Influence of Screw Surface Treatment on Retention of Implant-Supported Fixed Partial Dentures

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The aim of this study was to assess the effect of a diamond-like carbon (DLC) coating on the removal torque of prefabricated implant screws after cyclic loading. Four groups with two crowns supported by two implants (n = 5) were obtained according to splinted and nonsplinted prosthesis, using titanium or DLC screws (splinted crowns with titanium screw [STi], splinted crowns with DLC screw [SC], nonsplinted crowns and titanium screw [NSTi], and nonsplinted crowns and DLC screw [NSC]). The prosthetic screws were tightened at 32 Ncm and retightened, and the specimens were submitted to 106 mechanical cycles (4 Hz/98 N). After cyclic loading, loosening torque was evaluated, and the final measurements were performed. Data were analyzed by two-way analysis of variance and Tukey’s test (α = 0.005). There was statistically significance in the interaction of screw splinting (P = 0.003). For the group that used titanium screws, NSTi showed smaller removal torque compared with STi. It was concluded that the use of the DLC coating screws in nonsplinted prosthesis maintain the torque after cyclic loading.

Key Words: dental implants, implant prosthesis, implant screw, mechanical cycling, splinting

INTRODUCTION

Complications with single-tooth implant restorations frequently involve the integrity of the implant-abutment screw joint, with screw loosening as a common implication.1–4 Loss or decrease on the retention torque of screws, with consequent abutment screw loosening, may be caused by different factors and/or their interaction.5–7 Occlusal forces seem to play an important role in screw loosening of implants with hexagonal connections, in which preloading is the only force that resists these forces, avoiding the abutment to separate from the implant. The axial load generated in the screw on tightening, called preload, induces the clamping force that acts at the interface between the abutment and the implant-bearing surfaces, which holds the joint closed and also counteracts any load applied on the joint. Thus, if the preload is exceeded by the occlusal force, the screw will loosen.8

The tension generated in the screw as a result of the applied torque depends on friction and some characteristics of screw material, such as yield strength, elasticity modulus, and fatigue life.9,10 Clearly, the coefficient of friction is a major factor influencing the preload achieved at a given torque force.11 The coefficient of friction is influenced by the hardness of the threads, surface finishing, speed of torquing, surface treatments, presence and quality of lubricants, and fit and machining tolerances.12–14 Therefore, implant screw manufacturers have used dry lubricants such as gold coating, diamond-like carbon (DLC), and nitride coating to reduce friction, increase fastening, and allow more turning of the screw for a given torque.15–17 Among the many favorable properties of DLC films, the most valuable for dentistry is the compatibility to titanium and 316 stainless steel.17 However, the effects of the use of DLC film on screw removal torque (RT) have not been clearly reported in the literature.

Splinting implants with prosthetic crowns may provide better stress and strain distribution to the bone to avoid overloading,18,19 especially for those placed in poor-quality bone, such as the posterior region of the jaws.20 Nevertheless, compared with nonsplinted single crowns, there are some disadvantages in the splinting approach, including difficulties to fit the framework and to provide adequate emergence profile, besides interproximal hygiene issues.21

Thus, the objective of this study was to evaluate the effect of DLC coating on the RT of the prefabricated implant screw after mechanical cycling (MC) in splinted and nonsplinted prostheses. The hypothesis tested was that the DLC coating and splinting of the prostheses are factors that influence the screw loosening.

MATERIALS AND METHODS

Specimen manufacturing

Forty implants analogues of the Branemark system (Neodent, Curitiba, Brazil), with platform 4.1 (external hexagon interface)
were used. Forty metallic crowns were made, including 20 premolars and 20 molars. The specimens were set in 10 splinted and 10 nonsplinted, each sample having a premolar and one molar, and divided into 4 groups (n = 5): splinted or nonsplinted crowns using titanium screw or titanium screw with DLC coating surface (Neotorque, Neodent, Curitiba, PR, Brazil). The specimens consisted of two metallic structures (Ni-Cr) simulating fixed partial dentures over two adjacent implants corresponding to teeth #29 and #30 as follows: STi, splinted crowns with titanium screw; SC, splinted crowns with DLC screw; NSTi, nonsplinted crowns and titanium screw; NSC, nonsplinted crowns and DLC screw. The wax patterns for the crowns were produced with the CAD/CAM system (Milling Unit MS, Zirkonzahn, Zirkonzahn, Germany) from the milling of wax discs (Grew Wax 95H10, Zirkonzahn). Optical impressions (Scanner 5600 ARTi, Zirkonzahn) to analogs were made. The crowns were designed (Zirkonzahn Software) with two types of interproximal contact: splinted or broad contact surface (3 mm²) (Figures 1 and 2).

The wax patterns were then invested in a rapid cycle, carbon-free, phosphate-bonded investment (Micro Fine 1700, Talamax, Curitiba, PR, Brasil) and cast using a nickel-chromium alloy (Fit CAST-SB Plus, Talamax). Castings were divested with no further polishing or finishing (Figure 3).

Implant analogues and metal crowns were placed in polyurethane molds (10 mm height and 18 mm diameter) and embedded in autopolymerizing acrylic resin (Jet, Classic Dental Products, São Paulo, SP, Brazil), 1 mm distant from the platform, to standardize the positioning with no vertical axis inclination. First, the crowns were slightly screwed to the implants by hand. The metal crowns were attached to each implant analog according to the screws of each group. Then, the set was placed in a socket at the device base to avoid any rotational movement. A torque of 32 Ncm was applied using a precision digital torque wrench (TQ-680, Instrutherm, São Paulo, SP, Brazil), according to the manufacturer’s recommendation. After 3 minutes, the screw was tightened to the same torque to minimize embedment relaxation (Figures 4 and 5).

**Cyclic loading**

All specimens were submitted to cyclic fatigue machine (Biocycle, Biopdi, São Carlos, SP, Brazil) and submitted to 1 × 10⁶ cycles at 4 Hz and 2 bar (50-N force in each tooth) in distilled water at 37°C. The eccentric load was applied on the occlusal surface of the crowns. Screw joint failure was defined as abutment mobility resulting from screw loosening (Figure 6).

**Removal torque**

After cyclic loading, loosening values of each specimen were measured with a digital torque meter (TQ-680, Instrutherm) connected to a data acquisition system (Lynx Technology, San Diego, Calif). To remove the screw, torque was applied in a counterclockwise direction, using a hexagonal wrench attached to the digital torque meter. The digital torque was recorded immediately after releasing the screw. All procedures were conducted by the same operator that was previously calibrated.

**Statistical analysis**

Two-way analysis of variance (ANOVA) and the Tukey post hoc test (α = .05) were made considering the screw type and splinting for each group of teeth (premolars and molars).

**Results**

The mean and standard deviation of loosening values are shown in the Table. The analyses were done for each type of tooth (molars and premolars separately), and there was no comparison between tooth types. For the group of molar teeth, there was no statistical difference for any of the evaluated factors.

For the premolar teeth, statistical analysis showed that for the interaction of splinting × screw type, there were statistically significant differences (P = .003). For the splinted group, the titanium screw showed a higher value (P = .039). Otherwise, for the nonsplinted group, it was the DLC screw that had higher values (P = .014). When the DLC screw was used, there was no difference between the splinted and nonsplinted groups (P = .381). However, with the use of a titanium screw, the splinted group had higher values (P < .001).

**Discussion**

The hypothesis was accepted. The factors studied (screw type and splinting) were found to be important for screw loosening. The cyclic loading was used to evaluate the torque maintenance on the retention of abutment screws. The mechanical cycling used represents 5 years of intraoral clinical service for the implant-supported restoration.

This study showed that all screws had reduced torque values after mechanical cycling. This can be due to low loosening values (the Table) compared with the initial torque of 32 Ncm. Each manufacturer establishes the correct value of torque that the screw needs to receive to be tightened and to achieve the required preload value to be resistant to loosening. The preload force is a compression force generated between the screw and the thread of the implant at the time the screw is tightened for the first time. Thus, it shows that mechanical cycling induced a loss in the initial torque for all groups.

The results of this study show that the titanium screw splinted prostheses demonstrated satisfactory performance, with higher values of torque at the time of loosening after mechanical cycling compared with the DLC screw. The coated screws may present lower reductions in preload after cyclic loading, depending on the clinical situation. When using the DLC screw, there was no significant difference between splinted and nonsplinted prostheses. Possibly, abutment screw coating provided greater preload and thus more stable joints, thereby resulting in less screw vibration and micromovements during cyclic loading.

The DLC coating is an engineering process that reduces the coefficient of friction and makes a smooth surface. This effect
may be responsible for the decreased torque to remove the 
DLC screw relative to the titanium screw splinted prostheses.
This result shows the importance of choosing the screw 
according to the type of prosthesis. For splinted prostheses,
titanium screws showed significantly greater values compared 
with loosening DLC screws. However, for the nonsplinted 
prostheses, the DLC screw presented greater loosening values.
This result corroborates with another study, which showed a 
similar result for single crowns after cyclic loading.

Implant failure depends on two distinct types of factors: 
biological and mechanical. Biological causes are essentially peri-
implantitis, affecting the soft and hard tissues surrounding 
dental implants, whereas mechanical causes involve implant-
prosthetic components in general. Mechanical complications 
are as follows: implant fracture, abutment fracture, screw 
loosening, loss, and overstructure (ceramic and/or metal) 
fracture.

The separation of the crowns may be beneficial to avoid 
peri-implant diseases, improving the interproximal contour and 
avoiding concentration of stress during jaw flexure, as well as 
increasing patient satisfaction. However, splinted crowns 
present biomechanical advantages compared with nonsplinted 
crowns, and this is because stress distribution is better and 
more homogeneous. Regarding the dissipation of stresses on
the implant/prosthesis system, some studies have used the finite element method (FEM), which reports the importance of the direction of application of the forces in the vertical/axial direction for the long-term success of prosthetic rehabilitation.32–34 These factors are important and should guide the dental surgeon in choosing the type of prosthesis.32 Factors such as the occlusal load must be considered during the treatment planning process to ensure that prosthetic design and the number and location of dental implants are not subject to overloading.35 In addition to the concern with implant planning, occlusal factors also influence prosthetic planning. Therefore, in areas of great masticatory effort, the option to splint the crowns is well indicated for a better distribution of stresses on the crown/implant system. Therefore, in this type of clinical situation, the titanium screw is indicated. In an analysis of stress distribution by FEM, Hasan et al36 showed that the splinting of implant causes a noticeable drop in the stress in the implant system and surrounding bone.

Considering that the value of the removal torque is a measure of the remaining preload in the abutment screw, the reduction in removal torque after cyclic loading in the present study conforms to the joint failure mechanism described by Bickford.14 The external forces progressively erode the preload resulting from screw vibration, wear of the mating surfaces, and settling (embodiment relaxation).9 Occlusal forces are complex in vector and magnitude; however, clinically, the occlusal forces are distributed over the prosthesis and remaining teeth, and cyclical forces vary in intensity.37 Hence, it is possible to find different results in the literature.

The clinical relevance of this is that, although screw loosening was detected, the significant decrease in preload indicates that patient follow-up is needed to ensure the integrity of abutment on single-implant restorations. This shows that the screwed prosthesis for single external hexagon implants is the best option because of the reversibility that ensures the case if there is screw loosening. Cemented prostheses for these cases are not indicated as well, because in the case of screw loosening, the crowns are lost.26 A study that used FEM reported that the cemented prosthesis presented significant physical and mechanical advantages because it did not present an occlusal orifice; this type of prosthesis presented greater resistance compared with the screwed one.38 Nevertheless, in the current study, we used screwed prostheses that had holes, but we believe that it was not a factor that could alter the result, because the application of load was always performed in the same place in all samples, and no load was applied to the areas of the holes. Currently, Morse taper implants guarantee a good indication for unitary prosthesis due to its esthetic and biomechanical characteristics related mainly to the advent of the use of the switching

![Figure 3](https://example.com/figure3.png)

**Figure 3.** Casting process. (a) Crowns at the end of the closure process, ready to be included. (b) Crowns attached to the sprues. (c) Crowns with inclusion of the coating material. (d) Crowns after casting and polishing.
platform, which means that there is a decreased microgap abutment/implant joint, reducing the biofilm accumulation and consequently the bone loss and soft tissue around the implant.39

Caution must be exerted in extrapolating laboratory data to clinical situations. Loading conditions in a clinical situation are not the same as in an in vitro investigation. Loading can vary in different patients. Each in vitro test may represent only one approach to a clinical situation, because many variables are usually excluded. Further laboratory and clinical studies should

**FIGURE 4.** (a) Crowns in position with its analogs, ready for inclusion. (b) Samples fixed on a solid base and ready to receive the resin. (c) Device of each sample after adding the resin. (d) Contact point of the assessment of nonsplinted samples.

**FIGURES 5 AND 6.** **FIGURE 5.** Evaluation of device removal torque. (a) Adjustable device for the digital switch setting. (b) Adjustable platform to hold the specimens. (c) Torquemeter connected to a data link receiver and software. (d) Capturing in real time any movement of screw loosening. **FIGURE 6.** Samples under cyclic load with two loading tips focusing in the center of each crown.
be conducted to confirm the effectiveness of coatings in preventing screw loosening and ensuring screw joint stability of abutments. Additionally, in vitro and in vivo studies should be done with Morse implants for comparison of real safety for the loss of torque and to promote a better planning scenario.

In conclusion, with the limitations of an in vitro study, the choice of the screw should be made according to the type of prosthesis. The use of the DLC coating screw in nonsplinted prostheses is important to maintain the torque after cyclic loading.

**ABBREVIATIONS**

DLC: diamond-like carbon
MC: mechanical cycling
NSC: nonsplinted crowns and DLC screw
NSTi: nonsplinted crowns and titanium screw
RT: screw removal torque
SC: splinted crowns with DLC screw
STi: splinted crowns with titanium screw

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