In vitro analysis of the influence of surface treatment of dental implants on primary stability

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Abstract: Surface treatment interferes with the primary stability of dental implants because it promotes a chemical and micromorphological change on the surface and thus stimulates osseointegration. This study aimed to evaluate the effects of different surface treatments on primary stability by analyzing insertion torque (IT) and pullout force (PF). Eight samples of implants with different surface treatments (TS - external hexagon with acid surface treatment; and MS - external hexagon, machined surface), all 3.75 mm in diameter × 11.5 mm in length, were inserted into segments of artificial bones. The IT of each sample was measured by an electronic torquemeter, and then the pullout test was done with a universal testing machine. The results were subjected to ANOVA ($p < 0.05$), followed by Tukey's test ($p < 0.05$). The IT results showed no statistically significant difference, since the sizes of the implants used were very similar, and the bone used was not highly resistant. The PF values (N) were, respectively, TS = 403.75 ± 189.80 and MS = 276.38 ± 110.05. The implants were shown to be different in terms of the variables of maximum force ($F = 4.401$, $p = 0.0120$), elasticity in maximum flexion ($F = 3.672$, $p = 0.024$), and relative stiffness ($F = 4.60$, $p = 0.01$). In this study, external hexagonal implants with acid surface treatment showed the highest values of pullout strength and better stability, which provide greater indication for their use.

Descriptors: Dental Implantation; Osseointegration; Tensile Strength; Torque.

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Introduction

In the 1960s, Brånemark[1] discovered that titanium was biocompatible with bone and could attach to it. Since then, many studies have been conducted to determine the nature of the interaction that occurs between the metal and the tissue[2-5] called osseointegration, in which the bone-implant unit becomes an anatomical structure[6] and supports patient function without causing injury.

Currently, the dental implant is an object of study by several researchers[7-11] whose goals are to develop design innovations and application techniques to optimize the implant's physical-chemical and mechanical properties.[7] One current area of research involves the treatment of implant surfaces for osseointegration stimulation due to a chemical or micromorphological alteration of the implant[9] that can facilitate early installation of the prosthesis.[12]

These innovations are designed to improve the technical conditions for implant insertion and improve osseointegration, which is possible only if primary stability of the implants is attained. Primary stability is defined as the resistance to micromovement of the implant in the surgical site immediately after its insertion, and is one of the main factors required for osseointegration, since stability facilitates the formation of bone cells around the implants. Primary stability is dependent on factors such as bone type, and on characteristics related to implants, such as design and surface topography.[13]

Primary stability of implants can be measured by the analysis of resonance frequency[14] or through the pullout assay.[15,16] Another property that must be considered is the implant's resistance to the forces to which it is subjected, such as the insertion technique, bone resistance, and chewing forces (in cases of immediate loading). Therefore, *in vitro* tests have been performed to evaluate the behavior of implants subjected to such forces.[17] In these tests, it was observed that the implants with treated surfaces behaved differently than the machined implants.[18,19]

This study aimed to evaluate the insertion torque and the pullout resistance of titanium dental implants with treated and untreated surfaces before osseointegration, and to evaluate the effects of these treatments on primary stability.

Materials and methods

In this study, 16 cylindrical external hexagonal implants, measuring 3.75 mm in diameter × 11.5 mm in length (Conexão, Arujá, Brazil), were evaluated. They were divided into two groups of samples, one with treated surfaces (TS) and another with machined surfaces (MS). Each implant was inserted into a femur of synthetic material (Symbone, Malans, Switzerland),[20,21] since artificial polyurethane bones have greater standardization of density, preventing the interference of this factor in the values of insertion torque and pullout resistance.

To obtain the portion of the synthetic femur with the desired characteristics, we sawed the upper portion of the femur just below where the implants were to be inserted. Next, we prepared an orifice for each implant using an electric motor under torque of 25N/cm and 1470 RPM (revolutions per minute), following the bur sequence recommended by the manufacturer. The implants were then inserted vertically by means of a ratchet key, and the insertion torque was measured by an electronic torquemeter.

To verify pullout strength, we developed a shield that was welded to the slap implant and attached to a piece to adapt to the load cell. This device was fixed to the base of a universal testing machine (model Emic DL-10000; Emic - São José dos Pinhais, Brazil) through a circular hole.

The test was performed under a load cell of 200 kgf, and the results were collected with Tesc 3.13 software (Emic - São José dos Pinhais, Brazil). In addition to the values of maximum force (Fmax), we also obtained values for maximum deflection (Def max), relative stiffness (RS), and modulus of elasticity in maximum flexion (EF max).

At the end of the test, results were subjected to statistical ANOVA to detect statistically significant differences between and among the different implants tested. Statistically significant variables were subjected to multiple comparisons with Tukey's HSD test. The significance level was 5%, and analysis was performed with SPSS Statistical Software, version 17 (SPSS, Chicago, USA).

Results

The medium insertion torques obtained were 11.39 N cm for the TS implants and 10.34 N cm for the MS implants. ANOVA showed that there was no significant difference ($p < 0.05$).

The pullout resistance tests were performed with the dependent variables maximum pullout strength, Def max, RS, and EF max (Tables 1, 2, and 3).

The results obtained by the ANOVA tests (mul-

Table 1 - ANOVA.

	Sum Square	Mean Square	F	*P*
Fmax	215529.89	71843.30	4.40	0.12
Def max	0.14	0.05	0.92	0.44
EF max	55689.01	18563.00	3.67	0.024
RS	376284.34	125428.11	4.6	0.01

Table 2 - Average values of maximum force, maximum deformation, maximum relative stiffness, and maximum EF obtained for each implant.

Implant	Fmax	Def max	EF max	RS
Treated Surface	403.7 ± 189.8	0.91 ± 0.23	198.77 ± 102.37	660 ± 187.44
Machined Surface	276.38 ± 110.05	0.77 ± 0.21	123.91 ± 62.95	518.1 ± 142

tivariate analysis of variance) showed significant differences between the two groups of implants in terms of pullout tests (Wilks' Lambda = 0.312, p = 0.001).

Discussion

Because of the great progress that has been made in the development of dental implants, these materials fill the market with different options regarding geometry, size, and surface characteristics. Given this variety, the dentist may choose an implant that favors rehabilitation, by increasing the surface available for bone-implant contact, and promotes good primary stability, osseointegration, and distribution of forces.[22,23]

However, this extensive range of available options can also generate doubts about the real advantages and benefits of each product.

With the aim of evaluating the insertion torque and pullout resistance of different implants, we opted to use synthetic bone, because its mechanical properties are similar to those of natural bones, except for trials involving twisting.[20,21] During processing, synthetic bone showed uniformity in density and geometry, favoring a standard analysis of the variable types of bones.

Primary stability is undoubtedly one of the main factors required for the occurrence of osseointegration; however, changes in the shapes and types of implants in the quest to increase this stability can often lead to necrosis of the bone surface[24] when the threshold of bone strength is crossed due to very high torque. In this study, when we measured insertion torque, there was no significant difference between the groups. It is believed that this is due to the lack of difference in diameter between the implants used.

Given the diversity of rehabilitation methods, mediated or delayed, a further difficulty may arise in the selection of the implant, since each requires

Table 3 - Means (± SD) of pullout strength (N) of implants (n = 8).

Implant	Pullout strength (N)	*p* value
Treated Surface	403.7 ± 189.8	0.214
Machined Surface	276.38 ± 110.05	0.214

correlation of bone type, implant type, and primary stability.

Some paradigms exist wherein the implant surface treatment influences mainly the primary stability of implants. This study showed that surface treatment also influences primary stability, which is extremely positive, since the cylindrical implants with treated surfaces showed superior results of pullout strength compared with those with machined surfaces. This result suggests that the roughness caused by surface treatment increases the friction between the implant surface and bone, influencing primary stability.[9,18,19] Moreover, when the surface treatment increased bone-implant contact, the likelihood of osseointegration increased.[11] However, the high pullout resistance of implants with treated surfaces compared with those having machined surfaces suggests that the surface influences initial stability even when osseointegration does not occur.

It is suggested that the correlation between primary stability and pullout resistance is biomechanical, since the higher stability of the screw in the bones suggests that the pullout resistance of the same is greater.[16]

The results demonstrated the great efficiency of implants with treated surfaces, and the literature shows that treating implants with acids, as in the present study, leads to the formation of surface roughness, allowing for greater contact with osteoblastic cells.[9,18,25]

When pullout tests are performed, the implant should be completely vertical, so that its pullout resistance would be influenced only by the surrounding bone, since if the implant was inclined, part of the bone would be around the implant, resulting in a resistance higher than that obtained. To prevent this, we developed a shield with a circular hole with a diameter smaller than that of the upper portion of the femur, and fixed it to a universal testing machine in which the sample was positioned with the implant, so that, when pulled, the implant would be positioned as vertically as possible.

The pullout tests simply evaluated the screw resistance after the application of axial force, which does not correspond to physiological forces on the implant. This was the most practical way to evaluate this variable, which is complex and, as mentioned before, is related to various factors such as bone quality and implant characteristics.[26]

Conclusion

The surface treatment of implants increases their primary stability. This suggests a greater indication for the use of surface-treated implants for oral rehabilitation and implantology.

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