Daniel Perrin
Serge Szmukler-Moncler
Casimir Echikou
Philippe Pointaire
Jean-Pierre Bernard

Bone response to alteration of surface topography and surface composition of sandblasted and acid etched (SLA) implants

Perrin Daniel, Echikou Casimir, Department of Odontology, CHU Dijon, *Philippe Pointaire*, Department of Anesthesiology & Reanimation, CHU Dijon, Dijon, *Serge Szmukler-Moncler*, UFR of Stomatology & Maxillo-facial Surgery, University of Paris VI, Paris, France, *Serge Szmukler-Moncler, Jean-Pierre Bernard*, Department of Oral Surgery, School of Dental Medicine, University of Geneva, Switzerland

Correspondence to:
Dr Daniel Perrin
Service d'Odontologie
CHU Dijon
3 rue du Faubourg Raines
Dijon, F-21033 Cedex
France
Tel: +33 80 29 39 88
Fax: +33 80 29 51 44
e-mail: daniel.perrin@u-bourgogne.fr

Key words: etched implants, hydrogen, pig model, SLA, surface alteration, titanium hydride

Abstract: The titanium surface obtained by sandblasting and etching (SLA) is an easily alterable surface that smears and loose its typical texture. In addition, the etching process modifies the surface composition of commercially pure titanium; the latter contains titanium and an added 20–40% of titanium hydride. Therefore, the influence of a heavy surface alteration and the influence of the composition at the SLA surface, i.e. with and without titanium hydride, were investigated *in vivo*. Three implant groups were inserted in the mandible of Land Race pigs and left to heal during 10 weeks in a submerged way: (1) a standard SLA control group (SLAstd) with the SLA surface containing titanium hydride; (2) a test group with the SLA surface heavily altered at the thread level (SLAalt); (3) a test group with an SLA surface devoid of titanium hydride (SLAT). Sample size was $n = 8$. Histomorphometry analysis did not show a statistically significant difference between the control group (SLAstd: 82.12 + 6.1%), the altered surface test group (SLAalt: 86.25 + 7.4%) and the SLA without titanium hydride test group (SLAT: 75.12 + 7.6%). The data suggest that alteration of the SLA surface, if it occurs, should not be detrimental to bone response. The soft and easy smearable SLA surface might even be an advantage when surface maintenance is required. Surface composition did not play a significant role in the bone response to the SLA surface and it can therefore be concluded that the osteophilic properties of the SLA surface are due to its surface topography and not to its specific surface composition.

Date:
Accepted 31 August 2001

To cite this article:
Perrin D, Szmukler-Moncler S, Echikou C, Pointaire P, Bernard JP. Bone response to alteration of surface topography and surface composition of sandblasted and acid etched (SLA) implants
Clin. Oral Impl. Res, **13**, 2002; 465–469

ISSN 0905-7161

The first *in vivo* study reporting on a textured titanium surface obtained by sandblasting and acid etching (SLA) was published in 1990 (Wilke et al. 1990). Several studies have investigated its biological properties (Buser et al. 1991; Cochran et al. 1994; Martin et al. 1995; Wong et al. 1995; Buser et al. 1998; Cochran et al. 1998; Buser et al. 1999), however, little is known about its physico-chemical characteristics. Observation has shown that the dull SLA surface is soft (Szmukler-Moncler et al. 1999), particularly when compared with a titanium–plasma sprayed (TPS) surface. Shiny spots appear at the SLA surface when damaged during the handling or packaging process, or when removed from the sterile ampoule. Scanning electron microscopy (SEM) demonstrated that these shiny spots correspond to smearing of the soft surface, with alteration of the microtopography (Fig. 1a). Subsequently, the question arose of how bone would respond to an extensive alteration of SLA-treated implants, as could happen during either implant insertion in hard bone or from undue implant manipulation.

It has also been reported that the etching process modifies the titanium surface composition of SLA-treated implants. X-ray diffraction (XRD) analysis of SLA-treated titanium samples showed the presence of

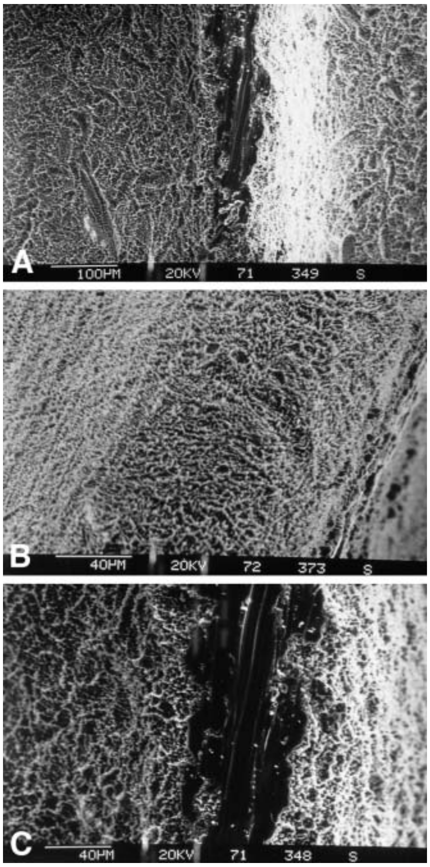

Fig. 1. Alteration of the SLA topography. (a) Alteration of the macro- and microtopography. The altered surface looks shiny when compared to the darkened unaltered surface (b) Micrograph of an unaltered implant belonging to the SLAstd control group.(c) Micrograph of an altered thread belonging to the SLAalt test group. The topography alterations were obtained by squeezing the whole thread perimeter with titanium tweezers.

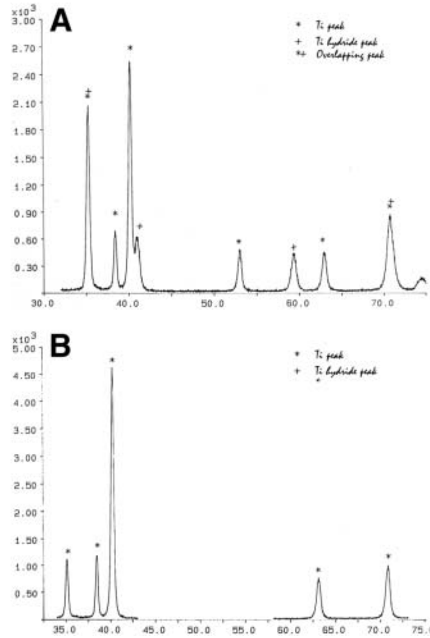

Fig. 2. X-ray diffraction spectra of a SLA-treated sample. (a) Spectrum issued from a control, untreated sample. Peaks belonging to titanium (*) and to titanium hydride (+) are seen. Some peaks belonging to the two structures overlap (* +). (b) Spectrum issued from a sample heat-treated at 200 °C for 3 h. The titanium hydride peaks (+) have disappeared and only the titanium structure (*) is found.

20–40% of titanium hydride (δ-TiH2-x) in addition to titanium (Szmukler-Moncler & Simpson 1996). Taborelli et al. (1997) confirmed the presence of a high and unusual amount of hydrogen in etched titanium samples. Consequently, it was questioned if the biologic and the osteophilic properties of the SLA surface were due to its defined surface micro- and macro-topography (Martin et al. 1995; Szmukler-Moncler & Simpson 1996) or rather due to its specific surface composition, i.e. enriched with titanium hydride.

The present paper addresses the issue of bone response to a heavily altered SLA surface and to modification of the surface composition, i.e. with and without titanium hydride.

Material and methods

Implants

ITI implants 4.1 mm in diameter and 8 mm long were sandblasted and acid etched in a hot mixture of HCl/H_2SO_4 (Wong et al. 1995), they were further separated in three groups, one control and two test groups. The implants of the first test group had all their threads damaged with titanium tweezers, to simulate a heavy surface alteration (SLAalt); Fig. 1 shows the aspect of the damaged SLA implants. The implants of the second test group were heat-treated at 200 °C over 3 h to remove the titanium hydride compound from the surface (SLAT). Fig 2 (a, b) shows the XRD spectra obtained at a reference SLA surface before and after heat treatment. The XRD patterns were recorded with a SIEMENS 8000 diffractometer using a CuKα source at 40 kV and 30 mA. Scans were conducted between 35° to 75° 2θ angle values. Before heat treatment, titanium (JPCDS 6–582) and titanium hydride (JPCDS 25–982, δ-TiH2) were identified on the surface (Fig. 2a). Following heat treatment, the peaks belonging to the titanium hydride compound disappeared (Fig. 2b), leaving a pure titanium surface (JPCDS 6–582) without modifying the typical SLA textured topography. The implants of the third group served as a control (SLAstd) to the two test groups. After etching, this implant group was not further treated; the SLA surface was therefore enriched with titanium hydride and presented its characteristic topography (Fig. 1b). Sample size was $n = 8$ for each group.

Animal model

Implants were inserted in the mandible of two adult female Land Race pigs weighting 180–200 kg. This specific animal model allows for the placement of up to 8–10 implants per hemi-mandible. Animal sacrifice is not necessary because implants can be retrieved through segmental osteotomy.

The canines and premolars were extracted in both sides and the sockets were left to heal for 3 months. This provided a 90–100 mm space per hemi-mandible for implant insertion. A flap was raised and implants were placed according to the manufacturer's instructions. Implants were left to heal in the submerged way instead of transgingivally because dental hygiene cannot be performed in this animal model without anesthesia. Implants were randomly inserted in alternation, starting with SLAstd, followed by SLAalt and then by SLAT. After placement, the flaps were sutured over the implants.

After 10 weeks of healing, the animals were anesthetized. Blocks containing the implants were obtained through segmental osteotomy. They were fixed in buffered formalin and processed for histology. Two thin central slices of 30–40 μm were obtained at each implant and stained with Paragon. Histomorphometry was performed using a light microscope coupled with a color image analyzing system (Samba, Allocate, France) at ×30–50 magnification.

Statistics

In this study, the first hypothesis was that surface alteration has the capacity to decrease the bone implant contact (BIC) when compared to the control surface state. The second hypothesis was that the titanium hydride-rich surface layer plays a determinant role in the bone response to

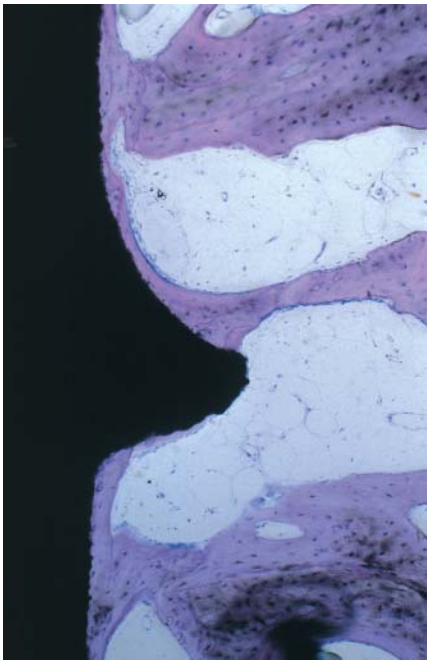

Fig. 3. Micrograph of an implant belonging to the SLAstd control group. The marrow spaces are closed by thin bone trabecules. This suggests that the SLA surface has good osteoconductive properties. Original magnification, ×25.

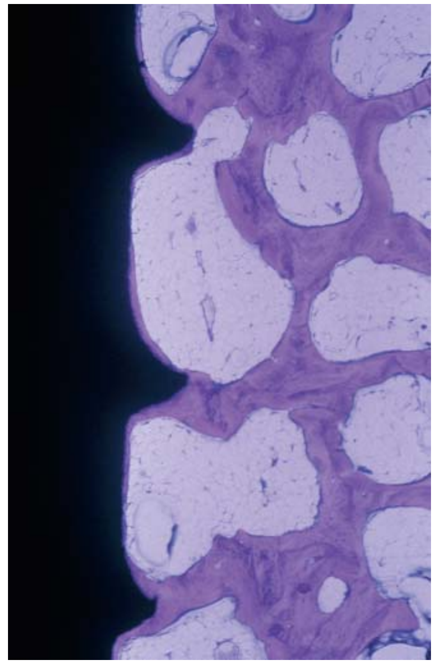

Fig. 4. Micrograph of an implant belonging to the SLAstd control group. Bones trabecules were found, oriented perpendicular to the threads. Note also the marrow spaces between the threads, closed by thin bone trabecules running along the SLA surface. Original magnification, ×10.

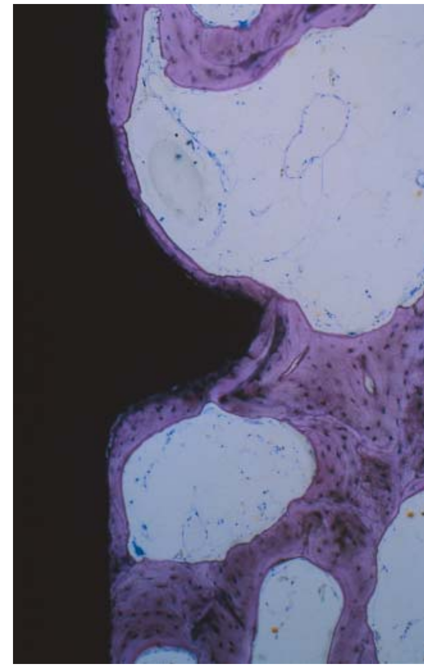

Fig. 5. Micrograph of an implant belonging to the SLAalt group. The alteration of the SLA topography at the thread level did not disturb the bone apposition process. Original magnification, ×25.

the SLA surface, i.e. the SLA surface with titanium hydride achieves a higher BIC than the SLA surface without titanium hydride. Statistical analysis was performed using the Wilcoxon signed rank test for nonparametric data. The SLAstd and SLAalt groups were compared in a test where surface alteration was the variable (respectively, nonaltered surface vs. altered surface). The SLAstd and the SLAT groups were compared in another test where surface composition was the variable (respectively, surface with titanium hydride vs. surface without titanium hydride). Statistical significance was set at 5%.

Results

All implants remained submerged. All three groups showed a similar bone response. Of note, new bone closed the marrow spaces in contact with implant surface (Fig. 3). Bone trabecules were found to be preferentially orientated at the thread level of the implants (Fig. 4). No specific bone features could be recognized at the heavily altered threads of the SLAalt group (Fig. 5). The BIC for this test group was 86.25 ± 7.4%, the BIC for the control SLAstd group was 82.12 ± 6.1%. The difference between these two groups was not statistically significant ($P = 0.09$); surface alteration did not decrease the level of BIC. The BIC for the test SLAT group without titanium hydride was 75.12 ± 7.6%; the difference with the control group was not statistically significant ($P = 0.05$). The titanium hydride did not play a contributing role to the level of BIC for the SLA surface.

Discussion

The present histological findings are consistent with the results of Cochran et al. (1998). The SLA surface seems to have the ability to close the marrow spaces with new bone when inserted in rather spongious bone, leading to a quasi-continuous layer of bone running along the implant surface. This property could explain the higher BIC level recorded at the SLA surface when compared to the TPS surface (Buser et al. 1991). When pooled together, the mean BIC of the three groups was 81.16%, higher than the 72.33% reported by Cochran et al. (1998) after 12 weeks of healing. In our study, bone was more spongious than in the dog experiment of Cochran et al. (1998). It is probable that the SLA surface expresses more readily its osteophilic properties in spongious bone rather than in cortical bone, as described for bioactive coatings (Szmukler-Moncler et al. 2001). Less bone apposition was noted at the implant apex only. Another consistent finding was the preferential trabecular orientation and distribution at the implant threads (Fig. 4). Gross et al. (1990) attributed this feature to rough surfaces, in contrast to machined surfaces, which lead to bone corticalization. Bone trabeculization instead of corticalization leads to a faster implant immobilization; this could explain why SLA implants can be predictably loaded as early as 6–8 weeks after surgery in the mandible and in the maxilla (Cochran et al. 2002).

Easy alteration of the SLA surface is reported in this study. This trait is not specific to the SLA surface but is common to all etched surfaces. The etching process carves the titanium surface at a depth of 2–5 μm (Taborelli et al. 1997) and leaves a soft and smearable surface. Although delicate, the SLA surface allows for high micromechanical anchorage of bone in the created pits (Wong et al. 1995). Curiously, this soft surface is able to achieve reverse torque resistance as high (Buser et al. 1999) or even higher than the hard TPS surface (Wilke et al. 1990).

Easy smearing of the SLA surface might be an advantage over the TPS surface when cleaning procedures are required at ITI implants, e.g. following surface exposure and plaque contamination. The TPS surface is peculiarly hard because the starting titanium hydride powder reacts with oxygen and nitrogen during the atmospheric plasma-spray process and forms hard oxynitride titanium compounds (Steinemann 1991). Its smoothing should require hard instruments. With the SLA surface, softer curetting instruments might be used, which could lead to a faster and more efficient cleaning procedure.

In the present experiment, heavy surface alteration was expressly performed. This is far from occurring under usual conditions, but may happen when implants are inserted in type I bone without pretapping. Our histological data show that it did not have any influence on bone response even at the threaded level. Surface alteration is spectacular as the darkened etched surface becomes shiny; however, the surface occupied by the smeared area is limited to approximately 50μm in width (Fig. 1c). Therefore, a deleterious bone reaction subsequent to any heavy SLA surface alteration is not to be expected.

Hydrogen diffusion in titanium is facilitated in the presence of native hydrogen (H^+), when high temperatures (>80°C) and acidic environments (pH<3) are encountered (ASM Handbook of metals). All these conditions are met during the etching process (Szmukler-Moncler & Simpson 1996), therefore the titanium hydride-rich layer that is built-up during preparation of the SLA surface cannot be avoided. This means that the surface that served to establish the biological properties of the SLA surface (Wilke et al. 1990; Buser et al. 1991; Cochran et al. 1994, 1998; Martin et al. 1995) contained this titanium hydride-rich layer. The titanium hydride-rich layer could have dictated a distinct arrangement of the superficial dense titanium oxide layer (TiO_2) as has been observed for titanium alloys (Lausmaa et al. 1990) and could have created a distinct surface reactivity. According to the present BIC data, the surface composition of the SLA surface (with or without titanium hydride) did not appear to be a significant parameter dictating bone response. Therefore, it can be concluded that it is the topography of the SLA surface, with its combination of macro- and microroughness, that is responsible for its enhanced bone response when compared to other titanium surfaces (Buser et al. 1991; Cochran et al. 1998) and not its specific surface composition.

The titanium hydride and the trapped interstitial hydrogen of the SLA surface are separated from the biological environment by a dense stoichiometric layer of TiO_2 that prevents them from effusing (Taborelli et al. 1997) and interacting. Hydrogen effusion out of acid-treated surfaces has only been measured at >400°C under high vacuum conditions, when the TiO_2 layer starts to decompose (Taborelli et al. 1997). Subsequently, the titanium hydride contained in the SLAT group disappears from the surface by being thermodynamically 'pushed' toward the bulk, therefore it was no longer detectable by XRD (Fig. 2b). The only way to remove the titanium hydride completely from etched implants is to submit them to temperatures >400°C in vacuum (Taborelli et al. 1997). However, this thermal treatment decreases the mechanical properties of titanium, especially when cold-worked (Steinemann 1991).

In conclusion, the present experiment has provided new information on the SLA surface implemented on ITI implants. Heavy local alteration of the topography and modification of the surface composition did not influence the bone response to the SLA surface. The soft and easily smearable surface may be advantageous when surface maintenance is required.

Acknowledgments: The staff at INRA Dijon is gratefully acknowledged for its outstanding professionalism. This study was partially supported by an AFI (Association Française d'Implantologie) grant.

Résumé

La surface de titane obtenue par sablage et mordançage (SLA) est une surface aisément altérable qui peut perdre sa texture typique. De plus, le processus de mordançage modifie la composition de surface du titane commercialement pur, ce dernier contenant du titane et 20 à 40% d'hybrides de titane. C'est pourquoi l'influence d'une altération de surface importante et l'influence de la composition au niveau de la surface SLA, c.-à-d. avec ou sans hybrides de titane ont été étudiées *in vivo.* Trois groupes d'implants ont été insérés dans des mandibules de porcs et laissés enfouis durant dix semaines; 1) un groupe contrôle SLA standard (SLAstd) qui renfermait de l'hybride de titane, 2) un groupe test avec une surface SLA fortement modifiée au niveau du filetage (SLAalt), 3) un groupe test avec une surface SLA sans hybride de titane (SLAT). La grandeur de l'échantillon était n=8. L'analyse histomorphométrique n'a pas montré de différence statistiquement significative entre le groupe contrôle (SLAstd : 82 + 6%), le groupe test à la surface altérée (SALalt : 86 + 7%) et le groupe test sans hybride de titane (SLAT : 75 + 8%). Les données suggèrent que l'altération de la surface SLA ne devrait pas être négative pour la réponse osseuse, si cela se produit. La surface SLA molle et facilement recouvrable peut être même un avantage lorsque la maintenance de surface est requise. La composition de surface ne jouait pas un rôle significatif dans la réponse osseuse pour la surface SLA. Les propriétés ostéophiliques de la surface SLA sont donc dûes à sa topographie de surface et non à sa composition de surface spécifique.

Zusammenfassung

Die Titanoberfläche, die man durch Sandstrahlen und Ätzen (SLA) erhält, ist eine leicht zu verändernde Oberfläche, die verschmieren kann, und so die typische Struktur verliert. Zusätzlich verändert der Ätprozess die Zusammensetzung der Oberfläche von handelsüblichem reinem Titan, so dass man dort Titan und 20 – 40% Titanhydrid vorfindet. Daher hat man die Auswirkungen einer massiven Oberflächenveränderung und den Einfluss der Zusammensetzung der SLA-Oberfläche, zum Beispiel mit und ohne Titanhydrid in vivo untersucht. Man implantierte in den Unterkiefer eines Schweins drei verschiedene Gruppen von Implantaten und liess sie während 10 Wochen subgingivai einheilen: 1) Die Kontrollgruppe mit standard mässigen SLA-Oberflächen, die Titanhydrid enthält (SLAstd), 2) eine Testgruppe mit SLA-Oberfläche, die bei den Schraubenwindungen massiv verändert worden war (SLAalt), und 3) eine Testgruppe mit SLA-Oberläche ohne Titanhydrid (SLAT). Die Anzahl der Testkörper war n=8. Die histomorphometrischen Analysen zeigten zwischen der Kontrollgruppe (SLAstd: 82.12 + 6.1%), der Testgruppe mit veränderter Oberfläche (SLAalt: 86.25 + 7.4%) und der Testgruppe ohne Titanhydrid (SLAT: 75.12 + 7.6%) keine statistisch signifikanten Unterschiede. Die Daten lassen vermuten, dass wenn eine Veränderung der SLA-Oberfläche eintritt, sich dies nicht unbedingt negativ auf die Knochenantwort auswirken muss. Die weiche und leicht verschmierte SLA-Oberfläche mag sogar ein Vorteil sein, wenn es um die Stabilität der Oberfläche geht. Die Zusammensetzung der Oberfläche spielte keine entscheidende Rolle bei der Knochenantwort auf die SLA-Oberfläche. Somit kann man schliessen, dass die knochenfreundlichen Eigenschaften der SLA-Oberfläche auf ihre Topographie und nicht auf eine ganz spezifische Zusammensetzung zurückzuführen.

Resumen

La superficie de titanio obtenida por pulverización y gravada (SLA) es una superficie fácilmente alterable que se descama y pierde su típica textura. Además, el proceso de gravado modifica la composición de la superficie del titanio comercialmente puro, este último contiene titanio y una adición del 20 – 40 % de hidruro de titanio. Por lo tanto, se investigó en vivo, la influencia de una fuerte alteración de la superficie y la influencia de la composición en la superficie SLA, i.e. con o sin hidruro de titanio. Se insertaron tres grupos de implantes en la mandíbula de cerdos Land Race y se dejaron cicatrizar durante 10 semanas de manera sumergida, 1) un grupo de control de SLA estándar (SLAstd), que contiene hidruro de titanio, 2) un grupo de prueba con una superficie SLA fuertemente alterada a nivel de las roscas (SLAalt), 3) un grupo de prueba con una superficie SLA sin hidruro de titanio (SLAT). El tamaño de las muestras fue de n=8. El análisis histomorfométrico no mostró una diferencia estadísticamente significativa entre el grupo de control (SLAstd: 82.12 + 6.1%), el grupo con superficie alterada (SLAalt : 86.25 + 7.4%) y el grupo de prueba de SLA sin hidruro de titanio (SLAT : 75.12 + 7.6%). Los datos sugieren que la alteración de la superficie SLA no debe ser perjudicial para la respuesta ósea si ocurriese. La superficie SLA blanda y fácilmente descamable puede incluso ser una ventaja cuando se requiere un mantenimiento. La composición de la superficie no jugó un papel significativo en la respuesta ósea a la superficie SLA, por lo tanto, se pude concluir que las propiedades osteofílicas de la superficie SLA se deben a la topografía de su superficie y no a la composición de la superficie.

要旨

サンドブラストとエッチングを施したチタン表面（SLA）は、容易に汚れて、その典型的な性状が失われる、変化しやすい表面である。さらにエッチングの過程により、商用純チタンの表面組成が変わり、チタンと約２０－４０％のチタン水素化物を含むようになる。従って本研究では、SLA表面において、顕著な表面変化と組成すなわちチタン水素化物を含む場合、含まない場合の影響をin vivoで調べた。Land Race豚の下顎骨に３群のインプラントを埋入して、そのまま１０週間治癒させた：すなわち１）チタン水素化物を含む標準ＳＬＡ対照群（ＳＬAstd）、２）ねじ山レベルで顕著に変化させたＳＬＡ表面を有するテスト群（ＳＬAalt）及び３）チタン水素化物を含まないＳＬＡ表面のテスト群（ＳＬＡＴ）である。標本サイズは、ｎ＝８であった。組織形態計測法による分析では、対照群（ＳＬAstd：８２．１２＋６．１％）、表面を変化させたテスト群（ＳＬAalt：８６．２５＋７．４％）及びチタン水素化物を含まないテスト群（ＳＬＡＴ：７５．１２＋７．６％）の間に、統計学的な有意差は認められなかった。同データは、ＳＬＡ表面はもし変化が生じても、骨の反応に悪影響を及ぼさないことを示唆している。柔らかく簡単に汚染されるＳＬＡ表面は、表面の維持が必要な場合には有利でありうる。表面組成は、ＳＬＡ表面に対する骨の反応において重要な役割を果たさなかったので、ＳＬＡ表面の骨親和性は、表面の局所形態によるものであり、特異的な表面組成によるものではないと結論しうる。

References

Anonymous (1987) Corrosion of titanium. In: *ASM Handbook of metals.* **Vol. 13**, Corrosion. Metal Park, OH: A.S.M.

Buser, D., Nydegger, T., Hirt, H.P., Cochran, D.L. & Nolte, L.P. (1998) Removal torque values of titanium implants in the maxilla of miniature pigs. *International Journal of Oral and Maxillo-Facial Implants* 13: 611–619.

Buser, D., Nydegger, T., Oxland, T., Cochran, D.L., Schenk, R.K., Hirt, H.P., Snétivy, D. & Nolte, L.P. (1999) The interface shear-strength of titanium implants with a sandblasting and acid-etched surface. A biomechanical study in the maxilla of miniature pigs. *Journal of Biomedical Material Research* 45: 75–83.

Buser, D., Schenk, R.K., Steinemann, S.G., Fiorellini, J.P., Fox, C.H. & Stich, H. (1991) Influence of surface characteristics on bone integration of titanium implants: a histomorphometric study in miniature pigs. *Journal of Biomedical Material Research* 25: 889–902.

Cochran, D.L., Buser, D., ten Brukkengate, T.M., Weingart, D., Taylor, T.M., Bernard, J.P., Peters, F. & Simpson, J.P. (2002) The use of shortened healing times on ITI implants with a sandblasted and acid-etched (SLA) surface: Early results from clinical trials. *Clinical Oral Implants Research* 13: 144–153.

Cochran, D.L., Schenk, R.K., Lussi, A., Higginbotom, F.L. & Buser, D. (1998) Bone response to unloaded and loaded titanium implants with a sandblasted and acid-etched surface. A histomorphometric study in the canine mandible *Journal of Biomedical Material Research* 40: 1–11.

Cochran, D.L., Simpson, J.P., Weber, H.P. & Buser, D. (1994) Attachment and growth of periodontal cells on smooth and rough titanium. *International Journal of Oral and Maxillo-Facial Implants* 9: 289–297.

Gross, U., Muller-Mai, C., Fritz, T., Voigt, C., Knarse, W. & Schmitz, H.J. (1990) Implant surface roughness and bone load transmission. Influence of peri-implant bone structure. In: Heimke, G., Soltész, U. & Lee, A.C.J., eds. *Clinical Implant Materials*, Vol 9: Advances in Biomaterials, 303–308. Amsterdam: Elsevier Science Publisher.

Lausmaa, J., Kasemo, B. & Mattsson, H. (1990) Surface spectroscopic characterization of titanium implant materials. *Applied Surface Science* 44: 133–146.

Martin, J.Y., Schwarz, Z., Hemmert, T.W., Schraub, D.M., Simpson, J., Lankford, J., Dean, D.D., Cochran, D.L. & Boyan, B.D. (1995) Effect of titanium surface roughness on proliferation, differentiation, and protein synthesis of human osteoblasts-like cells. *Journal of Biomedical Material Research* 29: 389–401.

Steinemann, S.G. (1991) The properties of titanium. In: Schroeder, A., Sutter, F. & Krekeler, G., eds. *Oral Implantology*, 37–58. Stuttgart: Thieme.

Szmukler-Moncler, S., Perrin, D., Ahossi, V. & Pointaire, P. (2001) Evaluation of BONIT, a fully resorbable CaP coating obtained by electrochemical deposition, after 6 weeks of healing: A pilot study in the pig maxilla. Key Engineering Materials, Volumes 192–195.

Szmukler-Moncler, S., Perrin, D., Bernard, J.P. & Pointaire, P. (1999) Biological properties of titanium acid etched surfaces: Effect of surface composition and surface alteration. Influence of sandblasting on bony anchorage. *Clinical Oral Implants Research* 10: 173.

Szmukler-Moncler, S. & Simpson, J.P. (1996) Physicochemical characterization of a titanium textured surface prepared by sandblasting and acid etching. *Transactions of the 5th World Biomaterials Congress, May 29-June 2,* 837. Toronto.

Taborelli, M., Jobin, P., François, P., Vaudaux, M., Tonetti, M., Szmukler-Moncler, S., Simpson, J.P. & Descouts, P. (1997) Influence of surface treatments developed for oral implants on the physical and biological properties of titanium. I. Surface characterization. *Clinical Oral Implants Research* 8: 208–216.

Wilke, H.J., Claes, L. & Steinemann, S.G. (1990) The influence of various titanium surfaces on the interface shear strenght between implants and bone. In: Heimke, G., Soltész, U. & Lee, A.J.C., eds. *Clinical Implant Materials*, **Vol. 9**: Advance in Biomaterials, 309–314. Amsterdam: Elsevier Science Publishers.

Wong, M., Eulenberger, J., Schenk, R. & Hunziker, E. (1995) Effect of surface topology on the osseointegration of implant materials in trabecular bone. *Journal of Biomedical Material Research* 29: 1567–1575.