Topographic analysis of the surface of commercially pure titanium implants. Study using scanning electron microscopy

Amanda Hora da **PAIXÃO***
José Rodrigo Mega **ROCHA****
Bruno **BOTTO*****
Dario Augusto Oliveira **MIRANDA******
Sandra de Cássia Santana **SARDINHA*******

Abstract

Objective: This study aims at carrying out a descriptive comparative analysis of four types of surfaces of commercially pure titanium implants by means of scanning electron microscopy (SEM). **Material and Methods:** Four implants of different commercial brands were used, as follows: Conexão – Sistemas de Próteses (Prosthesis system) and Straumann. The samples had their surfaces machined by means of acid etching, anodization (Conexão) and blasting followed by acid etching (Straumann) techniques, and were divided into four groups with one implant each. The areas of thread top and valley were determined for SEM analysis at different magnifications. **Results:** All samples assessed presented characteristics of surface rugosity, including the machined surfaces. The implants treated by anodization and blasting followed by acid etching had a greater surface pattern in comparison to the implants treated by acid etching due to their greater degree of rugosity. **Conclusion:** Surface treatment influences surface macro structure. Surfaces treated by anodization and blasting followed by acid etching presented a surface pattern that provides a greater area for bone apposition.

Keywords: Titanium implants. Surface treatments. Scanning electron microscopy.

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Contact address

Sandra de Cássia Santana Sardinha
Faculdade de Odontologia da UFBA – Departamento de Clínica Odontológica
Avenida Araújo Pinho, 62 – Canela – Salvador/BA — Brazil
CEP: 40.110-150 – E-mail: darioperiodonto@hotmail.com

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* Undergraduate student of Dentistry, Federal University of Bahia, UFBA.
** Adjunct professor, School of Dentistry, UFBA.
*** MSc in oral and maxillofacial surgery, UFBA.
**** Auxiliary professor, State University of Feira de Santana, UEFS.
***** Adjunct professor, School of Dentistry, UFBA.

Introduction

The objective of modern Dentistry is to restore patients' masticatory function, speech, health and esthetics, regardless of atrophy, diseases or lesions found in the stomatognathic system. Since the advent of osseointegration, the use of implants has proved to be a treatment option for edentulous patients.[1] After years of research as well as laboratory and clinical development, Branemark presented a system of implants that can replace lost natural teeth.[2]

In his researches, after trying to remove a titanium piece implanted in the tibia of a rabbit, Branemark observed that the piece had adhered to the bone. Based on this phenomenon, other studies, researches and trials were conducted and that is how the concept of osseointegration, defined as a stable union between the bone and the implant which can hold a prosthesis,[2,3] was developed.

Dental implants are considered suitable for masticatory function and esthetics when osseointegration is effective.[4] The high number of successful cases of osseointegrated dental implants led it be considered a realistic treatment option in modern Dentistry. However, despite the high number of successful cases reported by researches, there has been some failure in clinical practice regarding treatments performed with implants, causing some inconvenience for both professionals and patients.[5,6]

Commercially pure titanium is chemically stable and, for this reason, it allows satisfactory tissue reaction, stimulates bone matrix formation, presents high resistance to corrosion and does not cause significant immunological reactions, being the main material of choice for the manufacture of implants.[9]

Surface treatments promote different increases in rugosity that, when associated with the physical-chemical characteristics and properties of the material, influences not only the initial mechanical retention of implants, but also the increase in the contact area with the receiving bone bed, thus favoring osseointegration.[7] Studies confirm that textured surfaces have better implant-bone integration in comparison to smooth surfaces.[8]

Within this context, modifications carried out on implant surfaces have become of paramount importance for the researches conducted in the last few years. Different mechanical, chemical and optical methods have been used with the purpose of producing surfaces with different topographies. Furthermore, different types of coating can also be used to modify surfaces, and can be applied by means of different techniques.[10]

Among the techniques used to treat the surface of implants, the most important ones are: deposition of hydroxyapatite, acid etching, blasting of particles or blasting followed by acid etching, laser treatment, anodic oxidation, ion implantation, and isolated or simultaneous electrochemical deposition of calcium, phosphate, iron and magnesium.[11] These treatments, with their own peculiarities, promote different rugosity patterns.[12]

Based on the aforementioned facts, considering that the topography of implant surfaces directly influences osseointegration and that each type of surface, with its own peculiarities, has advantages, disadvantages and indications for use; the present study aims at carrying out a descriptive and comparative analysis of the different surfaces of commercially pure titanium implants by means of scanning electron microscopy.

Material and Methods

Implant selection

Four commercially pure titanium implants with different surface treatments were used for this research. They were obtained from the following implant systems: Conexão

Sistemas de Próteses (Prosthesis system) and Straumann. The material was divided into four groups in accordance with the surface treatment it had received. Such information is shown in Table 1, according to data provided by the manufacturers.

Analysis

The topographic characterization of surfaces was carried out by means of a Tescan scanning electron microscope, model VEGA 3 LMU, at the laboratory of the Federal Institute of Education, Sciences and Technology of Bahia (IFBA). The implants were provided by the manufacturers in specific, sealed and sterilized wrapping, each one containing a single sample. The samples were removed from the wrapping and directly placed into the sample holder by means of sterilized clinical tweezers so as to avoid contamination of surfaces. Afterwards, they were directly placed onto the scanning electron microscope and subjected to analysis for topographic characterization of surfaces.

A kilovoltage of 20 KV was used, and magnification was set at 10 to 37 mm, according to the intended degree of increase. Images at different magnifications (10x, 50x, 500x and 1000x) were obtained. With the objective of showing a panoramic view of the threads as well as their pace and shape, magnifications of 10x and 50x were used; whereas to show more details of the surface, magnifications of 500x and 1000x were used in the thread top and valley.

Results

The characterization of the implant surfaces carried out by scanning electron microscopy showed different aspects in the topographies of the surfaces in both thread valley and top due to the different treatments used by the manufacturers. In group I, which comprised machined implants without surface treatment, it could be observed that, with magnification set at 10 x and 50 x, the implant threads were uniform, the surface was regular and the thread tops had round angles, as shown in Figures 1A and 1B.

At a closer view, with 500 x magnification (Figs 1C, 1E) and 1000 x (Figs 1D, 1F), it could be observed that the thread top and valley had been marked by tools that are usually used for machining, which caused slight rugosity on the surface. No differences were found with regard to the topographic aspects between the marks found in the thread top and valley (Fig 1).

In group II, a sample treated by means of double acid etching was analyzed. With magnifications set at 50 x (Fig 2B), this sample presented uniform threads, with round tops and regular contour in the thread top and valley. With magnification set at 500 x (Figs 2C, 2E) and 1000 x (Figs 2D, 2F),

Table 1 - Specifications of implants according to data provided by the manufacturers.

Group	Brand	Implant	Surface treatment	Batch	Due date
Group I	Conexão	Master Screw	Surface machining	119881	June, 2015
Group II	Conexão	Master Porous	Acid etching	128272	May, 2016
Group III	Straumann	Straumann SLActive	Blasting + acid etching	CA212	July, 2016
Group IV	Conexão	Master Actives	Anodization	121175	August, 2015

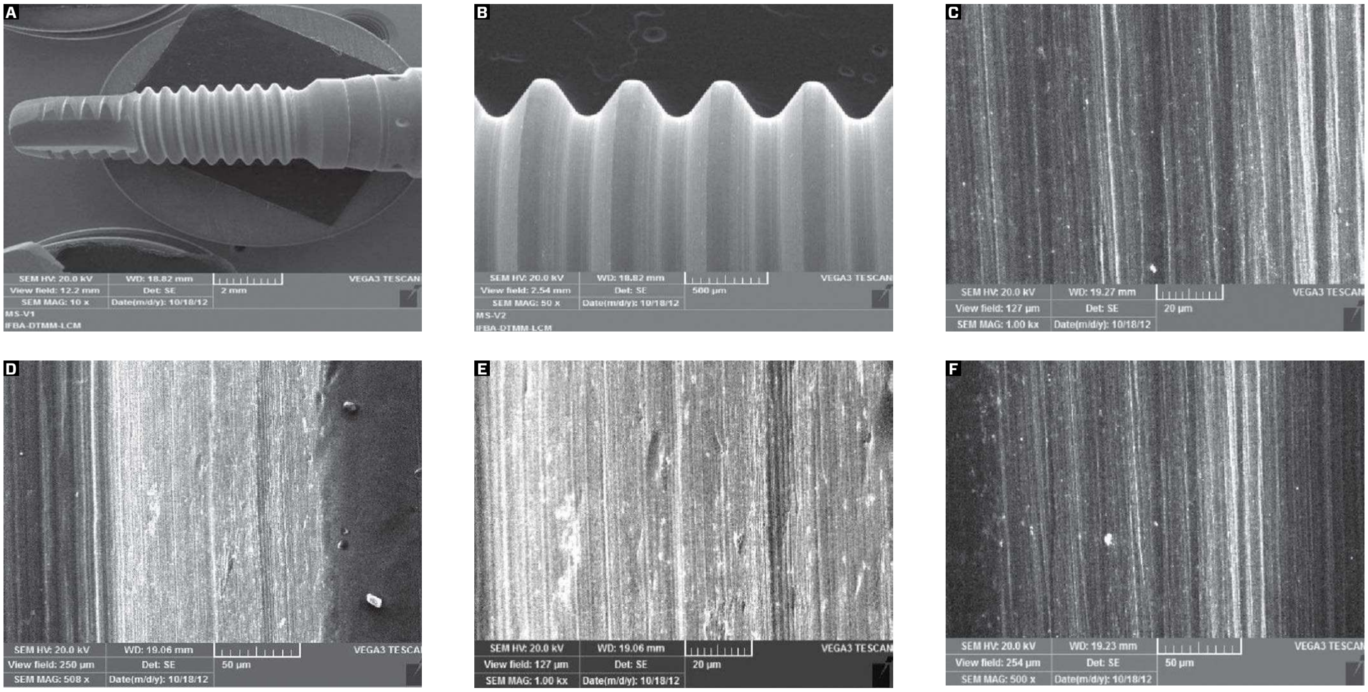

Figure 1 - Panoramic view of group I implant and threads with magnification set at 10x and 50x (**A, B**), and close view of the valley and threads with magnification set at 500x (**C, E**) and 1000x (**D, F**).

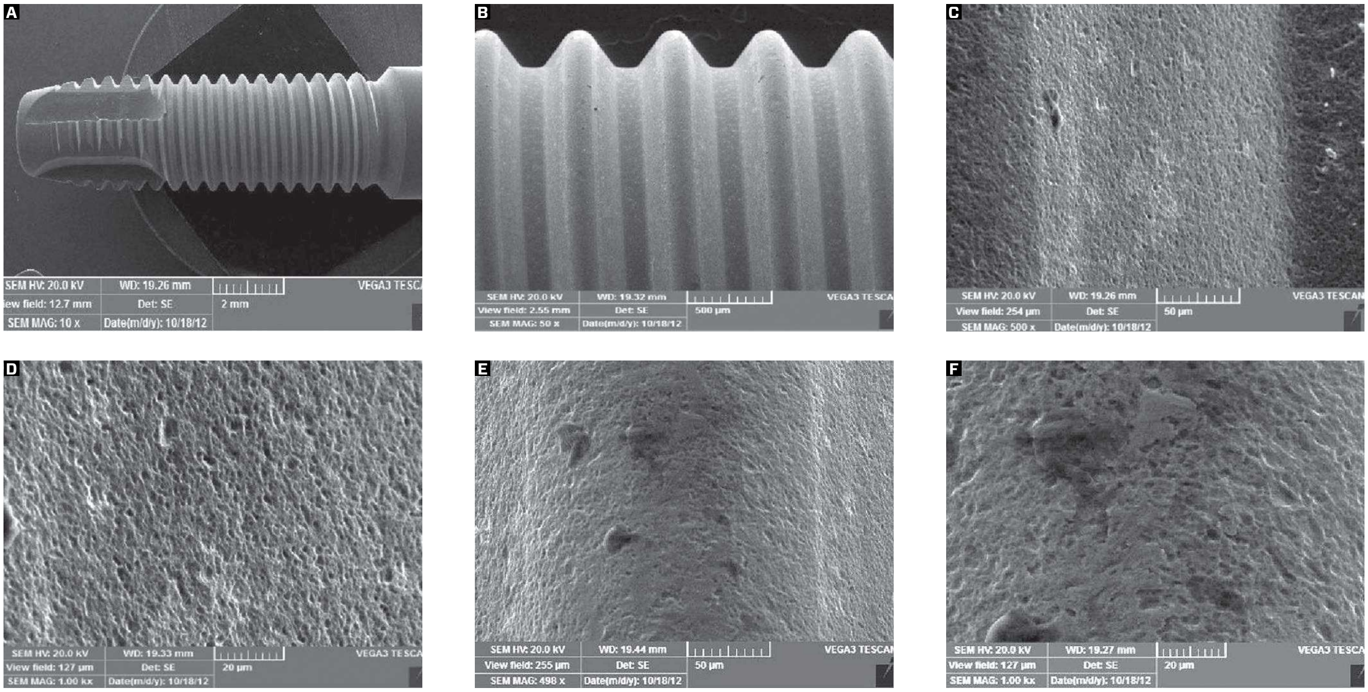

Figure 2 - Panoramic view of group II implant and threads with magnification set at 10x (**A**) and 50x (**B**). Surface porosity can be seen with magnification set at 500x (**C, E**) and 1000x (**D, F**).

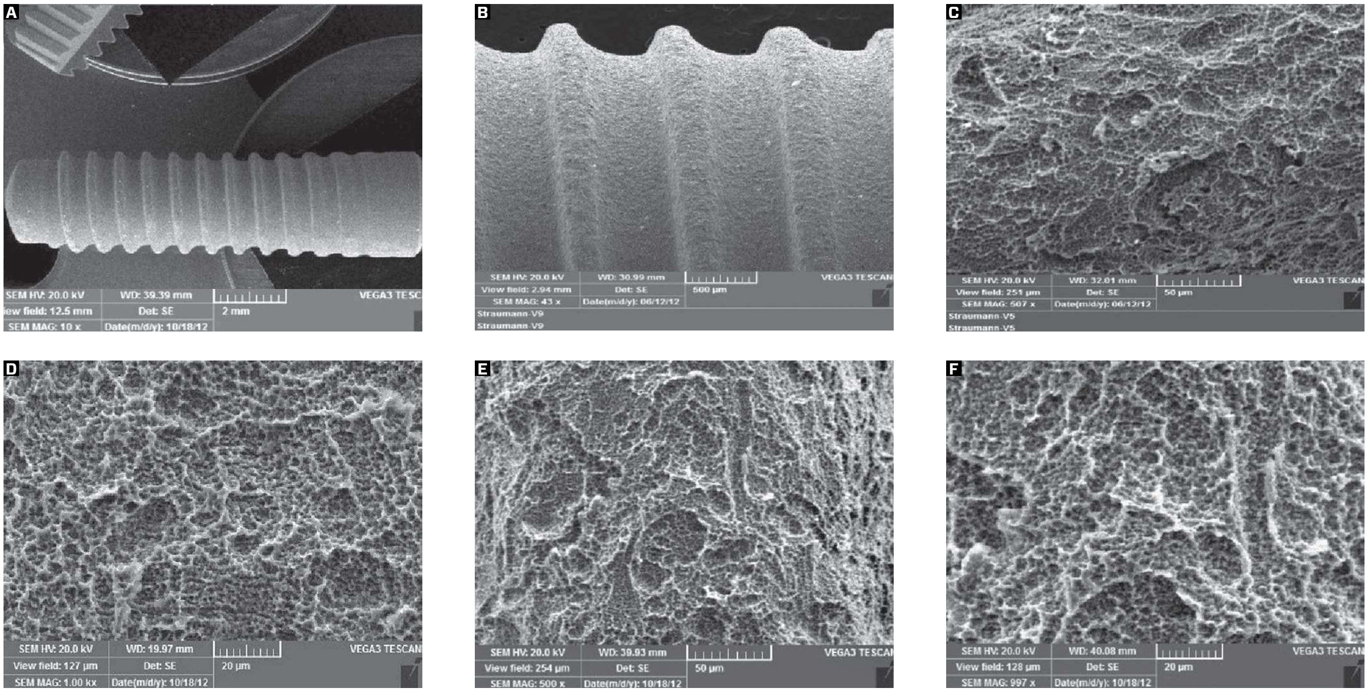

Figure 3 - Group III implant seen with magnification set at 10x, (**A**) 50x, (**B**), 500x (**C, E**) and 1000x (**D, F**) shows a rough surface with no differences between the thread top and valley.

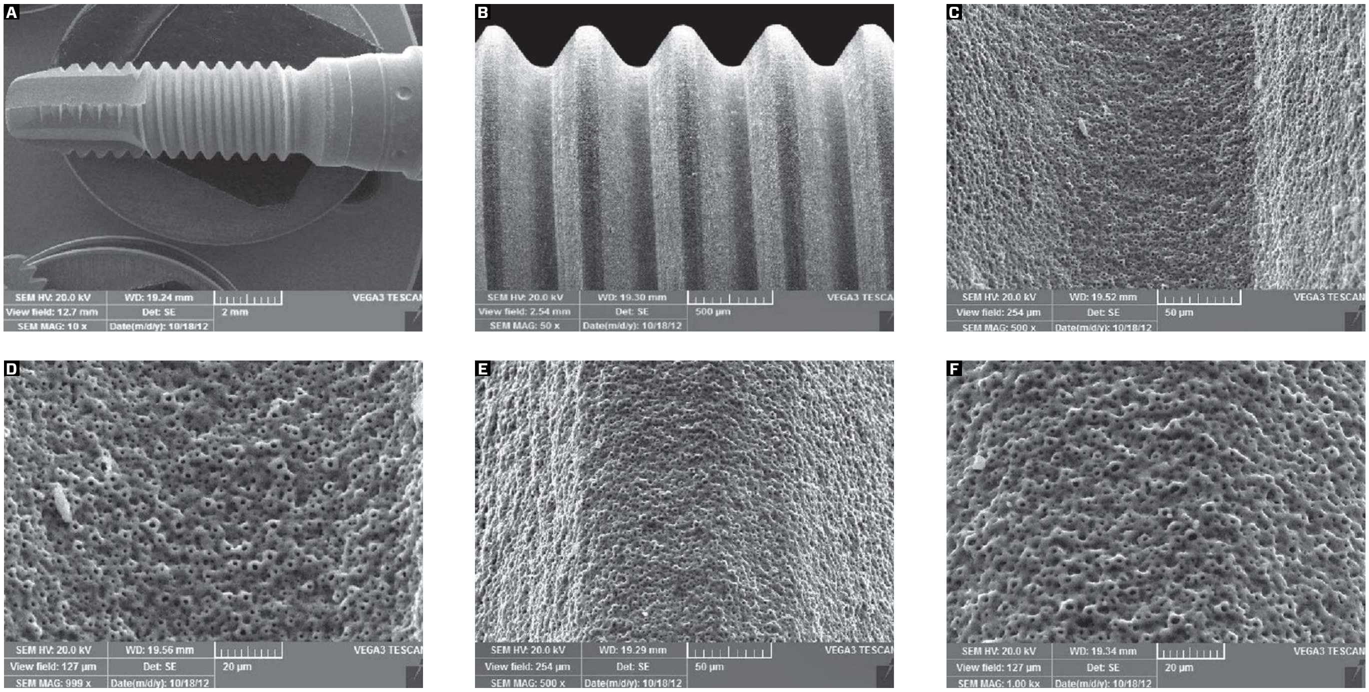

Figure 4 - Group IV implant seen with magnification set at 10x (**A**), 50x (**B**), 500x (**C, E**) and 1000x (**D, F**) present little volcanoes that vary in size and height.

areas with pores, typically caused by the surface treatment employed by the manufacturer, could be observed. However, the upper area of the thread top presented plane areas, with a mixed aspect. Using the same magnifications in the area of the valley, a regular and homogeneous pattern was observed in the pores, without any evidence of plane areas. All images obtained from the samples of group II presented the aforementioned topographic characteristics, in which acid etching removes the implant surface material, producing the porous aspect seen in these images.

In group II, a surface named SLA and which was treated by means of blasting followed by acid etching, was analyzed. With magnification set at 10 x (Fig 3A) and 50x (Fig 3B), this sample presented uniform threads, with round tops and minor irregularities in the contour of the thread top and valley. With magnification set at 500x (Figs 3C, 3E) and 1000x (Figs 3D, 3F), significant rugosity uniformly distributed in the thread top and valley was observed. No differences regarding the topographic aspect of these areas were found.

In group IV, a surface treated by means of anodization was analyzed. With magnification set at 10x (Fig 4A) and 50x (Fig. 4B), this sample presented uniform threads, with a round shape and regular contour in the top and valley. With magnification set at 500x (Figs 4C, 4E) and 1000x (Figs 4D, 4F), small volcanoes different in size and height, equally distributed between the top and valley, were observed. In comparison to the samples comprising groups II and III, the samples of group IV have a larger area for bone anchorage. The pattern observed in this group is characteristic of the surface treatment employed by the manufacturer.

Discussion

Based on the fact that the quality of osseointegration is directly related to the topography of dental implant surfaces, many techniques related to the modifications carried out on implant surfaces have been tested during the last thirty years. These tests take into account the principle that the topography of a rough surface presents an area for bone anchorage that is much larger than a smooth surface does.[13]

Although surface rugosity appears to be a favorable factor for cell biofixation, this is not considered as a general rule. A study conducted by Wennerberg et al[24] compared the tissue bone response to commercially pure titanium implants blasted with thin and thick particles of aluminium oxide. They found that surfaces blasted with thin particles produced medium rugosity topography that was more favorable to the healing process than surfaces blasted with thick particles, thus suggesting that the level of rugosity must be controlled.[8,14]

Some studies have been carried out with different methods of analysis with the purpose of assessing the characteristics of each treatment as well as their influence over the osseointegration process. Topography can be characterized by three methods with different purposes. Atomic force microscopy enables one to observe the surface at a level that is near the atomic level, and can be used with the objective of differentiating the nanotexture of surfaces. Interferometry, on the other hand, is used to analyze the microrugosities of larger areas. The third method is known as SEM, chosen for analysis of surfaces at a micrometric level.[15,16]

In the present study, the method chosen to characterize the topography of implant surfaces was SEM. We agree with Sardinha[17] who used SEM with the same reason of this research: for being a direct-viewing method that allows us to choose the most appropriate magnification for each image.[17]

According to Kahn,[18] the rugosity produced by different implant surface treatment techniques can be visualized through SEM by the mechanism of emission of electrons generated by a heated tungsten fiber, in a vacuum environment, which scans the surface of the samples, generating the images. The method also has the advantage of being operationally simpler, with a favorable cost-benefit relationship.[18] This method has been cited with the same purposes by other authors who have been mentioned in our study, namely: Ciotti et al,[7] Elias et al,[11] Joly et al,[12] Silva[20] and Ciuccio et al.[23]

Machined implants are considered of first generation. They have a soft surface texture and, for this reason, they are considered smooth.[19] In this study, the analysis of group I characterized a machined surface (thread®). With magnification set at 500x and 1000x, the areas of thread top and valley (Fig 1) presented grooves over the surface, which were caused by tools used in the machining process and resulted in mild rugosity, thus characterizing a surface liable to osseointegration.

The same author also claims that mild rugosity enables minimal osseointegration. In these surfaces, growth of cells occurs over the marks left by the machining process, however, these biological process are slower in the bone-implant interface due to the fact that there are no mechanical retentions that allow bone interlock. Additionally, these surfaces are not inducers.[11,20]

Stability and removal torque are two important factors of which values are used as an indication of success or failure of treatment performed with implants. Studies investigating the effect of implant surface treatment on stability and removal torque by comparing machined surfaces with implants being placed onto guinea pigs' bones, demonstrate that machined surfaces present lower primary stability and removal torque in comparison to implants that had undergone surface treatment. For this reason, some authors claim that these implants have currently been in decline.[11,20,21]

The decline of machined surfaces led to the development of many studies that aim at finding scientific evidence that suggests which surface treatment best produces a topography that is favorable to the osseointegration process. One of the most frequently mentioned treatments is that performed by acid etching. According to the researches carried out, acid etching results in an implant surface topography that stimulates bone apposition and surface decontamination.[22]

The second group analyzed in our study consisted of a surface treated by means of double acid etching (Porous®). Figure 2 shows a regular surface, presenting topography with uniform rugosity pattern, without any grooves caused by the machining process. Furthermore, small cavities surrounded by tapered micropeaks were also seen and, as a consequence, the area available for the osseointegration process was larger. These data corroborates the findings by Ciuccio et al.[23]

Other authors also studying this type of treatment found that it resulted in uniform rugosity that is favorable to increase the contact area between the bone and the implant. Moreover, they claim that treatment performed with acid not only results in a more homogeneous surface in comparison to machined surfaces, but also removes the marks left by the tools. Primary acid etching has the function of changing the micromorphology, whereas the second one has the function of allowing the formation of a more stable and uniform surface.[7,11]

Elias et al[11] conducted a study on implants placed on the tibia of rabbits and confirmed that they are recommended for low-density bones. Additionally, the authors found that implants induce a minor reduction in healing time, given that their morphology facilitates cell adhesion and differentiation, causing the time spent for load application to be inferior to that spent with machined implants.[11] However, although this type of surface presents many advantages in comparison to machined ones, it has been proved that although acid etching results in a rough surface, it may not be appropriate and it can affect the resistance of the material.[24]

Modifying the implant surface with blasting of particles followed by acid etching becomes a favorable treatment option, since this technique results in semi-porous rugosity that favors strong bone anchorage in comparison to surfaces treated with acid, only. Such surface is named SLA.[24] Blasting the implant surface results in texture macro rugosity and the acid etching that follows it promotes micro rugosity, decontamination and hydrophobic state of the surface, allowing better protein absorption.[25]

Modifying the SLA method by altering the surface chemical structure and changing it into active and hydrophilic allows quicker osseointegration and increases stability, thus suggesting that not only rugosity, but also the chemical characteristics of implant surfaces exert influence over osseointegration. This surface is known as SLA active.[26]

In group II, the topography of SLA active surface was analyzed. According to the manufacturer, it had been treated by means of thick sandblasting followed by acid etching. With magnification set at 500x and 1000x (Fig 3), this surface presented topography with significant micro rugosity that is interposed between microcavities in addition to being homogeneously distributed between thread top and valley, in accordance with what was described by the manufacturer.

According to some authors, these chemically active hydrophilic surfaces increase cell dissemination as well as the number of cells connected to the surface, which also increases the speed with which they produce the regulatory factors of differentiation in bone cell formation (osteoblasts), thus decreasing the activity of bone destruction cells (osteoclasts).[24] SLA active surfaces allow direct cell interaction in the first phase of the osseointegration process, which allows bone formation to immediately start, thus increasing initial stability, one of its advantages in comparison to other types of surfaces.[27]

A study conduct by Buser et al[29] assessed removal torque forces by comparing two different surfaces: a polished surface undergoing acid etching and a SLA one, in guinea pigs. After 4, 8 and 12 weeks of healing, a resistance test was performed to the removal torque. The authors concluded that the mean torsion removal force for the SLA was 75% to 125% greater than that of polished and acid-etched implants after 3 months of healing. This is due to the fact that SLA implants promote quicker osseointegration.[28]

Treatment carried out by means of anodization proves to be a favorable option for clinical use since it incorporates calcium and phosphate to titanium oxide, thus speeding up osteoblastic response and, as a consequence, osseointegration. This treatment significantly changes the morphology of implant surfaces, since titanium oxide grows in the shape of little volcanoes, different in size and height, which causes rugosity to significantly increase.[11]

The information aforementioned corroborates the present study. Group IV sample (Fig 4) shows an anodized surface (Vulcano actives) that presents a heterogeneous morphology with little cavitation that varies in size and height. Furthermore, this surface also presents greater rugosity in comparison to the samples that had been treated by acid etching, thus making a larger bone-implant contact area available.

The study carried out by Elias et al[11] on this type of surface proves that the removal torque was significantly greater for adonized implants in comparison to other groups that had been treated by acid etching, in a rabbit model after 12 weeks. Histologic results demonstrate that this is an inducing surface. Additionally, the authors show that bone deposition on the implant surface occurs simultaneously with bone growth from the alveolus walls. According to Elias et al,[11] clinically speaking, the implant that presents quicker osseointegration is the one with anodized surface followed by acid etching treatment.[11,21]

Our study presented the following limitation: no parameters regarding rugosity measurement were employed; only a description of what was observed through scanning the implants surfaces by means of SEM was adopted. In addition to the present study, other studies are warranted to further assess the topography of surfaces as well as the quality of the osseointegration process obtained with the different types of macro, micro and nanostructures.

Conclusion

Based on the results obtained through scanning electron microscope as well as in the literature review, it is reasonable to conclude that:

1. All groups analyzed revealed the presence of surface rugosity, however, with different characteristics according to the treatment employed by the respective manufacturers.

2. Machined surfaces presented a mild degree of rugosity, therefore, they cannot be considered as totally smooth.

3. Surfaces treated by adonization and those treated by means of blasting followed by acid etching (SLA) present a rougher surface patter that results in a larger area of bone contact, in comparison to surfaces treated by acid etching, only.

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