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Effect of mechanical loading cycles on different abutment types in implants with tapered internal connection

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ABSTRACT

Aim The purpose of this in vitro study was to evaluate the influence of the application of cyclic mechanical load on torque loss and on the seating installation of internal tapered abutments.
Materials and methods Forty tapered implants and 40 abutments were used and divided into four groups ($n=10$): Group 1 (Titamax CM) and Group 2 (Strong SW Morse) received one-piece abutments; Group 3 (Titamax CM) and Group 4 (Strong SW Morse) received two-piece abutments. Tightening torque and reverse torque were applied, after 5 minutes, on all abutments. After that, tightening torque was applied to all the abutments, and were mechanically loaded and uninstalled. The two-piece abutments of Group 3 and Group 4 were divided in two subgroups (Subgroup 3a and Subgroup 4a: traction test required to remove the implant - pull out). The specimens were submitted to fatigue tests consisting of 1.200.000 cycles at a frequency of 2 Hz, dynamic compressive load of 50 N, and an angle of 30°. Data were analyzed through the normal distribution (Shapiro-Wilk, $p > 0.05$), followed by parametric statistical tests.
Results After mechanical loading torque loss was higher in Group 4 (over 70% loss), followed by Group 1, Group 2 and Group 3 (over 50% loss). Group 1 and Group 2 presented no statistical difference. Subgroup 3a presented higher traction strength seating in post removal after mechanical loading (67.91 N), while Subgroup 4a presented only 1.92 N, it may present greater loosening of abutments.
Conclusions The mechanical load significantly reduced the removal torque of the four groups of abutments tested, in addition to increasing frictional lock installation to the abutments of Subgroup 3a in the pull out test.

KEYWORDS Bone quality, Dental implants, Primary stability, Secondary stability.

INTRODUCTION

A high frequency of complications related to treatment with dental implants is reported in the literature, with screw loosening being the most common, especially in single restorations (1). Screw loosening is more common in external hexagonal connections due to its mechanical properties under dynamic load (2,3). The internal tapered connections appear to be more resistant to screw loosening, abutment movement and loss of torque, thus being more resistant to fatigue loading (4).
The implant/abutment junction appears to be the most likely site of increased stresses as this is the area where the functional forces of the occlusion will be distributed to the implant platform and to the bone. As a consequence, it is likely that any stress or deformation of the prosthesis caused by problems of adaptation or misfit may lead to technical complications such as loosening or fracture of the screw, abutment movement and torque (4). To address these problems, a variety of models, implant/abutment connections, and prosthetic components have been developed by the implant industries (5). The biomechanical stability of the implant/abutment interface may depend on the type of connection, tolerance between components, freedom of rotation, and accuracy of fit (6).
The geometry of the implant/abutment interface also seems to be an influence factor for the transmission of tension around the implant (7). The effect of the biconic mechanical adjustment is increased by the use of a screw, which is applied from preload to the joint (7). In a study using Morse taper implants with one-piece abutments, various crown/implant ratios were assessed, and it was found that the upper anterior abutments showed a greater slackening tendency. In the posterior regions 2 mm diameter abutments fractured and 3 mm diameter abutments loosened. However, studies on the mechanical strength of implant systems with one-piece or two-piece abutments are still required (8).
Occlusal forces seem to play a key role in the loosening of implant screws, the preload is the only force that resists functional occlusal forces to prevent the

abutment from releasing from the implant. If the preload is exceeded by occlusal force, loosening of the screw may occur (1). Therefore, the eccentric and compressive forces produced by chewing movements can reduce the retention of the screw (2). In the internal tapered connections, the fixation and the stability are conferred by the frictional resistance resulting from the contact between the tapered coupling parts of the abutment and implant, not being a function of the screw. This coupling or tapered engagement of the implant/abutment joint will continue even if the screw loosened. Therefore, studies that prove that the abutment will not release even with screw loosening is important. The application of axial compressive forces causesan increase of the frictional resistance resulting from the contact of the tapered coupling parts (9). Mathematical formulas and finite element models have shown that more than 86% of the tightening torque and more than 98% of the relaxation torque are balanced by the tapered junction of these systems (9). The application of occlusal loading is a factor that can lead to loosening of the prosthesis retention screw (10). Therefore, several authors have successfully used fatigue tests for the application of dynamic cyclic loading to simulate masticatory forces (5,11-17).

The objective of this study was to evaluate the influence of dynamic oblique loads of compression and by simulated occlusal movements in the loss of torque and in the seating installation of abutments with tapered internal connections. Two types of abutments with tapered internal connections fabricated by two different manufacturers were evaluated: one-piece abutment, with threaded apical portion and two-piece abutment, with a transfixed screw. This study also evaluated the effect of tightening/loosening of these abutments before mechanical cycling simulation.

MATERIALS AND METHODS

For this *in vitro* study 40 implants were used, of which 20 implants (Titamax CM; Neodent, Curitiba, Parana, Brazil) had an internal tapered connection of 11.5°, Ø 4.0 mm x 11 mm in length and 20 implants (Strong SW Morse; SIN, São Paulo, SP, Brazil) had internal tapered connection of 16°, Ø 4.5 mm x 10 mm in length. Forty abutments were used and divided into 4 groups, all indicated for cemented restorations. All abutments were Ø 4.5 mm x 2.5 mm x 4.0 mm in height.

Implants and abutments were divided into four groups with different implant/abutment combinations as follows (Fig. 1).

Group 1: Titamax CM EX implants, Neodent with one-piece abutments (Neodent) (n=10).

Group 2 Strong SW Morse implants, SIN, with one-piece abutments (SIN) (n=10).

Group 3 Titamax CM EX implants, Neodent with two-piece abutments (Neodent) (n=10).

Group 4 Strong SW Morse implants, SIN with two-piece abutments (SIN) (n=10).

Before the mechanical loading test all four implant/abutment groups were subjected to tightening torque application and after 5 minutes, without mechanical loading application, reverse torque required to loosen the abutment fixation screw was applied and traction test (pull out) to measure the traction force of removal of the two-piece abutments was performed. The values of reverse torque of the implant/abutment assemblies were collected at this time and recorded, this first abutment loosening and pull out test was performed to analyze how much cycling could interfere with the final result, since insertion/removal torque even without cycling tends to decrease the removal torque values (12). Then all four groups with their implant/abutment assemblies were mechanically loaded. During the mechanical tests, the two-piece abutments (Group 3 and Group 4) could be frictionally stuck in the implants caused by mechanical loading. The removal action of this type of abutment presented two distinct moments: first, the amount of reverse torque required to loosen the fixation screw, and second, the pull out test to remove the locked abutment from the implant.

The torque values of the implant/abutment assemblies of Group 3 and Group 4 were collected at the first moment as: value of reverse torque that loosened the screw; in a second moment two subgroups were cataloged by Subgroup 3a and Subgroup 4a, where the values were collected as: traction force necessary to remove the abutment of implant. Thus, Subgroup 3a and Subgroup 4a had two different measurements collected from the same assemblies implant/abutments of Group 3 and Group 4.

The implants were inserted into a stainless-steel device, standardized to include vertical dental implants, (dimensions 26 mm in diameter and 24.5 mm in height).

FIG. 1 A: One-piece abutment (Group 1). B: One-piece abutment (Group 2). C: Two-piece abutment (Group 3). D: Two-piece abutment (Group 4). The dimensions of these abutments were: Height and diameter of the cementous area of 4.5 mm and 4.0 mm, respectively. Tapered connecting portion of 2.5 mm.

Then, a polystyrene resin (Aerojet; Santo Amaro, SP, Brazil) was poured over the implants, which were positioned 1 mm below the upper base of the device, simulating an infra-osseous placement.

The acrylic resin cylinder with the embedded implant and abutment was positioned at the base of a torque application device. In the upper part of this device a digital torque meter (MK Control and Instrumentation Ltda; São Paulo, SP, Brazil) was installed (with a calibration certificate issued by Calibratec; Curitiba, PR, Brazil),and connected to a system of analog-digital acquisition (Lynx; São Paulo, SP, Brazil). The acquisition of the real-time signal allows the real monitoring of the mechanical behavior of the test, minimizing errors of reading the applied torque value. The abutments were installed in the respective implants with the insertion torque recommended by the manufacturer, which was 32 Ncm for the one-piece abutments from Group 1; 20 Ncm for the one-piece abutments from Group 2 and for the two-piece abutments from Group 4; and 15 Ncm for the two-piece abutments from Group 3. The torque and pull out values were measured with decimal precision, using the torque application device, but with the installation of a load cell for pull out. The pull out test was performed with a traction force (N) required to remove the abutments and measured at a speed of 5 mm/min. To ensure that the traction force was applied parallel to the long axis of the test specimen, each specimen was firmly held and oriented at its bottom by a custom retention device. An upper component was securely attached to the upper adapter of the torque application device and firmly attached to the lower base of the component for parallel removal of the abutments. After 5 min, the abutments were loosened and the values of removal torque and traction force were measured and cataloged. Two experienced operators performed all tightening, loosening and traction tests during all of the tests of this study. A second tightening torque was then applied to all specimens from the four groups. Metal crowns were cemented on the abutments, made of nickel-chromium (Verabond II; California, EUA), by means of lost wax technique. The crowns were shaped as second inferior premolar and were standardized for the groups.

Temporary cement based on calcium hydroxide (Hydro C; Dentsply, Petropolis, RJ, Brazil) was used for cementation of the crowns. The cement was manipulated and then placed inside the crown, at this time excess cement was removed with an abutment analog and vertical pressure was placed on the crown/abutment/implant assemblies. Then, the 40 implant/abutment assemblies were subjected to mechanical loading process. The mechanical cycler with sliding of specimens (Biopdi; São Carlos, SP, Brazil) was used to apply the cyclic load simulating the effect of human mastication on the implant/abutment assemblies. This machine enables dynamic fatigue tests on 10 specimens simultaneously, with loading application independent on each specimen. The force applied to the specimens in each load cycle was generated by a spring system, measured through a load cell. The process is fully automated. The pistons, together with the loading tips, were adjusted to fit simultaneously on all mounted crowns, with a distance of 2 mm from the center of the crown and the chewing simulator also had a horizontal sliding movement of 2 mm, imitating chewing procedure. The specimens were inclined at 30° angle during testing, following ISO 14801 standard. The thermosetting system was adjusted to a temperature of 37°C ± 1°C, simulating the temperature of the oral cavity. The machine was set to apply a force load of approximately 50 N on average over each implant/abutment/crown assembly, with a frequency of 2 Hz. An amount of 102 cycles per min was applied, similar to human mastication, of 75 cycles per minute, during 1.200.000 cycles, with the aim of simulating approximately 5 years of mastication (18). The reverse torque at this second moment was given after mechanical loading, then the two-piece abutments were uninstalled from the implants using pull out test, and all values were recorded and catalogued.

All abutments were analyzed before and after mechanical loading in a scanning electron microscope (SEM, Vega 3 LMU, Tescan, Brno, Czech Republic). Images were obtained in 100x magnification. The implant/abutment assemblies from each group were analyzed, before and after mechanical loading, through a computerized microtomography device, model 1272 from the manufacturer (SkyScan; Kontich, Belgium). The pieces were positioned and fixed in an appropriate specimen port, allowing the stabilization and avoiding any type of movement during the scanning. After scanning the tomographic projections were reconstructed with the aid of the specific software (Nrecon; SkyScan, Kontich, Belgium). The initial and final images were defined by the evaluator showing the center of the implant/abutment assemblies in the same position.

Statistical analysis

The percentage values of removal torque in relation to the insertion torques of screws were calculated; that is, the percentage of torque loss or gain in comparison with the applied torque. These values were obtained using the formula: (removal torque x 100/insertion torque) – 100. The negative values represent torque gain.

The statistical analysis was performed using the normal distribution (Shapiro-Wilk, $p > 0.05$), followed by parametric statistical tests, statistical software Sigma Plot version 12.0 (Systat Software, Inc., San Jose, CA 95110 USA) was used. For the evaluation of the release and pull out test in the two moments studied (before and after mechanical cycling), the statistical analysis was performed using the paired T-test. Comparisons were made between the groups (Group 1 x Group 2; Group 3 x Group 4; Subgroup 3a x Subgroup 4a).

RESULTS

Before mechanical loading, the abutments of Group 1, Group 3 and Group 4 presented a loss of torque of approximately 5% to 9.5%, while Group 2 abutments presented a torque gain of almost 10%, the statistical comparison between the abutments (Group 1 x Group 2 and Group 3 x Group 4) is shown in Tables 1 and 2.

After mechanical loading the torque loss was higher in Group 4, which presented more than 70% loss. Group 1, Group 2 and Group 3 showed a loss of torque of 50% more. The results were significantly different and are recorded in the tables with means and standard deviation; only Group 1 and Group 2 showed no statistical difference. After mechanical loading, all groups presented loss of torque values.

Two-piece abutments presented different behaviors in Subgroup 3a and Subgroup 4a. In Subgroup 4a, the recommended 20 Ncm installation torque for these abutments was not sufficient to induce the frictional lock of the abutments in the implants, when the screws were loosened after mechanical loading, the abutments separated easily from the implants. For Subgroup 3a, after mechanical loading, the abutments showed frictional lock in the implants. After the reverse torque needed to loosen the screws, the abutments remained attached to the implants. Statistical comparison of pull out test values between Subgroup 3a and Subgroup 4a are shown in Table 3.

Analyzing the photomicrographs performed after the mechanical loading, it was observed that were no significant changes in positioning, it is possible to see the intimate contact between the abutment tapered portion and the internal walls of the implant, for both one-piece and two-piece abutments (Fig. 2, 3). SEM images showed variations in the morphology of the threads of all abutments before and after mechanical loading. The initial images showed that the screw threads had a non-homogeneous surface, even before the abutments were placed in function. One-piece abutments of Group 1 and Group 2 presented a more homogeneous surface on the ridges of the threads when compared to two-piece abutments in Group 3 and Group 4, both before and after mechanical loading.

Mechanical testing	Groups	
	Group 1	Group 2
Before mechanical loading	94.21(0.024)^a	-109.63(0.022)^b
After mechanical loading	45.22(0.017)^a	44.07(0.018)^a

Different letters show statistical difference in the horizontal. A comparison of torque loss between one-piece abutments Neodent (Group 1) and SIN (Group 2) before and after mechanical loading was performed. (There was no statistical comparison of torque loss before and after mechanical loading within each group and between one-piece and two-piece abutments).

TABLE 1 Percentage of torque before and after mechanical loading of Group 1 and Group 2.

Mechanical testing	Group 3	Group 4
Before mechanical loading	95.18(0.011)^a	91.5(0.023)^b
After mechanical loading	48.34(0.056)^a	28.85(0.016)^b

Different letters show statistical difference in the horizontal. A comparison of torque loss between two-piece abutments Neodent (Group 3) and SIN (Group 4) before and after mechanical loading was performed. (There was no statistical comparison of torque loss before and after mechanical loading within each group and between one-piece and two-piece abutments).

TABLE 2 Percentage of torque before and after mechanical loading of Group 3 and Group 4.

Mechanical testing	Subgroup 3a	Subgroup 4a
Before mechanical loading	2.44(0.61)^a	1.21(0.155)^b
After mechanical loading	67.91(6,50)^a	1.92(0.57)^b

Different letters show statistical difference in the horizontal. A comparison of the traction force between two-piece abutments Neodent (Subgroup 3a) and SIN (Subgroup 4a) before and after the mechanical loading was performed. (There was no statistical comparison of the traction force before and after the mechanical loading within each group).

TABLE 3 Values of the pull out before and after mechanical loading of Subgroup 3a and Subgroup 4a.

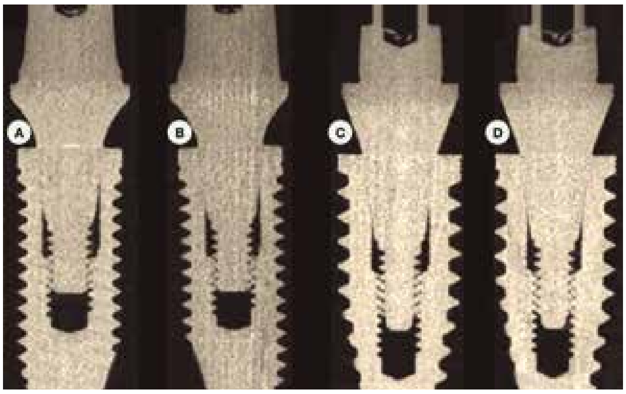


FIG. 2 The overview of the micromorphology of the one-piece abutments.
Abutment of Group 1 before (A) and after (B) mechanical loading.
Abutment of Group 2 before (C) and after (D) mechanical loading.

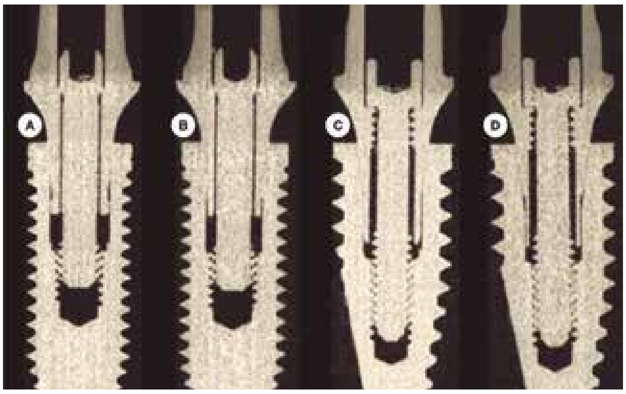
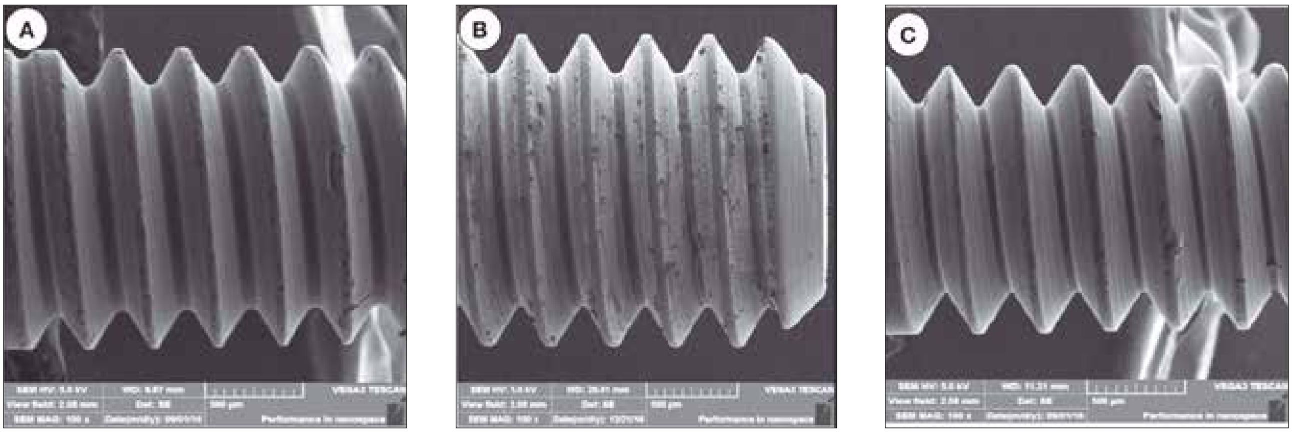


FIG. 3 The overview of the micromorphology of the two-piece abutments.
Abutment of Group 3 before (A) and after (B) mechanical loading.
Abutment of Group 4 before (C) and after (D) mechanical loading.



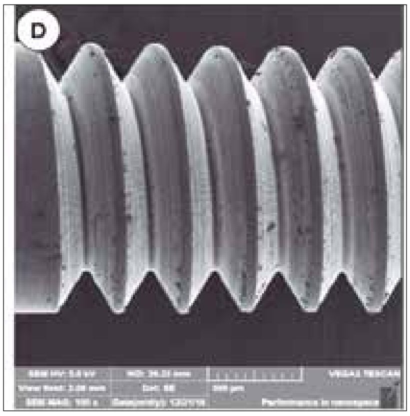
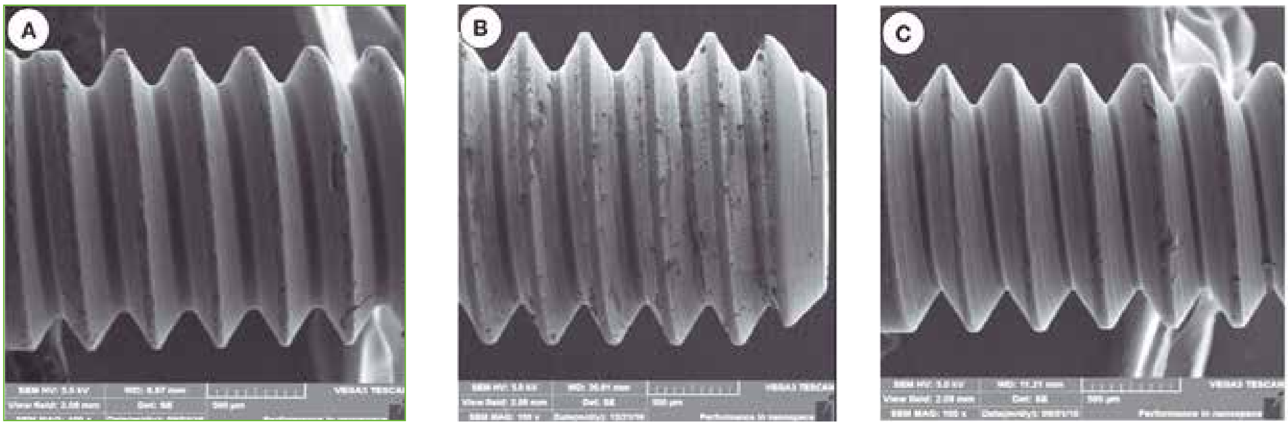


FIG. 4 Surface appearance of one-piece abutments screws.
A: Group 1 before the mechanical loading test, showing the ridges of tapered screw threads.
B: Group 1 after the mechanical test, with considerable wear and rounding on the ridges of the threads where they came in contact with the implant.
C: Group 2 before the mechanical test, showing tapered threads.
D: Group 2 after the mechanical test, with wear and rounding of the thread ridges and signs of wear on the inside of the threads.

The abutments of Group 1 and Group 2 presented even lower surface material release and low degree of striations and debris after mechanical loading, however, the crests of the threads presented greater deformation than the threads of the abutments of Group 3 and Group 4 (Fig. 4, 5).

DISCUSSION

The tapered connections present mechanical characteristics that must be observed; the screw, the tapered portions of the abutment and the implant act together in the process of insertion and removal of the abutments, both in one-piece and two-piece abutments (9). The fit between abutment and tapered connection implant is due to the resistance to friction resulting from the contact between the tapered coupling sections, and the screw only helps guiding the positioning (9). In this study it was not possible to distinguish the pull out values of one-piece abutments, since these abutments do not have a transfixation screw. For the two-piece abutments, however, pull out tests were performed to evaluate if there was resistance to the friction of the abutments after loosening of the screws. For Group 3 and Group 4 the screw loosening values were categorized. For Subgroup 3a and Subgroup 4a the values of the traction force required to remove the



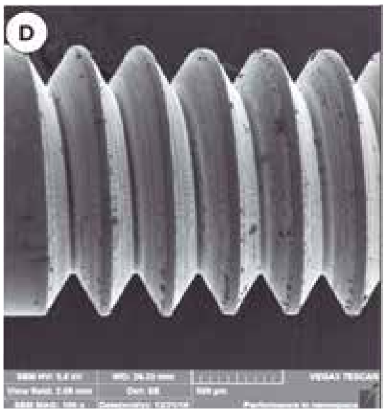


FIG. 5 Surface appearance of two-piece abutments screws.
A: Group 3 before the mechanical loading test, showing rounded threads and ridges imperfections.
B: Group 3 after the mechanical test, showing wear, rounding of the ridges and cuts in the apical part of the screw.
C: Group 4 before the mechanical test, showing imperfections in thread ridges.
D: Group 4 after the mechanical test, showing imperfections and wear in thread ridges.

abutments were categorized.

In the evaluation of the initial torque before mechanical loading, it was observed that there was loss of torque initially applied in three groups (Group 1, Group 3 and Group 4). This loss of torque can be explained by the "sedimentation effect" phenomenon, based on the hypothesis that all machined surfaces have a certain degree of micro-roughness (19). On the other hand, Group 2 presented torque gain, which could be explained by the internal cone diameter of 16° of this implant/abutment connections and did not present transfixing screw. Studies suggested that abutment material features an important role in the stability of the implant/abutment interface (4,11,15), however, the surface of all components of the 4 groups used in the current study was pure titanium type 4, so the type of material may not have had an impact on the gain or loss of torque.

Occlusal movements may generate moments of ascending intrusion loads that may negatively interfere with abutment retention, the axial compressive component of the occlusal forces acting in the direction of the insertion of the abutment, increases the contact pressure and the resistance to friction, but may increase abutment screw loosening (9). The results of the present study showed this, because mechanically loaded abutments showed a marked decrease in initial tightening torque values compared to unloaded abutments, most likely due to the effects of mechanical loading.

Previous studies have reported decreased post-loading mechanical torques in two-piece abutments installed in Morse taper implants. However, pull out values were equal to or greater than the initial values (12,20). There was no significant difference in torque loss compared to the two groups of one-piece abutments after mechanical loading, which means that in both groups the tendency for removal torque loss over the cycles was similar. Torque gain did not occur with one-piece abutments under mechanical loading, possibly because its apical thread portion did not allow complete compression of the abutment tapered portion in the corresponding part of the implant, reducing potential contact pressure (12). In the present study Group 3 and Group 4 showed a significant difference in loosening values after mechanical loading; the mean screw loosening torque was lower for Group 4 compared to Group 3 (Table 2). This current study used a load of 2 Hz frequency, which represents the best mechanical conditions under ISO conditions (13).

In the present study, the loosening values were lower compared to the initial tightening, these values greatly decreased, possibly due to the increased time of mechanical loading that simulated 5 years of masticatory function, besides the conditions of load and direction of the forces in an unfavorable condition of 30°. It has been reported in a recent study that a larger axial displacement occurred in an internal connection when compared to an external one. This direct comparison is made difficult by the different experimental parameters, such as the load conditions and force vectors (21).

Subgroup 3a presented high resistance to friction while in Subgroup 4a the abutments presented low resistance to friction after mechanical loading (Table 3). These results suggest the following explanation hypotheses:

the angulation difference of the internal tapered connections of the study; in Subgroup 3a (11.5°) and Subgroup 4a (16°), and the difference in size of the hexagon present in the lower part of the two-piece abutments, Subgroup 4a has a larger hexagon (Fig. 1). It is assumed that the internal tapered contact implant/abutment is larger in the abutments of Subgroup 3a, since it presents the internal hexagon smaller than the hexagon of Subgroup 4a, this can prove the largest resistance to the friction in the removal of these abutments. However, it was reported that the presence of the hexagon in the lower part of the abutment did not influence the screw removal torque, initially or after several tightening/loosening cycles (22).

Microtomography is a non invasive and non destructive evaluation (23) producing three-dimensional images. Despite so many advantages of this radiographic modality, there is no perfect radiographic precision to assess the implant/abutment connection (24). Usually the presence of a microgap may be due to improper manufacturing of the parts of the implant/abutment system or inadequate distribution of male-female contact (25). There are small differences that are observed between the right and left side of an abutment, and it is very difficult to produce a 100% accurate slice in the desired position (4). In the current study the microtomography was used only for a qualitative analysis, where an intimate contact between implant and abutment was observed in the four groups studied before and after the mechanical loading.

Scanning electron micrographs showed variation in the morphology of the threads of all specimens after the mechanical loading test, the edges of the threaded portion were shown to be more rounded, suggesting mechanical wear of these abutments after the cycle (Fig. 4, 5). The screws presented generally non-homogeneous surfaces and surface residuals. Other studies have shown changes and mechanical damage to the screw threads of the abutment after mechanical loading, especially on the flank near the thread crest (11,14). Based on these findings, it is advisable that abutments with internal tapered connections are not removed after installation in the mouth, unless much needed.

The load used in the mechanical loading of the four groups was 50 N, which is considered adequate, since the normal forces may be greater than 100 N. The number of masticatory cycles simulated 5 years of function, being enough to evaluate the behavior of the abutments, remembering that the ideal is that the abutment be removed only if necessary; this shows that after a simulated long time there was no release and/or fracture of screws and no fracture of abutments. The objective of the application of cyclic loads in this study was to observe its effect on the screw removal torque, different from the studies (12,22) that simulated only 4 days of masticatory function with a very low load, of approximately 5 N, and reported that the removal torques tend to decrease according to the number of mechanical cycles.

The present study presents limitations related to the environment because it is *in vitro*. Therefore, other in vivo investigations should be performed to better evaluate the implant/abutment junction studied in this study.

CONCLUSIONS

One-piece and two-piece prosthetic abutments have different manufacturing characteristics and behavior. The presence of the abutment screw is intended to prevent the abutment from loosening, however there is an abutment frictional lock in the implant tapered walls that may be a factor for clinically acceptable mechanical strength. Clinically, the mechanical frictional lock of the abutment is important, which prevents loosening of the screw and undesirable fractures.

Within the limitations of this in vitro study, the following conclusions were drawn: The long-term mechanical loading of the abutments with internal tapered connections greatly decreased the screw removal torque values when compared to abutments that were not mechanically loaded. Only one-piece abutments of Group 2 that were not mechanically loaded gained torque, presenting values higher than those initially applied. The mechanically loaded two-piece abutments of Subgroup 3a showed a considerable increase in the values of resistance to friction. This type of abutment is safer when installed in the mouth, there was loss of tightening torque of the bolt after loading, but the bonding of the parts provides greater stability against masticatory movements.

Contributions

MBM, KRTL, TGC, LPFR, data collecting and analyzing; MBM, manuscript writing; RT, PCSJ manuscript reviewing and references search.

Conflict of interests

When this study was carried out, the author MBM) was not yet working as a researcher at the Neodent company (Curitiba, Parana, Brazil), that provided part of the materials used in this study. This had no influence on the study results.

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