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SLActive

The surface with success built in.

Scientific overview

2005 FROST & SULLIVAN
Medical Device Technology of the Year Award

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Contents

Innovation SLActive

The clinical challenge

In the osseointegration process, two factors play an important role: Primary stability (mechanical stability) and secondary stability (biologic stability). Taking bone quality into consideration, achievement of primary stability is predictable thanks to key features of implant system design such as thread pitch, precision of implant dimensions, and corresponding drills.

Secondary stability is the result of the biologic healing process, and is therefore not under the direct control of the clinician. Achievement of full secondary stability is subject to numerous variables, the most significant of all being the speed of the osseointegration process. The implant surface can enhance the speed at which osseointegration occurs.

The sum of primary and secondary stability is referred to as total stability. A delay in the healing process leads to a marked decrease in the total stability of the implant between weeks 2 and 4, making this "stability dip" a critical time in the osseointegration process (Fig 1).

With this in mind, the clinician may be cautious in the selection of implant candidates and implant treatment options. This caution is noteworthy in today's market because it limits the application of stability-critical protocols such as early and immediate loading.

The innovation: "shift the dip"

The goal in the development of SLActive was to achieve secondary stability sooner by accelerating the osseointegration process. To reach this goal, researchers focused on understanding the biology behind the initial healing processes following implant placement.

The result of these inquiries is the new SLActive surface. SLActive takes the scientifically proven SLA® surface one step further through its improved surface chemistry. With its hydrophilic and chemically active properties, SLActive promotes faster osseointegration and leads to earlier secondary stability than SLA®. By achieving secondary stability sooner, SLActive "shifts" the stability dip (Fig. 2).

The benefits for patient and clinician:

By achieving implant stability earlier than SLA® in the critical treatment period of 2 to 4 weeks after implant placement, SLActive offers increased treatment predictability with shorter treatment times in all indications.

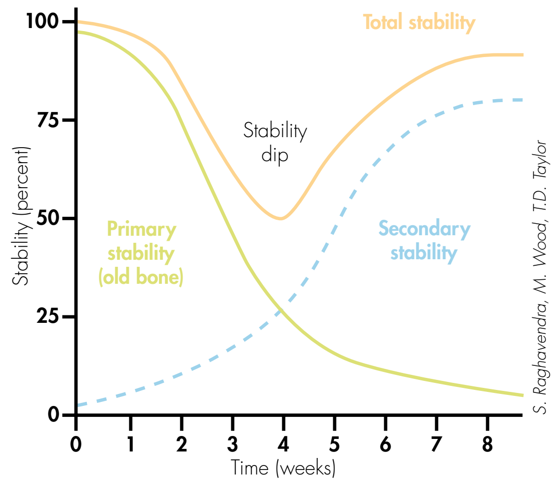


Fig. 1: *The decreasing primary stability and increasing secondary stability result in a decrease in overall stability (dip) between week 2 and 4 after implant placement.*

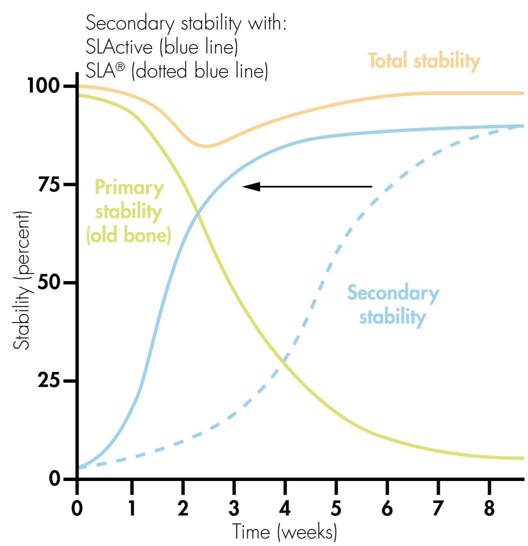
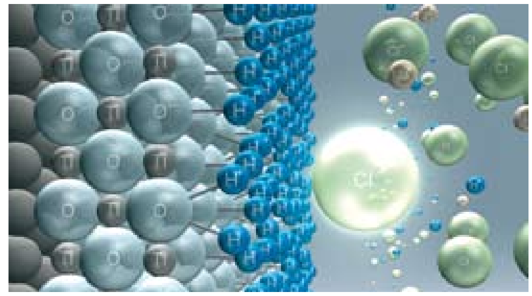


Fig. 2: *The faster osseointegration with SLActive leads to an earlier implant stability between week 2 and 4.*

Study overview

More than 14 studies have been initiated so far to substantiate the scientific evidence of SLActive. The main focus in the study design has been placed on the understanding of the initial healing processes. By understanding this early healing phase, the research team gained new insights that contributed to the development of this novel implant surface. The following overview presents a selection of the studies related to SLActive.



PRE-CLINICAL STUDIES

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Superhydrophilic SLActive implants

M. de Wild

Published 06/2005, Straumann document 151.527/d and 152.527/e

Abstract: Surface chemistry influences both surface charge and wettability. The purpose of this study was to investigate initial hydrophilicity of SLActive implants compared to standard SLA.

Introduction

Surface topography and chemistry both influence initial wettability and peri-implant bone apposition of implants. Up to now, conventional titanium surfaces (sandblasted and acid etched) were initially hydrophobic, due to microstructuring partial coverage with hydrocarbons and carbonates. SLActive, a modified sandblasted/acid-etched surface, is produced by rinsing under N_2 atmosphere. It is then submerged in an isotonic NaCl solution following acid etching to avoid contact with molecules from the atmosphere.

Material and Methods

SLA and SLActive implants were investigated by Dynamic Contact Angle analysis (DCA) [Rupp F et al. 2002]. Before testing, SLActive implants were dried at a pressure below 20 mbar. Hydrophilicity and contact angle hysteresis were then tensiometrically examined by the Wilhelmy method (Fig. 1 and 2) by means of an electrobalance (TE3, Lauda, Germany).

Results

The initial contact angle of SLA completely differs from SLActive. Repeated force loops of Wilhelmy-electrobalance measurements on SLA implants show hysteresis (Δm), which indicates contact angle hysteresis: The first advancing mean water contact angles were Θ^{1st}_{adv} >90° for SLA, but 0° for SLActive. Thus, the chemically modified samples show maximum hydrophilicity in contrast to hydrophobic SLA (Fig. 3 and 4), though SLA and SLActive are both identically microstructured [Zhao G et al. 2005]. DCA measurements on SLActive implants (packaged under certain principles) show no reduction in its hydrophilicity after 3 years of accelerated aging at enhanced temperature.

Conclusions

- Qualitative and quantitative enhancement of hydrophilicity of the SLActive implant surface
- Conservation of the super hydrophilic state over at least 3 years is possible
- Qualitative analysis on implants for quality assurance

DCA measurements

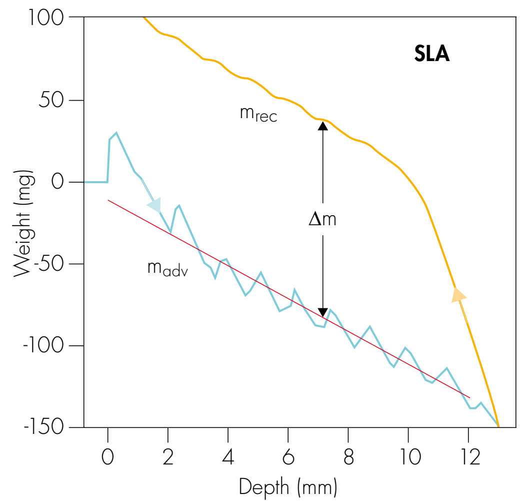


Fig. 1: *Wilhelmy Force loop for SLA, showing hysteresis (Δm).*

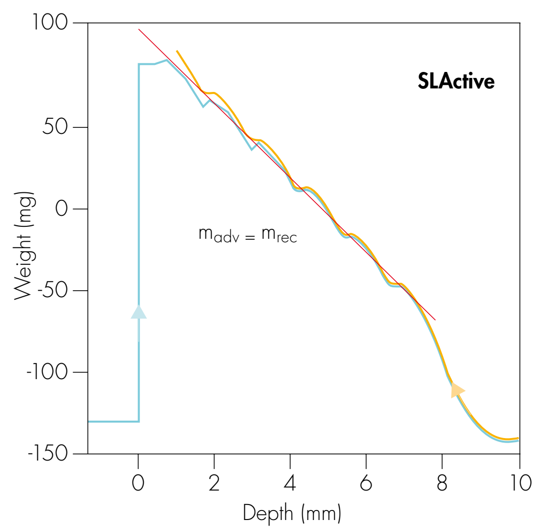


Fig. 2: *Wilhelny Force loop for SLActive, showing no hysteresis.*

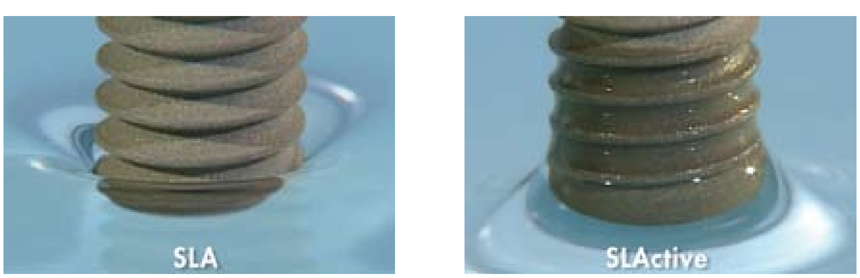


Fig. 3: *Immersion of SLA and SLActive implants in water demonstrates the wetting of SLActive and its meniscus at the water-air-implant interface.*

Fig. 4: *Demonstration of the superhydrophilic property of SLActive. Note the refractions below the water droplet resulting from air bubbles entrapped between the water and the SLA surface.*

Enhancing free surface energy and hydrophilicity through chemical modification of microstructured titanium implant surfaces

F. Rupp, L. Scheideler, N. Olshanska, M. de Wild, M. Wieland, J. Geis-Gerstorfer
J. Biomed. Mater. Res. A. 2005; DOI:10.1002/jbm.a.30518 – published online 3 Nov 2005

Abstract: Surface modification of the SLA surface was investigated by preparation under protective gas conditions and subsequent liquid storage. Surface free energy and hydrophilicity were increased, and atmospheric contamination of the implant surface was reduced.

Introduction

Roughness-induced hydrophobicity (water-repellency), well-known from natural plant surfaces and intensively studied on superhydrophobic surfaces, has recently been identified on microstructured titanium implant surfaces. Studies indicate that microstructuring by sandblasting and acid etching (SLA) enhances the osteogenic properties of titanium. The undesired initial hydrophobicity, however, presumably decelerates primary interactions with the aqueous biosystem.

Material and Methods

To improve the initial wettability while retaining the SLA microstructure, a novel surface modification was tested. This modification differs from SLA regarding its preparation after acid etching, which is done under protective gas conditions, followed by liquid instead of dry storage (Fig. 1). We hypothesized that this modification should have increased wettability, due to the prevention of contamination that occurs during air contact.

Results

The main outcome of dynamic wettability measurements was that the novel modification shows increased surface free energy (SFE) and increased hydrophilicity with water contact angles of 0° compared to 139.9° for SLA. This hydrophilicity was maintained even after drying. Reduced hydrocarbon contamination from the atmosphere was identified as playing a possible role in the altered surface thermodynamics. SLActive aims to retain the hydrophilicity and natural high surface energy of the Ti dioxide surface until surgical insertion of the implant. Titanium implants with various structural surface variants are compared in this *in vitro* study for roughness and chemically induced wettability. Tests showed that the unique characteristics of the chemically activated SLActive cannot be reproduced merely by soaking the SLA surface in a saline solution; the activity is achieved only through the complex production process under N_2 atmosphere.

Conclusions

- Higher surface free energy with SLActive resulting in a chemical activation of the surface
- SLActive is uniquely highly hydrophilic (water contact angle 0° compared to 139.9° for SLA)
- Reduced atmospheric contamination (hydrocarbons) on the implant surface

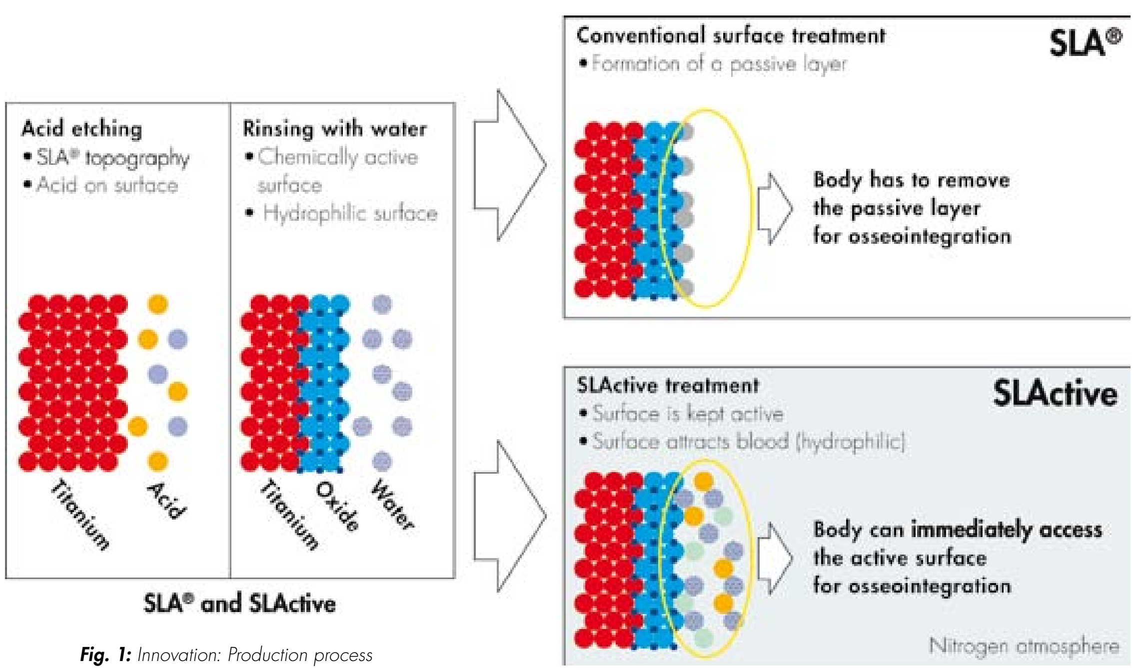


Fig. 1: *Innovation: Production process*

3

Storage conditions of titanium implants influence molecular and cellular interactions

L. Scheideler, F. Rupp, M. Wieland, J. Geis-Gerstorfer

Poster #870, 83rd General Session and Exhibition of the International Association for Dental Research (IADR), March 9–12 2005, Baltimore, MD, USA

Abstract: The effects of protein and cellular interactions were compared on a variety of treated titanium surfaces, including SLA and SLActive. The chemically modified surface of SLActive was found to increase osteoblast proliferation and significantly increase protein adsorption in the in vitro environment.

Introduction

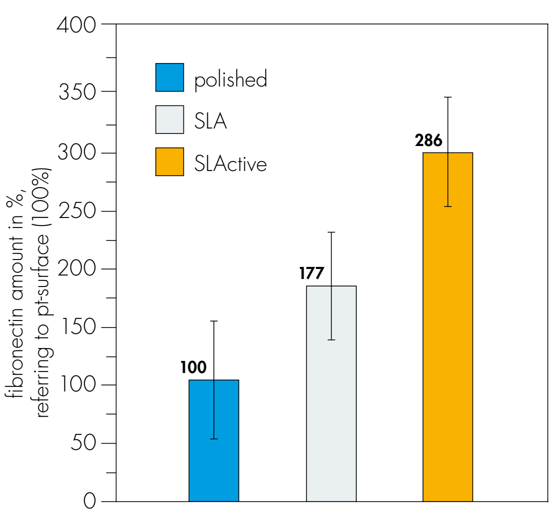
The initial hydrophobicity of sandblasted and acid-etched titanium implant surfaces is a result of the microtopography and atmospheric contamination, which can influence initial surface conditioning by blood components. Protein- and cell-surface interactions and cellular proliferation were therefore investigated on the hydrophilic SLActive surface compared to a variety of other surfaces.

Material and Methods

Various disks of grade II titanium were prepared:

- Polished
- SLA
- SLActive

Fibronectin adsorption was determined by ELISA, and the initial osteoblast proliferation rate was determined by BrdU-incorporation (DNA synthesis rate).



Results

Compared to the reference surface (polished Ti), the amount of fibronectin adsorption on the surface increased to 177% for SLA, and to 286% for SLActive. Compared to SLA as a reference point, this represented an increase of 162% for SLActive. Osteoblast proliferation increased to 117% for the modified acid-etched surface, compared to the acid-etched surface (both without sandblasting). Since the topography of the SLA and SLActive surfaces are the same, and the topography of the acid-etched and modified acid-etched surfaces are the same, it can be concluded that the effects are due to the altered surface chemistry.

Conclusions in this in vitro study

- SLActive surface enhances osteoblast – surface and protein-surface interactions compared to SLA
- SLActive showed a significantly higher fibronectin adsorption (162%) compared to SLA and other surface types
- Effects may be due to increased hydrophilicity and surface free energy

In vitro protein adsorption tests on SLActive

R. Seibl, M. de Wild, E. Lundberg
STARGET 02.2005

Abstract: *In vitro* tests conducted at Straumann research facilities in Malmö, Sweden, showed an increased protein adsorption on SLActive compared to the SLA surface.

Introduction

The complex processes of protein adsorption at the interfaces of implants are influenced by a number of physical and chemical factors, such as surface topography and wettability. Adsorption of serum proteins is important, as these are the first blood components to come into contact with the implant. The pattern of adsorption defines the type of cells adhering to the implant, thus the type of tissue that subsequently develops. On the basis of this observation, the adsorption patterns of two important proteins – albumin and fibronectin – for the osseointegration process on the SLA and SLActive surfaces were investigated (see also L. Scheideler et al. 2005).

Material and Methods

Adsorption of albumin was semi-quantitatively detected using polyacrylamide electrophoresis, and adsorption of fibronectin was assessed using direct ELISA (Enzyme-Linked Immunosorbent Assay).

Results

The amount of serum albumin adsorption from single protein solutions was much greater with the SLActive surface than on SLA (Fig. 1). Likewise, the adsorption of fibronectin, an important protein for collagen fiber attachment, also exhibited a high increase with SLActive, thereby confirming recent data from L. Scheideler et al. 2005.

Conclusions in this in vitro study

- SLActive showed a substantially increased protein adsorption on the surface compared to SLA
- Greater protein adsorption may lead to faster osseointegration compared to SLA

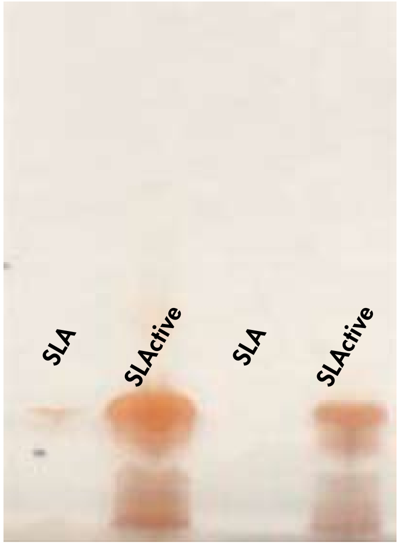


Fig. 1: *Adsorption of human serum albumin on dental implants with SLActive surface in comparison to implants with SLA. Adsorbed protein was semi-quantitatively detected after desorption using polyacrylamide electrophoresis. The greater amount of albumin adsorbed on SLActive compared to SLA is in clear evidence.*

High surface energy of SLActive implants enhances cell response to titanium substrate microstructure

G. Zhao, Z. Schwartz, M. Wieland, F. Rupp, J. Geis-Gerstorfer, D. L. Cochran, B. D. Boyan
J. Biomed. Mater. Res. A. 2005; 74A: 49–58

Abstract: The early cellular activity at the hydrophilic SLActive surface was evaluated and compared with the hydrophobic SLA. The osteoblast differentiation was enhanced with SLActive, and production of osteogenic factors, such as osteocalcin, alkaline phosphatase, PGE_2 and TGF-β1, was significantly increased in vitro.

Introduction
Investigations of osteoblast response to titanium surface chemistry have shown that osteogenesis is enhanced in vitro by hydrophilic surfaces. However, until recently, conventional titanium surfaces currently available have had low surface energy and distinct hydrophobic properties due to the microtopography and to adsorbed hydrocarbons. The purpose of this investigation was to compare the in vitro cellular response to different titanium microstructures, including SLActive.

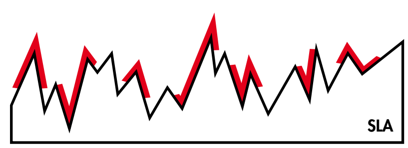
Material and Methods
Various disks of grade II titanium were prepared:
- Pre-treated titanium
- SLA
- SLActive

Osteoblasts were then cultured on these surfaces and cellular response evaluated by measurement of alkaline phosphatase, osteocalcin, PGE_2 and TGF-β1.

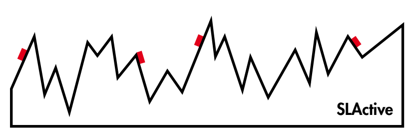
Results
Osteoblasts cultured on SLActive showed a more differentiated phenotype than those on the other surfaces tested. Compared to SLA, there was a 3-fold increase of cell layer alkaline phosphatase activity on the SLActive surface. In addition, osteocalcin (a late differentiation marker) was significantly increased (Fig. 1) and there was a higher production of the local growth factors PGE_2 (10-fold increase) and TGF-β1 (2.5-fold increase), creating a highly osteogenic microenvironment (Fig. 2). The effect of 1,25-dihydroxyvitamin D3, an osteotropic hormone that increases osteoblast differentiation, was also enhanced with SLActive, in a manner synergistic with high surface energy.

The results suggest that the increased bone formation observed with SLActive in animal studies is partly due to stimulatory effects of the increased surface free energy (chemical activity) on osteoblasts.

Conclusions in this in vitro study
- Osteocalcin production with SLActive was significantly increased
- Osteoblast activity was clearly enhanced as a result of the chemically activated SLActive surface
- A significantly enhanced production of local growth factors up to 10-fold was present
- Osteogenic properties were enhanced



Surface partially covered with carbons from atmosphere



56 % reduction of carbons on the surface

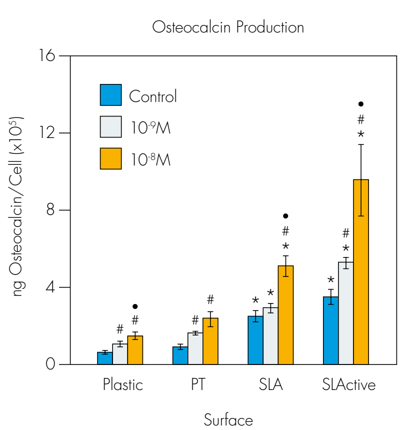


Fig. 1: *Osteocalcin production by MG63 cells during culture on plastic or Ti disks. Values are the mean ± SEM of six cultures. * $p<0.05$, Ti disks vs. plastic. # $p<0.05$, treated vs. untreated control for a particular surface. • $p<0.05$, $10^{-9}M\ 1\alpha,25(OH)_2D_3$ vs. $10^{-8}M\ 1\alpha,25(OH)_2D_3$.*

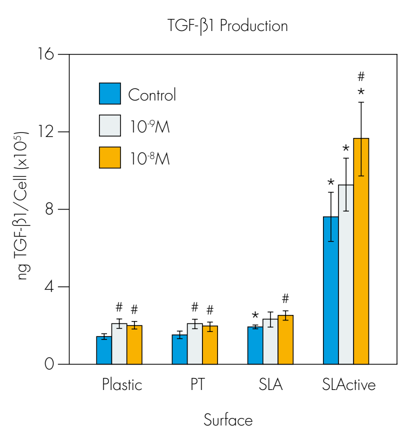


Fig. 2: *Latent TGF-β1 production by MG63 cells during culture on plastic or Ti disks. Values are the mean ± SEM of six cultures. * $p<0.05$, Ti disks vs. plastic. # $p<0.05$, treated vs. untreated control for a particular surface. • $p<0.05$, $10^{-9}M\ 1\alpha,25(OH)_2D_3$ vs. $10^{-8}M\ 1\alpha,25(OH)_2D_3$.*

The influence of hydrophilic versus hydrophobic Ti specimens with different topographical and roughness levels on contact guidance and cellular proliferation evaluated with time-lapse photography

X. Rausch-Fan, Q. Zhe, M. Wieland, M. Matejka, A. Schedle

Abstract: Early cellular processes were assessed on various treated titanium surfaces. Initial results show substantially increased production of osteocalcin and local growth and vascularization factors in vitro with SLActive.

Introduction

Implant surface properties such as topography or chemistry play a key role in the establishment of cell-biomaterial interfaces. Wettability and surface charge both play an important role in protein adsorption, which can be modulated according to changes in the physico-chemical characteristics of the surface, subsequently affecting cell attachment. Based on this, the process of cell attachment, time lapse motion, contact guidance and cell proliferation were assessed on titanium surfaces with different topographical and chemical attributes, in order to obtain a deeper understanding of how these different surfaces influence cell behavior.

Material and Methods

Four types of titanium disks were used: Acid-etched, SLA, modified acid-etched and modified SLA (SLActive). Human primary cells (osteoblasts, gingival fibroblasts and gingival epithelial cells) were used. In addition, appropriate cell lines were also used: MG-63 (human osteoblastic cell line), HGF-1 (gingival fibroblast cell line), HSC-2 (epithelial cell line) and an endothelial cell line. Growth on the titanium surfaces was monitored by fluorescence cell staining and time-lapse photography (Fig. 1).

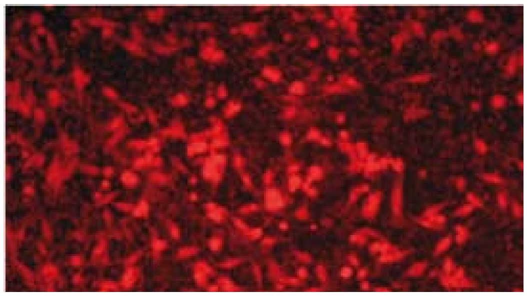


Fig. 1: *Living MG-63 cells, grown for 24 h on a mod. SLA surface (SLActive).*

Results

Initial results, from cultured MG-63 cells and alveolar osteoblasts, show that succinate dehydrogenase activity (indicative of cellular mitochondrial function), alkaline phosphatase synthesis (Fig. 2), and production of osteocalcin, osteoprotegerin (Fig. 3), TGF-β1 and VEGF (an important vascularization factor) were all increased with SLActive compared to the SLA, acid-etched or modified acid-etched surfaces.

Conclusions in this in vitro study

- A significantly enhanced early osteoblast activity was seen as a result of the chemically activated SLActive surface
- There was a substantially increased production of osteocalcin and osteoprotegerin with SLActive
- There was a substantially increased production of local growth and vascularization factors with SLActive

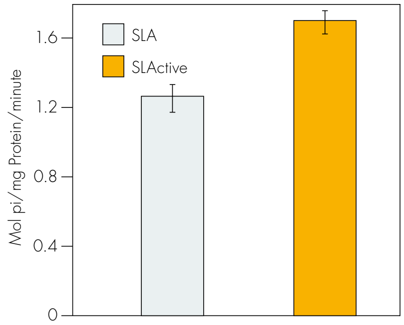


Fig. 2: *Alkaline phosphatase synthesis of MG-63 cells grown on SLA and SLActive.*

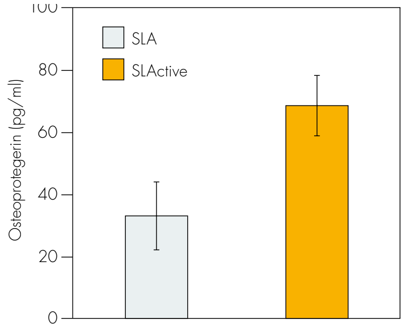


Fig. 3: *Osteoprotegerin production of MG-63 cells grown on SLA and SLActive.*

Histological and immunohistochemical analysis of very early periimplant tissue reactions to chemically modified and conventional SLA titanium implants: A pilot study in dogs

F. Schwarz, M. Herten, M. Sager, M. Wieland, M. Dard, J. Becker
Submitted, Clinical Oral Implant Research

Abstract: Early tissue reactions around SLA and SLActive implants were assessed. During a period of 14 days, faster and more structured bone formation was observed around the SLActive implants, with greater vascularization and increased osteocalcin activity.

Introduction

Assessment of bone-to-implant contact (BIC), an essential factor for successful osseointegration, is usually performed via conventional histological staining. However, this method may not be suitable for the investigation of very early tissue responses that begin with protein adhesion to the implant surface, which may in turn affect tissue development, depending on the type of proteins present. Osteogenic cells and osteoblast differentiation may also be important for osseointegration, and may also be associated with early angiogenic activity. The aim of this investigation was therefore to assess early tissue reactions to SLA and SLActive implants (up to 14 days) using conventional and immunohistochemical techniques.

Material and Methods

SLA or SLActive was placed in a split-mouth design 4 months following tooth extraction in four fox hounds; six implants (three of each type) were placed in the maxilla and ten implants (five of each type) were placed in the mandible of each animal. Specimens were retrieved for immunological and immunohistochemical assessment after 1, 4, 7 and 14 days of healing. Toluidine blue was used to assess the extent of new bone formation, and Massner Goldner Trichrome was used to assess the quality and quantity of collagen and new bone formation. Unlike conventional stains, this allows the differentiation of changes to be observed over a very short time period (e.g. days rather than weeks).

Results

Vascular infiltration of the blood clot adjacent to the implant was apparent for both implant types after 1 day, contacting the surface of SLActive implants but not SLA implants. The blood clot around SLActive implants appeared to be stabilized, whereas the clot around SLA implants appeared to be partially collapsed (Fig. 1). Infiltration of the clot by macrophages was also apparent.

At day 4, collagen-rich dense connective tissue was apparent around SLActive implants and the first indications of osteocalcin synthesis, which reached the implant surface, were observed (Fig. 2 and 3). Both of these suggest more rapid osseointegration processes. In contrast, SLA implants were surrounded by newly formed granulation tissue and some provisional connective tissue, with no osteocalcin synthesis (Fig. 2 and 3). The tissue around both implant types contained vascular structures, but these appeared to be of a higher density around SLActive implants.

At day 7, dense fibrous connective tissue, with collagen fiber bundles, blood vessels surrounded by newly formed trabeculae of woven bone and osteocalcin, indicating bone remodeling, were all apparent around SLActive implants (Fig. 4, 6 and 7). In con-

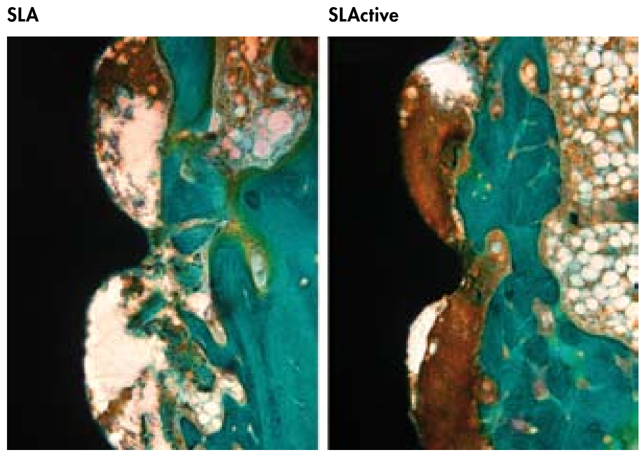


Fig. 1: *Histology at **Day 1**; collapsed blood clots (SLA) versus stabilized blood clots (SLActive).*

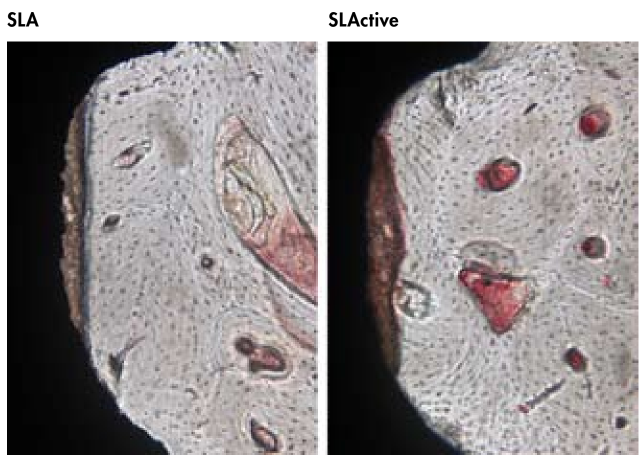


Fig. 2: *Histology at **Day 4**; no osteocalcin synthesis (SLA) versus first indications of osteocalcin synthesis (SLActive).*

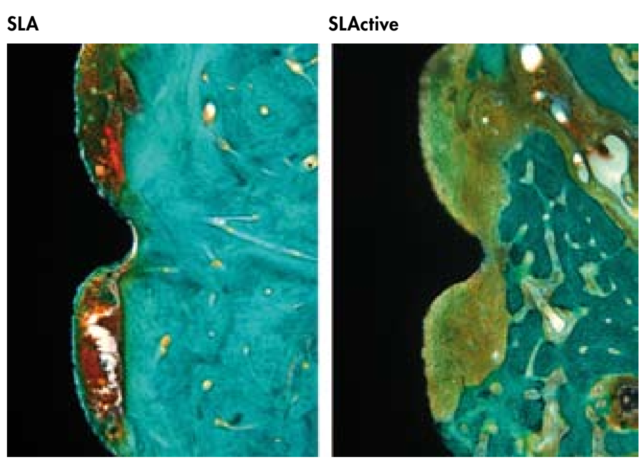


Fig. 3: *Histology at **Day 4**; granulation tissue (SLA) versus collagen-rich connective tissue (SLActive).*

trast, unstructured connective tissue with smaller blood vessel density and decreased osteocalcin concentration was observed around SLA implants (Fig. 4 and 6).

After 14 days, newly formed trabecular bone was formed around the SLA implants, whereas firmly attached, mature, parallel-fibered woven bone was present around the SLActive implants (Fig. 5 and 8). The formation of primary osteons was seen in the bone surrounding SLActive implants, with a radical deposition of lamellar bone around the core of connective tissue surrounding the blood vessels, whereas newly formed trabecular bone was observed around the SLA implants.

SLA **SLActive**

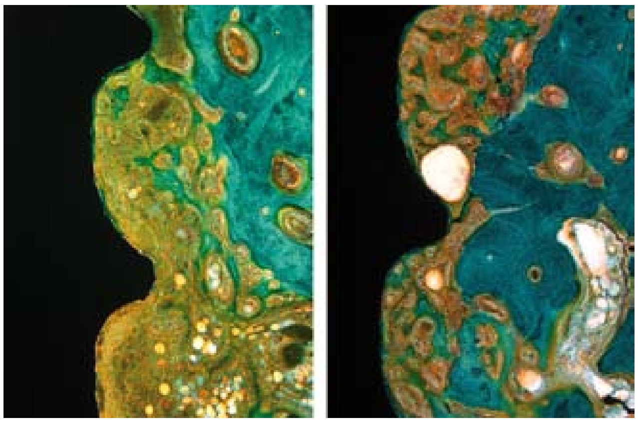


Fig. 4: *Histology at **Day 7**; not yet structured bone (SLA) versus mineralized and organized bone (SLActive).*

SLA **SLActive**

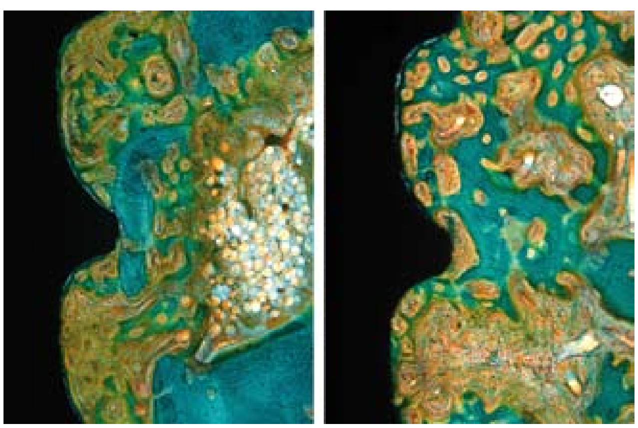


Fig. 5: *Histology at **Day 14**; newly formed trabeculae (SLA) versus firmly attached, mature, parallel-fibered woven bone and primary osteons (SLActive).*

Conclusions from this animal study:
- Significantly increased proliferation of vascular structures with SLActive throughout days 1–14
- Significantly increased activity of osteocalcin at the bone-to-implant interface, and enhanced bone formation processes with SLActive
- Quantitative and qualitative analysis showed significant differences in bone formation

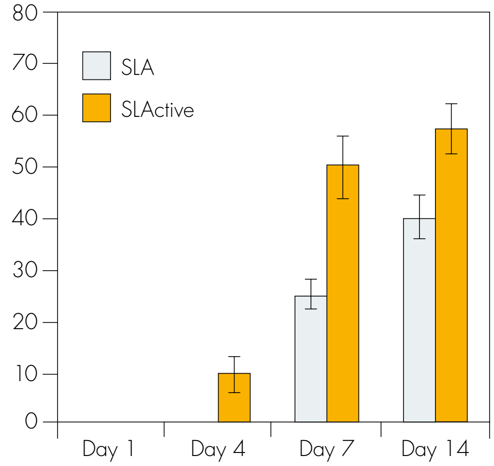


Fig. 6: *Osteocalcin, an indicator of bone remodeling, is synthesized faster and was consistently higher with SLActive.*

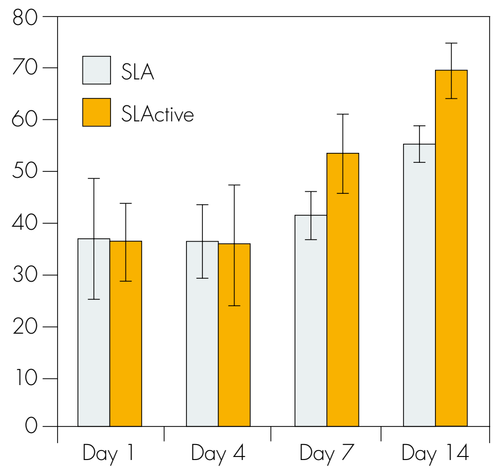


Fig. 7: *Transglutaminase levels consistently higher with SLActive.*

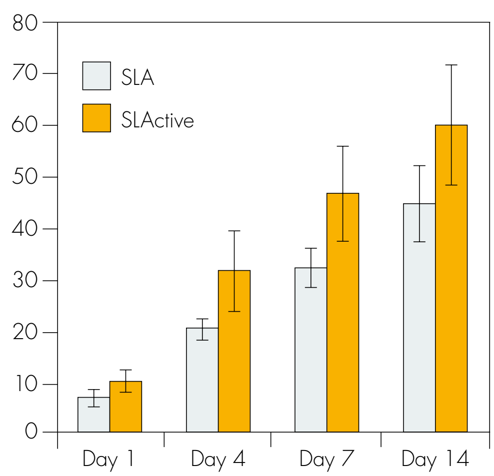


Fig. 8: *BIC was increased with SLActive from day 7 on.*

Enhanced bone apposition to a chemically modified SLA titanium surface

D. Buser, N. Broggini, M. Wieland, R. K. Schenk, A. J. Denzer, D. L. Cochran, B. Hoffmann, A. Lussi, S. G. Steinemann
J. Dent. Res. 2004; 83: 529–533

Abstract: The degree of bone apposition at the implant surface was compared between SLA and SLActive implants in miniature pigs. After 2 and 4 weeks, there was a significantly greater percentage (up to 60%) of bone-to-implant contact with SLActive.

Introduction

Enhanced bone apposition has been evaluated and demonstrated on rough surface implants, including SLA. However, more recently, it has been recognized that surface chemistry is another key factor in influencing bone-to-implant contact (BIC). Increased wettability and surface free energy both have been shown in pre-clinical studies to have a positive influence on bone apposition. The purpose of this study, therefore, was to evaluate the degree of bone apposition with the chemically modified SLActive surface versus the SLA surface, which has the same surface micro- and macrotopography.

Material and Methods

SLA and SLActive implants were placed in circular bone defects created in the maxillae of miniature pigs at least 6 months after tooth removal. Three or four implants were placed on either side of the maxilla in a split-mouth design and allowed to heal in a submerged position. The implants and implant sites were examined after 2, 4 and 8 weeks.

Results

Evidence showed that the amount of BIC was significantly greater with SLActive after 2 and 4 weeks of healing. At 2 weeks, the BIC on SLActive was 60% greater than that on SLA (49.30% ± 7.49 versus 29.42% ± 7.58; $p < 0.02$). Moreover, the typical pattern of new bone formation with a scaffold of woven bone was observed. (Fig. 1a). At 4 weeks, the BIC for SLActive was 81.91% ± 3.59, compared to 66.57% ± 8.14 ($p < 0.02$) for SLA. Bone density increased, as indicated by the reinforcement of woven bone trabeculae (Fig. 1b). Both surfaces showed similar results after 8 weeks (Fig. 1c), where early signs of bone remodeling were apparent. Thus, SLActive promoted enhanced bone apposition during the early stages of bone regeneration.

Comparison of percentage of bone-to-implant contact (BIC) between SLA and SLActive

Period	Implant surface	n	Mean in %	St. dev.
2 weeks	SLActive	8	49.30	7.49
	SLA	8	29.42	7.58
4 weeks	SLActive	8	81.91	3.59
	SLA	8	66.57	8.14
8 weeks	SLActive	7	78.47	11.14
	SLA	7	75.45	7.66

Conclusions from this animal study

- Bone apposition was significantly enhanced in the early osseointegration stages with SLActive
- SLActive implants exhibited 60% more bone after 2 weeks compared to SLA
- Earlier formation of more mature bone
- SLActive further reduces the healing period following implantation

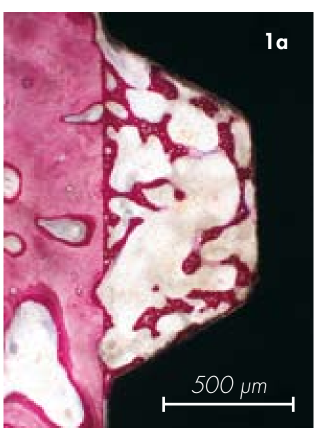


Fig. 1a: *At 2 weeks, bone is deposited upon the bony wall of the tissue chamber and upon the implant surface. Both layers are connected by a scaffold of tiny trabeculae. Woven bone is characterized by the intensive staining of the mineralized matrix and the numerous osteocytes located in large lacunae (undecalcified ground section, surface stained with toluidine blue and basic fuchsin. bar = 500 µm).*

Fig. 1b: *At 4 weeks, the volume density of this scaffold has increased both by the formation of new trabeculae and by deposition of more mature, parallel-fibered bone upon the primary scaffold. Woven bone is mainly recognized by the numerous large osteocytic lacunae (bright). The gap between bone and implant surface is an artifact (bar = 500 µm).*

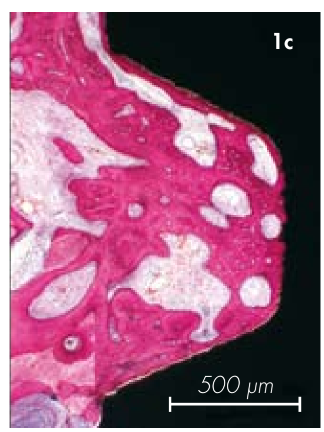


Fig. 1c: *At 8 weeks, growth and reinforcement result in a further increase in bone density and an almost perfect coating of the implant surface with bone. Remodeling has started, replacing the primary bone by secondary osteons (bar = 500 µm).*

Biomechanical evaluation of the interfacial strength of a chemically modified SLA titanium surface

S. J. Ferguson, N. Broggini, M. Wieland, M. de Wild, F. Rupp, J. Geis-Gerstorfer, D. L. Cochran, D. Buser
J. Biomed. Mater. Res. A. – accepted

Abstract: The biomechanical properties of SLActive and SLA implants were compared in a split-mouth study in adult miniature pigs. After 2, 4 and 8 weeks of healing, removal torque and interfacial stiffness values were significantly higher for SLActive.

Introduction

The capacity of osseointegrated dental implants to bear load depends largely on the bone-to-implant interface, which can be greatly influenced by the characteristics of the implant surface. The hydrophilic, chemically activated surface of SLActive implants has been shown in vitro and in animal studies to enhance bone apposition and promote rapid bone-to-implant contact. One might suggest, therefore, that the enhanced osseointegration could lead to greater initial implant stability. In order to assess this, the biomechanical characteristics of the SLActive surface were compared with those of SLA.

Material and Methods

SLActive and SLA implants 4.8 mm in diameter were placed in a split-mouth design (three implants per side) in nine adult miniature pigs following at least 6 months of healing after tooth removal. After 2, 4 and 8 weeks, the implants were evaluated by removal torque testing using a torque rotation curve to assess the interfacial shear strength and removal torque of each implant.

Results

Both the healing period and the implant surface type were shown to be significant factors affecting the biomechanical performance. Overall, removal torque for both SLA and SLActive implants increased to a peak value at 4 weeks, and then decreased (Fig. 1). Removal torque values for SLActive were significantly higher (8–21 %; p = 0.003) than those for SLA at each individual time point (1.485, 1.709 and 1.345 Nm for 2, 4 and 8 weeks, respectively, compared to 1.231, 1.585, and 1.143 Nm for SLA). Interfacial stiffness values were approximately 9–14 % higher for SLActive implants than for SLA implants (p = 0.038). Changes in the biomechanical characteristics of the interface may reflect the natural process of bone apposition and remodeling, as the interface is transformed from a purely mechanical to a biologically integrated system. The evidence from this animal study therefore suggests superior bone anchorage with the SLActive implant surface.

Conclusions from this animal study

- Bone apposition is enhanced with the SLActive surface
- Interfacial mechanical stiffness and strength is significantly greater with SLActive
- SLActive gives higher implant stability than SLA during the early critical weeks of osseointegration

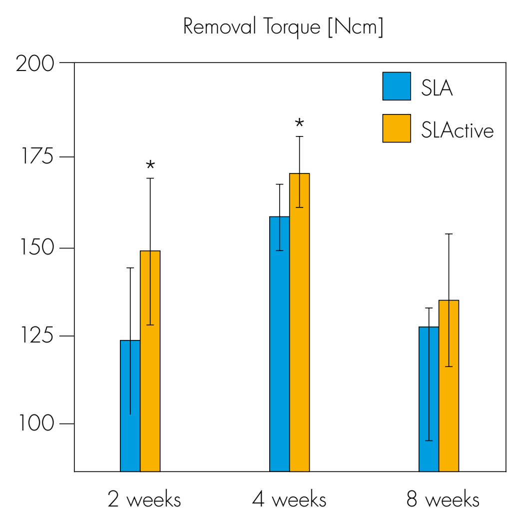


Fig. 1: *3 Animals per timepoint and 3 implants (3+3) per animal [3].*

Comparison of bone apposition between SLA and SLActive in foxhounds

D. Cochran et al.
Ongoing study

Abstract: The degree of bone apposition around SLActive compared to SLA implants was compared in foxhounds. Early results suggest greater and more mature bone growth from 2 weeks after implant placement.

Introduction

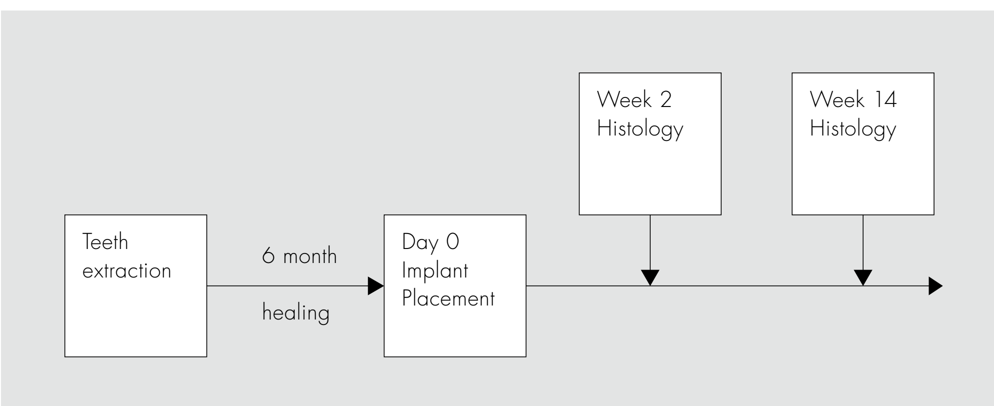
The purpose of this pre-clinical research study is to evaluate the characteristics of bone apposition with SLActive in comparison to SLA in the canine mandible. The aim is to investigate and compare bone formation at the surface of the implants at 2 and 4 weeks.

Material and Methods

The foxhound model was chosen to allow *in vivo* evaluation of SLActive in a higher animal species biologically similar to humans. Mandibular teeth were extracted from six adult foxhounds and the spaces allowed to heal. Alternating SLA and SLActive implants were then placed in the healed edentulous spaces and left unloaded. The implants were evaluated by histological and histomorphometric analysis up to 4 weeks after implant placement.

Planned evaluations

- This study will evaluate bone apposition around implants in a foxhound model with SLActive in comparison to SLA.



Evaluation of the SLActive implant surface in loaded conditions after implantation in foxhound dogs

D. Cochran et al.
Ongoing study

Abstract: The implant stability and influence of the SLActive surface under loaded conditions is being investigated in foxhounds. First results of the study will be available in 2006.

Introduction

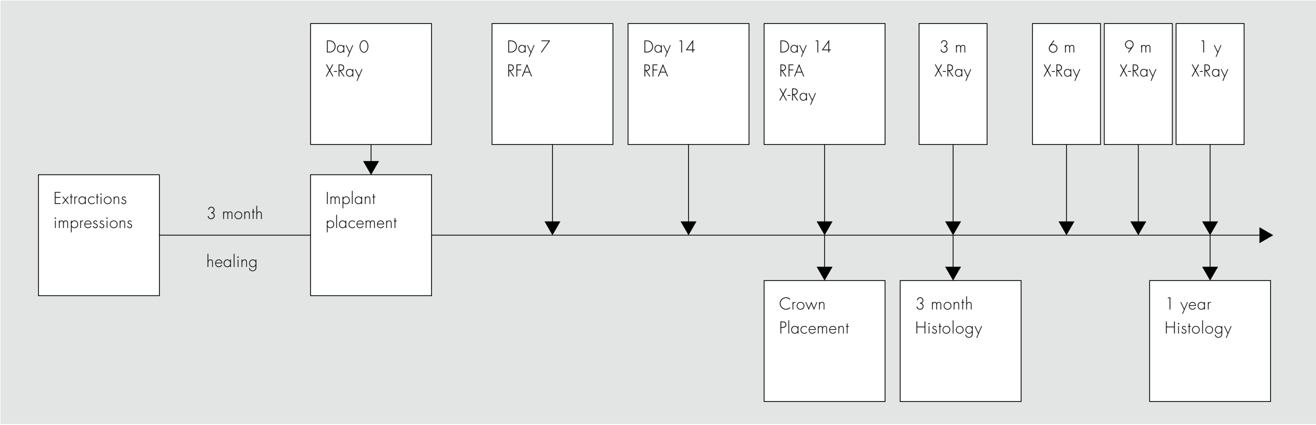
The purpose of this study is to evaluate SLActive implants under loaded conditions in the canine mandible. The specific aim is to evaluate the outcome of loading SLActive implants soon after implantation (3 weeks).

Material and Methods

The foxhound model was chosen to allow in vivo evaluation of SLActive in a higher animal species biologically similar to humans. Mandibular teeth were extracted from six adult foxhounds and the spaces allowed to heal. SLActive implants were placed in the healed edentulous spaces. After 3 weeks of healing, the implants were loaded with gold crowns. The implants were evaluated after short- and longer-term healing by clinical, radiographic, resonance frequency and histological analyses. Radio frequency analysis measurement was performed after 1, 2 and 3 weeks of healing. A peri-apical radiograph will be taken 3 months after loading, and a full histological and histomorphometric evaluation performed with three of the dogs. The remaining three animals will be evaluated by peri-apical radiography at 6, 9 and 12 months post-loading, with a full histological analysis after 12 months.

Planned evaluations

- The study will evaluate SLActive implants under loaded conditions in animals
- Radio frequency analysis will be carried out after 1, 2 and 3 weeks
- Peri-apical radiographs will be taken after 3, 6, 9 and 12 months
- The results will give an indication of the implant stability under early loaded conditions in an animal model



Clinical Impact Study 1: Multicenter
Immediate and early loading of Straumann 4.1 mm and 4.8 mm SLActive implants in the posterior mandible and maxilla
A controlled randomized study of single or 2–4 unit restorations loaded immediately or in the fourth week after surgery

A. Zöllner, first clinical results from the SLActive Multicenter study. European Association for Osseointegration, 14th annual scientific meeting, September 22–24, 2005, Munich, Germany
Ongoing study

Abstract: SLActive implants were placed in the mandible or maxilla and loaded either immediately or after four weeks. Immediate and early loading protocols appear to be similarly secure for SLActive implants, and the success rate thus far is promising.

Introduction

Immediate and early loading protocols are becoming increasingly important as patients' esthetic demands and expectations increase. Since SLActive implants promote more rapid osseointegration, they may be particularly useful in immediate and early loading protocols, with good survival and stability.

Material and Methods

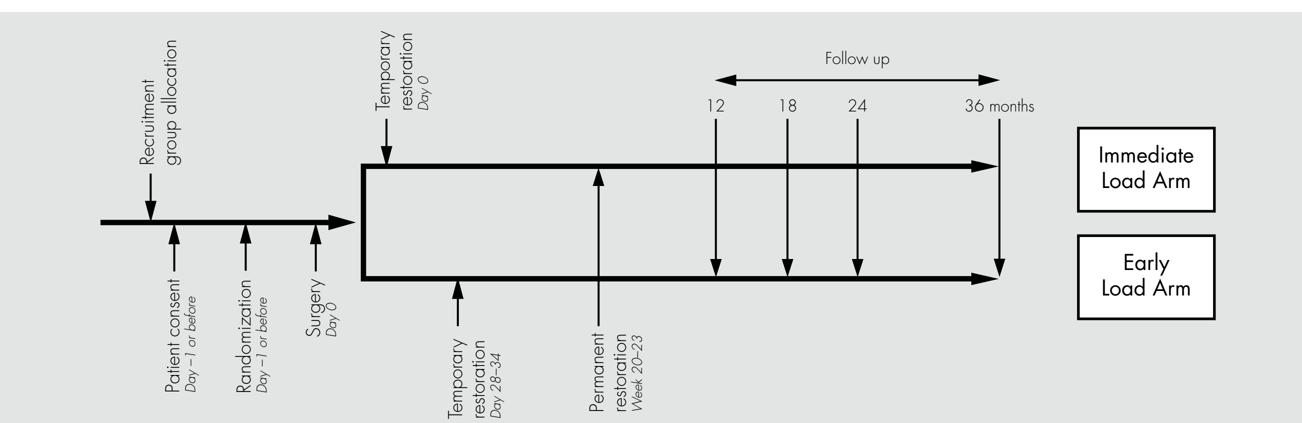
The Clinical Impact Study is being conducted at 19 centers in 10 countries worldwide (in Austria, Germany, Ireland, Netherlands, Portugal, Spain, Sweden, Switzerland, UK and USA). SLActive ∅ 4.1 and 4.8 mm implants were placed in patients in the posterior maxilla or mandible or both, and were either loaded with temporary restorations immediately (same day as surgery) or after 28–34 days. The permanent restoration for both groups was placed at weeks 20–23. To date, 249 patients have been randomized and a total of 363 implants placed (average 1.5 implants per patient). Success criteria include implant survival, lack of mobility, absence of radiolucency, infection, pain or structural failure, and < 2 mm bone resorption around the implant between visits.

Results

At the time of presentation, an implant survival rate of approximately 98 % was reported. The number of implants lost was approximately the same in both arms of the study. This suggests a similar degree of success for both protocols. Patient satisfaction, which includes evaluation of criteria such as comfort, appearance, and ability to chew and taste, has been reported as good or excellent in both groups.

Conclusions

- The interim results are in alignment with those from previous pre-clinical and ongoing clinical studies
- Immediate and early loading protocols have equal success rates for SLActive implants
- Impressive implant survival rate despite aggressive protocol can be shown



Clinical Impact Study 2: Field Trial
Clinical results with the SLActive surface in a 2-center study

D. Morton, first clinical results from the SLActive Field Trial, International Team for Implantology World Symposium, June 18–20, 2005, Munich, Germany and D. Buser, further clinical results, Congresso Italiano, November 25–26, 2005, Milano, Italy
Ongoing study

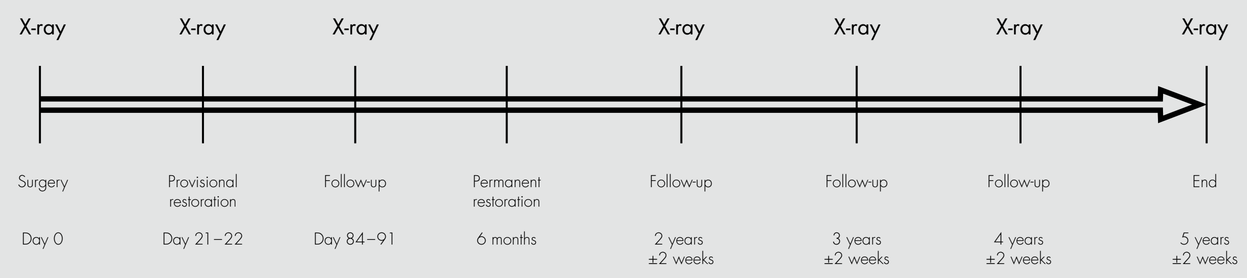
Abstract: The faster osseointegration with SLActive may allow for potentially more aggressive early loading protocols. Preliminary results from early loading suggest that aggressive early loading protocols and soft tissue healing are predictable after 3 weeks.

Introduction
The earlier increase in stability and faster osseointegration observed during investigations with SLActive may allow for increased predictability early and immediate loading procedures for dental implants. For early loading procedures, therefore, it is useful to investigate the earliest possible time at which permanent loading could be performed. The time hypothesized to be the earliest in which post-surgical discomfort and soft tissue swelling have subsided is 21–22 days.

Material and Methods
The study is being conducted at two centers in Switzerland (University of Berne; D. Buser) and the US (University of Florida, Center for Implant Dentistry; D. Morton). Up to 80 SLActive implants (Ø 4.1 and 4.8 mm) will be placed in the mandible or maxilla of 60 patients and allowed to heal. After 21–22 days, the implants are restored with a temporary restoration in functional occlusion. X-rays are taken at the time of surgery and at follow-up visits after 3 months and 1 year.

Results
Preliminary analysis of 45 implants so far suggests that early loading after only 3 weeks does not increase the risk of implant loss when compared to conventional implant loading protocols of between 6 weeks and 3 months. Furthermore, results suggest that soft tissue is ready three weeks after implant placement.

Preliminary findings
- Results suggest that an aggressive early loading protocol (3 weeks) is predictable with SLActive
- Soft tissue is ready 3 weeks after implant placement



Clinical Impact Study 3: Osstell
A prospective randomized clinical trial to compare the stability of standard SLA and SLActive implants during the first 6 weeks of healing using resonance frequency analysis

T. Oates, P. Valderrama, M. Bischof, R. Nedir, A. Jones, J. Simpson, D. L. Cochran
Submitted to J. Dent. Res.

Abstract: Implant stability, measured by resonance frequency analysis, was compared for SLA and SLActive implants over the first 12 weeks following implant placement in humans. After an initial decrease in stability for both groups, stability increased with SLActive implants at a much earlier stage than with SLA implants (2 weeks versus 4 weeks).

Introduction
Advances in understanding the influence of implant surface properties on osseointegration have led to shorter healing times from implant placement to permanent restoration. More recently, investigations into the effects of alterations of the surface chemistry have also translated into potential clinical benefits. The chemically modified hydrophilic SLActive surface has been shown in animal studies to increase bone-to-implant contact during the first 4 weeks of healing, compared to SLA. This suggests an enhancement of osseointegration that may translate into an improvement in initial implant stability. The aim of this clinical study, therefore, was to measure and compare the implant stability over the first 3 months following implant placement using resonance frequency analysis.

Material and Methods
In a total of 31 patients with at least 2 missing teeth in the posterior mandible or maxilla, 62 implants were placed (one SLA and one SLActive implant in each patient). No bone grafting or guided bone regeneration was used; implants were placed only into healed ridges (> 4 months post-extraction) with sufficient bone. Resonance frequency analysis, by use of an Osstell device, was measured at 0, 1, 2, 3, 4, 5, 6 and 12 weeks after implant placement. The Osstell device measures stability by an implant stability quotient over a range from 1 to 100. Statistical analysis was performed by means of the Chow test, which makes the assumption that data can be represented by two straight lines and then identifies the break point in the data.

		Number of implants	Breakpoint	Significance
SLActive	maxilla	6	3 weeks	0.00078*
	mandible	**25**	**2 weeks**	**0.00001***
SLA	maxilla	6	3 weeks	0.64277 (n.s.)
	mandible	**25**	**4 weeks**	**< 0.00001***

*** = significant** **n.s.= no significance**

Results
All 62 implants were successfully restored and osseointegrated. Both SLA and SLActive implants showed a similar initial level of stability, decreasing initially and then increasing within the first 6 weeks. Within this 6-week period, however, SLActive implants demonstrated a significantly different change in stability patterns compared to SLA implants. The break point, i.e. the change from decreasing to increasing stability, occurred after 2 weeks with SLActive ($p < 0.0001$), compared to the change with SLA implants, which occurred at 4 weeks. Significance was not seen in the maxilla. However, the much smaller implant numbers for the maxilla may be an important factor.

The identification of the breakpoint suggests a change in the overall bone remodeling from predominantly resorptive to predominantly formative. The shift in this transition point from 4 weeks with SLA to 2 weeks with SLActive therefore suggests accelerated osseointegration on the SLActive surface compared to SLA.

Conclusions
- Significant improvement in the stability pattern with SLActive
- Increase in stability at an earlier stage with SLActive (break point after 2 weeks with SLActive versus 4 weeks with SLA)
- Results support faster osseointegration with SLActive

5-year meta-analysis on the Straumann SLA Implant Surface: Clinically proven reduced healing time

Documented 04/2004, M. de Wild

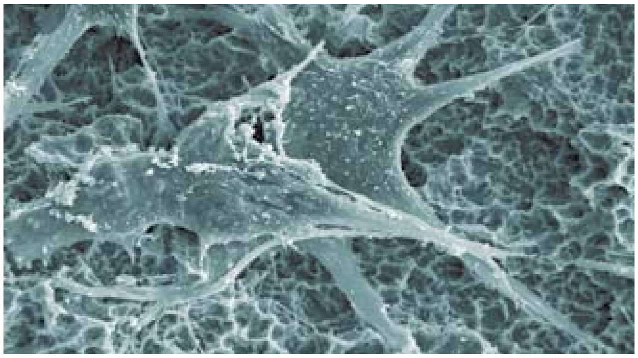
SLActive is based on the scientifically proven SLA topography. For the first time a meta-analysis has been done with 5-year data, showing exceptional success and survival rates with SLA implants. The SLA meta-analysis can be ordered from Straumann under the article number 152.526.

Summary

Straumann dental implants with an SLA endosseous surface offer a promising solution for rapid anchoring in the bone. Restoration as early as after six weeks of healing with a high predictability of success is the standard treatment of today.

In vitro experiments on cell cultures attest the SLA surface an osteoconductive property. Removal torque experiments and histologic analyses from animal studies further confirm the fast osseointegration of the implants with the SLA surface.

Results from clinical studies are excellent. Five years after restoration, the overall implant survival rates to date are greater than 99%, as shown in a prospective multicenter study. Patients benefit from early-loaded implant restorations. They resume function quickly following surgery and provisional restoration.



Conclusions

In summary, animal studies consistently demonstrate that the performance of the rough SLA surface is superior to smooth surfaces with respect to bone contact levels and removal torques and thus early loading. Cell culture studies found that surfaces modify the phenotypic expression of osteoblasts, suggesting that surface-modulated cellular processes may explain the histological and biomechanical performance. The most important property of this surface, which is relevant to implant design and use, is its high load-bearing capability, as demonstrated in the removal torque animal experiments. The SLA surface, throughout all the tests, performed better than the other titanium surfaces tested. The clinical trials demonstrate that, under defined conditions, Straumann Standard implants with an SLA endosseous surface can be restored after six weeks of healing with a very high predictability of success, defined by abutment placement at 35 Ncm without counter torque, and with subsequent implant survival rates of greater than 98.62% five years after restoration. The SLA implant surface is optimized mechanically and topographically and is state of the art for dental implants.

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