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Clinical Analysis of the Influence of Surface Roughness in the Primary Stability and Osseointegration of Dental Implants: Study in Humans

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Abstract: In past decades, the success rates of the first dental implant treatments were low (75%). Nowadays, oral rehabilitation with titanium dental implants has a high success rate (95%–98%). The success rate significantly increases due to increased scientific knowledge about osseointegration, changes in surgical techniques, and the development of implant surface treatments. Despite the high success rate of implants, there are no protocols to define the time for the prosthesis to be installed, the insertion torque, and the prosthesis loaded after surgery. This work compares a new dental implant's primary (mechanical) and secondary (osseointegration) stability. Dental implants with micro- and nano-roughness surfaces were placed in 24 patients with a minimum of 35 N·cm and a maximum of 60 N·cm. Primary stability was quantified with a torque wrench and an Ostell Mentor Device. The secondary stability 45 and 60 days after surgery was measured with Ostell. The results showed no statistical difference in secondary stability at 45 and 60 days postoperatively among implants. The success rate of dental implants can be associated with the surface morphology with micro- and nano-roughness, the insertion torque value, and the shape of the implant threads. When the manufacturer's guidelines are followed, it is possible to prosthetically rehabilitate the patient with an implant 45 days after surgery.

Keywords: dental implant; primary stability; secondary stability; osseointegration; edentulous

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1. Introduction

The first osseointegrated dental implants were probably made with unalloyed commercially pure titanium (cp Ti), also used to manufacture parts for aircraft bodies, and they did not have surface treatment. The Ti cp used today in medical devices has a lower percentage of impurities than the old implant. The ASTM F67 technical standard [1] specify the cp Ti for biomedical applications. The titanium for biomaterials applications has a lower percentage of impurities (Fe, C, N, O) than the cp Ti used in other areas. Unalloyed Ti is classified into grades 1 to 4 (Ti G1 to G4). The most used dental implants are grades 2 and 4, which have adequate biocompatibility, mechanical strength, and corrosion resistance. Ti Grade 4 has higher percentages of alloying elements (C, O, and Fe) and mechanical properties than Ti G1-G4. The addition of alloy elements increases the Ti mechanical strength. Dental implants with small diameters and orthopedic prostheses are made with Ti-6Al-4V alloy according to the ASTM F136 Standard (Ti grade 5) specification [2]. The disadvantage

of Ti G5 is the possibility of delivering harmful ions (Al and V) [3]. In each country, the medical Ti manufacturing is controlled by the country's Health Agency.

The Harvard Consensus Development Conference on Dental Implants [4], held in 1979, mentioned that the implants should have a success rate of at least 75% during the first 5 years. Even with the need for knowledge of the mechanisms involved in osseointegration and the interactions of proteins with the surface of the implants, this low success rate was reached. With the increase in scientific knowledge about osseointegration, modifications in surgical instruments and techniques, changes in the shape and dimensions of implants, and better dental implant surface treatments, the success rate of dental implants increased. The success rates are different by anatomical region, as follows [5]: anterior maxilla (95.52%), posterior maxilla (97.53%), anterior mandible (97.13%), and posterior mandible (98.90%). The dental implant success rate is higher than hip and knee orthopedic prostheses (75%).

In implantology, it is considered that only dental implants with a layer of titanium oxide (TiO_2) have osseointegration. Implants without a TiO_2 layer, like CoCrMo, NiCr, and zirconia, induce the formation of a fibrous tissue interface. Both unalloyed titanium implants (ASTM F67) and those made of the Ti-6Al-4V alloy (ASTM F136) form the TiO_2 layer. With the development of the titanium implant surface, it is possible to obtain thicker titanium oxide layers with different morphologies that contained hydroxyapatite, F, Ca, and P. These surfaces improve osseointegration and reduce the time it takes to place loads on the implants. Despite the improvements in the implant surface quality, there is no consensus on the influence of ion release in the organism. Some studies show that releasing ions harms the body [3], while others state that the amount released is low and less than that which induces harm [6].

The dental implant's surface treatment changes the roughness, increases the surface area, stimulates interactions with proteins, promotes cell adhesion, and reduces osseointegration time [7]. After surface treatments, it is possible to stimulate cell proliferation, reduce the time for the formation of bone matrix around the implants, reduce the reopening time for prosthesis installation, and increase the predictability of the treatment [8].

Implants with nanometric surface characteristics allow for prosthesis placement and loading in less time and have higher success rates. Surfaces that combine micro- and nanometric roughness are better than macrometric or micrometric surfaces. The combination of roughness with the deposition of Ca, Mg, F, P, and hydroxyapatite nanoneedles is better than acid-etched and blasted surfaces. Changes in the surface have changed the paradigm of the minimum torque required to insert dental implants. In the past, it was recommended that high implant insertion torques above 80 N·cm were necessary to ensure mechanical stability (primary stability). With changes in the implant surfaces, it was observed that high torques damaged the surface characteristics and modified the interactions of proteins with the TiO_2 layer [8]. Currently, it is possible to obtain primary stability with insertion torques between 40 and 50 N·cm [9]. With current implants, it is possible to achieve secondary stability (osseointegration) in shorter times and an implant–bone interface with sufficient mechanical resistance to support the oral loads transmitted by the prosthesis.

The classification of prosthesis types based on implant placement timing has been consolidated. This classification into immediately placed, early placed, or delayed placed implants was made based on clinical observations without scientific proof or explanation. Some studies show that an insertion torque higher than 35 N·cm guarantees the osseointegration of implants with treated surfaces [9]. The aim is to reduce the time needed to apply the load safely and in shorter times.

In clinical practice, the two most straightforward procedures to quantify the primary stability of implants are to measure the insertion torque and implant stability quotient (ISQ) value calculated using a resonance frequency analyzer. The disadvantage of torque is the impossibility of following the secondary stability (osseointegration) during tissue healing. The torque measurement during tissue healing can cause damage to the implant–bone interface. The recommended methodology to monitor the rise in secondary stability is to use the resonance frequency to measure the ISQ (implant stability quotient), such as

is achieved with the Ostell Mentor® device. The Ostell Mentor® device calculates the ISQ and measures primary stability (immediately after insertion) and secondary (after osseointegration). The ultrasonic vibration produced by the Ostell Mentor® device varies with the percentage of the surface of the threads in contact with the bone. It discriminates the fixation of the implant in one or two bone walls. Some studies have shown discrepancies between the ISQ value and implant stability measurements based on insertion torque and bone density.

Mia Rakic [3] analyzed the influence of the release of titanium particles (TPs). They collected samples from patients with peri-implantitis and compared them with samples collected from periodontitis patients. The aim was to analyze whether the presence of TPs could alter inflammatory patterns. The authors observed that the granulation tissue of peri-implantitis presented intense neovascularization and the presence of a chronic inflammatory infiltrate dominated by plasma cells, neutrophils, and macrophages. Samples from peri-implantitis tissues presented higher proportions of macrophages and more intense neovascularization than those with periodontitis. Tissues with peri-implantitis presented greater expression of CD68 and VEGF.

The objective of the present work was to compare the primary and secondary stability of titanium dental implants 45 and 60 days after insertion surgery in humans.

2. Materials and Methods

Dental implants were inserted in humans, and the variation in stability was analyzed 45 and 60 days after surgery. The methodology and implants used are described below.

2.1. Patient Selection

The sample size was calculated based on the effect sizes found in the previous study. A sample size of 8 units per group was necessary to give 80% power to detect a significant difference between groups, with a type I error of 5% and a type II error of 20%. To account for a rate of 20% of possible losses, a final sample size of 12 units per group was used.

Twenty-four dental implants were inserted in 24 patients treated at the Specialization Clinic in Implant Dentistry at the State University of Rio de Janeiro (UERJ, Brazil).

Patients were divided into two groups with 12 patients. The first group returned for prosthetic rehabilitation 45 days after implant placement, and the 12 patients from the second group returned 60 days after surgery. The patients were informed about the surgical procedures. All volunteers gave written consent for the scientific use of the data. The study was conducted following the Declaration of Helsinki and approved by the Institutional Review Board (Ethics Committee) of the UERJ implant dentistry specialization (protocol 01-2022 of 5 December 2022).

Table 1 describes the inclusion and exclusion criteria and characteristics of the study patients. Men were 33.3% (N = 8), women were 66.6% (N = 16), white skin color (Caucasian) was 50%, and brown (Latino) or black skin color (African) was 50%.

Table 1. Criteria for patient inclusion and exclusion.

Parameter	Inclusion	Exclusion
Patient age	18–75 years	<18 or >75 years
Chronic disease	No	Yes
Implant manufacturer	Systhex Ltda	Other manufacturers
Implant length size	≥8.5 mm	<8.5 mm
Bone quality	Natural	After graft
Insertion torque	≥35 and <60 N·cm	<35 N·cm or >60 N·cm
Prosthesis loading	45 or 60 days	<45 or > 60 days

2.2. Dental Implants

Systhex Company supplied the analyzed cp Ti G4 dental implants (Curitiba, PR, Brazil). The implant model Avantt was used with a diameter of 3.5 mm and a length of

8.5 mm. Figure 1 shows details of the Avantt implant design. It has an internal hexagonal connection and a Morse taper. The coronal region is enlarged to provide better mechanical locking. The implant has a conical apex with three V-shaped threads. The apex is dome-shaped, without a hole, and has grooves that allow for better cutting and anchoring of the implant in the bone. The surface was acid-etched.

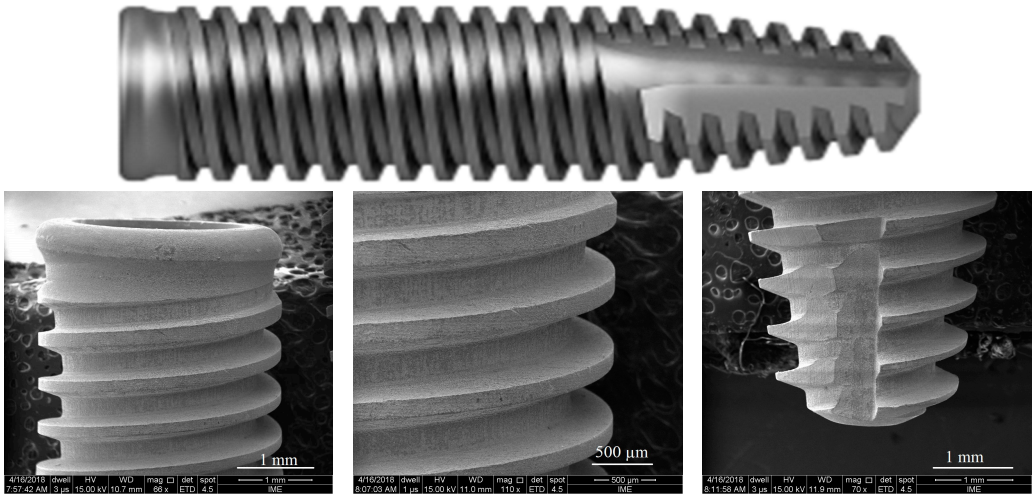

Figure 1. The dental implant used in the present work. The implant has a hybrid body shape (cylindrical and conical) and an internal hexagon for abutment fitting. From left to right: coronal region (66×), middle region (110×), and apex region (70×).

2.3. Surgery Procedure

Four students from the same specialization class in implantology performed the implant insertion surgeries. The surgeons followed the placement instructions and protocol suggested by the manufacturer. Before the surgery, the surgical team was trained with the Systhex system.

The literature results suggest that osseointegration occurs in implants inserted with a torque greater than 32 N·cm [9] and an average torque of 33.4 N·cm and 40.81 N·cm [10]. A similar value was obtained by Turkyilmaz and McGlumphy [11], who inserted the implants with 37.27 N·cm and observed failure when the implants were inserted with 21.84 N·cm.

The secondary stability of the implants increases steadily after 2.5 weeks after implantation and reaches a plateau between 5 and 6 weeks. The critical mechanisms involved in osseointegration that require special care occur from 5 to 8 weeks after surgery [12]. Manfro et al. [9] evaluated the time needed to load implants inserted with 30–60 N·cm. The implant placement had a torque between 30 and 60 N·cm, and, 60 days later, secondary stability was determined. The results showed that the surgeon must analyze the primary stability of the implants, the type of bone, and the location of the implant placement. When adequate primary stability is achieved, carrying the prosthesis 60 days after surgery is safe.

Based on the literature results [8–11], the authors of the present work chose an implant insertion torque higher than 35 N·cm and lower than 60 N·cm. Implants that did not anchor with a torque less than 35 N·cm or greater than 60 N·cm were not considered adequate for this research. After the surgeries, the cover screws were placed on the implants and the implants were kept submerged for 45 and 60 days before receiving the prosthesis.

To quantify the dental implants' mechanical stability (primary stability), the clinician uses the insertion torque, resonance frequency with the Ostell Mentor, percussion (Periotest), and tactile sensation after installation. The application of torque is not recommended to qualify secondary stability (osseointegration). In the present work, the measurement of insertion torque and the ISQ value were used to quantify primary stability, and the ISQ measurement was used to quantify secondary stability. Before taking the measurements,

the torque wrench was calibrated and the manufacturer's recommendations for using the Ostell were followed.

The primary stability was measured at implant installation using a calibrated torque wrench with the Ostell Mentor® device. The secondary stability was measured 45 and 60 days after surgery using the Ostell Mentor® device.

Osseointegration was assessed using periapical or panoramic radiographs. The absence of a radiolucent image indicated bone loss around the implant. The treatment was successful, and there was a lack of implant mobility at 45 and 60 days at the prosthesis installation.

Early dental implant failure was defined as those that occurred before prosthetic rehabilitation. The implants were separated by insertion area: anterior and posterior maxilla and anterior and posterior mandible. The same examiner assessed primary and secondary stability. This procedure improves the reliability of the findings by eliminating subjective criteria. Clinical evaluation was performed by probing around the implant. The implants with a pocket depth smaller than 3 mm were considered to be healthy. Periapical radiographs and computed tomography complemented the clinical assessment. Images with a bone loss greater than 3 mm were considered unhealthy and classified as failures. The success rate was calculated based on primary and secondary stability. Implants with mechanical stability assessed by touch and an ISQ greater than 50 were considered to be successful.

2.4. Dental Implant Surface Morphology Analysis and Roughness Measurements

The surface morphology of the implants was analyzed using a scanning electron microscope (FEI QUANTA FEG 250) at different magnifications. The SEM analyses used a working distance (WD) of 11 mm, a voltage of 20 kV, and a spot size 4.5.

The results were complemented with 3D surface roughness measurements. Roughness analysis was performed by interferometry with the Zygo NewView 7100 optical roughness meter (Zygo Corporation, Middlefield, CT, USA). The implants' roughness parameters, Ra, Rsk, Rms, Rku, PV, Rpk, Rk, and R3z, were measured. The definitions of the roughness parameters are available in the Technical Standard ISO 21920-2:2021. Although the roughness parameter Ra is the most analyzed in the literature, previous results of the authors of the present work showed that other roughness parameters, such as Rz and PV, have the most significant influence on the osseointegration of dental implants. Three areas of each implant were measured. The interferometry technique produces a 3D image of the measurement region. Roughness measurement with a non-destructive optical interferometer provides a better understanding of surface morphology and roughness than measurements with a contact profilometer.

2.5. Dental Implant Stability Measurement (ISQ) and Statistic Analysis

The measured data of implant stability were expressed in frequencies (ISQ) and percentages. The percentages of successes and failures corresponding to the different times were compared and calculated using the D'Agostino and Pearson test for normality and independent samples. An ANOVA test was used to analyze the statistical differences among means. The Bonferroni Test, Scheffe Test, and Tukey Test were used. Statistical significance was fixed at $p < 0.05$. Origin 7.0 software was used for the calculations. The current study was reported according to the STROBE (strengthening the reporting of observational studies in epidemiology using Mendelian randomization) guidelines.

3. Results

Figures 2–4 show the surfaces of Avantt dental implants. A typical surface characteristic of acid etching treatment was observed in all analyzed regions. The surface is homogeneous and has micro- and nano-roughness. The surface of the implants did not show contaminants from the manufacturing process.

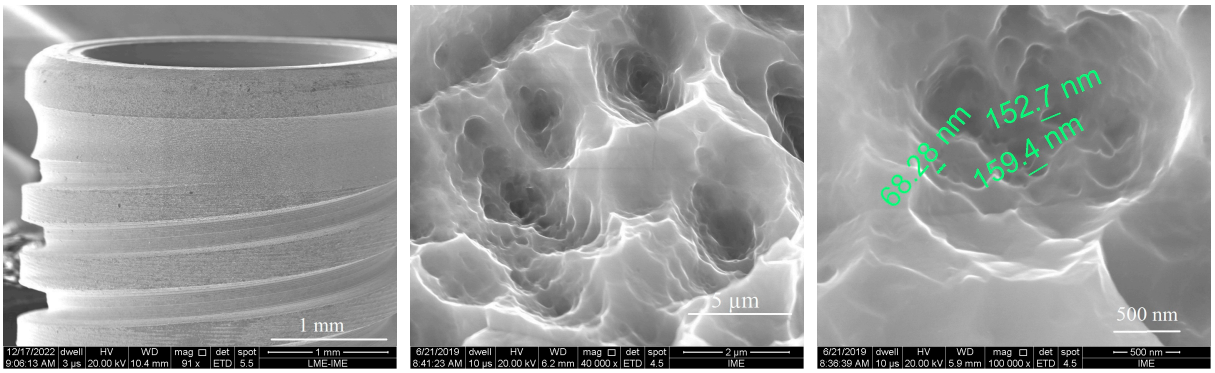

Figure 2. Dental implant surface morphology on the coronal region. Surface with micro- and nanocavities (91×, 40,000× and 100,000× magnifications).

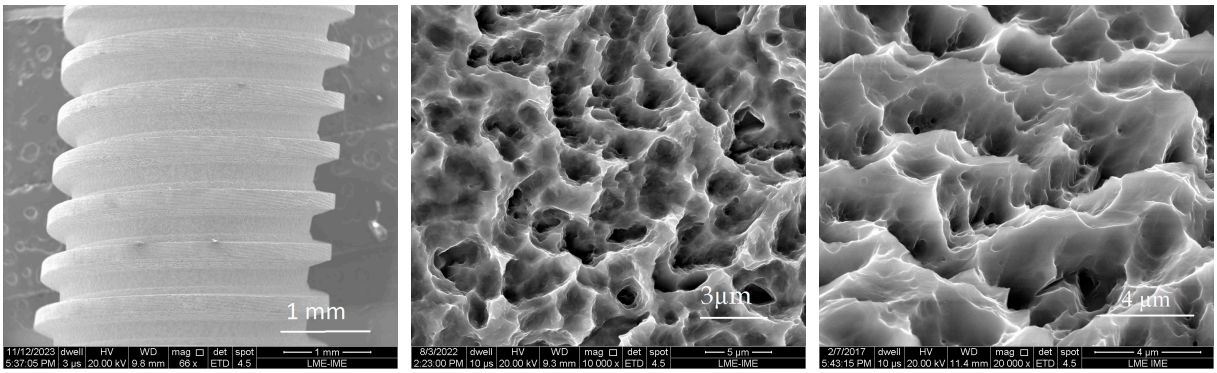

Figure 3. Dental implant surface morphology on the middle third length (66×, 10,000× and 20,000× magnifications).

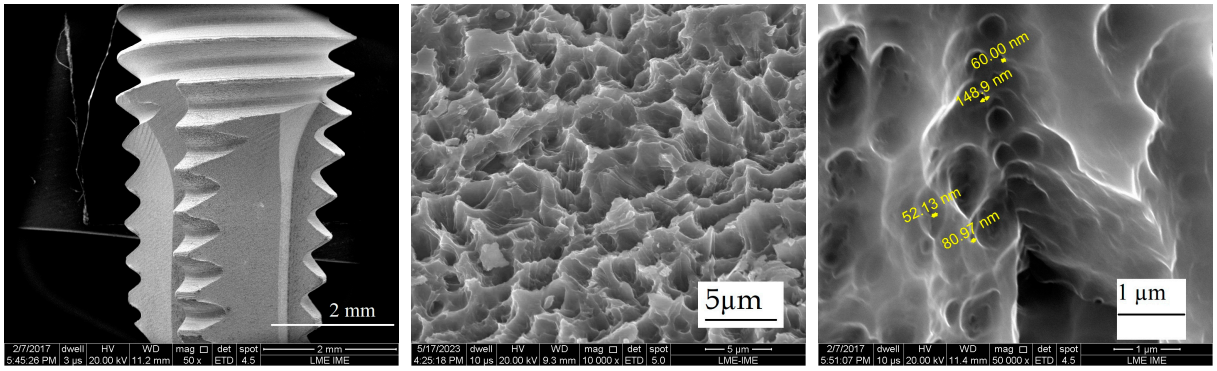

Figure 4. Dental implant surface morphology on the apical region. Surface with micro- and nanocavities (50×, 10,000× and 50,000× magnifications).

Figures 5–7 show the surface morphologies of the implants obtained by interferometry during roughness measurements. The results showed that the Avantt implant has a high level of mechanical locking, good primary stability, and a good ISQ index. The acid treatment increased the contact area between the implant and the native bone, contributing to the primary stability.

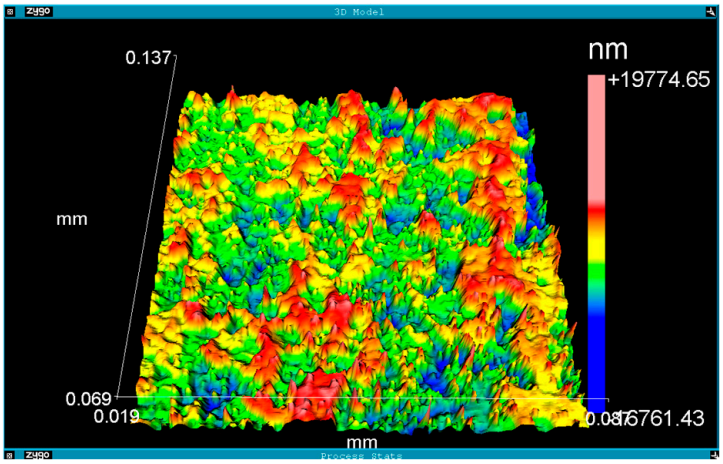

Figure 5. Dental implant surface morphology in the crest of the implant thread. Picture obtained by interferometry.

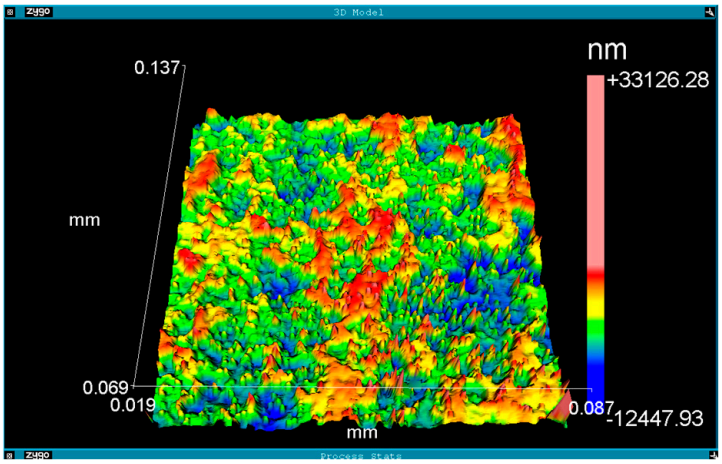

Figure 6. Dental implant surface morphology in the flank of the implant thread. Picture obtained by interferometry.

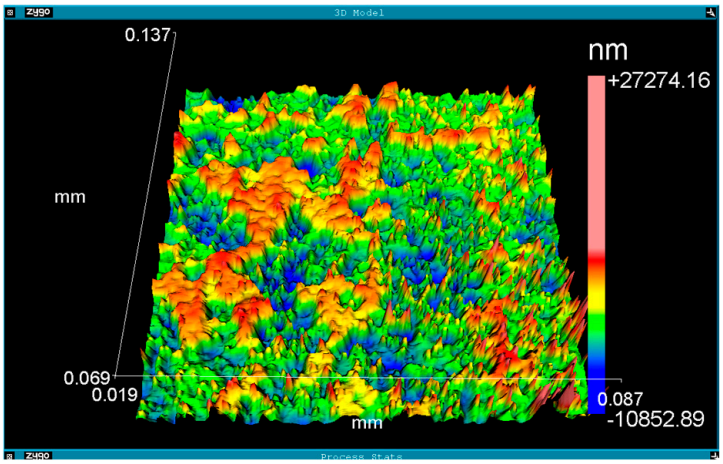

Figure 7. Dental implant surface morphology in the root of the implant thread. Picture obtained by interferometry.

Table 2 shows the descriptive statistical data of the ISQ after dental implant immediately after insertion and after 45 and 60 days after surgery. The ANOVA test at the 0.05 level

indicates that the ISQ means are significantly different. The ISQ value 45 days or 65 days after the surgery is lower than that measured after insertion, meaning the implant is not fully osseointegrated.

Table 2. The ISQ values (mean and standard deviation) immediately after implant insertion (primary stability) and 45 and 60 days after the surgery (secondary stability).

	Start	**45 Days**	**Start**	**65 Days**
Mean	88.8	64.7	87.4	64.3
SdDev	3.3	3.7	5.1	4.3

In the statistical analysis of the stability values measured with the ISQ, it was considered that the null hypothesis is that the means of all ISQs immediately after implant insertion as well as those 45 days after surgery or 60 days after surgery are equal. The alternative hypothesis is that the mean ISQs are different.

The ANOVA test shows that, at the 0.05 level, the data means are significantly different (p = 0.0 and F = 124.7). Table 3 shows the statistical analysis of the comparison of the mean using the Bonferroni Test. The same result was obtained using the Scheffe Test, the Scheffe Test, and the Tukey Test, which show that the ISQ values after 45 days and 60 days are significantly different from the start value.

Table 3. The ISQ values (mean + standard deviation) immediately after implant insertion (initial), 45 and 60 days after the surgery (final). Means comparison using the Bonferroni Test.

Group	**ISQ**	**Mean ± SD**	**Difference between Means**	**Simultaneous Confidence Interval**		**Significant at 0.05 Level**
45 days	Initial Final	88.8 ± 3.3 64.7 ± 3.7	23.25	Lower limit 18.6	Upper limit 27.9	Yes
60 days	Initial Final	87.4 ± 5.1 64.3 ± 4.3	0.58 23.7	−4.1 18.9	5.2 28.3	Yes

Roughness measurements were taken at the implant threads' vertices, flanks, and root. Table 4 shows the averages and standard deviations (StDev) of different roughness parameters. The analyzed regions presented homogeneous roughness with similar values for all areas.

Table 4. The surface roughness parameters of five dental implants. The measurements were on five thread regions.

		Ra	**Rsk**	**Rms**	**Rku**	**PV**	**Rpk**	**R3z**	**Rk**	**Rz**
Crest	Mean	1.32	−0.39	2.57	2.96	1,84	1.68	1.32	6.15	2.60
	StDev	0.01	0.06	0.07	0.03	0,69	0.18	0.00	0.13	0.32
Flank	Mean	1.76	−0.20	2.76	3,16	1.93	1.86	1.75	6.34	2.80
	StDev	0.21	0.03	0.04	0.02	0.41	0.10	0.17	0.07	0.22
Root	Mean	2.25	−0.21	2.74	3.15	22.84	1.81	14.50	6.32	16.64
	StDev	0.04	0.02	0.03	0.01	6.86	0.07	4.03	0.05	4.42

The roughness size can be defined by its height from the surface for randomly shaped elements. Parameters normally quantify the surface roughness into three groups according to its functionality. These groups are defined as amplitude parameters, spacing parameters, and hybrid parameters. These parameters can be calculated in two-dimensional (2D) or three-dimensional (3D) forms. On the surface, roughness parameters were quantified in 3D form.

There is no definition or analysis of roughness parameters that influence bone integration. Ra is the most analyzed in the literature. Previous results of the authors of the present work showed that other roughness parameters influence the osseointegration of dental implants. In the present study, nine parameters of implant surface roughness were quantified.

The Ra parameter quantifies the mean absolute deviation of the roughness irregularities from a mean line along a measured length. This parameter is easy to quantify and provides a general description of the height variations in the irregularities. The disadvantage is that Ra does not give information on the wavelength and is not sensitive to small changes in the profile.

Rsk defines the asymmetry of the profile in relation to the midline. The symmetry can be positive or negative. Negative asymmetry indicates a more significant percentage of the profile above the mean line, and a positive value indicates that a more significant percentage is below the midline.

The RMS (root mean square) is the root mean square of the profile height deviations from the mean line. This parameter is used to analyze the surface smoothness statistically.

The Kurtosis, Rku, measures the profile's peaking relative to the mean line.

The maximum profile valley depth (PV) indicates the point along the sampling length at which the profile curve is lowest.

The peak Height (Rpk) is the distance between the highest point of the profile and the mean line within the evaluation length.

The R3z is the mean of the third maximum peak-to-valley height in the evaluation length.

The parameter Rz is the maximum height of the profile. It indicates the absolute vertical distance between the maximum peak height and the maximum valley depth of the profile along the gage length. Rz is referred to as the maximum roughness.

The statistical analysis showed that the ISQ 45 days after surgery was not different from 60 days after surgery (Table 3). The secondary stabilities were similar 45 and 60 days after surgery. Loading the dental prostheses on the Avantt implant platform 45 days after insertion in natural bone is possible. The natural tissues in the implant installation region are entirely healed and follow the inclusion and exclusion criteria shown in Table 1.

Table 5 shows data from the D'Agostino and Pearson test. This statistic test aims to verify whether the shape of the distribution is similar to the shape of the normal distribution. It is a combination of the skewness test and the kurtosis test. According to Table 5, there was no statistical difference in the results obtained in the ISQ indices between the groups studied in the periods of 45 and 60 days after insertion ($p > 0.05$).

Table 5. Statistical parameters analysis using the D'Agostino and Pearson omnibus normality test.

	45 Days	**60 Days**
Standard. Deviation	7.665	5.401
Mean	23.25%	23.92%
p-value	0.8077	

4. Discussion

Planning for implant-supported prosthetic rehabilitation time involves assuring the primary stability of the implant [13]. The prosthesis loading can be immediate, mediate, or delayed. The immediate placement of implants immediately after tooth extraction influences the physiological remodeling of the alveolar bone. The surgeon must take special care and analyze the patient's biotype to prevent biological and aesthetic complications. The most common complication is the resorption of the bone ridge, which occurs even without the placement of the implant. With the immediate placement of the implant, changes occur in the volume of peri-implant soft tissues and the loss of mucosa. Some authors cite significant mucous recession around immediately placed and loaded implants [14]. The

results of the present study showed that it is safe to load the definitive prosthesis 45 days after surgery, which is a delayed procedure.

Aiquel et al. [14] performed a systematic review to evaluate the timing of implant placement and loading influence on biological outcomes. The results indicated that the loading time influences survival rates between implants immediately and delayed the loading after delayed placement. The results showed no differences in survival rates or marginal bone levels between delayed placement + delayed loading and delayed placement + early loading.

Immediate implant insertion (IIP) in sockets where a recent tooth extraction occurred presents survival and success rates similar to placing delayed implant placement (DIP) in sockets with healing. The advantages of the IIP methodology are shorter patient treatment times, fewer invasive surgeries, and reduced patient discomfort. The disadvantages are that there is less bone support due to a gap between the socket wall and the implant, difficulty in covering the fixation with soft tissue, greater risk of infection, and a greater possibility of implant loss. The literature data show that the survival and success rates of IIP are similar to DIP in healed sockets [15]. Some systematic reviews and meta-analysis studies [14] cited that IIP survival rates are lower than DIP in healed sockets

In the present study, the DIP criterion was adopted to reduce the risk for the patient and because it is considered safer. The objective was to determine the secondary stability of the implant for placement and loading of the prosthesis within 45 days after insertion of the implants.

The surface treatment to form nano- and microcavities was another characteristic of the implants that influenced the results obtained in the present work. The dental implant surface treatment changes the morphology, increases the contact area of the implant with the native bone, increases insertion torque, and improves interactions between proteins and the implant surface [16]. The literature results [9] show good clinical results of dental implants with anodized surfaces installed with 25 to 45 N·cm in the mandibles and tested by applying a counter torque of 25 N·cm. The success rate was 97.7% after 60 days of healing [9].

The clinical results of the present study showed that the implants installed with torques above 35 N·cm obtain primary stability to allow events associated with the mechanisms of osseointegration. In addition, the surgeon must avoid high torques to not deform and damage the implant surface and induce crack nucleation in the bone [8]. The literature showed no relationship between insertion torque and resonance frequency [17,18].

There are divergences in the literature regarding the influence of the diameter and shape of the dental implant on primary stability. Researchers evaluated the primary stability of 60 implants divided into three groups with different geometries and observed no statistical difference between the cylindrical and conical implants [19]. These data are relevant to the results of the present work. The results of the present work showed that, regardless of implant surface area and diameter, there is no significant difference in the ISQ index between both groups. Primary stability must be higher than 35 N·cm [18,20]. Other researchers found that the stability increases as the implant length and diameter increase, as well as that the mechanical stability of a conical implant is greater than that of a cylindrical one.

The implant shape has become an excellent choice for better locking and primary stability at the time of its installation. Many researchers [21–23] have been studying this relationship between the locking potential of conical and cylindrical implants. The results showed that the percentage of locking in conical implants in both the maxilla and the mandible is higher than in cylindrical ones [17,21]. The literature data [8,22] showed that high insertion torque causes mechanical damage to implants. The insertion of implants with an external and internal hexagon connection with a torque greater than 80 N·cm must be avoided because it deforms the hexagon [22].

The results of the present study showed that the insertion of dental implants with torques between 35 N·cm and 60 N·cm prompted osseointegration. The analysis showed no statistically significant difference in secondary stability measured with an Ostell device

at 45 and 60 days after surgery. This result can be associated with good primary stability, the implant body's conical shape, and the surface's homogeneous morphology with micro- and nano-roughness.

To minimize the influence of various parameters on the results of the present work, the same methodology was followed for the installation of all implants. The implants were inserted into healed ridges to avoid the influence of bone variation. The implants were not inserted into healed ridges where grafts were used. The bone quality of grafted sites varied with the time, size, and chemical composition of the particles. The early and late ISQs of dental implants inserted into sites with bone grafts were lower than implants inserted in natural bone, but both groups exhibited satisfactory and successful outcomes.

The results of the present work confirmed those in the literature [9]. Manfro et al. [9] evaluated the time required to load implants inserted with 30–60 N·cm. The implants were inserted with a torque between 30 and 60 N·cm, and, 60 days later, secondary stability was determined. The results showed that the surgeon must analyze the primary stability of the implants, the type of bone, and the location of the implant placement. If there is primary stability, it is safe to load the prosthesis 60 days after surgery.

Although the results of the present study show that it is possible to load the implants between 45 and 60 days after surgery, consideration should be given to analyzing each patient and the conditions of the surgery with criteria. It is essential to consider the dimensions of the implants (diameter and length); the treatment and morphology of the surface (acid etching, sandblasting, with Ca, Pa, or hydroxyapatite); the cylindrical, conical, or hybrid shape; the insertion site (anterior region or posterior mandible); bone conditions (type, density, and volume); and immediate insertion upon removal or socket regenerated with graft.

A limitation of the present work is that only conical implants with equal diameters/lengths (3.5/8.5) and thread shapes were used. New investigations need to be carried out to analyze the influence of the implant surface treatment, diameter, and length size. It is essential to analyze the bone quality and density.

5. Conclusions

Based on the results obtained in this work, and considering the limitations of the methodology used, the following can be concluded:

(a) Dental implants installed with adequate primary stability do not show a statistical difference between secondary stability (osseointegration) 45 and 60 days after surgery.
(b) For dental implants with micro- and nano-rough surfaces inserted with a torque between 35 and 60 N·cm, it is possible to perform prosthetic rehabilitation six weeks (45 days) after surgery.

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