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# Influence of surface treatment on the primary stability of osseointegrated dental implants quantified with a strain gauge

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*ABSTRACT: There are several hypotheses to explain the failures of osseointegrated titanium dental implants. Some possible explanations are the alterations in the mechanical properties of the maxillary bones, the surgical technique employed with excessive torques, the inadequate shape of the implants, and the deficient treatment of the surface of the implants. This work aims to measure the strain in the bone, quantify the insertion torque, and analyze the influence of surface treatment on the primary stability of dental implants. Extensometry tests were performed using strain gauges, and the insertion torque of the implants in synthetic polyurethane bone with a density of 30 PCF (0.48 g/cm³) was determined. The tests quantified the deformations in the synthetic bone and the maximum insertion torques of implants with the surface treated with double acid etching and without treatment (machined). The results showed that implants without surface treatment induce greater bone deformation, require lower insertion torque, have lower primary stability, and, in some essays, induce microcracks formation in the bone during insertion. Implants with an acid-treated surface perform better.*

*KEYWORDS: Dental Implant, Surface Treatment, Primary Stability.*

*RESUMO: São propostas várias hipóteses para explicar as falhas dos implantes dentários de titânio osseointegráveis. Entre as possíveis explicações destacam-se as alterações das propriedades mecânicas dos ossos maxilares, a técnica cirúrgica empregada com uso de torques excessivos, a forma inadequada dos implantes e o tratamento deficiente da superfície dos implantes. Os objetivos deste trabalho são medir a deformação no osso, quantificar o torque de inserção e analisar a influência do tratamento da superfície na estabilidade primária dos implantes dentários. Foram realizados ensaios de extensometria com o uso de strain gauges e determinado o torque de inserção dos implantes em osso sintético de poliuretano com densidade 30 PCF (0,48 g/cm³). Nos ensaios foram quantificadas as deformações no osso sintético e os torques máximo de inserção de implantes com a superfície tratada com duplo ataque ácido e sem tratamento (usinado). Os resultados mostraram que os implantes sem tratamento de superfície induzem maior deformação no osso, necessitam de menor torque de inserção, possuem menor estabilidade primária e em alguns ensaios induziram a formação de microtrincas no osso durante a inserção. Os implantes com superfície tratada com ácido apresentam melhor desempenho.*

***PALAVRAS-CHAVE:** Implante dentário, Tratamento de superfície, Estabilidade primária.*

## 1. Introduction

Dental implants' primary (mechanical) stability is quantified during or immediately after installation. Available studies do not provide data on the limit of compressive tension, which is transmitted to the bone during the insertion of dental implants. During implant installation, primary stability can be measured by insertion torque, with Periotest, or by resonant frequency analysis (RFA). Of these methods, measuring insertion torque is the simplest and provides the most accurate data to estimate the primary stability of implants. Compared to other methods, it is possible to more easily qualify bone density and primary stability at surgery by measuring the insertion torque. The primary stability of implants is affected by several factors, including body shape, diameter, length, and thread profile [1,2,3].

The surgical technique, the amount and density of bone available, and the morphology of the implant surface influence the success or failure of implants [2,3].

Nowadays, paradigm shifts have emerged in terms of how the surface characteristics of biomaterials influence biological response. Both microroughness and wettability increase surface energy, improve cell contact, and improve the osseointegration of titanium implants. Synergistic effects of nanoscale topography features, wettability, and quality of the implant-bone interface are relevant to the success of implant systems.

Surface treatments influence the osseointegration process, wettability, roughness, and morphology. The roughness of the implants' surface changes the adhesion and fixation of the osteogenic cells. Roughness can be quantified by several parameters, in which Ra is the most used, representing the arithmetic mean value of the size of the peaks and valleys on the surface regarding an imaginary mean line calculated. Regarding the roughness size of the implants, it can be divided into three levels: macroroughness, microroughness, and nanoroughness. Macroroughness with an order of magnitude of a millimeter does not influence osseointegration but affects the distribution of forces to the bone and the implant's stability [4]. Ideally, the roughness (Ra) of the implant body required for bone formation is between 1.0 and 2.0 μm [5]. Roughness around 1.0 μm (Ra) in the subepithelial segment region enables the subepithelial connective tissue adhesion. The endobone region's implant surface should induce bone regeneration and remodeling, promote optimal load distribution, increase the contact area, and lead to maximum cell deposition [4].

The surface wettability interferes with cell behavior and is evaluated by the contact angle. The chemical composition and surface energy are essential for osteoblast adhesion, the first phase of interaction between cells and the biomaterial, guiding cell proliferation in contact with the implant. Different surface treatments are used to change the morphology, topography, roughness, chemical composition, energy level, and decrease the contact angle to increase osseointegration with the best mechanical and biological anchorage [3].

Implant surfaces determine primary interfacial reactions with blood, bone cells, epithelial, and connective tissue components, such as macromolecule adsorption, cell adhesion, proliferation, and differentiation [5].

During surgery, the cavity prepared in the bone for the insertion of dental implants is filled with blood due to the rupture of damaged blood vessels and vascular trauma to the bone. Fibrin clot formation is associated with most wound healing processes and is linked to initial osseointegration reactions. The blood clot is used as a framework for migrating mesenchymal stem cells and the secretion of fibrinolytic enzymes. This migration process to a temporary connective tissue framework is called osteoconduction, being the first phase of osseointegration. After osteoconduction, the "new bone" formation occurs, which is initiated by the differentiation of osteoblasts [5].

Implant surface treatments aim to reduce the loading time of the prosthesis after surgery; accelerate bone growth and maturation to allow immediate loading; increase primary stability; ensure successful application in bone with lower density and quantity; obtain bone growth directly on the implant surface; obtain the largest possible area of osseointegration; obtain bone-implant contact without the interposition of amorphous protein layers; attract osteoblastic, pre-osteoblastic and mesenchymal cells; attract specific binding proteins to osteogenic cells (fibronectin); and obtain the highest possible concentration of cell-binding proteins [3].

Moderately rough oral implants are the most used, based on scientific evidence that such surfaces provide better bone response. A general trend in *in vivo* experiments is that the increase in the value of the As roughness parameter, which quantifies the arithmetic mean height of the peaks of the irregularities on the surface, increases the resistance to interfacial shear [6]. Halldin *et al*. (2015) [6] estimated the shear strength of the bone-implant interface for different surfaces. It was found that the surface with Sa of 1.51 μm increases the shear strength of the bone-implant interface by 45% relative to the surface with Sa of 0.91 μm after 12 weeks of healing [7].

Modifying the implant surface is recommended to increase the contact area of the implant with the bone, enable better shear strength of the bone-implant interface, and increase the friction coefficient [8]. It is essential to analyze the stress on the cortical bone and surface roughness in the region to avoid

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bone loss around the dental implant. It was observed that as the stress on the cortical bone increases, bone loss increases.

Tabassum *et al*. (2009) [9] measured the roughness of the implant surface and observed, by topographic evaluation, that the machined surface has a significantly lower mean surface roughness (Ra = 0.45 µm) than the acid-conditioned surface (Ra = 1.47 µm).

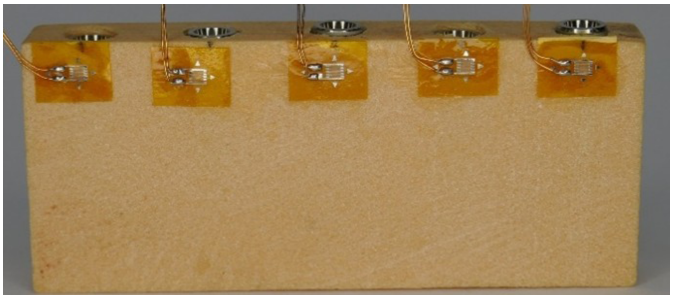
This work shows the purpose of evaluating the primary stability of implants with treated surfaces and machined using a strain gauge. This device is used in extensometry testing to measure the strain suffered by an object. The deformation changes the length of the strain gauge, varying its electrical resistance. The strain gauge is connected to an analog-digital amplifier and to the software that quantifies the deformation suffered by the material [1].

## 2. Material and method

In this work, dental implants were inserted into specimens made of rigid polyurethane foam (NacionalOssos ®, Jaú, São Paulo) with a density of 30 PCF (0.48 g/cm³) and a modulus of elasticity of 305.73 MPa, compatible with natural bone D2. Specimens in the form of a parallelepiped with a width of 50 mm and a height of 19 mm were used to insert the implants. The implants were 5 mm in diameter, and the specimen was 7 mm thick. The properties of the blocks are detailed in the ASTM F-1839-08 standard (Standard Specification for Rigid Polyurethane for use as a Standard Material for Testing Orthopaedic Devices and Instruments).

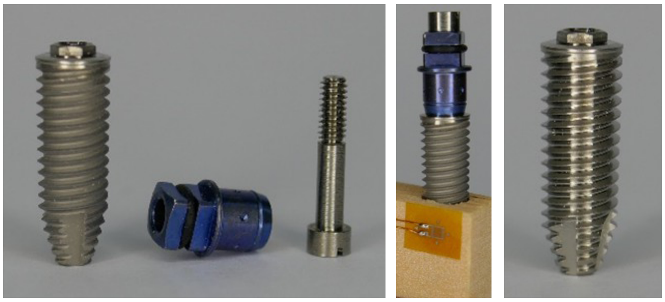
Strain gauges rectangular (Model PA-06-040 AB-120 - Excell Sensores, Taboão da Serra, São Paulo, Brazil) were glued to the upper edge of the specimens (Figure 1). The measuring axis was aligned perpendicular to the perforations. This configuration enabled the quantification of the deformations resulting from the compressive tension during implant insertion. In each polyurethane block, five implants were installed, with a spacing of 10 mm between them.

**Figure 1** - Strain gauges glued to the specimen



Two implant models (Figure 2) with two surface treatments were used. Easy-Grip implants with Porous surface® with double acid etching and the Master Screw machined implant from the company Conexão Sistema de Prótese (Arujá, São Paulo). The goal was to compare the influence of surface treatment on the insertion torque and synthetic bone strain.

**Figures 2** - a) Easy Grip 5x15mm implant with the Porous surface; b) Easy Grip implant installed in the specimen; c) Machined implant (Master Screw)



The implants with a diameter of 5.0 mm and a length of 15.0 mm were inserted into cavities prepared with the initial drilling performed with a pilot drill of 2.0 mm in diameter and rotation of 1,200 rpm. Next, 2.5, 3, 3.5, 4, and 4.5 mm diameter drills were used.

The block was attached to a TSS400 digital torque wrench (FUTEK, Irvine, CA, USA) with a capacity of 113 N.cm. The perforation for implant insertion was aligned with the rotation axis of the motor. The strain gauges were connected to the analog-digital-Spider 8 interface (HBM – Darms-

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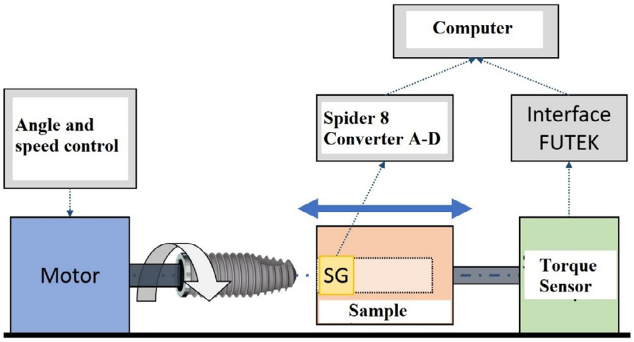
ladt- Germany). This system was configured for a data acquisition rate of 50 Hz, with a resolution of 16 bits. The implants were inserted by a stepper motor with a constant rotation of 25 rpm. Figure 3 shows the outline of the procedures.

**Figure 3** - Experiment assembly scheme




## Results

Figures 4 and 5 and Table 1 show the results of the extensometry tests. It was possible to note that the surfaces of the implants with treated surfaces showed greater plastic deformation, induced less tension in the bone, and required higher insertion torque.

**Figure 4** - Variation curves of plastic deformation and torque during the installation of implants without surface treatment (Master Screw)

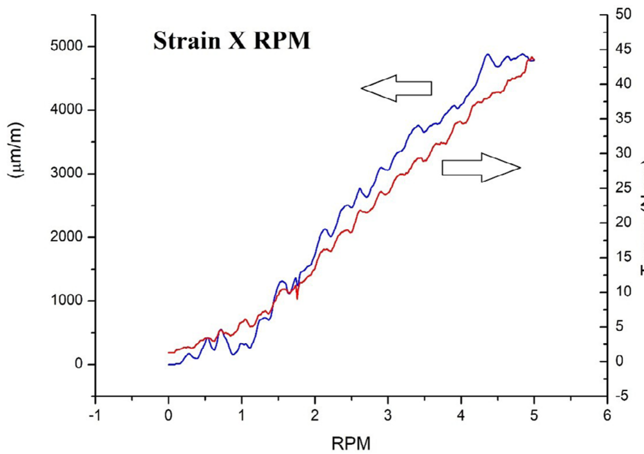



**Figure 5** - Plastic Deformation and Torque Variation Curves During Implants Installation with Surface Treatment (Porous Surface)

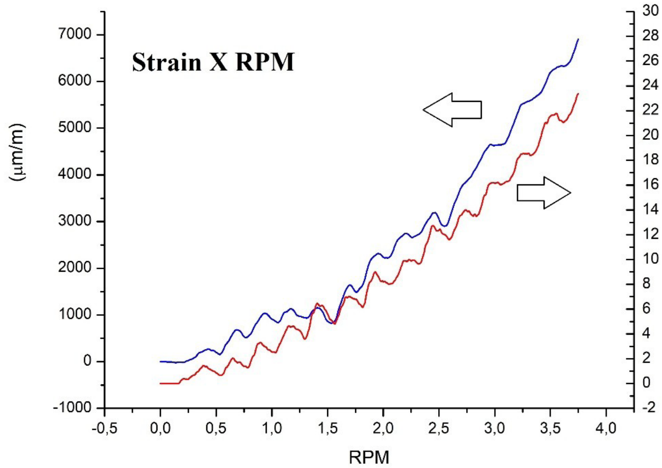



**Table 1** - Deformation, insertion torque, and compressive tension during implant installation in synthetic bone

| IMPLANTS | Mean Strain - ε (‰) | Mean Torque (N.cm) | σ (MPa) |
|---|---|---|---|
| Easy Grip | 5.73 ± 2.86 | 53.9 ± 12.3 | 1.753 |
| Master Screw | 6.47 ± 2.48 | 43.6 ± 7.5 | 1.987 |

## 4. Discussion

The superficial roughness of the implants reduces bone healing time, provides greater mechanical locking, and increases primary stability [2].

The machined Master Screw implant has circular grooves from the manufacturing process. The surface of acid-etched implants (Porous surface) is more homogeneous than the machined surface. Surface treatment significantly alters the roughness parameters, which influence the interaction of the surface with proteins and cells, inducing osteogenesis, which can be evaluated by the implant removal torque [2].

Elias *et al*. (2012) [2] obtained an insertion torque of 45.86 N.cm for the installation of 3.75 x 13

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mm Master Screw machined implants in polyurethane foam. The authors emphasize that machined implants surface have the lowest insertion torque compared to treated surfaces. The machined implant has lower surface roughness [1]. The insertion torque for the acid-conditioned implant is greater than that of the machined implant and less than that of the anodized implant. Implants with treated surfaces showed higher roughness, coefficient of friction, and insertion torque than machined implants. The surface roughness results and friction coefficients agree with the insertion torque results. Based on the results, the authors conclude that the anodized surface of the dental implant can be considered the best surface for osseointegration and primary stability [2].

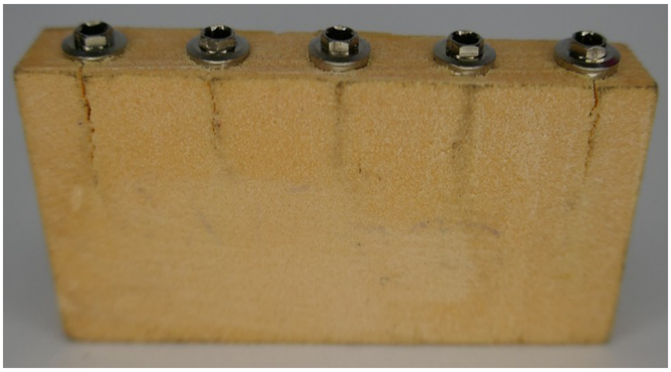
Modifying the implants' surface is recommended to increase the bone-to-implant contact area, enabling greater resistance to shear forces and a higher coefficient of friction [9].

Santiago Junior *et al*. (2016) [10] observed that surface-treated implants induce greater tension and deformation in the cortical bone than machined implants. However, axial tension distribution is better in the peri-implant bone. The authors attribute this result to the increase in implants with treated surface areas.

Veis *et al*. (2017) [11] recommend using implants with a rough surface to improve primary stability. The authors add that the surface morphology of an implant influences the rate and extent of bone-implant fixation, which is expressed by the amount of bone-implant contact (BIC). In low bone density places, implants with an acid-treated surface are indicated.

Through finite element analysis, Bahrami et al. (2014) [12] analyzed the effect of surface treatments on tension distribution at the bone-implant interface in implants inserted in the mandible with immediate loading. The implant surfaces were divided based on the coefficient of friction: polished (CA = 0.4), plasma spray (CA = 1.0), sandblasted (CA = 0.68), implant with roughness in the polished coronal region (CA = 0.4), and treated with plasma spray (CA = 1). The increase in the roughness of the implant surfaces increases the maximum tension on the cortical bone, and the increase in the coefficient reduces the tension levels at the interface with the trabecular bone. Using a two-part surface treatment technique, with a low coefficient of friction at the interface with the cortical bone and a higher coefficient of friction at the interface with the trabecular bone, optimizes the tension levels at the bone-implant interface.

**Figure 6 -** Specimen showing cracks after machined implants insertion (Master Screw)



In this study, the machined implants induced greater bone deformation and were inserted with lower torque when compared to implants with an acid-etched surface (Porous). In addition, cracks were observed in the synthetic bone after the installation of machined implants.

The data in this study are different from those in the literature. One explanation for this contradiction is that, in the available studies, the tension on the bone is calculated by applying axial and oblique loading force to the implant abutment. However, the circumferential compression tension during implant insertion was determined. The tension is better distributed by increasing the surface area of the surface-treated implants, and the higher torque can be attributed to the coefficient of friction caused by the increase in roughness.

## 5. Conclusion

The results show that:

a. Machined implants induce greater deformation and compressive tension in the bone and require lower insertion torque. This result can be attributed to the smaller bone-implant contact area and the lower frictional force.

b. The machined implants induced the formation of cracks in the bone during insertion due to the lower distribution of tension in the synthetic bone.

c. Implants with a surface treated with double acid etching (Porous) induce less deformation and tension in the bone during insertion, minimizing the risks of excessive compression, bone necrosis, and microfractures, which would lead to implant loss.

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