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Influence of Mechanical Cycling on Torque Values of Tapped-In and Screw-In Implant-Supported Crowns

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ABSTRACT

This study investigated the influence of mechanical cycling on screwed-in and tapped-in implants restored with screw-retained metallic crowns. Three implant-abutment-crown systems were evaluated: T1 (multi abutment) and T2 (standard abutment) received tapped-in abutments and S received a screwed-in abutment. The specimens were subjected to two million cycles of 0-150 N load, at 2 Hz, 30° inclination in a dry medium, and torque evaluation. Survival and removal torque were analyzed using chi-square, ANOVA, followed by Tukey's test. Differences between installation and removal torque were determined using a T-test for dependent samples. Analyses were performed in SPSS, considering $\alpha = 0.05$. All specimens survived mechanical cycling in S, 40% in T1, 80% in T2 ($p=0.008$). Failures occurred due to loosening of the crown screw. A significant decrease in torque ($p=0.000$) was found. Group T1 had the lowest removal torque (1.6 ± 0.84 N.Cm^2), followed by T2 (3 ± 1.49 N.Cm^2) and S (6.3 ± 1.16 N. Cm^2), and a statistical difference was found between Groups T1 and S. Both types of implant-abutment connections were stable and can be considered for rehabilitative treatment, but failure and removal torque were influenced by the design of prosthetic abutment. Crowns were more susceptible to becoming loose in tapped-in systems.

INTRODUCTION

Over the years, different types of abutment-implant connections have been developed and studied.[1] However, the use of screws remains the most common fixation method for both abutments and prostheses on implants. Screw-retained systems have the advantage of reversibility, enabling the prostheses removal and reinstallation for evaluation and repair. However, the loosening or fracture of the fixation screws of the abutment is a common complication.[2,3]

Internal tapered connection implants stand out for the lower occurrence of bacterial infection in the implants and micromovements, when compared to non-tapered connections. It also results in lower occurrence of loosening of the abutment and greater stability of the marginal bone crest over the years.[4] Given the stability of internal tapered implant-abutment interface, tapped-in locking-taper retention systems were proposed. This connection does not employ screws; abutments are tapped in place and fixation of the components occurs through friction between the prosthetic component and the inner walls of the implant. This fixation method is a concept of mechanical engineering,[5] in which tapered, almost parallel walls generate high contact pressure and components are interlocked due to the breakup of the surface oxide layer, which is a phenomenon known as cold soldering.[6]

Tapped-in connections present high tensile strength but can be broken by shearing forces,[7] which generates a certain distrust on the part of dentists regarding the influence of occlusal forces on this retention system. When directed vertically along the axis of the implants, the repeated forces generated during mastication are believed to increase mechanical interlocking, which may hinder the removal of the prosthetic abutment.[8] On the other hand, oblique or lateral forces can lead to micro-rotation,[9] resulting in shearing forces that could cause the loss of retention of the abutments. Although the few clinical studies on this type of connection report high success rates,[8-11] the loss of retention of the prosthetic reconstruction is reported mostly on anterior teeth,[8] which lends support to the hypothesis that prosthetic components are less stable in the presence of non-axial occlusal forces.

To avoid the exclusively friction-based implant-prosthesis union, some systems designed implants with greater taper between the inner walls, in which the abutments have less friction-based retention and are fixed with screws, combining the biological and mechanical benefits of internal tapered connections and the removal ease of prosthetic components. Both cemented and screw-retained prostheses are recommended for internal conical connection single implants, screw-retained crowns are still preferred when reversibility is a concern. The influence of mechanical cycling on this hybrid system with tapped-in abutments and screw-retained crowns has not been evaluated.

Therefore, the aim of the present study was to evaluate the influence of mechanical cycling on screwed-in and tapped-in internal tapered connection implants restored with screw-retained crowns The following were the null hypotheses: 1) there is no difference in survival rate of tapped-in and screw-in implant systems to two million cycles of mechanical loading with a load of 0-150 N at 2 Hz; and 2) there is no difference between removal toque of the prosthetic crown between the different systems.

MATERIALS AND METHODS

Specimens were composed of an implant, abutment, and screw-retained crown (n = 30). Groups T1 and T2 were composed of 20 internal tapered connection implants, which received tapped-in abutments with different designs: T1 received a multi purpose abutment, indicated to both single and multi-unit prosthesis, T2 received an standard abutment for screw-retained single crowns, both with a transmucosal height of 2.5 mm and friction retention. This system has a locking taper (frictional) connection of 3° and 2.5 mm of prosthetic diameter, and it was chosen due to evaluate the stability of a screwless connection, and also due to the variety of prosthetic abutments. Group S consisted of internal tapered connection implants with 11.5 degrees taper, restored with a one-piece screw-in abutment with a transmucosal height of 2.5 mm. This system was chosen as control group, to evaluate the stability of a screw-in connection. Abutments are shown in Figure 1. All groups received identical screw-tightened metal crowns. All implants are manufactured from Ti6Al4V alloy (material according to ASTM F136), the abutments and prosthetic screws are manufactured in implantable stainless steel (material according to ASTM F138).

The implants were embedded in acrylic resin to the height of the platform, simulating an implant installed at bone level, presenting an angle of 30 ± 2 degrees with the long axis of the actuator of the mechanical cycling simulator.

The abutments were cleaned with ethyl alcohol and dried. Groups T1 and T2 were tapped into the implants, receiving three activations with the driver. The specimens were stabilized in a vise to standardize the activation, avoid movement and the loss of activation force. The abutments of Group S were screwed onto the implant with the aid of a hexagonal wrench (diameter: 1.6 mm) in a digital torquemeter with torque of 32 N.Cm^2.

The metallic crowns were designed such that the center of the crown provided a moment arm 11 mm in length in relation to the base of the implants, as suggested by ISO norm 14801 (2012), representing a "worst-case" scenario. A cast with a semi-spherical shape was made with low-contraction acrylic resin and replicated with polyvinil siloxane to standardize the specimens. The casts were forged in beryllium-free nickel-

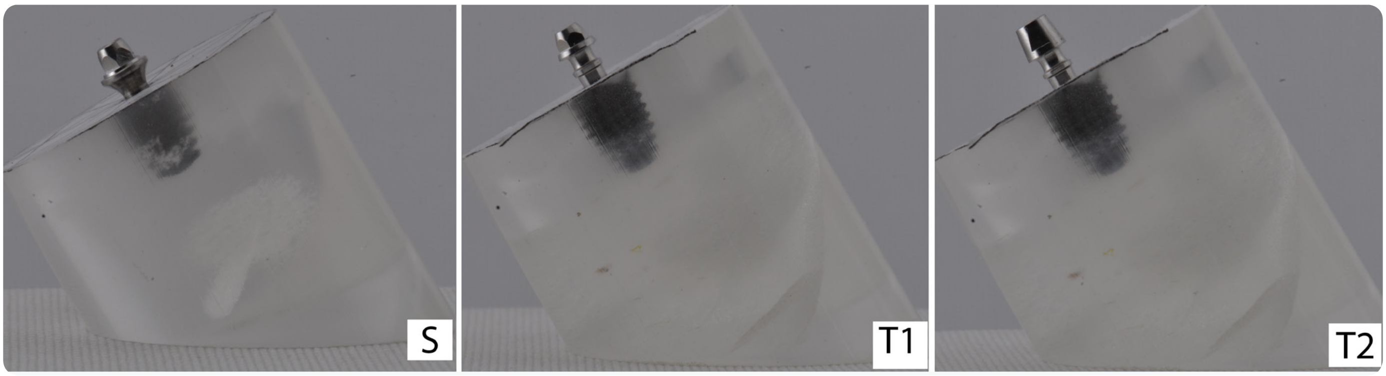

Figure 1: Test specimen form Groups S, T1, T2, and (left to right).

chrome alloy on calcinable cylinders with a cobalt-chrome base. The metallic crowns were screwed onto the abutments with the aid of a digital torquemeter with torque of 10 N. Cm^2, as recommended by the respective manufacturers.

The three-component specimens were submitted to mechanical cycling in a mechanical fatigue simulator with a load of 0-150 N at 2 Hz for two million cycles, exposed to air at 37±3 ºC. The flat actuator contacted the crown in a single point (*Figure 2*). Specimens were inspected each 500.000 cycles with a magnifying glass, and stability of abutments and crowns were checked. After mechanical cycling, the removal torque of the crown screw was measured using a digital torquemeter.

Sample size was based on a pilot study, which showed statistical differences between groups. Survival data were analyzed statistically using the chi-square test (α=0.05), followed by Tukey's *post hoc* test. Shapiro-Wilk and Levene's tests were used to verify normality and homogeneity of variances. Differences between installation and removal torque values were determined using t- test for dependent samples. Differences in removal torque between groups were determined using ANOVA followed by Tukey›s *post hoc* test. All analyses were performed using SPSS (IBM, New York, NY), considering α=0,05).

Figure 2: Test specimens positioned in fatigue machine.

RESULTS

At the end of two million cycles, 100% of specimens in Group S, 80% in Group T2, and 40% in Group T1 survived the mechanical cycling. In the failed specimens, loosening of the crown was found at the 2 million cycles inspections. No fractures of the implants, abutments, or crown fixation screws occurred. Moreover, no deformation or detachment of the abutments was found. The chi-squared test showed statistical differences in survival between groups (p=0.008). No significant difference was found between Groups T1 and T2 or between Groups T2 and S. However, a significant difference was found between Groups T1 and S.

Figure 3 displays the distribution and variability of the sample for removal torque. Group T1 had the lowest mean removal torque (1.6±0.84 N), followed by T2 (3±1.49 N) and S (6.3±1.16 N). Removal torque differed significantly from the initial torque (10 N) in all groups, according to the t-test for dependent samples (p=0.000). The ANOVA test followed by Tukey's HSD test revealed significant differences between all groups for removal torque (p=0.000).

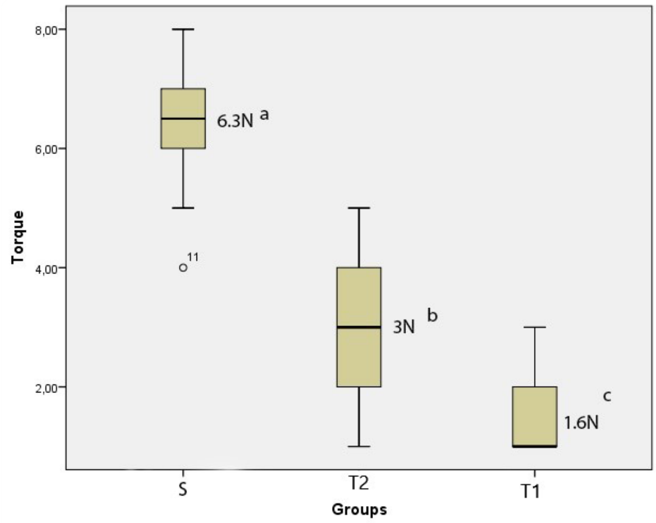

Figure 3: Mean, distribution and variability of removal torque values. Different letters indicate statistical difference between groups.

DISCUSSION

The present study evaluated the influence of mechanical cycling on screwed-in and tapped-in internal tapered connection implants restored with screw-retained crowns. The mechanical cycling exerted a negative influence on the crowns installed on tapped-in abutments, resulting in failures due to the loosening of the crown fixation screws. However, no failures occurred due to the loosening or fracture of the abutments. Thus, in this study, both tapped-in and screw-in connections for internal tapered implants were stable and capable to survive the mechanical cycling, but the loosening of the crowns on tapped-in abutments contributed to the lower survival rate for this system. Therefore, the first null hypothesis was rejected once the mechanical cycling influenced on the survival of the implant-abutment-prosthesis interface.

In most studies evaluating the influence of mechanical loads on different implant-abutment connections, the performance of internal tapered connections is evaluated comparatively to traditional external connections. Such studies state that internal connections exhibit considerable strength and reliability when submitted to fatigue and are capable of resisting micromovements that could lead to the loosening or fracture of the abutment fixation screw.[1,13] From the authors' best knowledge, a single study evaluated tapped-in implants in comparison to screw-in internal connections implants, and found lower fatigue resistance for the tapped-in connection.[14] In contrast, clinical studies on another tapped-in system report high survival rates and few failures due to the loss of retention of the abutment-prosthesis system.[8,10,11]

Unlike the present investigation, previous *in vitro* studies reported no failures related to the prosthetic reconstruction. As the studies cited above exclusively analyzed the performance of the implant-abutment interface, most experimental designs have either not involved the placement of the prosthetic crown[1,15] or used cemented reconstructions.[13,14] However, both abutments and prosthetic crowns affixed with screws are subjected to fatigue and micromovements during mastication. Therefore, the implant-abutment-screw retained crown system as a whole was evaluated in the present study and mechanical cycling was found to lead to failure by loosening of the crowns on the tapped-in system.

The force that is generated when a screw is tightened within a given torque is known as preload. When the forces applied onto the system are greater than the preload, screw loosening may happen.[16] In this study, a torque loss of 37 to 84% was found, showing that mechanical cycling generated micromovements that resulted in the progressive rotation of the screw, the loss of the pre-load force, and loosening of the screw.

The loss of 16 to 25% of the pre-load force is expected after mechanical fatigue tests.[16] The loosening of a screw is a multifactor event influenced by the screw design and material, type of prosthetic connection, and type of abutment.[17-20] The differences in the design of the abutments and screws evaluated in the present study may explain the lower removal torque and higher incidence of failure due to loosening of the crowns in Groups T1 and T2, what leads to the rejection of the second null hypothesis.

Figures 1 and 4 shown the screw-in abutment has a broad, flat base for the lodging of the crown. On the other hand, the tapped-in abutment used in Group T1 has a narrow base with a beveled finish such that the crown is lodged on the top of the abutment *(Figure 1B)*. The tapped-in abutment in Group T2 has a conical shape with an angle of 7 degrees between its walls in relation to the long axis of the component; the prosthesis is not lodged on the sides of the component, but rather the base of the prosthesis sits on top of the component *(Figure 1C)*. This difference in abutment design may have exerted an influence on the loosening of the screws of the tapped-in abutments, favoring micromovements in the crowns.[21] Micromovements lead to the loss of the pre-load force of screws. Indeed, some researchers have found that abutments with external connection and greater rotational freedom have a greater occurrence of screw loosening.[22]

In this study, the implant-abutment-crown systems were submitted to a mechanical loading of two million cycles, following the guidelines of ISO norm 14801 to represent a "worst-case" scenario. Loads of 0 to 150 N were applied at an angle of 30º

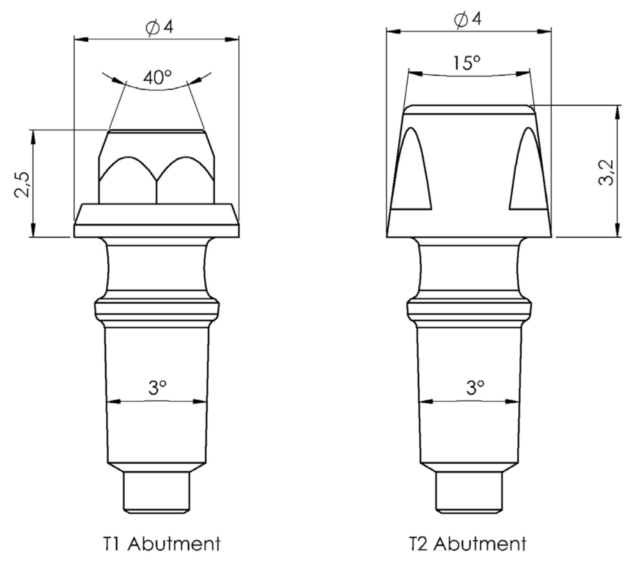

Figure 4: Schematic representation of T1 and T2 tapped in abutment design

in relation to the long axis of the implant, simulating non-axial masticatory loads at a frequency of 2 Hz, which is close to the frequency of mastication. The maximum load of 150 N was chosen because it is compatible with the physiological masticatory load. Loads much higher than the masticatory load can lead to results that are not representative of clinical performance, which would only demonstrate the survival capacity of the materials tested at forces of high magnitude.[23]

The present *in vitro* study has limitations that should be considered. Although saliva can exert an influence on the mechanical properties of different restorative materials, the tests were performed in a dry environment to simplify the execution, as there is no statistically significant difference in the survival/resistance to fatigue of implants with metal components when the mechanical cycling is conducted in a dry or wet medium.[24] Another limitation is that the differences among the systems did not enable an evaluation of the influence of mechanical cycling on the stability of the abutments. The different types of connections make the comparison of the data a complex task, as the retention of screw-in abutments can be measured by the removal torque of the screws, whereas tapped-in abutments must be submitted to a tensile test. The evaluation of the samples using scanning electron microscopy rather than a magnifying glass would have revealed deformations of a small magnitude. However, as the objective of this study was to simulate a clinical situation, only changes that could be detected clinically were considered as failures.

All data considered, although the stability of the implant-abutment interface is important to the clinical longevity of prostheses on single implants, a more in-depth investigation of the fixation methods of prosthetic crowns should be performed. Whether tapped-in or screw-in, the tapered connections remained stable during mechanical cycling.

In contrast, the crown fixation screw proved to be highly susceptible to the loss of its pre-load force and the lower survival rates of the tapped-in systems suggest that the design of the abutment and screw is the weak link in these systems. Cemented crowns may be an option that is less susceptible to fatigue in tapped-in connection systems. Future studies on the survival of tapped-in abutments that support cemented crowns could assist in the understanding of the behavior of this implant system.

The present *in vitro* study found that:

- Internal tapered connection with tapped-in systems have lower survival to mechanical cycling when compared to screw-in systems due to failure at the abutment-crown interface.
- The mechanical cycling exerted a negative influence on the screw-retained crowns on all abutments, but the loss of the pre-load force was statistically significant in the tapped-in abutments.
- Both types of abutment-implant connections were stable and can be considered options for rehabilitative treatment, but screw-retained crowns were more susceptible to becoming loose in tapped-in systems.

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Author contributions: FF and RMF conceived the ideas; KS and RET collected the data; AAM and AMP analyzed the data; all authors contributed to writing and editing, FF and RMF led the writing.

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