Misfit of Three Different Implant-Abutment Connections Before and After Cyclic Load Application: An In Vitro Study

Sergio Alexandre Gehrke, DDS, PhD[1]/Rafael Arcesio Delgado-Ruiz, DDS, PhD[2]/
Juan Carlos Prados Frutos, DDS, PhD[3]/María Prados-Privado, PhD[5]/
Berenice Anina Dedavid, PhD[4]/Jose Manuel Granero Marín, DDS, PhD[5]/José Luiz Calvo Guirado, DDS, PhD[5]

Purpose: *This study aimed to evaluate the misfit of three different implant-abutment connections before and after cycling load.* ***Materials and Methods:*** *One hundred twenty dental implants and correspondent prefabricated titanium abutments were used. Three different implant-abutment connections were evaluated: Morse taper (MT group), external hexagon (EH group), and internal hexagon (IH group). Forty implants and 40 abutments were used per group. The parameters for the mechanical evaluation were set as: 360,000 cycles, load of 150 N, and frequency of 4 Hz. Samples were sectioned in their longitudinal and transversal axes, and the misfit of the implant-abutment connection was evaluated by scanning electron microscopy analysis. One-way analyses of variance, Tukey post hoc analyses (α = .05), and t test (P < .05) were used to determine differences between groups.* ***Results:*** *At the longitudinal direction, all the groups showed the presence of microgaps before cycling load; after cycling load, microgaps were reduced in all groups (P > .05). Transversally, only the MT group showed full fitting after cycling load compared with the other groups (EH and IH) (P < .0001).* ***Conclusion:*** *The application of cycling load produces an accommodation of the implant-abutment connection in internal, external, and Morse taper connections. In the longitudinal direction, the accommodation decreases and/or eliminates the gap observed initially (before load). In the horizontal direction, Morse cone implant-abutment connections experience a complete accommodation with the elimination of the gap.* Int J Oral Maxillofac Implants 2017;32:822–829. doi: 10.11607/jomi.5629

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For some decades, dental implants with an external-hexagon connection have been used for replacement in single, partial, and edentulous patients.[1–3] These implants had originally used the implant-abutment interface of an external-hexagon connection with 0.7 mm height.[3] In experimental in vitro studies, external connections compared with internal connections showed lower fracture strength[4]; in addition, external-hexagon connections compared with internal-hexagon connections demonstrated a higher mean microgap (1.22 mm external hexagon vs 0.97 mm internal hexagon).[5]

Microleakage at the implant-abutment interface can happen,[6] and bacteria have been observed within and between implant components.[7] The system consists of two or more parts that must be connected to each other, and there is a dimensional difference between the parts that allows for the connection.[8] This dimensional difference determines the accuracy of the system and is referred to as "tolerance," which is a valuable tool for the evaluation of the misfit caused by fabrication, processing, and wear.[8]

There is a great deal of information about the clinical consequences of a misfit between the implant and the prosthetic abutment.[9–11] Discrepancies greater than 10 mm have biologic effects (eg, bacterial microfiltration),[9] and produce inadequate mechanics (eg, the loosening and rotating of the screws) that may

[1]Full Professor, Biotecnos – Technology and Science, Santa Maria, Brazil; Department of Materials Engineering, Pontificia Universidade Católica do Rio Grande do Sul, Porto Alegre, Brazil; Department of Research, International Biomaterials Research Group, Universidad Catolica del Uruguay, Montevideo, Uruguay.
[2]Associate Professor, Department of Prosthodontics and Digital Technology, Stony Brook University School of Dental Medicine, New York, USA.
[3]Associate Professor, Department of Medicine and Surgery (Stomatology Area), Rey Juan Carlos University, Madrid, Spain.
[4]Full Professor, Department of Materials Engineering, Pontificia Universidade Católica do Rio Grande do Sul, Porto Alegre, Brazil.
[5]Full Professor, Department of Research, International Dentistry Research Cathedra. Faculty of Medicine & Dentistry, San Antonio Catholic University of Murcia (UCAM), Murcia, Spain.

Correspondence to: Prof Dr Sergio Alexandre Gehrke, Rua Dr. Bozano, 571, 97015-001 – Santa Maria (RS) – Brazil. Phone/Fax: 55 55 3222 7253. Email: sergio.gehrke@hotmail.com

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Table 1 Experimental Groups and Characteristics of Each Implant Model

Group	Connection type	Implant diameter (mm)	Connection length (mm)	Connection diameter (mm)	n
MT	Morse taper	4.0	3.5	2.5	40
EH	External hexagon	4.0	0.7	2.7	40
IH	Internal hexagon	4.0	1.8	2.5	40

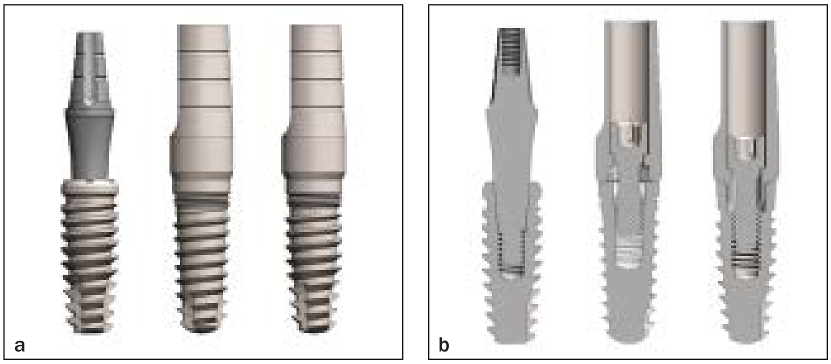

Fig 1 Schematic drawings of the *(a)* implants and abutments and *(b)* internal connection of each system used in this study.

lead to complete treatment failure.[9] Discrepancies of 10 mm or less do not seem to have consequences for the hard or soft tissues.[11] Thus, the long-term success of a prosthetic restoration supported by an osseointegrated implant is directly related to the precision of fit of the prosthetic components.

In this way, Ribeiro and colleagues (2011) related that the two most common causes of abutment screw loosening are excessive bending of the joint and a lack of precision components.[12]

The implant and abutment are connected with a retention screw with a torque level determined by the manufacturer. That torque produces a clamping force called “preload,” which is critical for preventing screw loosening.[13] A lower preload allows significant micromotion in the joint.[14]

These factors (the tolerance and the preload) dictate the stability of the interface between the abutment and implant and the strength of the interface when subjected to the loads produced by mastication.[7,15] To replicate and evaluate the behavior of implant systems, the standard ISO 14801:2007 was developed with the intention to standardize these tests using cyclic fatigue.[16]

However, there is a lack of references in the literature evaluating and comparing the mechanical behavior of external-hexagon, internal-hexagon, and Morse taper connections under cycling load. Therefore, the aim of this study was to evaluate the longitudinal and transversal interface tolerance of three different connections (MT, EH, and IH) before and after load cycling.

MATERIALS AND METHODS

Implant Characteristics and Preparation

A total of 120 titanium dental implants (Implacil De Bortoli Implants) with 4 mm in diameter and 11 mm in length and their respective standard titanium abutments (Implacil De Bortoli Implants) were divided into three groups of 40 implants with different abutment connection designs: Morse taper (MT group), external hexagon (EH group), and internal hexagon (IH group) (Table 1 and Fig 1).

The abutments were connected to the implants with a clamping force of 30 Ncm with a CME-30 Nm torque machine (Técnica Industrial Oswaldo Filizola). To limit the effect of settling of the screws, which could reduce the preload, the components were retightened to their respective torque values 10 minutes after the initial torque.[16]

Load Cycling Application

Sixty sets (20 implant-abutment sets per group) were immersed in a rigid epoxy resin model GIV (Polipox) with a Young’s modulus of elasticity of 3.2 GPa, using cylindrical acrylic tubes with 20 mm in diameter. The sets (implant-abutment) were immersed, leaving 3 mm of exposed implant to reproduce bone loss. Afterward, a metallic crown with a semi-circular shape was cemented on each abutment using a zinc phosphate cement in accordance with the standard ISO 14801:2007[17] (Fig 2). After the resin polymerization, the samples were immersed in water at 37°C ± 2°C and placed on a mechanical cycler (BioPDI), and 360,000 cycles of 150 ± 10 N of

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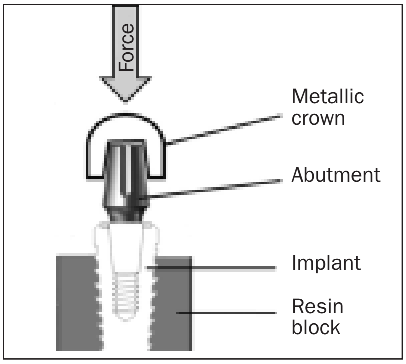

Fig 2 *(Left)* Image showing a schematic of the details used in this study (ie, metal crown–shaped semi-circle, 3 mm without implant insertion, direction of the applied load).

Fig 3 *(Right)* Image showing the samples immersed in water at 37°C ± 2°C and placed on a mechanical cycler with the Biocycle machine.

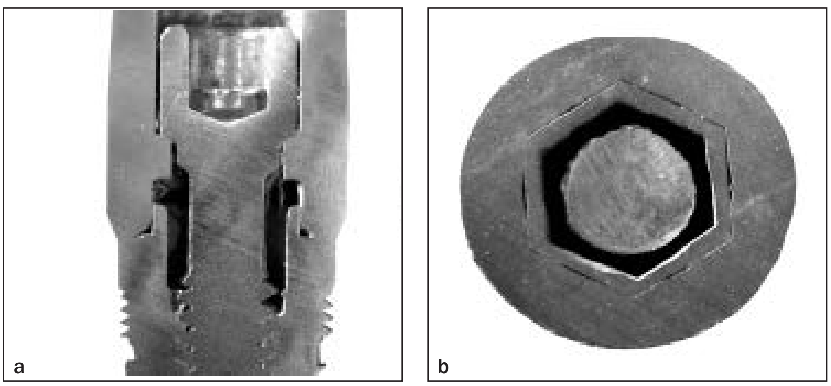

Fig 4 Images showing the two cut directions applied to the samples for the analyses of the fits between the abutments and implants: *(a)* longitudinal and *(b)* transverse.

controlled axial force were applied at 4 Hz (Fig 3), as used in publications of previous studies.[18,19]

Metallographic Preparation and Scanning Electron Microscopy Analysis

All samples (60 before load cycling and 60 after load cycling) were fully embedded in metallographic resin Embed-812 (EMS) for cutting and metallographic analyses of the interfaces. A metallographic cutter (Isomet 1000) was used to produce cuts in two directions in each of the implant-abutment sets. The cuts were made at the center of the longitudinal joint (n = 20 per group) and transverse (n = 20 per group) to the long axis in the center of the length of the connection (Fig 4).

The resulting pieces were polished using a sequence of abrasive papers that were 240-, 320-, 400-, 600-, and 1,200-grit abrasive (Polipox). Subsequently, the samples were cleaned in an ultrasonic bath with 96% isopropanol.

These samples were analyzed with scanning electron microscopy (SEM) using a Philips XL30 (Philips) instrument to record a series of images based on secondary electrons (SEs).

A magnification of 1,000× was used to examine the longitudinal cuts. For the EH and IH groups, three positions (p1 to p3) were examined and measured in each side (right and left) of the image: p1 was in the more external border, p2 was in the center, and p3 was in the more internal border (Fig 5a). Regarding the transverse cuts, a magnification of 500× was used, and each sample of the EH and IH groups was measured at each interface of the hexagon at four positions and at each angle (ie, the right and left of the image) and at 300 µm in the center direction (p1, p2, p3, and p4) according to the scheme presented in Fig 5b.

For the implants of the MT group, the measurements were performed at four positions for the transverse cuts (Fig 6a) and at two positions on each side (right and left) of the image for the longitudinal cuts (Fig 6b). The measurements were obtained with the aid of ImageJ software version 1.44 (National Institutes of Health), as shown in Fig 7.

Statistical Analysis

The statistical analyses were performed using one-way analysis of variance (ANOVA) and subsequent Tukey tests. The *t* test was used to determine the significant differences between each group before and after the load cycling ($P < .05$). The statistical analyses were performed using the SPSS 21.0 package (SPSS). Statistical significance was set at $P < .05$.

RESULTS

There was no loosening, separation, or fractures in any of the samples during the load cyclic test. Table 2 shows the measurements between the walls before and after the mechanical cycling.

Transverse Cuts

All groups exhibited partial contact at the implant-abutment interface without statistical differences

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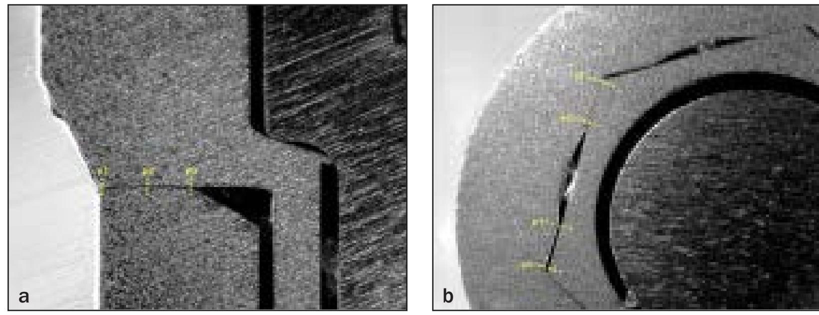

Fig 5 Images showed the positions of the measurements of the fits between the abutments and implants in the in the EH and IH groups: *(a)* longitudinal cuts and *(b)* transverse cuts.

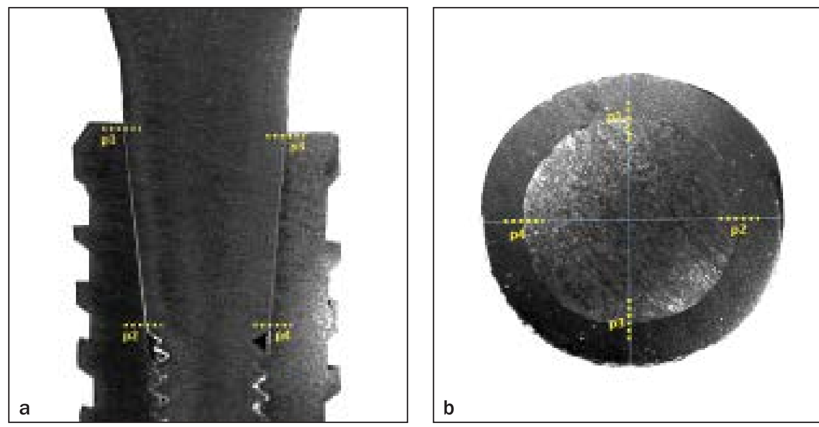

Fig 6 Images showing the positions of the measurements of the fits between the abutments and implants in the MT group: *(a)* longitudinal cuts and *(b)* transverse cuts.

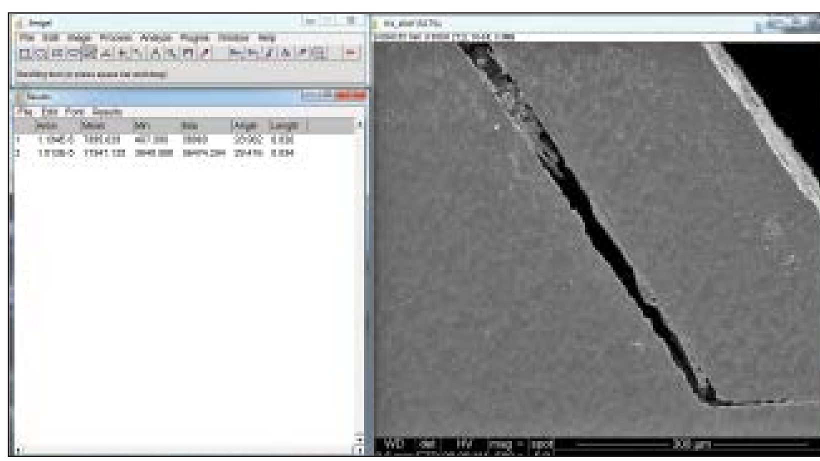

Fig 7 Image showing the use of the measurement software.

within the groups before the load (P = .021); in the EH and IH groups, the positions p3 and p4 showed no contact before and after the load applications.

In the MT group, full contact at all walls of the implant-abutment sets was found after the load cycling (P < .00001). The sequences in Fig 8 show the image from before the loading for each group.

Longitudinal Cuts

Before the load cycling, all groups exhibited space between the implant-abutment sets and the contacts in the different positions of each connection type after the torque (Fig 9). After the load application, all the groups exhibited complete contact between the

Table 2 Mean ± SD Values of Contact Measurements Between Walls of Implant-Abutment Sets Before and After Mechanical Cycling Load in Longitudinal and Transversal Cuts

	Longitudinal cut (µm)		Transversal cut (µm)	
Groups	Before load	After load	Before load	After load
MT	4.0 ± 1.0	0	13.0 ± 2.1	0
EH	4.1 ± 0.9	0	15.3 ± 4.9	11.5 ± 3.8
IH	3.6 ± 0.9	0	13.8 ± 4.2	10.6 ± 3.7

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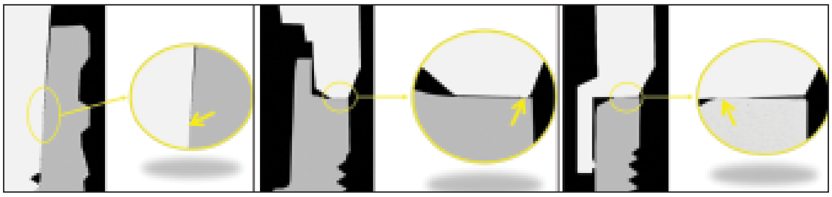

Fig 8 Scheme of the contact positions of the sets before the load for the MT, EH, and IH groups, respectively.

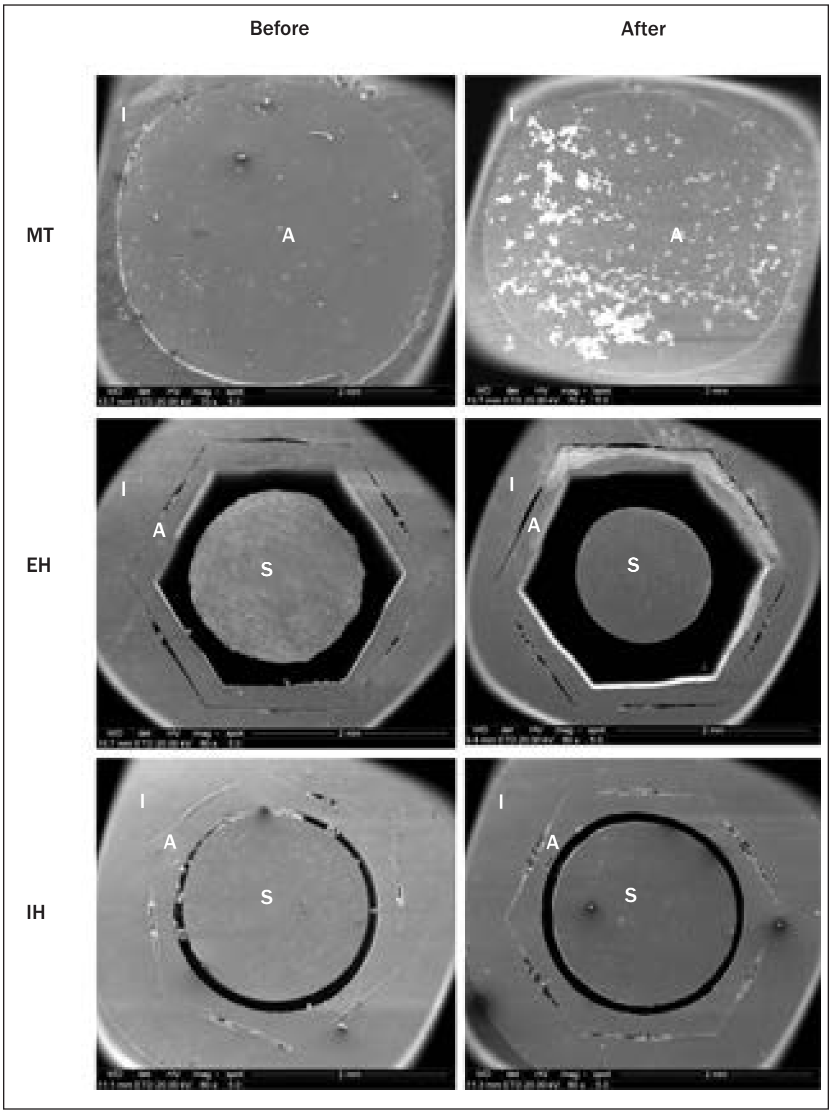

Fig 9 Sequence of images of transversal cuts showing the groups before and after the load application. I = implant; A = abutment; S = screw.

interfaces. The sequences in Fig 10 show the image from before and after the loading for each group. No statistical differences were observed among the groups before and after the load ($P = .408$).

DISCUSSION

The present study evaluated the misfit of the interface between the abutments and implants of three different connections (EH, IH, MT) before and after the application of mechanical load cycling. Two sections were analyzed (longitudinal and transversal) to understand how the load cycling affects different levels of the interfaces.

The transversal section was included because it allowed a 360-degree view and analysis of the implant-abutment connection and gave information about the rotational freedom. The observations were more meaningful at the MT connection, in which the connection showed full contact even before the application of the cycling load.

Several studies have shown the benefits of implants with an MT connection over the implants with an IH connection[20]; however, many professionals continue

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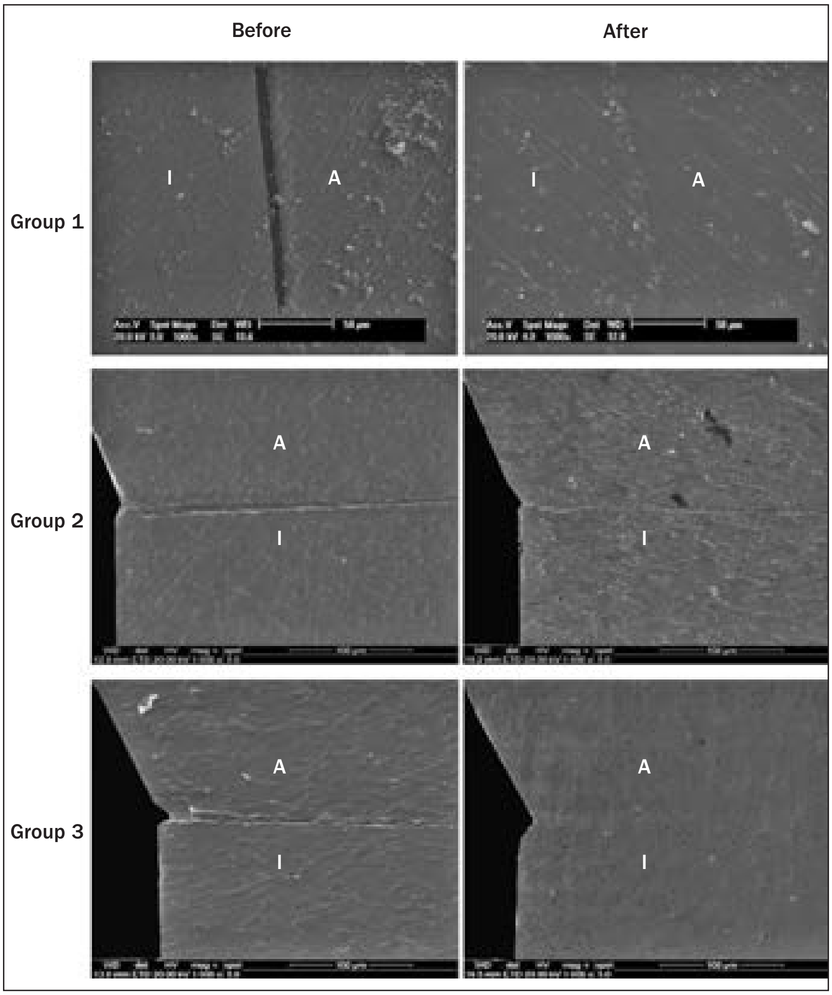

Fig 10 Sequence of images of longitudinal cuts showing the groups before and after the load application. I = implant; A = abutment.

using these implants with high success rates, even in unit rehabilitations. Theoharidou et al, in a systematic review, showed that abutment screw loosening is a rare event in single-implant restorations regardless of the geometry of the implant-abutment connection.[21] Furthermore, in vitro studies of bacterial microleakage showed that the three implant-abutment connections (EH, IH, and MT) showed some contamination.[22,23]

Various techniques have been used to analyze the implant-abutment interface, including human observation of samples under magnification, measurements of the cross sections, impression techniques, three-dimensional microtomographic techniques, and others.[23–25] In the present study, SEM measurements were chosen for their precision and simplicity, similar to other studies developed by the present group of authors.[18,19,26,27]

After the application of mechanical cycling (corresponding to 1 year of loading), microgaps were reduced or no longer observed between the abutments and the implants in all groups, which confirmed the hypothesis that the abutment contact increases after load application.[24,25]

The mechanical cycling altered the fit between the implant and the abutment in all groups. Thus, increased contact between the implant-abutment connection might improve the resistance to loosening and prevent the entry of bacteria and fluids.[27–29]

Studies have reported vertical misfits between 2.3 and 6.4 mm for machined abutments with different connections.[30,31] In the present study, the measurements were performed after assembly without load and after assembly with load application. The results revealed that all the connections exhibited better fits after the load applications.

Misfits between the components of screwed connections have been considered to be possible causes of mechanical complications, such as screw loosening and/or fractures.[32,33] Some studies have reported that frameworks that are cast as single pieces exhibit distortions that compromise their accurate fit to the implant-abutment interface.[33,34] Although misfit has been indicated as a possible cause of the loosening of retention screws,[31,35] no evidence relating the level of misfit and its relation with the percentage of screw loosening have been described.

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The results obtained in this study led the authors to hypothesize that two factors are responsible for the microgap changes and variations in micromovement of the implant-abutment connection: first, the differences in the torque of the internal- and external-hexagon implants compared with the torque of the Morse taper implants demonstrated in previous studies,[16] which are directly related to the micromovement of the assembled parts (implant and abutment); and second, the assembly adjustments caused by the deformations after load.

The stability of a screwed connection is directly related to the preload achieved during the torqueing.[30] A dynamic finite element analysis revealed that with repetitive cycles of load application, a lack of contact between the head of the screw and the prosthesis was observed, which indicates that unscrewing and failure could be caused by this separation and by the higher levels of stress that are generated over the screws.[35,36] In addition, the lack of adaptation between the implant-abutment components will facilitate the rotation of the abutment screw (screw loosening) or the abutment part (abutment loosening).

Some studies have suggested a correlation between the misfit at the implant-abutment interface and screw loosening,[30,32,35–38] but no studies have examined the correlation between unscrewing and the level of vertical misfit, and few studies have evaluated the interaction between the external hexagon of the implant and the internal hexagon of the abutment or rotational freedom.[37,38]

In a dynamic analysis, Cibirka et al (2001) evaluated the differences in the torque required to unscrew abutment screws after fatigue tests while altering the dimensions of the external and internal hexagons or eliminating the external hexagon.[31] These authors observed applied torque losses of 48% to 55%. Binon (1996) and Binon and McHugh (1996) evaluated the misfits between the external hexagons of implants and the internal hexagons of abutments and the unscrewing of the abutments during simulated oral function.[39,40] A direct correlation was observed between the rotational freedom at the implant-abutment connection and screw loosening.

Previously reported fatigue tests were used to simulate masticatory loading on the implants and to determine the stabilities of the interfaces. Variations in the numbers of load cycles, frequencies of loading, direction of the load, forms of application, and other factors vary greatly, and the comparison with this study was not possible.[16,39–45]

The first time that an abutment screw is tightened within an implant, contact between the implant and the threads of the screw occurs only via the microroughnesses of the surfaces. A reduction of 2% to 10% in preloading should occur within the first few seconds or minutes after clenching due to the relaxation phenomenon that is termed "settling."[16] Therefore, in this study, the abutment screws were retightened to the initial torque value 10 minutes later.[16]

The different style of the Morse taper connection system has advantages over hexagonal connections because this connection type works with the friction between two walls, ie, the wall of the internal implant (diverging taper) and the outer wall of the abutment (convergent taper).[46–48] A screw receives the tightening torque to settle the implant and control the friction between the walls. The intimate contact between the implant and the abutment reduces micromotion because the two parts behave as a single structure.[24,25]

There are some drawbacks in the present work. First, the forces were applied axially, which works mainly for premolar and molar regions[49]; therefore, there is a lack of information for the effect of nonaxial forces on the implant-abutment interfaces produced by misplaced teeth/implant restorations or orofacial movement disorders.[50] Second, the forces were controlled, which excluded the probable effect of parafunctional noncontrolled forces on the implant-abutment interface.[51] Third, the results of an in vitro study cannot be extrapolated to the clinical setting.

CONCLUSIONS

Within the limitations of this experimental study, it can be concluded that the application of cycling load produces an accommodation of the implant-abutment connection in internal, external, and Morse taper connections. In the longitudinal direction, the accommodation decreases and/or eliminates the gap observed initially (before load). In the transversal cuts, Morse cone implant-abutment connections experience a complete accommodation with the elimination of the gap. The presence of implant-abutment misfit results in an increment of the wear and deformation of the implant-abutment components after cycling loading plus screw loosening after preload loosening. To reduce the wear, deformation, and risk of fracture of the implant-abutment components, as well as reduce the screw loosening, implant-abutment connections with a Morse taper connection are recommended.

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