The Effects of Superficial Roughness and Design on the Primary Stability of Dental Implants

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ABSTRACT

Background: Primary implant stability has been used as an indicator for future osseointegration and whether an immediate/early loading protocol should be applied. Implant stability is the key to clinical success.

Purpose: The aim of this work was to analyze the influence of the design and surface morphology on the primary stability of dental implants. The insertion torque and resonance frequency analysis (RFA) were the parameters used to measure the primary stability of the implants.

Materials and Methods: Thirty implants, divided in six groups of five samples were placed in cylinder of high molecular weight polyethylene. The groups were different upon two designs (cylindrical and conic) and three implant surfaces finishing (machined, acid etched, and anodized). The insertion torque was quantified by a digital torque driver (Lutron Electronic Enterprise Co., Taipei, Taiwan) and the resonance frequency was measured by Osstell mentor™ (Integration Diagnostics AB, Göteborg, Sweden). The implant surface morphology was characterized by scanning electron microscopy, roughness measurement, and friction coefficient.

Results: The machined implants showed smaller insertion torques than treated implant surfaces. There were no differences between the RFA measurements in all tested surfaces. Statistical analyses demonstrated no correlation between the dental implant insertion torque and primary stability measured by the RFA. The implants with treated surfaces showed greater roughness, a higher friction coefficient, and demanded a larger insertion torque than machined implants. The results of the surface roughness and friction coefficients are in accordance with the results of the insertion torque. The difference, across the insertion torque values, between conical and cylindrical implants, can be explained by the different contact surface area among the thread geometry of these implants.

Conclusion: The maximum implant insertion torque depends on the implant geometry, thread form, and implant surface morphology. The placement of conical implants with treated surfaces required the highest insertion torque. There was no correlation between RFA and insertion torque implant.

KEY WORDS: implants, insertion torque, primary stability, resonance frequency analysis

INTRODUCTION

The conventional two-stage surgical protocol for dental implant insertion recommends an interval from 3 to 6 months between the surgery and the implant loading.[1,2] This protocol is necessary for bone healing, cell interactions with the implant surface, and implant stabilization. Implant stabilization is a very important parameter in reducing fibrous tissue formation around the implant. The maximum acceptable micromovement described in the literature is between 50 and 150 µm; above these values, the activity of the osteoblasts can be affected.[3,4] However, some studies have shown good results using one-stage surgical protocol, which objective is to reduce the number of surgical interventions, in order to minimize the time for the prosthesis installation and implant loading.[5–7] In this protocol of one-stage, primary stability is an essential prerequisite for early loading.

Some factors affect the implant's primary stability, including the bone density, the implant design, the

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surgical technique, the insertion torque, and the instrumentation protocol. Among these parameters, the insertion torque has not yet been sufficiently analyzed. The insertion torque is a function of the implant surface treatment, design, and screw-thread geometry.

The implant surface treatments change its roughness and morphology. The dental implant surface treatments have been developed with the objective of improving the osseointegration mechanisms and reducing the loading time of the implants.[8,9]

The primary stability of an implant fixture at the time of placement is often estimated by judging the presence of any mobility. In clinical work, primary stability can be evaluated by mobility using a blunt instrument such as a mirror handle. The follow-up of the implants can be estimated by devices such as Periotest, Periometer, resonance frequency analysis (RFA), and placement torque.[10,11]

Meredith and colleagues[12] have shown that the Osstell™ (Integration Diagnostics AB, Göteborg, Sweden) transducer is a device used to evaluate the initial stability of a dental implant, monitors the implant stability over time, and can discriminate successful implants and clinical failures. The Osstell™ is a product that allows the evaluation of an implant's stability by resonance frequency. A smart peg transducer is attached to the implant, and a magnetic pulse from the measurement probe on the handheld instrument excites the smart peg, then the resonance frequency is calculated from the response signal. Results are displayed on the instrument as the Implant Stability Quotient (ISQ), which is scaled from 1 to 100. Higher ISQ numbers indicate greater implant stability. The ISQ number is related to the lateral stability of the implant, which depends on the rigidity of the bond between the implant surface and the bone.[13] Another method to evaluate implant's primary stability is the measure of the insertion torque. The value of the final torque placement is the clinical parameter most often chosen by the surgeon to measure immediate load. However, the insertion torque value above which primary stability to apply immediate loading has not been well defined, but some authors found that values above 32 Ncm would be an indication of primary stability. Some researchers[13–17] have discussed the correlation between the torque and ISQ; however, a consensus does not exist about this correlation.

The present work evaluated the effect of the surface morphology and titanium dental implant design on the primary stability of an implant's surgical placement. In this work, two different implant geometries and three surface treatments were analyzed through resonance frequency, using the Osstell mentor™ device (Integration Diagnostics), and the insertion torque, measured with an electronic device.

MATERIALS AND METHODS

In the present work, a commercial screw-shaped dental implants of cp Ti ASTM grade 4, with a diameter of 5.0 mm and length of 13.0 mm was used. Forty-five dental implants (Conexão Sistemas e Prótese, São Paulo, Brazil) with cylindrical or conical designs and three surface finishes (machined, acid-etched, and anodized) were used in this study. The designs of the analyzed dental implants are shown in the Figure 1. Figure 2 shows the surface morphologies of the dental implants.

In the present work, dental implants were inserted into high molecular weight polyethylene (HMWPE) cylinders. The HMWPE (Ciplast, Rio de Janeiro, Brazil) presents better homogeneity than cancellous or cortical bone, and possesses a density and hardness close to those of cortical bone from a jaw. The mechanical properties of the HMWPE used are shown in Table 1. The cylinders of HMWPE, with a diameter of 16.0 mm and length of 20.0 mm, were cut from the same bar.
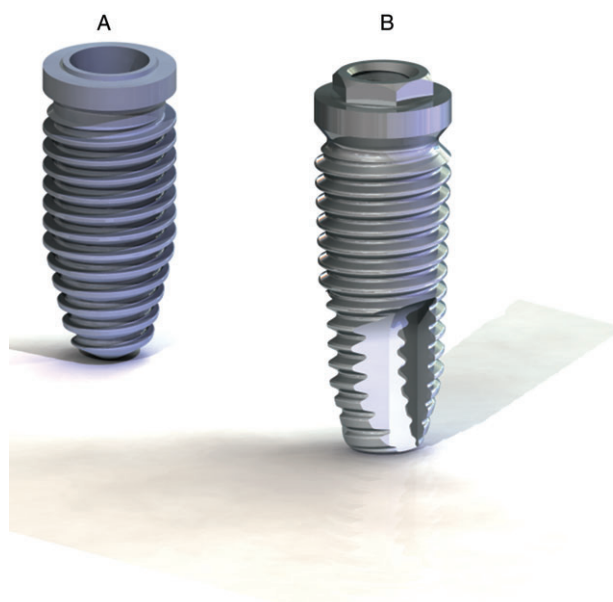
Figure 1 The dental implant designs. *A,* Conic. *B,* Cylindrical.
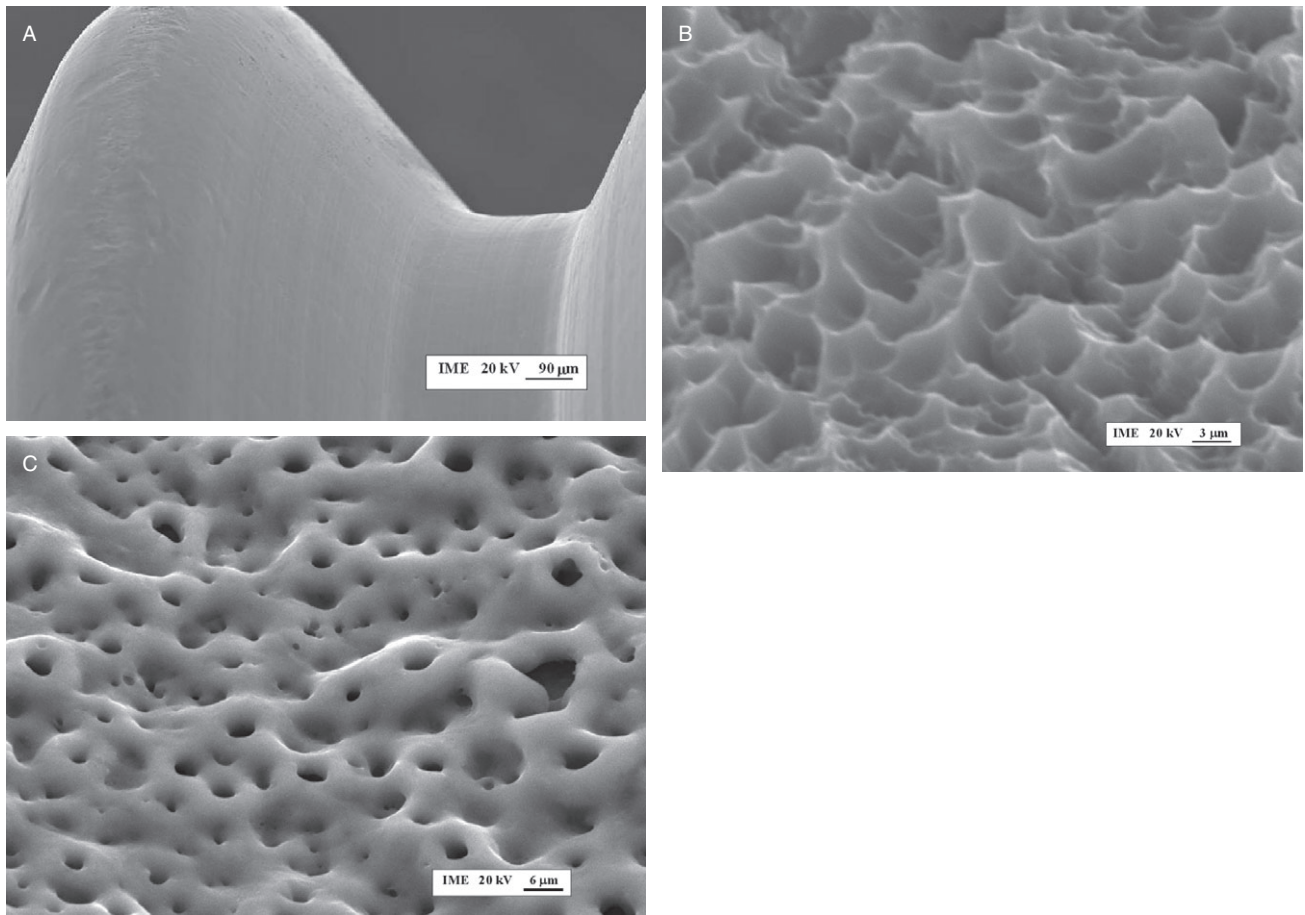
Figure 2 Dental implant surface morphologies. *A,* As-machined. *B,* Acid-etched. *C,* Anodized.

Friction Coefficient

Commercially pure Ti grade-4 discs were machined and submitted to the same surface treatments as commercial dental implants (machined, acid-etched, and anodized) used in this work for implant insertion testing. The discs were used to determine the friction coefficient between the titanium and the HMWPE.

Figure 3 illustrates the friction test set-up for measuring the friction coefficient. In this figure, W is the cylinder weight and F_f is the friction force. The Ti cylinders were put on the surface polymer plate, which was slowly raised; when the cylinder began to slide, the plate's angle of inclination was measured. The friction coefficient was considered to be the tangent of the angle (α) of inclination of the polymer plate. For each cylinder surface finishing, five samples were used. Each sample was tested three times, totaling $n = 15$ for each surface finishing group.

Surface Roughness

The surface roughness was measured in the discs after the same dental implant surface treatments. Three discs

TABLE 1 Density, Ultimate Tensile Strength, Elongation, and Rockwell Hardness of the HMWPE Cylinder into Which the Implants Were Inserted	
Density (g/cm³)	0.95
Tensile strength (kgf/cm²)	2.4
Elongation (%)	500
Rockwell hardness	60 R
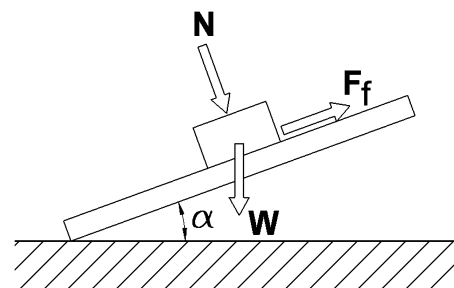
Figure 3 Set-up for friction coefficient measurement.

from each implant group were used; the roughness parameter was determined in five directions in each sample ($n = 15$). The roughness parameters were measured two-dimensionally with a non-contact method using a laser profilometer (Perthometer Concept, Mahr GmbH, Brauweg 38 Gottingen, Germany). The parameters for numerically characterizing roughness were: the arithmetic mean of the absolute values of roughness (Ra), the peak-to-valley roughness, (Rz) and the root square value of average roughness (Rq).

Hole Drilling

The HMWPE cylinders were attached in a device coupled to an electronic digital torque transducer. The holes were drilled according to the surgical protocol suggested by the implant manufacturer. Holes were drilled in the center of the disc's face through standard placement protocol. The holes were drilled to a depth of 15 mm to guarantee that the apex of the implant did not contact the bottom of the hole, which can induce a force resistance against the implant insertion. When the implant contacts the bottom of the hole, the insertion torque increases and it becomes impossible to measure the true insert torque induced by the friction between the implant and the wall of the hole.

For cylindrical implant site preparation, an initial mark was made in the HMWPE discs. Next, the following were used: a spherical drill with diameter of up to 2 mm and length of 13 mm; a pilot drill between 2- and 3-mm wide; a cylindrical drill 3-mm wide; a pilot drill between 3- and 4.3-mm wide; and a cylindrical drill 4.3-mm wide. To measure the influence of a screw tap on the insertion torque, three groups of HMWPE cylinders were drilled to a diameter of 4.3 mm and a parallel tap used as the final step of the site preparation, before implant insertion. For a conical implant site, the same process was used as in cylindrical implant placement preparation, except that the drills were conical and no tap screw was used.

The drills were changed after every 10 drills to reduce the possibility of inaccurate diameter, and to avoid eccentric hole and poorly finished walls. These would result in possible alterations in the primary stability and increase the initial mobility of the implants.

To drill the HMWPE cylinder, a surgical, electric-motor, dental implant Omega, MC 01OM (Dentscler, Ribeirão Preto, Brazil) was coupled to the hand-piece Anthogyr 20:1 (Anthogyr, France).

Implant Insertion

To insert the 45 implants into the HMWPE cylinders, a low-speed (20 rpm) surgical motor with handpiece was used. For the insertion, a Nobel Biocare (Nobel Biocare, Yorba Linda, CA, USA) motor model DAE 028 was used with reduction 20:1 until the maximum motor torque range (45 Ncm); after this, a hand torque wrench was used to submerge the implants until their upper part became parallel to the site's platform. Five implants of each geometry and finishing surface were inserted.

Torque and Resonance Frequency

The insertion torque was recorded during site drill preparation and implant placement. The torque was recorded by an electronic torque transducer, Lutron TQ8800, with an accuracy of 0.1 Ncm. The electronic torque device (Lutron Electronic Enterprise Co., Taipei, Taiwan) was connected to a computer and the data were recorded. For statistical analysis, the maximum insertion torque value was considered to be the insertion torque.

Immediately after the implant's placement, the HMWPE cylinder was removed from the digital torque device and the primary stability was quantified with Osstell mentor™. For each specimen, the same operator manually attached the smartpeg transducer to the top of the implant. Three resonance frequency measurements were conducted for each sample ($n = 15$ for each group). Resonance frequency is given in the form of an ISQ to allow comparison among implant designs or surface finishing. The ISQ values were averaged to reduce artifacts caused by noise and human error. The mean and standard deviation were calculated for later comparison and discussion. Insertion torque and resonance frequency were subjected to correlation analysis.

Statistical Analysis

For descriptive statistical analysis, the maximum values of insertion torque and ISQ for each procedure were used. One-way analysis of variance (ANOVA) with Tukey's test was used to evaluate the association of the insertion torque, ISQ values, implant design, and surface morphology. Pearson's correlation was used to evaluate the influence of the screw tap on the torque insertion and on ISQ. As the data obtained in the tests are not parametric, evaluating the influence of the different surface treatments on the torque and ISQ required the use of Spearman's correlation.

TABLE 2 Roughness Parameters and Friction Coefficients (μ) of the Ti Discs against the HMWPE Plate

Surface	Ra (μm)	Rq (μm)	Rz (μm)	μ
Machined	0.78 ± 0.06	1.06 ± 0.10	5.67 ± 0.92	0,34 ± 0.01
Acid-etched	0.84 ± 0.05	1.20 ± 0.15	6.03 ± 0.84	0.42 ± 0.02
Anodized	0.92 ± 0.11	1.31 ± 0.17	6.09 ± 1.12	0.49 ± 0.01

Implant Surface Area

The external areas of the dental implants were calculated with drawings done in the CAD system using the software Solid Works (DS SolidWorks, Concord, MA, USA). The drawings were available from the manufacturer. The software Solid Works allows the calculation of the surface area of irregular shape.

RESULTS

The values of the numerical roughness (μm) and the friction coefficients (μ) among the Ti discs and the HMWPE plate are shown in Table 2. Figure 4 shows the implant thread geometry of the cylindrical and conical screw implants.

Table 3 shows the mean and standard deviation values of the maximum implant insertion torque and the implant stability quotient measured with the resonance frequency.

Figures 5 and 6 show the influence of implant design on the insertion torque and the ISQ, respectively. The torque to install the conical implant is larger than the torque to install the cylindrical implant. However, the stability measured by the resonance frequency is smaller for the conical implant.

DISCUSSION

To eliminate the effects of any parameter on the implant's primary stability, the implants were inserted into a homogeneous material. In vivo model could increase the heterogeneity, once bone presents different density, hardness, and mechanical properties in the same segment; this considerably affects the implant's primary stability.[18]

Huang and colleagues[19] measured implant stability using resonance frequency (RF). The test implants were embedded into gypsum blocks, which were used to simulate the mass effect of alveolar bone. It was observed that boundary height, width, and density factors can influence the resonance frequency. The authors found that a lower boundary density and greater boundary thickness can lead to more obvious RF changes. Consequently, use of homogeneous material ensures that the results are functions only of the implant design and morphology.

In previous studies, a polymer has been used to evaluate the effect of the density of the bone on the dissipation of the implant's energy at the moment of placement.[18] The most important aspect is the use of a homogeneous material, which allows analysis of the

TABLE 3 Mean and Average Deviation of Insertion Torque (Ncm) and Implant Stability Quotient (ISQ) for Each Model of Tested Implant
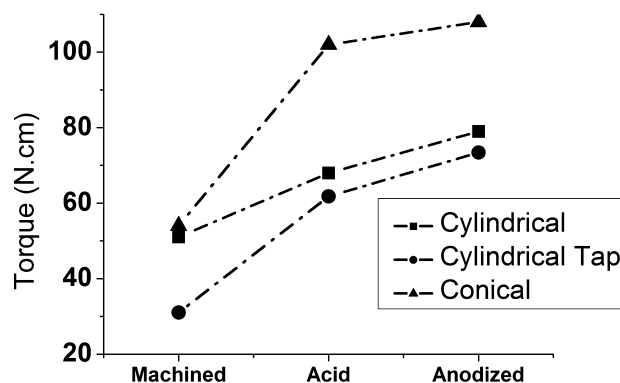
Design	Surface	Thread Tap	Insertion Toque (Ncm)	ISQ
Cylindrical	Machined	No	51.0 ± 3.0	85.0 ± 3.0
	Machined	Yes	31.0 ± 3.0	82.0 ± 1.0
	Acid-etched	No	68.0 ± 2.8	87.0 ± 2.0
	Acid-etched	Yes	61.8 ± 2.1	86.0 ± 1.0
	Anodized	No	79.0 ± 3.0	84.0 ± 3.0
	Anodized	Yes	73.4 ± 3.6	83.0 ± 1.0
Conical	Machined	No	54.0 ± 1.1	81.0 ± 1.0
	Acid-etched	No	102.4 ± 4.0	81.0 ± 3.0
	Anodized	No	108.1 ± 4.2	80.0 ± 2.0
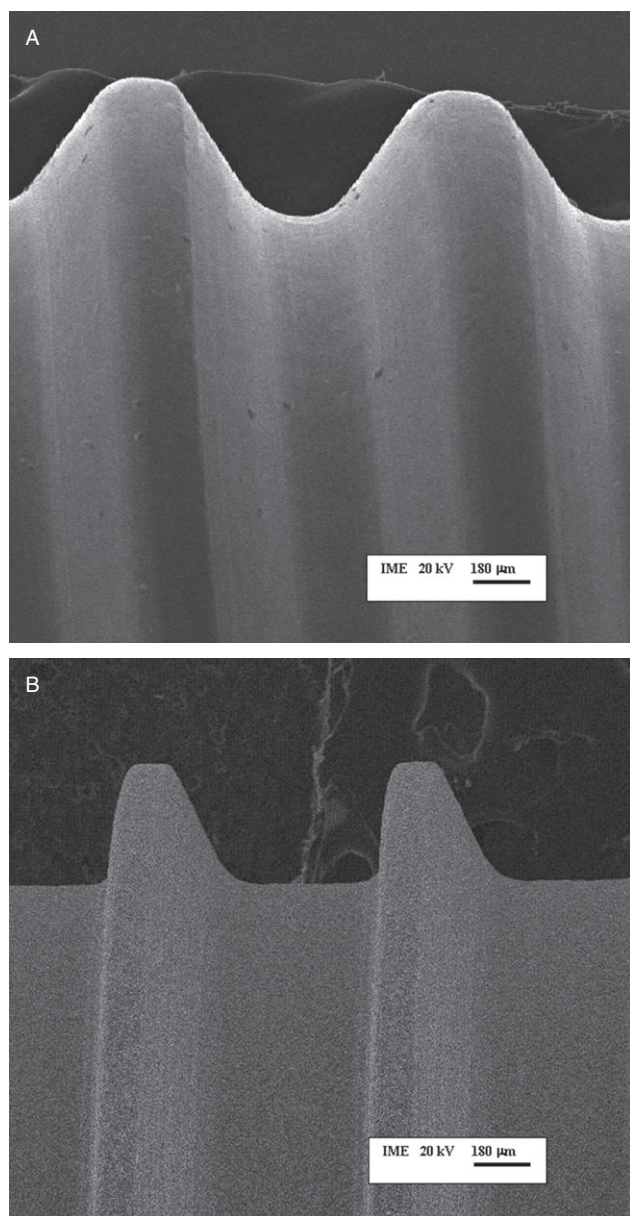
Figure 4 Thread geometry of the implants. *A,* Cylindrical. *B,* Conical.
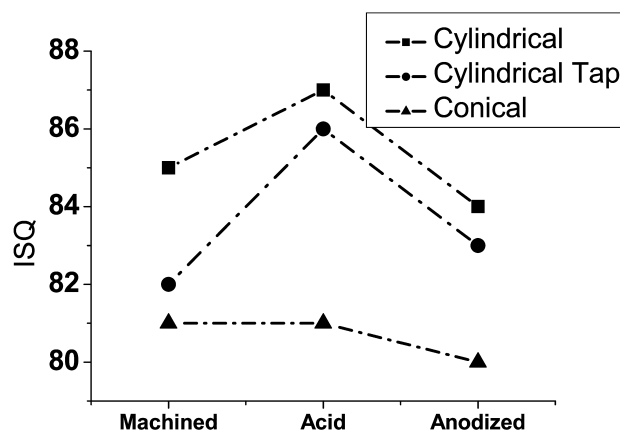

Figure 5 Effect of the implant design and surface treatment on the insertion torque (Ncm).

torque for the acid-etched implant was significantly different from the anodized implant.

Use of the screw tap as the final site-preparation step reduced the insertion torque of the cylindrical implant with a treated surface.

For the same finishing surface, the differences in insertion torques reflect different implant geometry, where the cylindrical implant has a lower value than the conical one.[16] This behavior can be attributed to the different thread forms, the implant geometry, and the surface area. Figures 4 and 7 show the implant thread geometries. The screw threads are different between cylindrical and conical implant. The thread geometry of the conical implant increases the implant surface area in contact with the host tissue. The reduction in pitch of the conical implant thread increases its contact area as compared with the cylindrical implant. The conical implant has a larger area (343.4 mm^2) than the cylindrical implant (316.9 mm^2). As surface area

effect of implant design and surface morphology on the primary stability without being influenced by any other parameter.

The results showed that the maximum torque to insert the implant depends on the friction coefficient, implant design, implant thread geometry, and surface treatment. The implants submitted to a surface treatment presented a higher roughness and higher friction coefficient than the machined one. The implant that required the smaller insertion torque was the machined one, which possesses a smooth surface compared with the acid-etched or anodized samples. The insertion

Figure 6 Effect of the implant design and surface treatment on the Implant Stability Quotient.
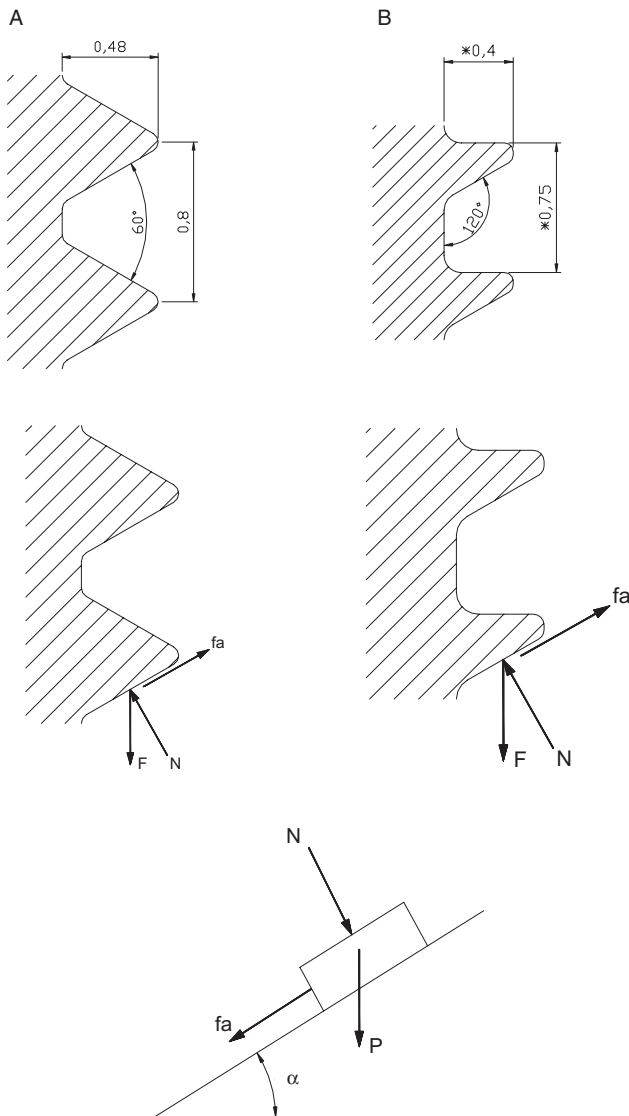
Figure 7 Thread geometries of the implants. *A,* Cylindrical. *B,* Conical.

increases, the friction surface between the implant and the site wall increases, demanding a larger insertion torque.

The corresponding analysis for ISQ showed no statistically significant difference (two-way ANOVA, $p = .05$) between the conical and cylindrical implants. This result shows that the geometries do not have as much influence on the ISQ values as the insertion torque in the present experimental model.

In the present work, it was determined that there was no relationship between insertion torque and ISQ. Those results corroborate data presented by literature.[4,15,19] A correlation of ISQ and insertion torque exists only within the cylindrical implant groups

inserted in the tap-prepared sites. The machined implant has a lower ISQ and insertion torque than the surface-treated implants. Possibly, the values of the resonance frequency were high enough that the equipment was insufficiently sensitive to detect the differences.

The difference in the contact area, which was associated with the implant shape, screw thread geometry and surface roughness, interfered directly in the implant insertion torque. To understand the influence of these parameters on the primary stability, a dental implant screw was compared with a screw used for fastenings.

Fastening screws are used for holding two or more parts of an assembly together or for adjusting one part relative to another. In fastening screws, the threads are made in several standard forms. The fastening screw is tight through the application of a torque in its head; as the screw is tightened, tension is generated in the screw body. The force generated in the body of the screw is named preload, or torquing up. The stability of the screw joint is a function of the initial tension achieved in the screw when applying the preload tightening torque to clamp the components together. The optimum preload torque is influenced by the geometry of the screw, the contact relationships between the screw and its bore and threads, the friction coefficient, and the properties of the materials used.[14] The preload generated in the screw-joining and the screw-holding union can be associated with the dental implant's primary stability. During the implant insertion, the interaction mechanisms between the implant and the bone can be explained using the classic theory of screw fastening for holding two or more parts together or for adjusting one part with relation to another, as described by Shigley[14] and analyzed by Elias and colleagues.[20] During the screw tightening or during the implant insertion, the frictional resistance of the thread creates a tensile stress in the screw.

Based on an analysis of the implant forms shown in Figure 1, the cylindrical implant has a cutting thread and a camera for collection of the removed material. The cylindrical implant has geometry more favorable to the insert than the conical implant. During the insertion of both implants, the torque increases as the implant is inserted; a self-locking occurs. The effectiveness of the self-locking depends on the tightness with which the spiral sloping surfaces of the root of the implant and the crest of the hole material's tread jam against each other.

Consequently, the insertion torque increases during insertion because the implant's contact surface with the host increases.

The experimental results of the present work show that, aside from the implant geometry, the surface morphology also interferes with the implant's primary stability.

Although real bone tissue was not used in the experiments, the results of this investigation provide useful quantitative data on the influence of implant design and surface finishing. The results of the present work showed that both implant surface treatments analyzed (acid-etching and anodizing) present similar insertion torques.

The maximum implant insertion torque depends on the friction coefficient, implant thread geometry, and morphology. The friction is sensitive to the implant surface treatment. The implants with treated surfaces presented a larger superficial roughness and larger friction coefficient than machined dental implant.

CONCLUSION

Based on the results obtained in the present work, it is possible to conclude:

1. The maximum implant insertion torque depends on the implant geometry, thread form, and surface roughness.
2. The implants submitted to surface treatment have greater roughness, higher friction coefficient, and larger insertion torques than machined implants.
3. In the machined cylindrical implants inserted after preparation with the tap, generated torques were smaller than recommended (45 Ncm) for immediate load.
4. Implants with treated surfaces had higher insertion torques and ISQ than machined implants.
5. The insertion of a conical implant with a treated surface requires the highest insertion torque.
6. ISQ values of implant placement did not correlate with the insertion torque.

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