a result of bone formation and increased stiffness of the interface. Histology is probably the least precise technique used in the present study but can give some valuable information about the biological event at the implant interface. For instance, both surfaces showed bone formation directly to the implant surface. Measurements of bone-to-implant contact and bone fill around the implant are commonly used and it is generally anticipated that higher values indicates a better response. However, the present study shows little correlation between the biomechanical and histological data. The HSBA implants showed better fixation in spite of less or equal BIC compared to the oxidized implant. Moreover, more bone was seen after 10 days than after 3 and 6 weeks, reflecting rapid formation of woven bone and the following remodeling process. In fact, there seemed to be an inversed correlation between the biomechanical parameters and histology. As previously mentioned, the BIC measurements are made at the 0.1–0.01 mm level, thus not taking into account the surface topography and surface area at the micron- and nanolevel, whereas the removal torque measurements are influenced of the "true" three-dimensional surface topography and the resulting bone-implant interlocking. It is the opinion of the present authors that the biomechanical tests are more relevant than histology.

Surface modified implants show more bone-to-implant contact at an earlier stage than control surfaces,[6,8,10,11,25] which may have implications on clinical protocols and outcomes. The original protocols prescribed healing periods from 3 to 6 months prior to loading. Today, clinicians are generally using shorter healing periods from 6 weeks to 3 months for two-stage implant, or no healing periods. However, the few comparative studies that are available on two-stage procedures have not shown any significant difference in clinical results between a machined and surface modified implants.[26,27] Studies have indicated better results with surface-modified implants in immediate/early loading protocols[28–31] and in different bone augmentation procedures,[32] which makes sense since the biological differences between surfaces are seen in the early phase of healing. To the knowledge of the present authors, there are no comparative clinical studies on different surface modified implants such as the ones used in the present investigation. The Nobel Replace Select Tapered implant has been available for more than 10 years and is by the manufacturer claimed to be the most used implant design in the world. In spite of this, only few follow-up studies could be found in the literature. Bahat[16] reported a CSR of 99.3% after three years of loading of 290 Replace Select implants in compromised maxillary bone. Two studies on immediate/early loading by Rao & Benzi[14] and Fischer et al.[15] showed good clinical outcomes of the same implant design after one-year. The SLActive implant is a more recent innovation and numerous experimental and clinical studies have been published over the last five years.[19] Clinical follow-up studies have reported survival rates of 97 to 100% when used for immediate /early loading[17,18] and in irradiated patients.[33] The results from both implant types are in line with the notion that good clinical results can be achieved with surface modified implants in challenging situations.

Both HSBA and OX implants were well integrated in bone and showed firm and increased stability from placement to after 6 weeks of healing. The HSBA implant showed more BIC after 10 days and the OX implant more BIC after 6 weeks of healing. The HSBA implant showed significantly higher shear strength after 3 and 6 weeks and higher RTQ values after 3 weeks than the OX implant. The results may be due to differences in surface roughness and hydrophilic properties.

ACKNOWLEDGMENTS

The study was supported by Institut Straumann AG, Basel, Switzerland.

Statistical analyses were performed by Dr. L. Grize, Biostatistics and Computational Sciences Unit, Department of Epidemiology and Public Health, Swiss Tropical and Public Health Institute, Basel, Switzerland.

REFERENCES

1. Albektsson T, Wennerberg A. Oral implant surfaces: part 1 – review focusing on topographic and chemical properties of different surfaces and in vivo responses to them. Int J Prosthodont 2004; 17:536–543.
2. Stanford CM. Surface modifications of dental implants. Aust Dent J 2008; 53 (Suppl 1):S26–S33.
3. O'Sullivan D, Sennerby L, Meredith N. Measurements comparing the initial stability of five designs of dental implants: a human cadaver study. Clin Implant Dent Relat Res 2000; 2:85–92.
4. Osborn JF, Newesely H. Dynamic aspects of the bone-implant interface. In: Heimke G, ed. Dental implants: materials and systems. Munchen: Carl Hansen Verlag, 1980:111–123.
5. Davies JE. Understanding peri-implant endosseous healing. J Dent Educ 2003; 67:932–949.
6. Zechner W, Tangl S, Fürst G, et al. Osseous healing characteristics of three different implant types. Clin Oral Implants Res 2003; 14:150–157.
7. Ivanoff CJ, Hallgren C, Widmark G, Sennerby L, Wennerberg A. Histologic evaluation of the bone integration of TiO(2) blasted and turned titanium microimplants in humans. Clin Oral Implants Res 2001; 12:128–134.
8. Burgos PM, Rasmusson L, Meirelles L, Sennerby L. Early bone tissue responses to turned and oxidized implants in the rabbit tibia. Clin Implant Dent Relat Res 2008; 10:181–190.
9. Buser D, Broggini N, Wieland M, et al. Enhanced bone apposition to a chemically modified SLA titanium surface. J Dent Res 2004; 83:529–533.
10. Schwarz F, Ferrari D, Herten M, et al. Effects of surface hydrophilicity and microtopography on early stages of soft and hard tissue integration at non-submerged titanium implants: an immunohistochemical study in dogs. J Periodontol 2007; 78:2171–2184.
11. Schwarz F, Sager M, Ferrari D, Herten M, Wieland M, Becker J. Bone regeneration in dehiscence-type defects at

non-submerged and submerged chemically modified (SLActive) and conventional SLA titanium implants: an immunohistochemical study in dogs. J Clin Periodontol 2008; 35:64–75.
12. Wall I, Donos N, Carlqvist K, Jones F, Brett P. Modified titanium surfaces promote accelerated osteogenic differentiation of mesenchymal stromal cells in vitro. Bone 2009; 45:17–26.
13. Lai HC, ZHuang LF, Zhang ZY, Wieland M, Liu X. Bone apposition around two different sandblasted, large-grit and acid-ecthed implant surfaces at sites with coronal circumferential defects. An experimental study in dogs. Clin Oral Implants Res 2009; 20:247–253.
14. Rao W, Benzi R. Single manibular first molar implants with flapless guided surgery and immediate function: preliminary clinical and radiographic results of a prospective study. J Prosthet Dent 2007; 97:3–14.
15. Fischer K, Bäckström M, Sennerby L. Immediate and early loading of oxidized tapered implants in the partially edentulous maxilla: a 1-year prospective clinical, radiographic, and resonance frequency analysis study. Clin Implant Dent Relat Res 2009; 11:69–80.
16. Bahat O. Technique for placement of oxidized titanium implants in compromised maxillary bone: prospective study of 290 implants in 126 consecutive patients followed for a minimum of 3 years after loading. Int J Oral Maxillofac Implants 2009; 24:325–334.
17. Ganeles J, Zöllner A, Jackowski J, ten Bruggenkate C, Beagle J, Guerra F. Immediate and early loading of Strauman implants with a chemically modified surface (SLActive) in the posterior mandible and maxilla: 1-year results from a prospective multicenter study. Clin Oral Implants Res 2009; 19:1119–1128.
18. Bornstein MM, Wittneben JG, Brägger U, Buser D. Early loading at 21 days of non-submerged titanium implants with a chemically modified sandblasted and acid-etched surface: two-yer results of a prospective two-center study. J Periodontol 2010; 81:809–818.
19. Wennerberg A, Galli S, Albrektsson T. Current knowledge about the hydrophilic and nanostructured SLActive surface. Clin Cosmetic Inv Dent 2011; 3:59–67.
20. Hall J, Lausmaa J. Properties of a new porous oxide surface on titanium implants. Appl Osseointegration Res 2000; 1:5–8.
21. Ivanoff CJ, Sennerby L, Johansson C, Rangert B, Lekholm U. Influence of implant diameters on the integration of screw implants. An experimental study in rabbits. Int J Oral Maxillofac Surg 1997; 26:141–148.
22. Ivanoff CJ, Sennerby L, Lekholm U. Influence of mono- and bicortical anchorage on the integration of titanium implants. A study in the rabbit tibia. Int J Oral Maxillofac Surg 1996; 25:229–235.
23. Sul YT, Byon E, Wennerberg A. Surface characteristics of electrochemically oxidized implants and acid-etched implants: surface chemistry, prophology, pore configurations, oxide thickness, crystal structure and roughness. Int J Oral Maxillofac Implants 2008; 23:631–640.
24. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: biological and biomechanical aspects and clinical implications. Periodontol 2000 2008; 47:51–66.
25. Buser D, Schenk RK, Steinemann S, Fiorellini JP, Fox CH, Stich H. Influence of surface characteristics on bone integration of titanium implants. A histomorphometric study in miniature pigs. J Biomed Mater Res 1991; 25:889–902.
26. Astrand P, Engquist B, Anzén B, et al. A three-year follow-up report of a comparative study of ITI Dental Implants and Brånemark System implants in the treatment of the partially edentulous maxilla. Clin Implant Dent Relat Res 2004; 6:130–141.
27. Astrand P, Engquist B, Dahlgren S, Gröndahl K, Engquist E, Feldmann H. Astra Tech and Brånemark system implants: a 5-year prospective study of marginal bone reactions. Clin Implant Dent Relat Res 2004; 15:413–420.
28. Glauser R, Rée A, Lundgren A, Gottlow J, Hämmerle CH, Schärer P. Immediate occlusal loading of Brånemark implants applied in various jawbone regions: a prospective, 1-year clinical study. Clin Implant Dent Relat Res 2001; 3:204–213.
29. Glauser R, Lundgren AK, Gottlow J, et al. Immediate occlusal loading of Brånemark TiUnite implants placed predominantly in soft bone: 1-year results of a prospective clinical study. Clin Implant Dent Relat Res 2003; 5 (Suppl 1):47–56.
30. Rocci A, Martignoni M, Gottlow J. Immediate loading of Brånemark System TiUnite and machined-surface implants in the posterior mandible: a randomized open-ended clinical trial. Clin Implant Dent Relat Res 2003; 5 (Suppl 1):57–63.
31. Ostman PO, Hellman M, Sennerby L. Immediate occlusal loading of implants in the partially edentate mandible: a prospective 1-year radiographic and 4-year clinical study. Int J Oral Maxillofac Implants 2008; 23:315–322.
32. Brechter M, Nilsson H, Lundgren S. Oxidized titanium implants in reconstructive jaw surgery. Clin Implant Dent Relat Res 2005; 7 (Suppl):S83–S87.
33. Herberer S, Kilic S, Hossamo J, Raguse JD, Nelson K. Rehabilitation of irradiated patients with modified and conventional sanblasted acid-etched implants: preliminary results of a split-mouth study. Clin Oral Implants Res 2011; 22:546–551.