
The Straumann SLA® Implant Surface: Clinically Proven Reduced Healing Time

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 in-vivo 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.

Introduction

For many patients, immediate functional loading of implants is an obvious advantage. A long treatment period that involves the wearing of a temporary restoration may be of great inconvenience and is sometimes the reason for not choosing implant-supported restorations. However, early loading requires a fast integration of the implant into the surrounding bone, and the osseointegration strongly depends on the material properties of the implant. A typical dental implant is shown in figure 1.

Titanium is among the most biocompatible materials known [1–2], and the metal has demonstrated such success in biomedical devices, including dental and orthopedic implants, that titanium for medical purposes promises to develop into a multibillion-dollar market. The widespread and successful application of titanium in dental implants is unquestionable. The endosseous part of the implant, which appears grayish, is equipped with the SLA surface. The abbreviation SLA was introduced by Buser et al. in a histomorphometric study in 1991 [3] and stands for **S**and-blasted, **L**arge grit, **A**cid-etched.

This titanium surface has been intensively tested in recent years both in-vitro [4–6] and in-vivo [3, 7]. Cell culture tests, bone histologies and removal torque tests in animals demonstrate the SLA surface to be a superior choice of implant-to-bone interface. This trend for a better and faster bone integration of SLA implants in the initial healing period, reported by several authors, may be due to a higher production of local cytokines and growth factors, as demonstrated

by Kieswetter et al. [5] in an in-vitro study with osteoblast-like cells. The in-vivo studies demonstrated predominantly superior results for the SLA surface concerning implant integration and implant anchorage compared with other surfaces (titanium plasma-sprayed, machined), in particular during the initial healing period after implant placement.

The Straumann SLA surface (US Patent Number: 5,456,723) has performed extremely well in a prospective multicenter clinical study up to 5 years (between 2 and 5 years) on 145 patients.

The surface was developed to produce both high percentages of bone-to-implant contact in descriptive histomorphometric studies [8] and high removal torque values in functional studies [9].

The Straumann SLA® Implant Surface

The SLA surface is produced by a large grit sand-blasting process with corundum particles that leads to a macro-roughness on the titanium surface. This is followed by a strong acid-etching bath with a mixture of HCl/H₂SO₄ at elevated temperature for several minutes. This produces the fine 2–4 µm micropits superimposed on the rough-blasted surface, as seen in the scanning electron microscope (SEM) picture of the SLA surface in figure 2. The surface is not microporous and therefore provides no enclosed volumes to reduce vulnerability to bacteria.

The chemical composition of the SLA structure was found to be titanium oxide (TiO₂) using X-ray photoelectron spectroscopy. This method analyses the first few atomic layers of the surface, and thus the chemical composition of the material which is in direct contact and interacts with tissue fluids and cells.

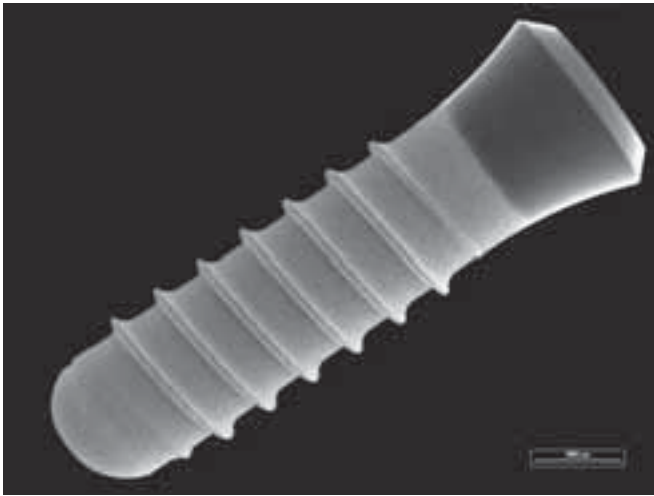


Figure 1: Straumann Standard Implant with endosseous SLA surface and polished neck.

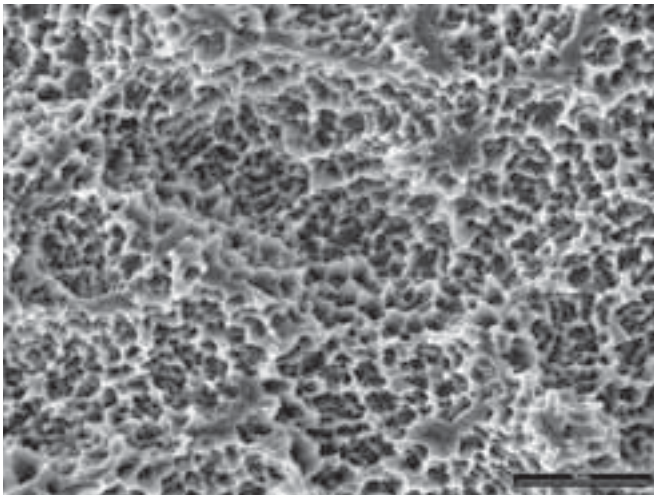


Figure 2: SEM picture of the SLA surface. $100 \times 75 \mu\text{m}^2$. The macro and the micro roughnesses are identifiable.

In-vitro Data

The first reaction between the host and the implant is conditioned by body tissue fluids. This produces a layer of organic macromolecules and water, which influences the behavior of cells when they encounter the surface. Following these events, a series of cell/surface interactions takes place leading to the release of chemotactic and growth factors, which modulate cellular activity in the surrounding tissue. Because the surface-chemical composition of all titanium surfaces studied is almost identical, any differences in cell modulation are most likely to be due to variations in the surface topography [6, 10].

Surface roughness was shown to have an effect on the proliferation, differentiation, and protein synthesis (including growth regulatory substances) of human osteoblast-like cells [4–5]. The Prostaglandin enzyme E_2 (PGE_2) production of MG63 human-like cells, that serves as a marker for early differentiation, is enhanced at increasing substrate roughness [5] and is significantly higher on the SLA than on other surfaces, see figure 3. PGE_2 is a local factor produced by osteoblasts and is important in promoting wound healing and bone formation, and a high production enhances implant integration. Kieswetter et al. [5] further looked at cytokines and growth factors, which could influence the quality, extent,

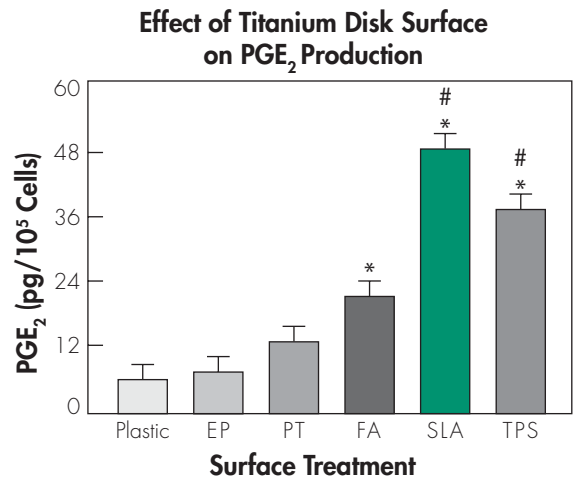


Figure 3: Prostaglandin E_2 (PGE_2) production per 10^5 cells cultured on tissue culture plastic, or Ti with one of the five following surfaces, ranked from smoothest to roughest: electropolished (EP), pretreated surface (PT), fine grit-blasted (FA), coarse sand-blasted, etched with HCl and H_2SO_4 , and washed (SLA), and Ti plasma-sprayed (TPS) [5].

and rate of bone formation at the bone/implant interface. This roughness dependence can be the result of the surface roughness itself or the result of the reactions which occur as the material surface is conditioned by the media and serum. This initial interaction produces a layer of macromolecules that modify the behavior of the cells.

These in-vitro studies [5] have shown that osteoblasts grown on the SLA surface exhibit properties of highly differentiated bone cells suggesting that this surface is osteoconductive. Results from these experimental studies reinforce the concept of enhanced bone formation around the sand-blasted and acid-etched surface and the possibility of reduced clinical healing times prior to restoration.

In-vivo Data

The anchorage of implants in grown bone was analyzed in in-vivo studies. The rigid bone/implant interface (see figure 4) was originally observed in a histological investigation [3]. The bone-to-implant contact is found to be higher on rougher surfaces like the SLA surface than on smoother interfaces. With five different titanium surfaces, Buser demonstrated that a positive correlation exists between the percentage of bone-to-implant contact and the roughness value of similarly shaped implants under short-term healing periods of 3 and 6 weeks.

Many dental clinical implant studies [8–9, 11] have focused on the success of endosseous implants with a variety of surface characteristics. Most of the surface alterations have been aimed at achieving greater bone-to-implant contact as determined histometrically at the light microscopic level.

For the first time, Buser et al. studied the SLA surface biomechanically in jaw bone, evaluating the interface shear strength of SLA implants in the maxilla of miniature pigs [8]. This animal was chosen as the pig bone structure is comparable to the bone structure of humans. The two best-documented titanium surfaces in implant dentistry, the machined and the titanium plasma-sprayed (TPS) surface, served as

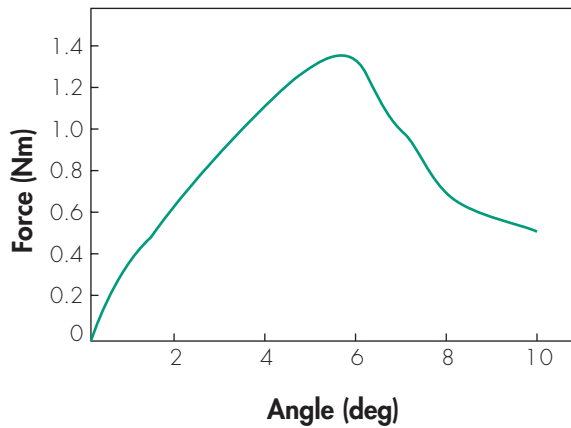


Figure 5: Typical graph of a removal torque test. The peak of the curve was deemed the failure torque of the bone/implant interface [8].

controls. The removal torque testing was performed on a biaxial hydraulic materials testing machine by applying a counterclockwise rotation to the implant axis at a rate of 0.1°/sec. The torque-rotation curve was recorded as shown in figure 5. To characterize the bone/implant interface, the removal torque was defined as the maximum torque on the curve.

The removal torque, which is a measure of the degree of osseointegration, of the SLA implants demonstrated a higher mean removal torque value at 4 and 8 weeks of healing than the control surfaces (figure 6). The two rough surfaces, the SLA and the TPS surfaces, show a significant difference to the machined surface.

Further, the bone/implant interface was analyzed histologically after the removal process. The histological samples of the machined implants always demonstrated a separation along the implant surface at the bone/implant interface. The SLA surface, on the other hand, often showed fractures of bone trabeculae close to the implant surface, but an intact bone/implant interface, indicating a strong physical interlock between the rough titanium surface and bone.

These findings indicate that SLA implants feature a greater bone-to-implant contact and higher removal torque values than comparably shaped implants with different surfaces.

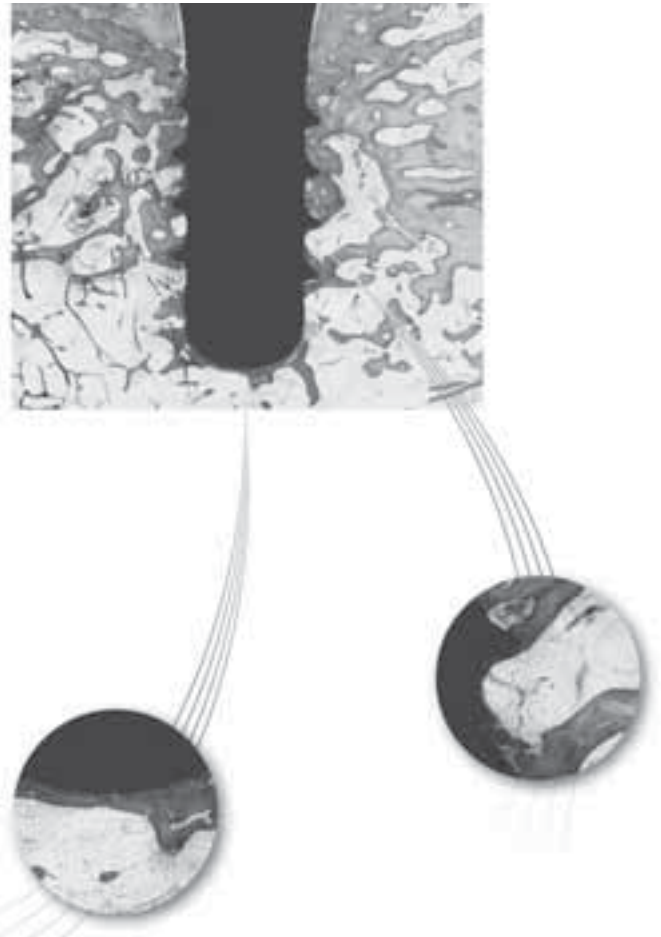


Figure 4: The histologic analyses of SLA implants demonstrate improved osseointegration with a high percentage of bone/implant contact.

Courtesy of Dr. Paul Quinlan, Private Practice, Dublin, Ireland, and Department of Periodontics, University of Texas Health Science Center at San Antonio, Texas, and Prof. Robert Schenk, University Bern, Switzerland.

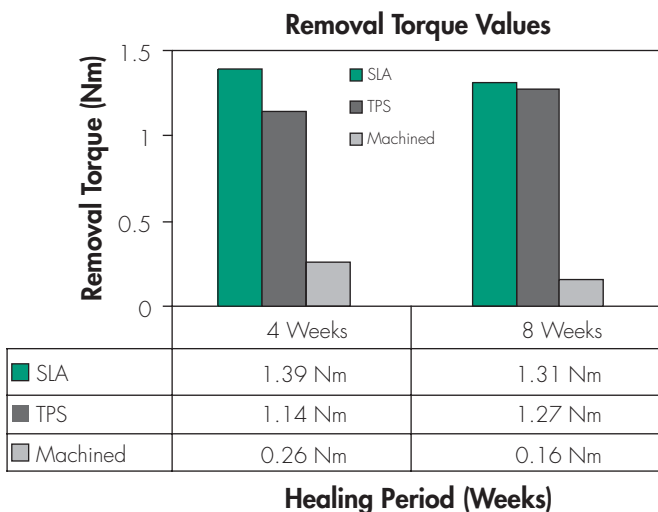


Figure 6: Removal torque values of the three implant types after 4 and 8 weeks of healing [8].

Clinical Data

In a prospective clinical study, Cochran et al. [12] reported that 4.1 mm diameter Straumann Standard implants can be predictably and safely restored as early as six to eight weeks after implant placement for bone classes I to III, and 12 to 14 weeks for bone class IV.

This study, including six centers in four countries, was approved by local IRB and Ethics Commission. The purpose of the study was to evaluate the placement and restoration of endosseous dental implants that had a sand-blasted and acid-etched surface, where the implant was in contact with osseous tissue and the abutment was placed after approximately six weeks of healing, see figure 7. The results demonstrated a high success rate for abutment connection, using 35 Ncm without counter torque, as well as a high rate of implant success after five years of loading.

Patients were divided in three different groups:

A: Patients with more than one tooth missing in the posterior mandible.

B: Patients with more than one tooth missing in the posterior maxilla.

C: Patients with four or more implants in the mandible.

One hundred and forty five patients received 431 implants. The average age of the patients was 55.5 years (21.4 to 82.1, standard deviation 11.36, see figure 8). The implants were placed using the surgical procedure that was advocated by the manufacturer. Three hundred and seventy implants (86%) underwent the 3-year, 260 (60%) the 4-year follow-up. Apart from the 3 implants which were reported as failures by Cochran et al. no additional implant failed at follow-up giving an cumulative survival rate of 99.29% at five years (group A: 99.54%, group B: 100%, and group C: 98.62%, see table 1). All implant failures were due to lack of osseointegration and were detected at abutment placement or earlier. The five-year follow-up results (minimum 2 years and maximum 5 years) confirm the results already reported [12-14].

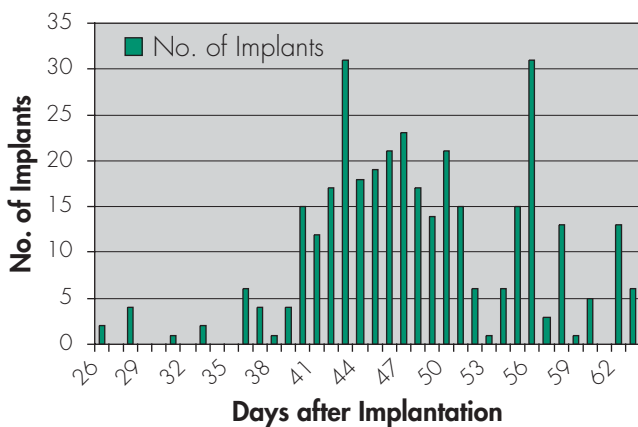


Figure 7: Time of abutment placement for bone quality III.

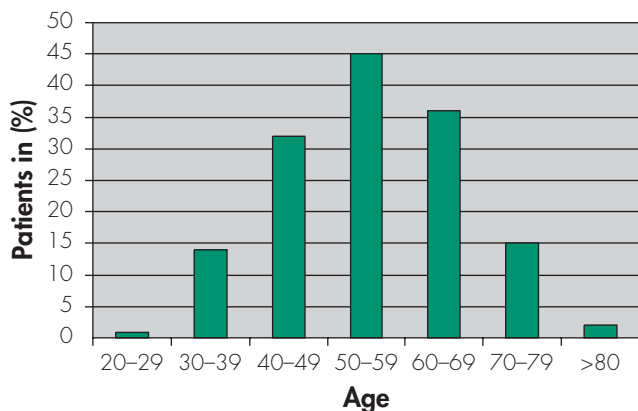


Figure 8: Patient age distribution.

| Group | Interval (month) | No. of Implants (4.1 mm only) at start of interval (n) | Number of terminal events (n) | Survival rate for interval (%) | Cumulative implant survival (%) |
|----------------|------------------|--|-------------------------------|--------------------------------|---------------------------------|
| A, B, C | 0-12 | 431 | 3 | 99.29 | 99.29 |
| | 12-24 | 414 | 0 | 100 | 99.29 |
| | 24-36 | 404 | 0 | 100 | 99.29 |
| | 36-48 | 370 | 0 | 100 | 99.29 |
| | 48-60 | 260 | 0 | 100 | 99.29 |
| | 60- | 43 | 0 | 100 | 99.29 |
| A | 0-12 | 221 | 1 | 99.54 | 99.54 |
| | 12-24 | 215 | 0 | 100 | 99.54 |
| | 24-36 | 208 | 0 | 100 | 99.54 |
| | 36-48 | 187 | 0 | 100 | 99.54 |
| | 48-60 | 126 | 0 | 100 | 99.54 |
| | 60- | 25 | 0 | 100 | 99.54 |
| B | 0-12 | 52 | 0 | 100 | 100 |
| | 12-24 | 52 | 0 | 100 | 100 |
| | 24-36 | 49 | 0 | 100 | 100 |
| | 36-48 | 44 | 0 | 100 | 100 |
| | 48-60 | 22 | 0 | 100 | 100 |
| | 60- | 4 | 0 | 100 | 100 |
| C | 0-12 | 147 | 2 | 98.62 | 98.62 |
| | 12-24 | 141 | 0 | 100 | 98.62 |
| | 24-36 | 141 | 0 | 100 | 98.62 |
| | 36-48 | 133 | 0 | 100 | 98.62 |
| | 48-60 | 108 | 0 | 100 | 98.62 |
| | 60- | 13 | 0 | 100 | 98.62 |

Table 1: Life table analysis

These results are in accordance with the results obtained by Rocuzzo et al. [13] in a prospective double blind clinical study, including 32 patients with bilateral and similar edentulous areas. In this study sand-blasted and acid-etched implants were compared to titanium plasma-sprayed implants under loaded condition after one year. Abutment connection was carried out at 35 Ncm after 43 ± 1 days for test site and after 86 ± 2 days for control site. No significant differences were found with respect to presence of plaque, bleeding on probing, mean pocket depth or mean marginal bone loss.

Clinical results demonstrate that the restoration of a Straumann SLA implant from six weeks after implant placement is an excellent treatment option in healthy patients with good bone.

Conclusions

In summary, 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 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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National Distributor

International Headquarters

Institut Straumann AG
Peter-Merian-Weg 12
Postfach
CH-4002 Basel
Switzerland
Phone +41 (0) 61 965 11 11
Fax +41 (0) 61 965 11 01
www.straumann.com
