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An Indirect Method to Measure Abutment Screw Preload: A Pilot Study Based on Micro-CT Scanning

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This study aimed to measure the preload in different implant platform geometries based on micro-CT images. External hexagon (EH) implants and Morse Tapered (MT) implants (n=5) were used for the preload measurement. The abutment screws were scanned in micro-CT to obtain their virtual models, which were used to record their initial length. The abutments were screwed on the implant with a 20 Ncm torque and the set composed by implant, abutment screw and abutment were taken to the micro-CT scanner to obtain virtual slices of the specimens. These slices allowed the measurement of screw lengths after torque application and based on the screw elongation. Preload values were calculated using the Hooke's Law. The preloads of both groups were compared by independent t-test. Removal torque of each specimen was recorded. To evaluate the accuracy of the micro-CT technique, three rods with known lengths were scanned and the length of their virtual model was measured and compared with the original length. One rod was scanned four times to evaluate the measuring method variation. There was no difference between groups for preload (EH = 461.6 N and MT = 477.4 N), but the EH group showed higher removal torque values (13.8±4.7 against 8.2±3.6 Ncm for MT group). The micro-CT technique showed a variability of 0.053% and repeatability showed an error of 0.23 to 0.28%. Within the limitations of this study, there was no difference between external hexagon and Morse taper for preload. The method using micro-CT may be considered for preload calculation.

Key Words: dental implants, dental prosthesis, torque, screw joint.

Introduction

One of the main complications in a single-unit implant supported prosthesis is abutment screw loosening (1,2). This problem occurs due to the reduced torque of the abutment screw (3). Torque maintenance depends on the preload and this in turn depends on the screw joint stability (4).

In the process of tightening, the screw elongates, bringing the implant and abutment together. This leads to the development of preload that causes a compressive axial force on the system, known as "clamping force", which then maintains the union between the components (5). The screw has to clamp the joint members together with enough force to prevent separation, slippage and self-loosening when exposed to vibration, shock, and repeated cyclical external loads (4,6).

Screw joint stability depends on the geometry of the implant/abutment connection. Internal connections have the advantage of protecting the screw from external non-axial forces, which can lead to loss of preload and screw loosening (7,8).

Considering that the maintenance of preload reduces abutment screw loosening (2,9), the measurements of the preload in different implant/abutment joint designs can increase the knowledge of how the abutment screw loosening occurs and might help to prevent this clinical problem with implant prostheses.

Measuring the screw elongation provides the possibility of measuring the preload. This could be achieved by using a specific equation, based on the Hooke´s Law, which allows for the calculation of the force on a member starting from the elastic modulus of the screw material, the cross-sectional area of the screw, and the length of the screw elongation (10). Thus, this study presents a new technique used to measure the abutment screw elongation for the preload calculation in different implant platform geometries and also tests the null hypothesis: There is no difference in preload values among different implant-abutment connection designs.

Material and Methods

Two groups were used for the experiment; the composition of these groups is described below (Fig. 1):

External Hexagon Group (EH)

Five implants with an external hexagon platform, 10 mm high and 3.75 mm diameter (Master Screw; Conexão Sistemas de Prótese Ltda; Arujá, SP, Brazil). One type of pre-fabricated abutment made in cobalt-chromium alloy (Conexão Sistemas de Prótese Ltda) was attached to these implants with hex-headed titanium screws (Conexão

Sistemas de Prótese Ltda) with a 20 Ncm torque as recommended by the manufacturer.

Morse Taper Group (MT)

Five Morse indexed tapered implants presenting a platform, 10 mm high and 4 mm diameter (AR Morse; Conexão Sistemas de Prótese Ltda). One type of pre-fabricated abutment made in cobalt-chromium alloy (Conexão Sistemas de Prótese Ltda) was attached to these implants with hex-headed titanium screws (Conexão Sistemas de Prótese Ltda) with a 20 Ncm torque as recommended by the manufacturer.

The abutments were screwed onto the implants, and these specimens were positioned in a vise-grip for the abutment screw tightening with a digital torque wrench (Instrutherm, São Paulo, SP, Brazil). After two minutes, the screw was re-tightened to avoid its surface setting effect and improve the torque maintenance (11) (Fig. 2). Distilled water was used to lubricate the abutment screw and simulate the moisture present in mouth environment.

The implant/abutment specimens were placed in a computerized tomography scanner (Skyscan 1172 High Resolution, Brukker, Belgium) for the acquisition of solid models in order to analyze the abutment screw elongation after torque application. The position of the implant was standardized by a silicone matrix (Fig. 3). The scanning process allowed for .tiff format image acquisition. This image set was transposed to .bmp files by the NRecon software (Skyscan, Aartselaar, Belgium) using the Volume of Interest (VOI) tool, which allows the determination of a standardized virtual cube for all specimens. Due to standardization of specimen position, it was possible to ensure the same position of the specimens in the virtual cube, facilitating the image section for the measuring procedure.

After the solid model construction, the DataViewer software (Skyscan) was used to section the virtual cube and, consequently, the virtual specimens in half, resulting in a 2D image. These images were used to measure the screw length using the Image J software (Figs. 4A and 4B). To quantify the screw elongation, the screw alone was scanned in a micro-CT scanner to register its original length by the same method (Fig. 5). The measurements of each specimen were repeated three times by the same operator.

Method Accuracy and Repeatability

A rod with determined length was inserted into the implant chamber, and this set was taken to the micro-CT scanner to obtain the images by the same method used for the specimens (Fig. 6). This step was repeated four times to evaluate the repeatability of the process in seeking to separate the variation of the scanning process from the variation of the measuring process.

To evaluate the accuracy of the method, three rods with different lengths were used to evaluate if the micro-CT technique would be able to measure such low difference

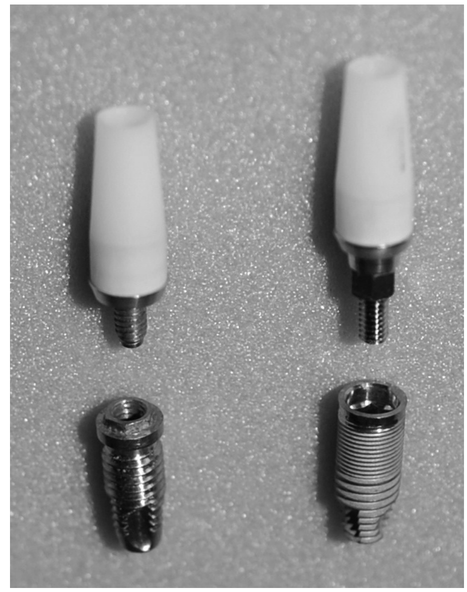

Figure 1. Specimen from group EH (left) and group MT (right).

Figure 2. Torque application; implant was positioned in a vise grip, and the digital torque wrench was used to apply a 20 Ncm torque.

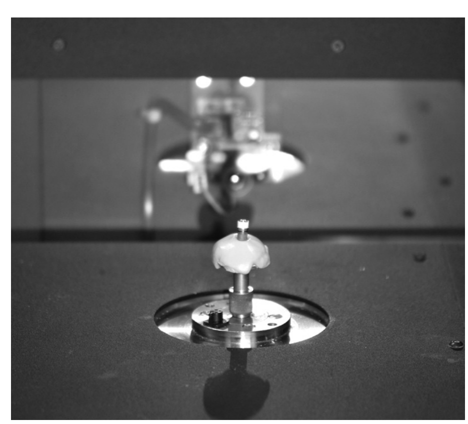

Figure 3. Specimen positioned in the Micro-CT chamber; a silicone matrix was used for standardize the position of specimens.

in length. The first rod had 5600 μm in length; the others had the same shape and diameter, but one of them was 25 μm shorter, and the other one 25 μm longer.

Pre-load Calculation

The screw elongation was converted to preload force using the Hooke's Law:

$$E = \sigma / \varepsilon = (F / A)/(\Delta l / l\_0)$$

where:

E = modulus of elasticity (N/m^2)

σ = stress, is the force F per sectional area A

ε = strain, is the change in length, Δl, per original length, l_0.

A preload value was obtained for each group from the arithmetic mean of the values of each specimen from the group. The titanium alloy elastic modulus used was 110 GPa and was based on the literature (12,13).

Loosening Torque Measurement

The torque required to loose the abutment screw of each specimen was recorded. For this, 72 h after the abutment screw tightening, the specimens were positioned in a vise-grip and the torque to remove the screw was applied with a digital torque wrench (Instrutherm); the values required to loosen the screws were recorded.

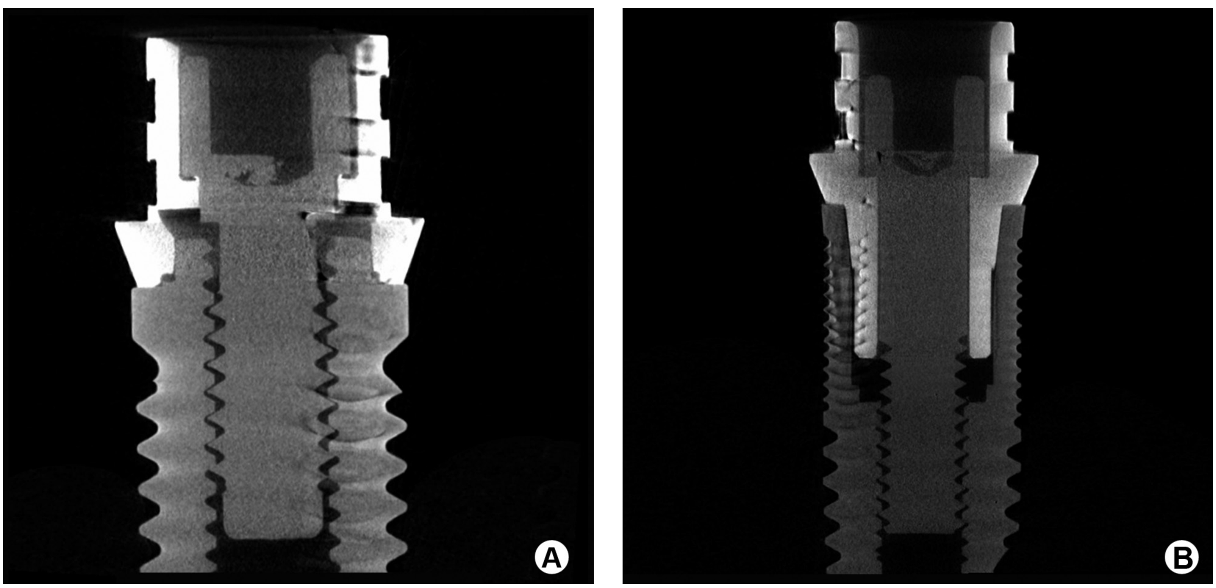

Figure 4. Images of coronal slices obtained from micro-CT scanning. A: External hexagon implant. B: Morse tapered implant.

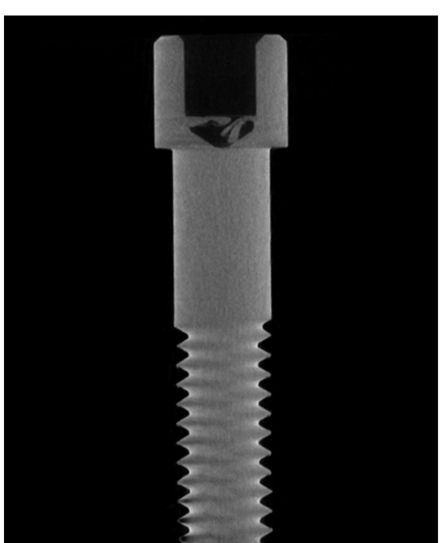

Figure 5. Image from micro-CT scanning of the abutment screw.

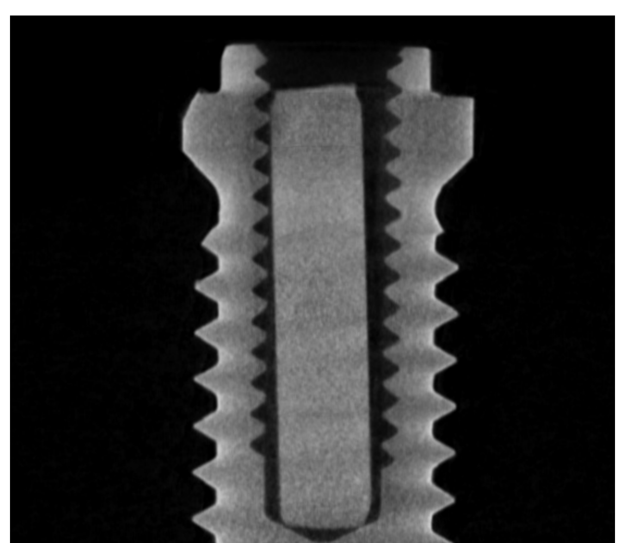

Figure 6. Micro-CT image (coronal slice) of a rod in the implant chamber.

Statistical Analysis

From the mean value for each group, it was possible to compare statistically the preload intensity for different implant/abutment joints when the same tightening torque value is applied (comparison between the groups EH and MT). For this, an independent t-test (α=0.05) was used.

Results

Method Repeatability and Accuracy

The results showed a coefficient of variation (CV) of 0.053% among the four scanning procedures made for the same rod (Table 1). The accuracy showed satisfactory results as shown in Table 2, the difference between the shorter rod and the medium rod for the micro-CT measurement was 24 µm (1 µm error), while the difference between the medium and the longer rod was 29 µm (4 µm error). The error between the methods used to measure the rod lengths is also in Table 2, representing a 0.2% to 0.3% error with a consistent positive bias, which means that the error is mostly cancelled when subtracting two values to calculate the screw elongation.

Table 1. Results for length (in µm) obtained from different scanning procedures for the same specimen

Scanning	Rod Length
1st	5587.79
2nd	5596.17
3rd	5591.71
4th	5592.80
Mean	5592.12
SD	2.99
Variability	0.053%

Table 2. Results for different rods with different lengths (in µm) and the error between the different methods used for measure the rods (in %)

Rod	Length from micro-CT	Length from caliper	Difference	Error
Shorter	5588	5575	13	0.23
Medium	5612	5600	12	0.21
Longer	5641	5625	16	0.28

Loosening Torque

The torque required to loosen the abutment screw is in Table 3. The MT group presented lower torque maintenance.

Preload Measurement

The mean original screw length obtained from micro-CT measurements was 9,170 µm for MT group and 7,150 µm for EH group. The results for elongation and preload for both groups are presented in Table 4. The EH group presented higher variability. The statistical results showed no statistically significant difference between the groups for preload ($p<0.05$).

Discussion

Based on the results, the method using micro-CT

Table 3. Loosening torque for both groups (Ncm)

Specimen	External hexagon	Morse taper
1	17	10
2	16	4
3	5	5
4	18	14
5	13	8
Mean	13.8	8.2
SD	4.7	3.6

Table 4. Results and standard deviation (S.D.) for elongation (µm and %) and preload (N) for both groups

Specimen	External hexagon			Morse taper		
	Elongation (µm)	Elongation (%)	Preload (N)	Elongation (µm)	Elongation (%)	Preload (N)
1	28.6	0.40%	440	47.8	0.52%	572
2	14.3	0.20%	220	36.2	0.39%	429
3	13.6	0.19%	209	18.9	0.20%	220
4	43.6	0.61%	671	49.8	0.54%	594
5	49.3	0.69%	768	48.7	0.52%	572
Mean	29.87	0.42%	461.6	40.2	0.43%	477.4
SD	14.67	0.21%	228.2	11.7	0.13%	141.5

scanning may be considered to evaluate the abutment screw elongation, since the variability of 0.053% for a specimen can be considered low. Furthermore, the measurement of specimens with known length, in this case the rods, proved to be possible to measure small changes in length as occurs with screws. However, based on the numerical results of standard deviation, the coefficient of variation for preload was approximately 50% for the EH group and 30% for the MT group, and probably it is the reason for absence of statistical difference between the groups. A larger number of specimens could reduce the high coefficient of variation.

The null hypothesis was confirmed. This study found comparable values for preload among both implant/abutment joints design (External Hexagon and Morse Tapered), as stated by Coppedê et al. (14). These data disagree the ones from other studies, which found higher preload values and/or higher torque maintenance for internal connections (15-17). However, the number of specimens used in the present study was small and the comparison with other studies should be done carefully.

Comparing the mean preload values with those obtained by Haack et al. (10), the present study found slightly higher values. Haack et al. (10) found a mean preload of 381.5±72.9 N against 461.6 ± 228.2 N obtained in the present study for an external hexagon joint with a titanium screw and a torque of 20 Ncm. This difference could be attributed to the fact that Haack et al. (10) cut the apical third of the implant, and thus a contact surface between the screw and the implant was lost. Furthermore, the previous study of Haack et al. (10) did not use lubricant, which may have interfered on the results of preload.

A relationship between preload and abutment screw loosening torque was expected. However, as seen, the preload did not necessarily influence the loosening torque. This may be explained by the friction coefficient between the abutment screw and the implant surfaces. Variations in the fabrication process can lead to different contact surfaces between these parts, causing some difference in the friction coefficient. Furthermore, in this study the preload calculation was based on Hooke's law, as done by Haack et al. (10). This calculation did not consider the friction coefficient between the abutment screw and the implant surfaces. Lang et al. (16) showed in a finite element analysis that there is an influence of the friction coefficient on the preload intensity.

The torque applied for the abutment installation was not maintained in both implant/abutment joints. The MT group lost 59% while the EH group lost 31% of the applied initial torque. The torque reduction is well documented in the literature (11,18-20) and occurs independent of the implant/abutment configuration (17). The cycling procedure can accelerate the process of torque reduction (9,20), but it was not considered in this pilot study.

The time after torque application can influence the preload value, as demonstrated by Cantwell and Hobkirk (18), who monitored the preload for 15 h after torque application and found a continuous reduction of preload values. This could be the reason for the lack of correlation between the results obtained for preload from those obtained for loosening torque, as the preload was measured immediately after the torque application while the loosening torque was measured 72 h after torque application.

Since this is a pilot study, there are some limitations that should be considered for future studies. The number of specimens was too low to provide results with reliable statistical power. Furthermore, the utilization of a cycling procedure to simulate the clinical situation must be considered, as this can directly affect the results for preload and torque maintenance. So, a study with a higher number of specimens with cycling procedure is recommended to evaluate more reliably and to compare the preload for different implant/abutment joints using the method based on micro-CT images.

Thus, the method using micro-CT images showed consistent results to measure small changes in length and could be considered to evaluate the abutment screw elongation. Within the limitations of this study, there was no difference between external hexagon and morse taper for preload, despite the higher removal torque values shown by the external hexagon group.

Resumo

Este estudo teve como objetivo medir a pré-carga em diferentes conexões implante/pilar baseado em imagens de micro-CT. Implantes de hexágono externo (EH) e Cone Morse (MT) (n = 5) foram utilizados para a medição de pré-carga. Os parafusos de pilares foram digitalizados em um micro-CT de alta resolução para obter seus modelos virtuais, que foram utilizados para registrar o comprimento inicial. Os pilares foram parafusados sobre o implante com um torque de 20 Ncm e, o conjunto composto por implante, parafuso do pilar e pilar foi levado para o micro-CT para obter cortes virtuais dos espécimes. Esses cortes permitiram a medida do comprimento dos parafusos após a aplicação do torque. Assim, com base no alongamento dos parafusos, os valores de pré-carga foram calculados usando a Lei de Hooke. A pré-carga de ambos os grupos foram comparados pelo Test-t independente. O torque de remoção de cada espécime foi registrado. Para avaliar a precisão da técnica de micro-CT, três bastões foram escaneados em micro-CT e o comprimento do seu modelo virtual foi comparado com o comprimento original dos bastões. Um bastão foi digitalizado e mensurado quatro vezes para avaliar a variação do método de medição e a sua repetitividade. Não houve diferença entre os grupos para a pré-carga (EH = 461,6 N e MT = 477,4 N), no entanto o grupo EH apresentou maiores valores de torque de afrouxamento do parafuso (13,8 ± 4,7 contra 8,2 ± 3,6 Ncm para o grupo MT). A técnica de micro-CT mostrou uma variabilidade de 0,053% e a repetitividade apresentou um erro de 0,23 a 0,28%. Dentro das limitações deste estudo, não houve diferença entre Hexágono Externo e Cone Morse para pré-carga. O método baseado em imagens de micro-CT pode ser considerado para mensuração da pré-carga.

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