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Surface roughness of biomaterials and process parameters of titanium dioxide gritblasting for productivity enhancement

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Abstract. Titanium is used in dental implants because of its properties as a biomaterial. Surface roughness is very important and fundamental for obtaining required results of biocompatibility. Dental implants with moderately rough surfaces are commonly used in the treatment of edentulous patients. Aiming for improvements in productivity, experiments were conducted in a dental implant industry to evaluate the influence of machining parameters on the surface of dental implants. Samples of different diameters were machined with specific parameters and their roughnesses were measured, before and after blasting, with and without asepsis chemical attack. The results indicate a random increase in roughness according to increase of feed parameter, evidencing that there is no relation between roughness and machining feed after gritblasting. Samples exposed to gritblasting that did not undergo chemical asepsis showed a decrease in roughness, compared to roughness of blasted samples and submitted to asepsis process. However, this trend remained constant leading to the conclusion that titanium-blasting process makes the surface roughness uniform, independently of first roughness variation. No relationship was observed between the variation of feed and the variation of roughness. Thus, in terms of productivity, cutting feed was increased with no harm to the biocompatibility. After more than twenty years of its first use in the industry, this study proves the possibility of changes in the process parameters of titanium dioxide gritblasting to increase productivity in the manufacture of dental implants.

Keywords. *Productivity in machining, cutting feed, roughness and biocompatibility*.

Introduction. Titanium is a biomaterial commonly used in the manufacture of dental implants because it exhibits excellent chemical characteristics such as high stability in surface oxide layer (1-3). Dental implants with moderately rough surfaces are commonly used in the treatment of edentulous patients (4-7). In addition, mechanical properties like hardness and toughness or biological properties like biocompatibility and low reactivity with living organisms are requirements to this material selection (8-11).

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Thus, surface mapping on titanium implants can provide better understanding of interaction between biomaterial and living tissues, culminating in osseointegration. Osseointegration can be described as the ability of interact harmoniously with a living organism in order to complete the bone recovery and perform the function in which it was assigned (12-14).

The gritblasting of titanium dioxide (TiO_2) on dental implants surface aims to improve the osseointegration, as it forms a rough layer (1, 3-5). After more than twenty years of its first use in the industry, this study aims to find the best machining parameters in the manufacture of dental implants to enhance productivity (15).

Wettability. The first property that may explain the surface interaction of the biomaterial with surrounding tissues is wettability. Wettability is the ability of a liquid to adhere to a surface when deposited forming a film. A surface is considered to be completely hydrophilic when the liquid forms a flat film on it and the contact angle θ0 is equal to 0°. As the word itself suggests, hydrophobia basically means water aversion (16,17).

A completely hydrophobic surface, in opposite, is energetically unfavorable for a drop to occupy part of the surface with θ0 of 180º. All droplets that have contact angles between these two values are partially wettable. Hydrophilic surfaces are covered with cells faster than others, presenting centers of mineral nucleation in an earlier period than on the hydrophobic surfaces (18-19).

The wettability tests shown in Fig. 1 illustrate the behavior of a one-microliter water drop in contact with three different surfaces exhibiting hydrophobic characteristic (A) with θ0 of 110°, another surface with θ0 of 100°, and hydrophilic characteristic (C) with 76°.

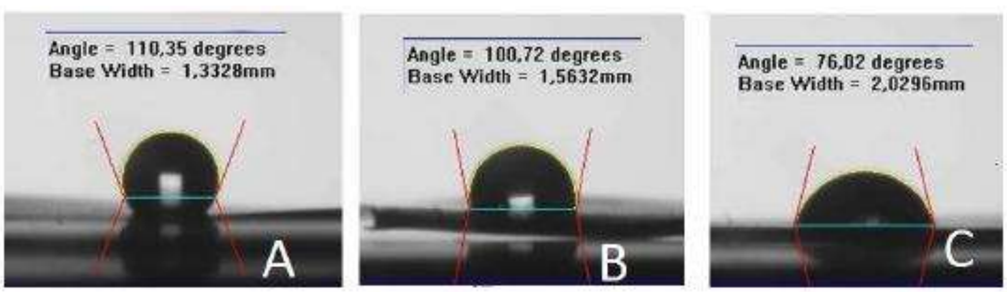

Figure 1. Micro droplet of water on three different surfaces from a hydrophobic surface (A) to a hydrophilic surface (B).

The wettability test consists of depositing a micro droplet on the surface and measure its contact angle with a goniometer. The goniometer has an optical device and camera to measure the contact angle. The image of the analyzed drop acquired by the camera appears on the computer screen and data is storage in specific software (19).

In order to perform the wettability test, it is necessary that test samples have a flat and clean surface prepared before experiments. Due to chemical and physical interactions between the studied surface and liquid, the samples should be subjected to characterization analyzes with profilometry. The test of profilometry consists in subjecting a flat surface to the action of a needle with diamond single-crystal tip in a certain length to realize the measurement of the peaks and valleys originating from the surface roughness. Thus, during measurement, the arithmetic roughness (Ra) value and the total roughness (Rz) value can be defined according to the experiment needs (2, 6, 8, 14).

Materials and Methods. In this paper, we studied the machining process uniformity of samples with same dimensional characteristics of dental implants in market. The roughnesses obtained with machining processes were verified, as well as the consequent gritblasting operation, in order to find the process that offers the best characteristics for the osseointegration of the implants (1-5).

For the gritblasting process, 1.5 kg of TiO_2 is necessary to blast 8000 implants. Samples with different roughness were produced varying the cutting feed so that it is possible to study variations in the surface caused by the alteration of this parameter.

The starting point for this analysis was based on machining parameters already commonly used in industry (14, 17). The samples used in experiments were produced with variations in the cutting feed, in order to establish an ideal process that presents greater possibility of osseointegration.

According to results, it is possible to offer options of machining parameters improvement to enhance productiveness without decreasing the osseointegration capacity of dental implants.

Samples were made of commercially pure titanium (ASTM F67 Grade 2) and (ASTM F67 Grade 4) according to ISO 5832-2 in round and rectified bars with h9 or h7 tolerance, annealed. This titanium demonstrated previous good mechanical resistance to torsion and fracture in dental implant (1, 2).

Two 7-axis computerized numerical control (CITIZEN, C12 VII, Nagano, Japan) and 8-axis (CITIZEN, M12 VIII, Nagano, Japan) CNC machining centers were used, Fig.2.

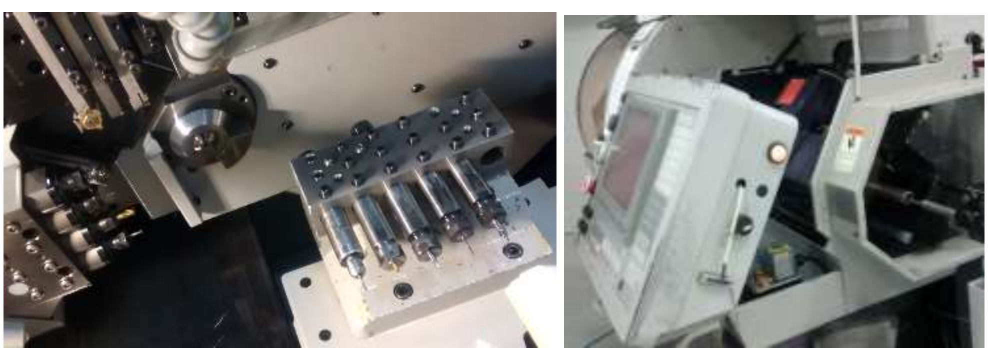

Figure 2. Pictures of CNC machining center with 7-axis and Lathe during samples machining.

The number of samples defined for experimental procedure was 40 pieces divided into two groups, a group for gritblasting without etching, which consists of subjecting implants to acidic solution

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with purpose of cleaning surface, and another group with blasting and etching. All samples were submitted to roughness tests before and after blasting. Samples were blasted with titanium dioxide (99.5%) after machining in a sealed metal case uniformly throughout.

Results. After all measurements, two graphs were plots with the value of roughness before and after the dioxide gritblasting process for samples with or without asepsis. In Figure 3, the graph presents an overview of samples roughness behavior before (the blue line) and after blasting (orange line), without the described aseptic process.

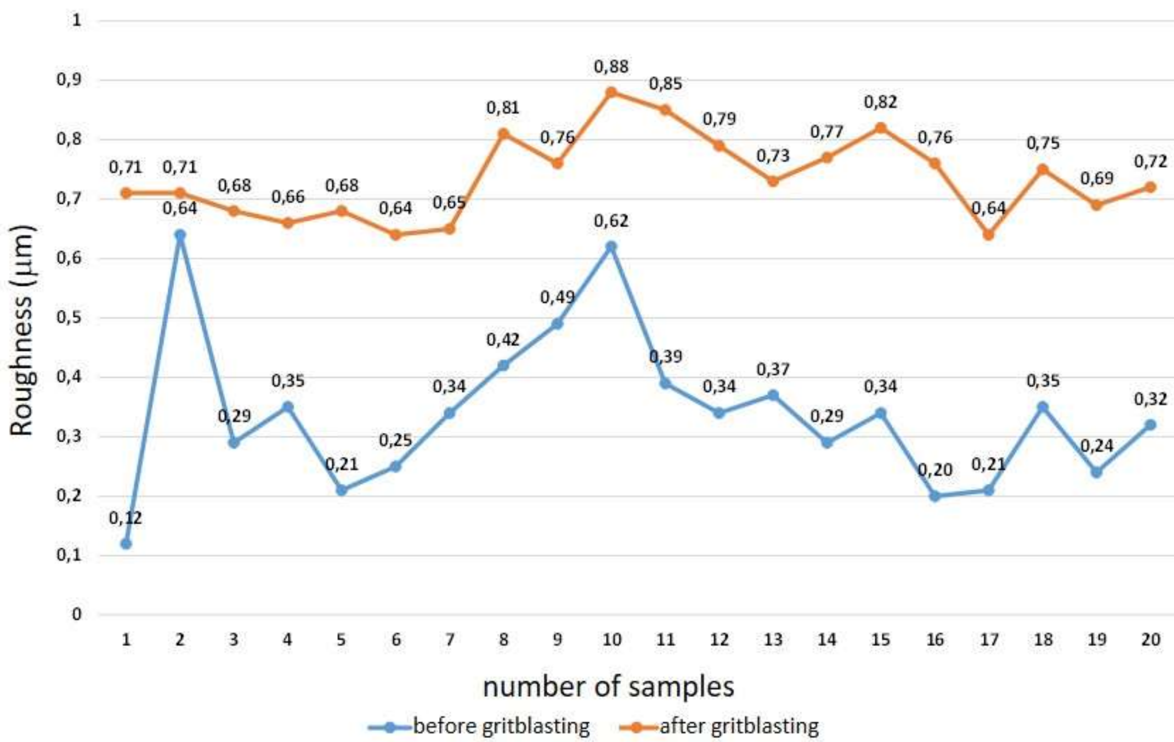

Figure 3. Comparative graph of samples before and after the gritblasting both without asepsis.

It clarifies that before blasting the roughness variation is larger, configuring the absence of uniformity in the surface. Figure 4 shows an overview of the samples before gritblasting (in blue line) and after the gritblasting process (in orange line), and which were also submitted to the asepsis process.

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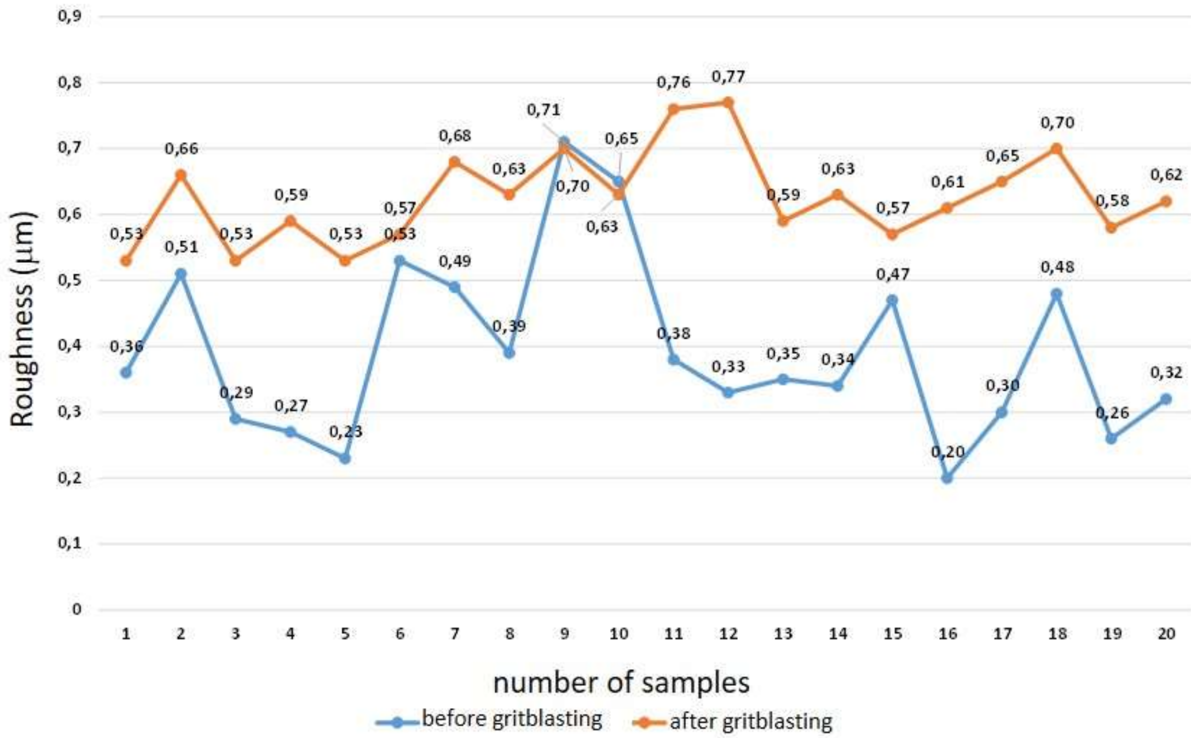

Figure 4. Comparative graph of samples before and after the gritblasting both with asepsis.

The Table 1 below shows a comparison between the conditions with blasting and without blasting, the values of general averages for drops 1 and 2 of each sample. Samples without blasting had contact angles between 40.2º and 82.7º, while samples with blasting had angles between 121.4º and 124º.

Table 1. Contact angles of the four groups before and after gritblasting, with and without cleaning.

Groups	**#1**	**#2**	**#3**	**#4**
without gritblasting	40.2°	67.3°	82.7°	80.6°
with gritblasting	121.4°	124.6°	131.6°	134.0°

Conclusions. According to this work proposal, one justification for this study is the increase of productivity in dental implant industry. Contrary to what was known in industry, the variation of machining parameters did not interfere in the final roughness of the blasted samples. It only change the roughness after machining but before titanium dioxide gritblasting. This observed behavior can have influence in the implants manufacturing process, increasing productivity.

Since parameters of the machining performed before blasting do not offer changes in samples manufacturing, these parameters can be adjusted according to the production demand. In situations where there is an increase in demand, it is possible to accelerate the production process, reducing lead time (15).

On the other hand, in situations of falling demand, it is possible to adopt procedures that allow reducing wear in cutting tools, consequently increasing their useful life and improving their performance.

Uniformity was observed on the blasted surfaces. The blasting process decreases the standard deviation of the measured roughness for samples that have not undergone this procedure.

The asepsis process had an influence on finishing. The chemical attack called "asepsis", which is carried out after blasting, has altered the roughness data, since it theoretically causes a slight wear on the samples surface. The group of samples that did not undergo the asepsis process had a average roughness of 0.64 μm and 0.88 μm, while the group of samples that underwent the asepsis process had average roughness between 0.53 μm and 0.77 μm.

The group of samples that was produced to be used in the wettability test showed average roughness between 0.11 μm and 0.25 μm before the blasting process and average roughness between 0.64 μm and 0.79 μm after the blasting process.

The wettability test showed that surfaces with less roughness, represented by samples denominated "without gritblasting" present hydrophilic characteristics and surfaces with greater roughness represented by samples denominated "with gritblasting" presented hydrophobic characteristics. The group of samples that did not underwent gritblasting showed average values of contact angle between 40.2º and 82.7º, evidencing hydrophilic characteristics. The group of blasted samples presented average values between 121.4º and 124º, thus presenting hydrophobic characteristics.

Although the Rasmusson *et al.* (2005) affirm dioxide titanium gritblasted implants perform better in low-density bone and marginal bone remains stable at these microroughened surfaces, besides the hydrophobic character, dental implants must have a slightly rough surface so that there is anchorage that provides integration with the bone, preventing an undesired movement of the implant.

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Disclosure. The authors report no conflicts of interest in this work.

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