Brazilian Dental Journal (2014) 25(4): 343-345
http://dx.doi.org/10.1590/0103-6440201302402
ISSN 0103-6440

In Vitro Microstructural Analysis of Dental Implants Subjected to Insertion Torque and Pullout Test

Mariana Lima da Costa Valente[1], Cesar Penazzo Lepri[2], Andréa Candido dos Reis[1]

[1]Department of Dental Materials and Prosthetics, School of Dentistry of Ribeirão Preto, USP - University of São Paulo, Ribeirão Preto, SP, Brazil
[2]Department of Biomaterials, School of Dentistry of Uberaba, UNIUBE - University of Uberaba, Uberaba, MG, Brazil

Correspondence: Profa. Dra. Andréa Candido dos Reis, Avenida do Café, s/nº, 14040-904; Ribeirão Preto; SP, Brasil. Tel: +55-16-3602-0477. e-mail: andreare73@yahoo.com.br

The change in the implant microstructure during handling may reduce the potential of surface treatment on the osteoinduction and, therefore, on the osseointegration. The aim of this study was to evaluate by energy-dispersive X-ray spectroscopy (EDX) the effect of insertion torque and pullout test on the microstructure of dental implants with different shapes. Four shapes of implants (n=8) were selected: conical with surface treatment (COTS), cylindrical with surface treatment (CTS), cylindrical with double surface treatment (CTSD) and cylindrical with machined surface (CSU). Before and after performing the mechanical tests, the screw surfaces were subjected to analysis of chemical composition by EDX. The results obtained by the microstructural analysis showed presence of three main chemical elements: Ti, C and O. There was a significant change in the concentration of Ti and C. The implant with double surface treatment (CTSD) showed the greatest Ti reduction and the greatest C increase. It may be concluded that the mechanical manipulation may alter the implant surfaces as regards their microstructure. Therefore, surgical planning should take into consideration the choice of surface treatment because the characteristics of the implants may be modified as they are inserted and removed from the bone site.

Key Words: dental implants, torque, x-ray emission spectrometry, osseointegration.

Introduction

The contact between bone and endosseous implant is established and maintained after installation by the osseointegration process, in which the main element of the whole system is the implant itself, considering its macroscopic and microscopic characteristics (1-3). Morphological and chemical surface changes may alter the response of the bone tissue adjacent to the screw by inducing specific responses in the osteoblastic cells (4).

Modifications made by the manufacturers in the macro and microstructure of the implant, such as changes in shape and surface treatments, aim at increasing the success of oral rehabilitation by promoting greater surface area and bone/implant contact, induction of bone growth and load distribution (5-7) in order to obtain maximum surface anchoring, insertion with less bone trauma and greater resistance to insertion and removal torques (8).

Titanium (Ti) and its alloys are widely used as biomaterials, either in the medical or dental field, due to its good mechanical strength, chemical stability and biocompatibility that are fundamental characteristics to the success of osseointegration, as stated by Branemark (9,10). Among the characteristics of Ti, biocompatibility is the one most related to its microstructure, i.e., chemical composition, roughness and surface energy (11).

The intimate implant/bone tissue contact originates on the surface. Therefore, it is important to keep it free from impurities to allow bone formation in this region. The Ti on the screw surface reacts spontaneously with the oxygen in the air to form a stable oxide layer (TiO_2) (1). This layer responds for the biocompatibility of this material due to its low electrical conductivity, high corrosion resistance and thermodynamic stability at physiological pH. However, the natural oxide layer can be easily broken, impairing the bone formation at the implant/bone interface (12,13).

Incidents during surgery or absence of initial planning may require the replacement of the previously inserted implant in the bone site. In these cases, the action of inserting or removing the screw may alter its surface chemistry, especially as regards to breaking the Ti oxide layer, which may lead to damage in the bone tissue responses.

The purpose of the present study was to evaluate the effect of insertion torque and pullout test on the microstructure of dental implants of different shapes using energy-dispersive X-ray spectroscopy (EDX).

Material and methods

Four different shapes (n=8) of dental implants (Conexão®, Arujá, SP, Brazil) were selected: conical with surface treatment (COTS); cylindrical with surface treatment (CTS); cylindrical with double surface treatment (CTSD) and cylindrical with machined surface (CSU). All implants had the same dimensions (Ø 3.75 mm x 11.5 mm), except for the conical one (COTS), which had a slightly smaller diameter (3.5 mm) (Table 1). The receptor site of choice for implant insertion was the femur head of a synthetic polyurethane bone (Synbone®, Malans, Switzerland), since this material is indicated as bone substitute due to its close characteristics to the natural bone (14-15).

Implant Microstructure Analysis

An EDX device (IXRF Systems, Houston, TX, USA) was used to quantify the elements on the surface of the implants, before and after the insertion torque and pullout test. This device emits a thermal ionic beam of primary electrons from a tungsten filament and, after path correction by condenser lenses and focus adjustment by the objective lens, the beam hits the sample to be analyzed. This interaction generates X-ray photons, yielding the energy spectra (16).

Mechanical Tests

A single operator performed all assays for standardization purposes. The surgical insertions were performed with the sequence of bits specified by the manufacturer of an electric motor (MC 101, Omega; Dentscler®, Ribeirão Preto, SP, Brazil). The implants were inserted in the polyurethane femoral head (Synbone, BaySystems®) with a standardized torque of 32 N.cm. Four implants (n=4) were inserted into each femoral head; one of each type (COTS, CTS, CTSD, CSU).

For the pullout test, a universal testing machine (Emic DL-10000; São José dos Pinhais, PR, Brazil) was used with a 200 kgf load cell. The screw head was attached to the testing machine by connectors that allow multidirectional movements and applying axial tensile load without torque application. Pre-load of 5 N and settling time of 10 s were used. The axial tensile load was applied at constant 0.2 mm/min speed until pullout of the implant. These parameters were defined according to the need to adapt the implant to the machine (2).

Data Analysis

Quantification of Ti and carbon (C) in the samples before the insertion torque and after the pullout test yielded the percentage of each ion analyzed by EDX and conducted a descriptive analysis.

Results

The microstructural EDX analysis showed that the main components of the tested implants were Ti and C. Comparing the concentration of each chemical element (Table 2), before and after the test pullout, there was a significant decrease in the concentration of Ti and increase of C, especially in the implants with treated surface (COTS, CTS, CTSD). The CTSD implant showed greater reduction of Ti, while the CSU presented an increase of this element.

Discussion

Since the discovery of osseointegration, different models of implants have been developed. Modifications occurred in both shape and surface, with the evolution of smooth machined to microscopically rough surfaces, which enhance bone healing around implants (4,17).

The titanium alloy used for manufacturing of implants has in its composition a wide variety of elements and chemical compounds, beyond the pure metal, as this would only be only possible under auto vacuum or equivalent conditions (18). In addition to the elements present in the material, the impurities on the screw surface, both due to poor handling or by contamination during surgery, can lead to the destruction of titanium dioxide (TiO_2) layer and result in the failure of osseointegration, by the development of pathological processes such as periimplantitis (19).

The surface treatment modifies the implant insofar as it promotes micro-roughness (porosity), responsible for increasing the mechanical imbrication at the implant/bone interface (17,20,21). This modification on the implant surface leads to a thicker TiO_2 layer, favoring the process of bone neoformation (9).

In the present study, implants with treated surface (COTS, CTS and CTSD) showed the greatest reduction in the concentration of Ti, which indicates a greater reduction of the TiO_2 layer when compared with implants presenting smooth/machined surface (CSU). This result suggests that inserting and removing the implant at the surgical site can break the surface TiO_2 layer , especially in surface-treated implants. Comparing the surface-treated screws, it was found that the CTSD model (cylindrical) showed the highest reduction of Ti and the COTS model (conical) presented the smallest reduction.

The presence of C in the sample is related to the

Table 1. Shape, surface treatment and size of the tested implants

Implant	Shape	Surface treatment	Size
COTS	Conical	Porous®	Ø 3.5 mm x 11.5 mm
CTS	Cylindrical	Porous®	Ø 3.75 mm x 11.5 mm
CTSD	Cylindrical	Double Porous®	Ø 3.75 mm x 11.5 mm
CSU	Cylindrical	Machined	Ø 3.75 mm x 11.5 mm

Table 2. Chemical elements percentage

Implant	Before insertion	After pullout
COTS	Ti=94.64% - C=0%	Ti=85.26% - C=8.08%
CTS	Ti=75.49% - C=1.29%	Ti=53.49% - C=31.88%
CTSD	Ti=86.27% - C=7.13%	Ti=51.61% - C=34.64%
CSU	Ti=77.30% - C=0%	Ti=85.38% - C=6.89%

presence of organic material particles. In the present study, it is represented by the synthetic bone. The machined-surface implants (CSU) had a lower aggregation of organic particles and, therefore, showed lower C concentration. On the other hand, the surface-treated implants (COTS, CTS and CTDS) showed higher C concentration after the mechanical test, demonstrating the influence of the surface roughness produced by the treatment, on the mechanical imbrication (22).

Despite the limitations of this study, the obtained results confirm the importance of conducting a surgical planning prior to implant placement and contraindicate the reuse of previously inserted screws due to the alteration of the superficial TiO_2 layer. Given the benefits of the TiO_2 layer to increase the biological responses and subsequent osseointegration success (23,24), it was found that the surface-treated implants exhibited the greatest modifications in the TiO_2 layer, demonstrating the need for greater care when handling these implants.

Resumo

A alteração da microestrutura do implante durante seu manuseio pode reduzir o potencial do tratamento superfícial na osteoindução e consequentemente na osseointegração. O objetivo deste estudo foi avaliar o efeito do torque de inserção e do ensaio de arrancamento, na microestrutura de implantes odontológicos de diferentes formatos, por meio de espectometria de energia dispersiva de raios-X (EDS). Para a realização do estudo foram selecionados quatro modelos de implantes Conexão® (n=8): Cônico com tratamento de superfície (COTS), Cilíndrico com tratamento de superfície (CTS), Cilíndrico com duplo tratamento de superfície (CTSD) e Cilíndrico com superfície usinada (CSU). Antes e após a realização dos ensaios mecânicos, os parafusos foram submetidos à análise da composição química de suas superfícies, por meio de EDS. Os resultados obtidos com a análise microestrutural demonstraram a presença de três elementos químicos principais: Ti, C e O. Foi verificada alteração estatisticamente significante na concentração dos elementos Ti e C. O implante com duplo tratamento de superfície (CTSD) foi o que apresentou a maior redução do Ti e maior aumento do C. A partir dos dados obtidos foi possível concluir que a manipulação mecânica pode alterar a superfície dos implantes quanto à sua microestrutura. Sendo assim, o planejamento cirúrgico deve levar em conta a escolha do tratamento de superfície, pois uma vez que o implante é inserido e removido do leito ósseo suas características podem ser alteradas.

Acknowledgements

The authors wish to thank the financial support of FAPESP.

References

1. Albrektsson T, Nemark BR, Hansson A, Lindstrom J. Osseointegrated Titanium Implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. Acta Orthop Scand 1981;52:155-170.
2. Mazzo CR, Reis AC, Shimano AC, Valente ML. *In vitro* analysis of the influence of surface treatment of dental implants on primary stability. Braz Oral Res 2012;26:313-317.
3. Aleo E, Varvara G, Scarano A, Sinjari B, Murmura G. Comparison of the primary stabilities of conical and cylindrical endosseous dental implants: an *in-vitro* study. J Biol Regul Homeost Agents 2012;26:89-96.
4. Marin C, Bonfante EA, Jeong R, Granato R, Giro G, Suzuki M, et al.. Histologic and biomechanical evaluation of 2 resorbable-blasting media implant surfaces at early implantation times. J Oral Implantol 2013;39:445-453.
5. Orsini E, Giavaresi G, Trirè A, Ottani V, Salgarello S. Dental implant thread pitch and its influence on the osseointegration process: an *in vivo* comparison study. Int J Oral Maxillofac Implants 2012;27:383-392.
6. Elias CN, Rocha FA, Nascimento AL, Coelho PG. Influence of implant shape, surface morphology, surgical technique and bone quality on the primary stability of dental implants. J Mech Behav Biomed Mater 2012;16:169-180.
7. Bressan E, Sbricoli L, Guazzo R, Tocco I, Roman M, Vindigni V, et al.. Nanostructured surfaces of dental implants. Int J Mol Sci 2013;14:1918-1931.
8. Teixeira ABV, Beja GBSP, Shimano AC, Macedo AP, Oliscovicz NF, Reis AC. Influence of the ultimate torsion on the geometry of dental implants. Braz Dent J 2013;24:213-217.
9. Kim K, Lee BA, Piao XH, Chung HJ, Kim YJ. Surface characteristics and bioactivity of an anodized titanium surface. J Periodontal Implant Sci 2013;43:198-205.
10. Uzumaki ET, Santos AR, Lambert CS. Titanium oxide (TiO_2) coatings produced on titanium by oxygen plasma immersion and cell behavior on TiO2. Key Eng Mater 2006;18:367-370.
11. Kasemo B. Biocompatibility of titanium implants: surface science aspects. J Prosthet Dent 1983;49:832-837.
12. Sul YT, Johansson CB, Jeong Y, Roser K, Wennerberg A, Albrektsson T. Oxidized implants and their influence on the bone response. J Mater Sci Mater Med 2001;12:1025-1031.
13. Faeda RS, Tavares HS, Sartori R, Guastaldi AC, Marcantonio JRE. Biological performance of chemical hydroxyapatite coating associated with implant surface modification by laser beam: biomechanical study in rabbit tibias. J Oral Maxillofac Surg 2009;67:1706-1715.
14. Cristofolini L, Viceconti M, Capello A, Toni A. Mechanical validation of whole bone composite femur models. J Biomech 1996;29:525-535.
15. Bayarchimeg D, Namgoong H, Kim BK, Kim MD, Kim S, Kim TI, et al. Evaluation of the correlation between insertion torque and primary stability of dental implants using a block bone test. J Periodontal Implant Sci 2013;43:30-36.
16. Alonso-Mori R, Kern J, Gildea RJ, Sokaras D, Weng TC, Lassalle-Kaiser B, et al.. Energy-dispersive X-ray emission spectroscopy using an X-ray free-electron laser in a shot-by-shot mode. Proc Natl Acad Sci USA 2012;109:19103-19107.
17. Le Guéhennec L, Soueidan A, Layrolle P, Amouriq Y. Surface treatments of titanium dental implants for rapid osseointegration. Dent Mater 2007;23:844-854.
18. Klauber C, Lenz LJ, Henry PJ. Oxide thickness and surface contamination of six endosseous dental implants determined by electron spectroscopy for chemical analysis: preliminary report. Int J Oral Maxillofac Implants 1990;5:264-271.
19. Dohan Ehrenfest DM, Coelho PG, Kang BS, Sul YT, Albrektsson T. Classification of osseointegrated implant surfaces: materials, chemistry and topography. Trends Biotechnol 2010;28:198-206.
20. Dos Santos MV, Elias CN, Cavalcanti Lima JH. The effects of superficial roughness and design on the primary stability of dental implants. Clin Implant Dent Relat Res 2011;13:215-223.
21. Dohan Ehrenfest DM, Coelho PG, Kang BS, Sul YT, Albrektsson T. Classification of osseointegrated implant surfaces: materials, chemistry and topography. Trends Biotechnol 2010;28:198-206.
22. Gottlow J, Barkarmo S, Sennerby L. An experimental comparison of two different clinically used implant designs and surfaces. Clin Implant Dent Relat Res 2012;14:204-212.
23. Albrektsson T, Brånemark PI, Hansson AR, Kasemo B, Larsson K, Lundström L, et al.. The interface zone of inorganic implants *in vivo*: titanium implants in bone. Biomedical engineering 1983;11:1-27.
24. Sul YT, Johansson CB, Petronis S, Krozer A, Jeong Y, Wennenberg A, et al.. Characteristics of the surface oxides on turned and electrochemically oxidized pure titanium implants up to dielectric breakdown: the oxide thickness, micropore configurations, surface roughness, crystal structure and chemical composition. Biomaterials 2002;23:491-501.

Received February 6, 2014
Accepted May 11, 2014