Effect of Surface Modifications of Abutment Screws on Reverse Torque Values: An In Vitro Study

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Purpose: To investigate the reverse torque values of abutment screws subjected to various surface modifications. ***Materials and Methods:*** Sixty abutment screws were divided into two groups of 30 each: with thermomechanical cycling (240,000 cycles) and without thermomechanical cycling. Each group was then divided into three subgroups according to surface treatment: nontreated (NT, n = 10); anodic oxidation (AO, n = 10); and diamond-like carbon (DLC) coating (DLC, n = 10). All abutment screws were tightened to 30 Ncm using a digital torque meter. The reverse torque values of the abutment screws with and without thermomechanical cycling were then measured. The percentage of deviation (PERDEV) for reverse torque values was calculated. Two-way analysis of variance followed by Tukey Honest Significant Difference test were used for intergroup comparisons. ***Results:*** Significant differences were found among the PERDEV values of the groups based on thermomechanical cycling and surface treatment ($P < .001$ for each). A significant interaction was found between surface treatment and thermomechanical cycling ($P < .001$). ***Conclusion:*** Reverse torque values of abutment screws were found to be higher after surface treatments. The abutment screws with AO exhibited the lowest torque value loss in groups with and without thermomechanical cycling. *Int J Prosthodont 2020;33:401–409. doi: 10.11607/ijp.6581*

The dental implant has become the method of choice for single-tooth replacement. The advantages of dental implants are avoidance of the preparation of adjacent teeth and the restoration of a single tooth with a simple, predictable, and cost-effective solution. However, surgical and prosthetic complications may arise during the clinical course of implantation.[1–3] Since osseointegrated implants have no periodontal ligaments or resilience, forces resulting from occlusal activity cause various complications, such as screw loosening or screw fractures.[4,5]

Screw loosening is one of the most frequent complications in implant prosthetics. Abutment screws may loosen as a result of insufficient tightening torque, settling of implant components, improper implant position, inadequate occlusal scheme or crown anatomy, inadequate adaptation of substructures, presence of microleakage in the implant-abutment interface, incorrect screw design/material, and/or extreme occlusal forces.[6] Abutment screw loosening was reported in 7% of implants restored as single-molar or -premolar crowns.[7] Jemt et al reported that the prevalence of screw loosening was 43% in the first year following implant placement.[8] In addition, biologic complications are associated with mechanical complications (eg, increased torque loss and failure of the abutment-implant joint). The micromovement of the

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Fig 1 Single-unit implant-abutment connection embedded in an acrylic resin model.

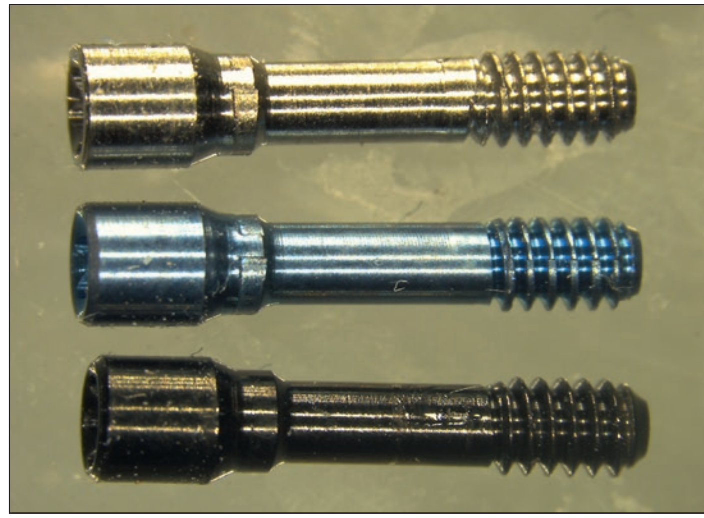

Fig 2 Abutment screws subjected to different surface treatments in the experimental groups. From top to bottom: nontreated, anodic oxidation, and diamond-like carbon coating.

abutment-implant interface causes colonization of bacteria, leading to inflammation in the peri-implant soft tissues.[9]

Various solutions have been proposed to minimize these problems, such as changing the surface properties of the base screws using various materials, repeated tightening cycles after the first tightening, and increasing the torque value.[10]

The stability of the abutment screw depends on the preload. Preload is the initial load on the screw; the applied torque improves the force on the screw. The preload of the abutment-implant joint depends on the tightening torque, modulus of material elasticity, coefficient of friction on the contact surfaces, speed of tightening, lubrication, component fitness, and screw design parameters.[11]

Friction and preload are inversely correlated, as preload increases with decreasing friction.[12] It has been reported that the coefficient of friction was a significant factor influencing the preload achieved at a given torque force.[13] Therefore, implant screw manufacturers have used dry lubricants such as gold, diamond-like carbon (DLC), and nitride coating to reduce friction.[14,15]

The anodic oxidation (AO) process is used to overcome the weak tribologic properties of titanium, to increase the corrosion resistance, and to provide hard– and abrasion-resistant–surface modification to ensure longevity in use.[16,17] However, the effects of anodizing vs coating the titanium components on their resistance to loosening have not been compared.

The present study aimed to examine and evaluate the effects of different surface modifications of abutment screws on reverse torque values after thermomechanical cycling.

MATERIALS AND METHODS

This study was conducted in the Research Laboratory at Erciyes University Faculty of Dentistry and in the Erciyes University Technology Research and Application Center.

This study included a total of 60 implants (4.1 mm × 10 mm, non–surface roughened, bone level; Bilimplant, Proimtech) and their straight abutments. The specimens were prepared with one implant each. The implants were embedded in autopolymerized acrylic resin (INTEGRA) (Fig 1). All of the abutment screws were Grade 5 titanium alloy and divided into two groups: screws with thermomechanical cycling and screws without thermomechanical cycling. Each group was further divided into three subgroups according to surface modification (Fig 2): nontreated (NT, n = 10); anodic oxidation (AO, n = 10); and DLC coated (DLC, n = 10).

Surface Modifications with Anodic Oxidation

Twenty abutment screws were subjected to the titanium AO process. This procedure begins with 10-second incubation in 35% phosphoric acid (Ultra-Etch, Ultradent) prepared by dilution at a ratio of 1:1 to remove undesirable contamination on the surface of the material. The abutment screws were rinsed with water, transferred to a system consisting of an anode, cathode, electrolyte, power supply, and mixer, and prepared for the oxidation process. The voltage was set to 27 V to obtain a blue color on the abutment screws. Total applied voltage time was 35 seconds.

Surface Modifications with DLC Coating

Twenty abutment screws were coated with DLC (Oerlikon Balzers). This surface coating provides excellent

Fig 3 Digital torque meter used to test the implant-abutment connection.

Fig 4 Chewing simulator used for thermomechanical cycling.

protection against abrasion, tribo-oxidation, and adhesive wear while permitting high surface pressures that could cause cold welding. The coating procedure was as follows: *(1)* the material to be used was manually checked; *(2)* the surface was cleaned with an ultrasonic bath; *(3)* the material was placed on a holder; and *(4)* the material was coated using the plasma vapor deposition method.

Tightening Procedure

After surface modification of the abutment screws, the implants and abutments were connected. The implants and abutments were tightened to 30 Ncm using a digital torque meter (Cap Torque Tester Series TT01-12, Mark-10) according to the manufacturers' instructions (Fig 3). The tightening was repeated after 10 minutes.

Thermomechanical Cycling

Cyclic loading was carried out using a thermomechanical testing device (Chewing Simulator CS-4.8; SD Mechatronik) (Fig 4). The force applied by the device was set to 120 N in the middle of the abutment (Fig 5). A total of 240,000 chewing cycles and thermal cycles of 5°C to 55°C were performed to represent approximately 1 year of clinical usage.

Measurement of Reverse Torque Values

The reverse torque values of abutment screws without thermomechanical cycling were measured using the same digital torque meter immediately after tightening. The reverse torque values of abutment screws with thermomechanical cycling were measured after cycling with the same torque measurement device. The absolute difference between the measured reverse torque

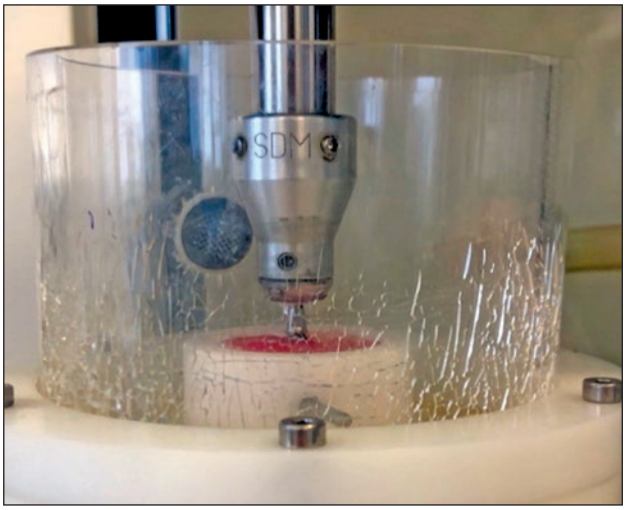

Fig 5 Force applied in the middle of the abutment.

value and the targeted torque value was recorded. The percentage of deviation (PERDEV) for reverse torque values was calculated using these values [PERDEV = (absolute difference/target torque) $\times$ 100].[18] The PERDEV values give the percentage of deviation from the targeted torque value to determine the amount of torque loss. When the reverse torque value decreases, the PERDEV value increases.

Analysis with Scanning Electron Microscopy

Screws were analyzed with scanning electron microscopy (SEM) (GeminiSEM 500, Zeiss) to investigate the surface morphology of the screws, to evaluate the deformations that may occur in the screw grooves after dynamic fatigue, and to investigate the surface properties

Table 1 Descriptive Statistics and Two-Way ANOVA Test for Percentage of Deviation Values of Each Experimental Group

		Min–max	Mean ± SD	F value	P^a
Surface treatment	Thermomechanical cycling				
NT	Yes	21.67–57.67	44.74 ± 12.43		
	No	8.67–19.33	12.4 ± 3.15		
AO	Yes	6.67–20.00	13.81 ± 4.15		
	No	6.67–14.33	11.03 ± 2.55		
DLC	Yes	10.33–35.67	24.62 ± 7.12		
	No	12.33–22.33	17.13 ± 3.76		
Main effects					
Surface treatment				30.90	< .001
Thermomechanical cycling				71.72	< .001
Interaction					
Surface treatment*thermomechanical cycling				29.87	< .001

ANOVA = analysis of variance; NT = nontreated, AO = anodic oxidation; DLC = diamond-like carbon coating.

Table 2 Tukey Post Hoc Test for Multiple Comparisons

	PERDEV		Mean difference	P
Thermomechanical cycling	NT: 44.74 ± 12.43	AO: 13.81 ± 4.15	30.926	< .001
	NT: 44.74 ± 12.43	DLC: 24.62 ± 7.12	20.112	< .001
	AO: 13.81 ± 4.15	DLC: 24.62 ± 7.12	–10.814	.024
Non–thermomechanical cycling	NT: 12.4 ± 3.15	AO: 11.03 ± 2.55	1.367	.61
	NT: 12.4 ± 3.15	DLC: 17.13 ± 3.76	–4.733	.007
	AO: 11.03 ± 2.55	DLC: 17.13 ± 3.76	–6.100	.001

Percentage of deviation (PERDEV) values are reported as mean ± standard deviation. NT = nontreated; AO = anodic oxidation; DLC = diamond-like carbon coating.

of the screws subjected to surface modification. Two samples were randomly collected from each subgroup, one from the group that underwent thermomechanical cycling and one from the group without thermomechanical cycling, for a total of six samples analyzed under SEM. Screws were positioned perpendicular to the floor. The images were adjusted to cover the last three threads in the apical region of each abutment screw and obtained at ×50 magnification. Subsequently, the abutment screws were sectioned from the tip of the screw horizontally (Minitom, Struers), and nano-scale images were obtained at ×1.00 k magnification in order to examine the surface modifications and evaluate the thickness of the coating.

Statistical Analyses

The PERDEV values for the various groups were subjected to statistical analysis. The conformity of the data to normal distribution was tested with Kolmogorov-Smirnov test. Two-way analysis of variance (ANOVA) was used to analyze the effects of surface modification and thermomechanical cycling on PERDEV (% torque loss). Tukey Honest Significant Difference (HSD) post hoc test was used for comparison of the subgroup means for different surface modifications. Independent samples *t* test was used for comparison of the subgroup PERDEV values in the presence and absence of thermomechanical cycling. The confidence interval (CI) was 95%, and the significance level was $P < .05$. All statistical analyses were performed with SPSS software (IBM, version 22.0).

RESULTS

The reverse torque values were normally distributed ($P > .05$). The PERDEV values increased for all three subgroups after thermomechanical loading (Table 1). Significant differences were found between various surface treatments and for thermomechanical cycling in terms of the PERDEV values ($P < .001$ for each). There was also a significant interaction between surface treatment and thermomechanical cycling ($P < .001$).

Significant differences regarding PERDEV values were found among the different surface treatments in the thermomechanical cycling group ($P < .001$, $P < .001$, and $P = .024$) (Table 2). The PERDEV values of the NT group were significantly higher than those of the AO and DLC groups, and the PERDEV values in the DLC group were higher than those in the AO group. In the non–thermomechanical cycling

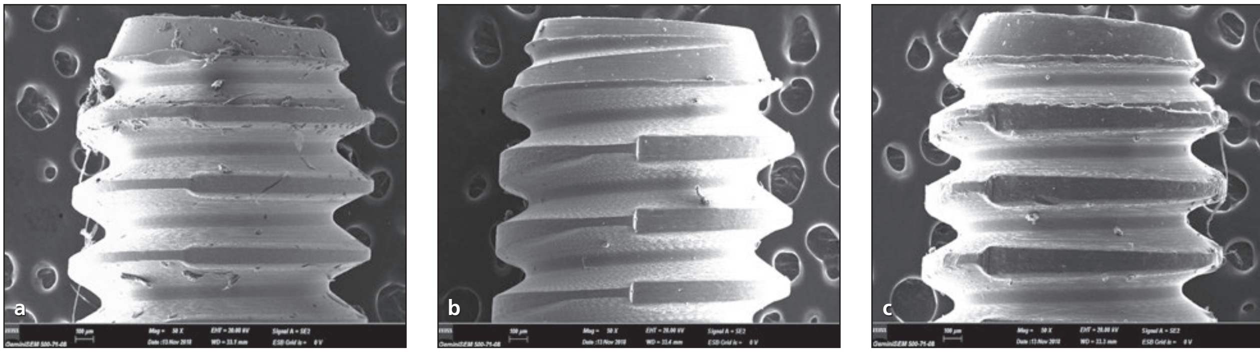

Fig 6 SEM images of abutment screws in the non–thermomechanical cycling group. *(a)* Nontreated. *(b)* Anodic oxidation. *(c)* Diamond-like carbon coating.

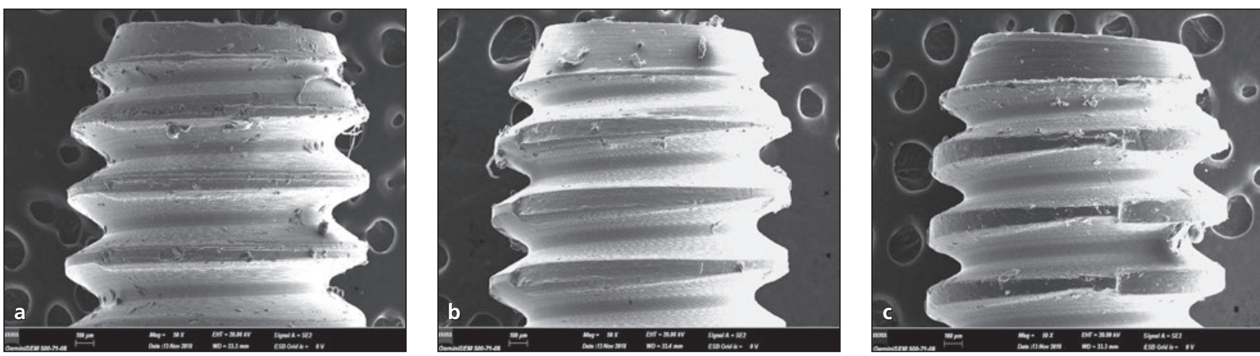

Fig 7 SEM images of abutment screws in the thermomechanical cycling group. *(a)* Nontreated. *(b)* Anodic oxidation. *(c)* Diamond-like carbon coating.

group, however, no significant difference was found between the PERDEV values of the NT and AO groups (P = .61). Significant differences were found between the NT and DLC groups and between the AO and DLC groups (P = .007 and P = .001, respectively). For the NT and DLC groups, the PERDEV values of the screws with thermomechanical cycling were found to be significantly higher than those without ($P < .001$ and $P = .009$, respectively). However, no significant difference was found between the PERDEV values of the screws with and without thermomechanical cycling in the AO group (P = .88) (Table 3).

In the non–thermomechanical cycling group, the SEM indicated more particles on the surface of the screws in the NT group compared to the other groups (Fig 6). In all groups, irregularities and particles were observed in threads at ×50 magnification after thermomechanical cycling (Fig 7). In the NT and AO groups, the coating was not observed on the amorphous surface. In the DLC group, the coating could be observed clearly. The average coating thickness was 3 mm (Figs 8 and 9).

Table 3 Comparisons of Subgroup Means According to Thermomechanical Cycling

	PERDEV			
Surface treatment	Thermomechanical cycling	Non–thermomechanical cycling	Mean difference	*P*
NT	44.74 ± 12.43	12.4 ± 3.15	32.341	< .001
AO	13.81 ± 4.15	11.03 ± 2.55	2.781	.88
DLC	24.62 ± 7.12	17.13 ± 3.76	7.495	.009

Percentage of deviation (PERDEV) values are reported as mean ± standard deviation.
NT = nontreated; AO = anodic oxidation; DLC = diamond-like carbon coating.

DISCUSSION

This study evaluated the effects of various surface modifications with and without thermomechanical cycling on abutment screws for single-tooth implants. The effects on reverse torque values were investigated.

The external forces, vibration in the screw, wear of the joint surfaces, and forces resulting from the seating (embedment relaxation) gradually reduce

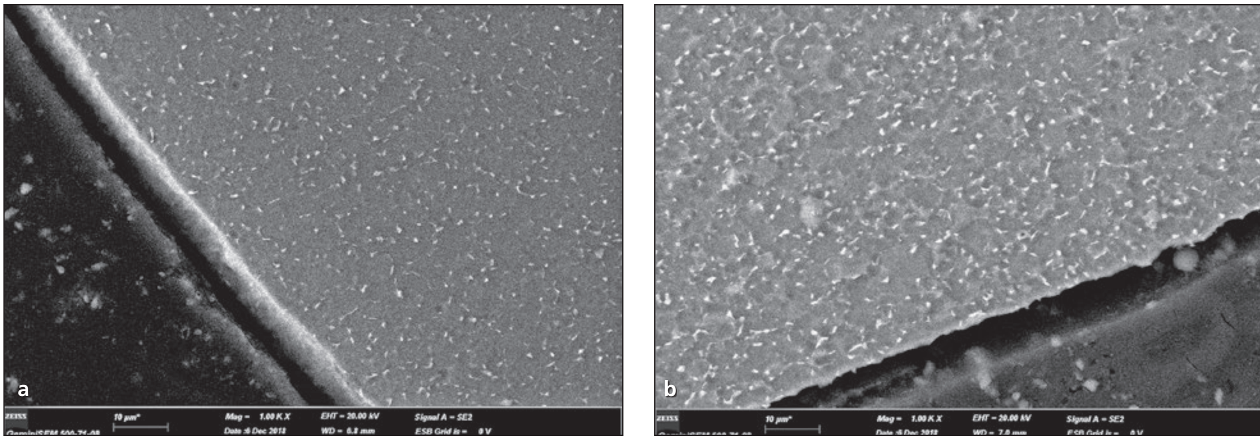

Fig 8 Cross-section of SEM images of abutment screws. *(a)* Nontreated. *(b)* Anodic oxidation.

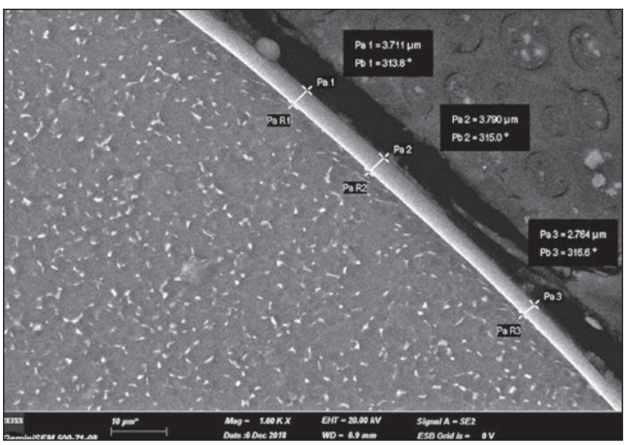

Fig 9 Measurement of diamond-like carbon thickness.

the preload. A decrease was observed in reverse torque values of all groups after thermomechanical cycling, which indicates a decrease in the torque of the screws. In the abutment screws with thermomechanical cycling, the mean PERDEV value in the NT group was significantly higher than values in the AO and DLC groups, and the mean PERDEV value in the DLC group was higher than that in the AO group (NT: 44.74 ± 12.43; AO: 13.81 ± 4.15; DLC: 24.62 ± 7.12).

The single-unit implant-supported fixed prosthesis design was used in this study, since screw loosening is more common in this situation. Pjetursson et al reported that screw loosening was observed in 12.7% of single-unit implant-supported fixed prostheses compared to 5.6% of implant-supported partial dentures.[19] In a clinical study conducted by Gracis et al, only 3 of the 25 screw-loosening or screw-fracture cases were implant-supported partial dentures.[20]

It was previously reported that the preload should not be too high—below 75% to 80% of the elastic limit of the material.[9] Screw loosening takes place if the force applied to the system is higher than the preload. The elastic recovery of the screw then pulls the components together, resulting in a clamping effect. The screw will loosen or fracture if external separating forces acting on the implant-abutment joint are greater than the clamping forces keeping the abutment and the implant together.[11] Studies have reported that the preload depends on the coefficient of friction between the contacting surfaces.[21] This coefficient depends on the roughness of the contacting surfaces, loading, hardness of the threads, and the presence, quantity, and quality of the lubricant on the surfaces.[22,23] When decreased to appropriate values, the friction coefficient increases the preload and reduces the possibility of screw loosening.[11] This study explored the idea of changing the surface properties of the abutment screws to increase the preload and to reduce the probability of abutment screw loosening.

Previous studies have shown that the effect of repeated tightening on screw loosening is still controversial. Byrne et al[14] reported a reduction in preload after repeated tightening and loosening cycles while Weiss et al[24] and Kim et al[25] suggested avoiding unnecessary repetitive tightening. Cardoso et al[26] suggested replacement of the abutment screw if 10 cycles of repeated tightening cannot increase the resistance to screw loosening; in contrast, Guzaitis et al[27] indicated that after 10 screw insertion cycles, a new screw must be used to maximize screw removal torque. Arshad et al[28] investigated the effects of repetitive tightening cycles on the removal torque. After each tightening and loosening cycle, they observed a reduction in the removal torque compared to the initial torque. In the present study, each abutment screw was used only once due to the possibility of a decrease in the removal torque after repeated tightening cycles and the deterioration of the abutment screw surface modifications.

The effect of the AO method in implant-supported fixed prostheses is not known. There is no consensus on how the anodization process affects the reversal torque values. Therefore, one of the abutment screw groups was subjected to AO, and another group was subjected to DLC.

The anodization process has been used to overcome the weak tribologic properties of titanium, to increase the corrosion resistance, and to provide a hard– and abrasion-resistant–surface modification.[29] In clinical usage, the gray reflection of titanium is known to produce an esthetically undesirable appearance, which can be reduced by anodizing the titanium supports or substructures. It has been reported by Yan et al[30] that gold-colored titanium supports or substructures produce more acceptable esthetic results for patients.

Squier et al[31] examined the effect of anodization on the reverse torque values of implants and abutments. In contrast to the present study, the removal torque values of the anodized abutments were lower than those of the non-anodized ones. This result can be attributed to the possible lubricant effect of AO on the abutment surface. Squier et al[31] reported that the AO decreased the resistance to screw loosening by approximately 20%. These findings can be attributed to the different types of abutment or anodization parameters.

A previous study by Van Vuuren et al[16] investigated the voltage-related variation of friction on the surfaces of titanium screws. When the voltage value was increased from 0 V to 50 V, the thickness of the oxide layer on the surface increased by approximately 0.23 mm. The increase in oxide layer increased the surface hardness and caused a reduction in the surface friction coefficient by 10% to 40%, depending on the load. The preload was reported to increase when the surface friction coefficient decreased.

For the AO group, the reversal torque values with thermomechanical cycling were found to be lower than those without, although these differences were not significant. In the AO group, the oxidation procedure might be changed by the tribologic properties of the titanium screw surface. The reduction of the coefficient of friction on the abutment screw surface can produce higher preload values. Smooth surfaces contact sufficiently under compression, thus reducing preload loss.[32] In the present study, the lowest torque loss values in the AO group might be due to this effect. Furthermore, it could be concluded that the screw stability was maintained even after the thermomechanical cycling. The anodization process was carried out at 27 V, and a light blue color was obtained. This color code was determined for the healing caps and abutment screws of the 4.1-mm–diameter implants that were used in this study. However, further studies are needed to examine the effect of different voltages on the removal torque values of the titanium screws.

Titanium alloys are frequently coated with dry lubricants such as DLC and tungsten carbide.[9] The DLC coating is recommended in titanium abutments and screws to improve the overall mechanical performance of the prosthetic system. DLC has become potentially useful on different surfaces due to its excellent wear and corrosion resistance, high hardness, and low coefficient of friction.[33]

In an in vitro study conducted by Corazza et al,[34] DLC-coated and noncoated abutments were examined before and after the dynamic loading. The results suggested that both dynamic loading and the effect of DLC coating were significant. The DLC coating is an alternative method to prevent screw loosening. de Moura et al[13] investigated the removal torque values of the DLC-coated screws in splinted and nonsplinted implant crowns. Torque values in all groups decreased after dynamic loading, but the decrease in the DLC-coated group was lower than the others. Bacchi et al[35] investigated the effects of tightening technique and abutment screw coating on the abutment screw loosening. According to the results of the study, tightening technique did not have a significant effect on screw loosening; standard abutment screws showed significantly lower removal torque values than DLC-coated screws. DLC-coated implants were more resistant to screw loosening, consistent with the results of the present study. Lepesqueur et al[36] reported that the DLC coating significantly affected the torque loss in external connection abutments. However, there was no significant difference between the internal-connection abutments. Diez et al[37] assessed the changes in the implant-abutment interfaces of the DLC-coated and noncoated screws. It has been reported that the DLC-coated group did not have a significant reduction in the implant-abutment interface. Other variables must be explored to improve the potential role of DLC-coated screws in implant dentistry.

Various amounts of torque loss have been reported for abutment screws in previous studies. Xia et al[38] found this rate to be 8.40% in the non–thermomechanical cycling group. Studies by Assunção et al[4] and Neto et al[39] revealed torque losses of 18.58% and 5.25%, respectively. Weiss et al[24] reported a torque loss of 11% to 24% immediately after the final tightening. For the non–thermomechanical cycling group, the torque loss was 12.4% in the NT group, 11.03% in the AO group, and 17.13% in the DLC group in this study. Thus, the torque loss in the present study was consistent with these studies.

The measurement of reverse torque values is one of the methods used to compare preload in abutment screws indirectly. The reverse torque value gives the residual preload value in the screw, and the remaining preload shows the screw stability. The loosening of the experimental groups was calculated using the PERDEV of the reverse torque values.[18] The PERDEV as a measure of torque loss is convenient to compare with outcomes from other studies.

The present study had some limitations. First, the study was performed in vitro, and in vivo studies may offer more insight into clinical relevance. The load was transferred directly to the abutment during thermomechanical loading. Furthermore, the abutment screws were evaluated based on a single voltage value. AO should be performed at different voltage values, and further studies should be conducted to examine the removal torque values. Another limitation was that the implant screw space was not evaluated for contamination with different liquids, and only 240,000 chewing cycles, simulating 1-year clinical use, were performed. Long-term simulations may provide further information about the screw loosening.

Within the limitations of this study, a significant increase was observed in the reverse torque values of abutment screws after surface modifications. The abutment screws with AO exhibited the lowest torque loss in groups with and without thermomechanical cycling. Further studies are needed to evaluate the possible effects of AO to maintain screw stability.

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Literature Abstracts

Primer on Etiology and Treatment of Progressive/Severe Periodontitis: A Systemic Health Perspective

Periodontology is an infectious disease–based discipline. The etiopathology of progressive/severe periodontitis includes active herpesviruses, specific bacterial pathogens, and proinflammatory cytokines. Herpesviruses and periodontopathic bacteria may interact synergistically to produce periodontal breakdown, and periodontal herpesviruses may contribute to systemic diseases. The infectious agents of severe periodontitis reside in deep pockets, furcation lesions, and inflamed gingiva, sites inaccessible by conventional (ie, purely mechanical) surgical or nonsurgical therapies, but accessible by systemic antibiotic treatment. This brief overview presents an effective, anti-infective treatment for severe periodontitis that includes systemic chemotherapy/antibiotics against herpesviruses (valacyclovir [acyclovir]) and bacterial pathogens (amoxicillin + metronidazole or ciprofloxacin + metronidazole), plus common antiseptics (povidone-iodine and sodium hypochlorite) and select ultrasonic scaling. The proposed treatment can cause a marked reduction or elimination of major periodontal pathogens, is acceptably safe, and can be carried out in minimal time with minimal cost.

Slots J. *Periodontol* 2000 2020;83:272–276. **References:** 45. **Reprints:** Jorgen Slots, jslots@usc.edu —*Howard Landesman, USA*

Outcome and Survival of Endodontically Treated Cracked Posterior Permanent Teeth: A Systematic Review and Meta-analysis

The aim of this systematic review and meta-analysis was to evaluate the success and survival rates of endodontically treated cracked posterior teeth and to assess the preoperative factors that affect tooth survival. The study protocol was registered on the PROSPERO international database of prospectively registered systematic reviews (CRD42019119091). An electronic search was performed for studies up to November 30, 2018 in the PubMed, Scopus, and Cochrane databases. All searches were done following PRISMA guidelines. Clinical studies evaluating the success and/or survival rate of cracked teeth that were endodontically treated with at least 1 year of follow-up were selected. The Newcastle-Ottawa scale was used to evaluate risk assessment. Publication bias was evaluated with funnel plots, and Egger test was performed to test asymmetry. Of the 410 studies identified in the initial search, 7 qualified for final analysis, all longitudinal cohort studies. The results of the meta-analysis indicated a survival rate of 88% (CI 0.81 to 0.94) and a success rate of 82% (CI 0.78 to 0.86) after 1 year of follow-up. The presence of a periodontal pocket associated with a crack resulted in a higher risk of tooth loss (relative risk 1.11). Patient sex, tooth type, position, the number of cracks present, and preoperative pulp status did not affect treatment survival rate ($P > .05$). Most of the included studies did not have an accurate record of many variables that could affect tooth survival. In addition, studies did not present extended follow-up periods or an adequate dropout rate to properly assess treatment outcome and survival. According to the results of the present systematic review and meta-analysis, root canal treatment in cracked posterior teeth can be considered a suitable treatment option. The presence of an associated periodontal pocket results in a lower survival rate.

Olivieri JG, Elmsmari F, Miró Q, et al. *J Endod* 2020;46:455–463. **References:** 53. **Reprints:** Juan Gonzalo Olvieri, jgolvieri@uic.se —*Ray Scott, USA*