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Assessment of removal torque values of anodized abutment screws at different voltages: an in vitro study

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Abstract

Background The purpose of this in vitro study is to compare the removal torque values of abutment screws anodized with different voltage values.

Methods The abutment screws were divided into 6 groups according to their surface treatment: non-treated (C) Control group ($n=24$), acid etched only (A) Acidic uncolored ($n=24$), anodized with 27 V and painted blue (B) Blue ($n=24$), after acid etching anodized with 27 V and painted blue (AB) Acidic Blue ($n=24$), anodized with 55 V and painted yellow (Y) Yellow ($n=24$) and after acid etching anodized with 55 V and painted yellow (AY) Acidic Yellow ($n=24$). 144 bone-level implants to which the abutments will be attached are embedded in auto polymerized acrylic resin. All abutment screws were tightened to 30 Ncm on the digital torque meter. The removal torque values of abutment screws were obtained, and A three-way ANOVA was performed for statistical analysis, and Tukey's test was used for multiple comparisons.

Results Decreased removal torque values were observed in all groups after thermomechanical cycling. Only application anodization process to abutment screws reduces removal torques of the screws. In case of acid etching before anodization, it was observed that removal torques increased. Applying only acid etching process to abutment screws reduces removal torques of the screws. However, when the screws are anodized after acid etching, it has been observed that removal torques increase.

Conclusion It was observed that anodizing the abutment screws with different voltages did not make a significant change in the removal torques.

Keywords Abutment screw loosening, Acid-etching, Anodization, Removal torque

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Background

Implant dentistry has shown promising outcomes of osseointegration; however, mechanical and biological complications commonly occur. The loss of torque value or screw loosening proves to be the most common mechanical hindrance faced by clinicians in dental practice. There are many factors that could increase or decrease the occurrence of this complication [1].

Abutment screw loosening is known to be the most common mechanical complication of implant-supported single crowns [2]. In the literature, a review was reported that "screw loosening occurs in 8% of cases and can reach up to 45% in single crowns" [3]. The most important causes of abutment screw loosening are loss of preload on the screw during torquing and fatigue of the screw material [2–4]. If the complication is neglected, there is an increased risk of a screw fracture occurring [1].

In order to prevent preload loss and minimize screw loosening in implant-supported fixed restorations, various solutions such as changing the surface properties of the abutment screws by applying various chemical treatments such as anodization or coating them with various materials, increasing the torque value applied during tightening, repeating tightening cycles during torquing, and waiting at that force for a certain period of time after reaching the optimum force in torquing have been proposed. Due to the increased preload, the micro-gaps between the abutment and the implant are reduced. Thus, complications related to these gaps, such as tissue overgrowth, can be reduced and the success rate of the implants can be increased [5].

Anodization is an electrochemical process applied to increase the thickness of the titanium oxide layer on the material surface [6]. The oxide layer formed during anodization is more stable than oxide layers formed on the alloy surface in contact with air [7]. Increasing the thickness of the oxide layer generally increases resistance to corrosion. Titanium oxide has an extremely high hardness value [8]. Therefore, the anodization procedure is applied to enhance the hardness of the titanium surface. The hardened surface reduces loosening between contacting parts and increases wear resistance [9, 10].

The oxide film formed on the surface by the anodization process of titanium not only increases the wear and corrosion resistance of the material but also plays a role in color coding metal parts and increasing surface roughness and biocompatibility [9, 10].

In the anodization procedure, it is a standard method to etch the sample before anodizing [11]. However, it is not yet known which of the etching or anodization process is the main reason for the change in surface properties after the process.

The response of the material when the applied voltage value changes during the anodization process has not been clarified in the literature. The aim of this study was to investigate and evaluate the effects of anodization of the abutment screws of dental implants at different voltage values on the removal torque values of the abutment screws under thermomechanical cycling.

The null hypothesis of the study is that anodizing the abutment screws with different voltage values in the anodization process will not have any effect on the removal torque of the screw.

Methods

This in-vitro study was conducted in the Research Laboratory at Erciyes University Faculty of Dentistry.

In the study, the effect of anodization process applied at different voltage values on the surface of the abutment screw at different voltage values in the groups with and without etching on the back removal torque values in the groups with and without thermomechanical cycling was investigated. Bone level, 4.1 mm diameter, 10 mm height dental implants from Bilimplant (Bilimplant, Proimtech A.Ş.; Istanbul, Turkey); 5 mm height, 1 mm gingival height and standard abutments of the implants were used.

The procedures in the study are as follows:

Sample size selection

The number of samples in the groups was considered in the Power analysis with $\alpha = 0.05$ reliability and power $\beta = 0.80$, and it was decided to start the study with 144 samples in total, with $n = 12$.

Placement of implants in acrylic models

The models were embedded in auto polymerized acrylic resin (Integra; Birleşik Grup Dental, Ankara, Turkey) to mimic the mandible. The models were fabricated using the own molds of the chewing and thermal cycling device (CS-4.8 Chewing simulator; SD mechatronik, Feldkirchen-Westerham, Germany) (Fig. 1).

Dental implants were placed and fixed in the center of the molds before the acrylic resin was poured. A total of 144 models were prepared with 1 implant-abutment connection on each model (Fig. 1).

Surface treatment of implant abutment screws

In the study, 72 of the abutment screws were etched and the other 72 were anodized without etching. The purpose of the acid treatment is to clean the titanium screw from surface oils and dirt. For this objective, the samples were placed in a solution of 35% phosphoric acid (Ultra-Etch; Ultradent Inc) diluted 1/1 for 20 s at room temperature. After treatment, the samples were rinsed thoroughly under running water. The samples were then dried in a laboratory dryer at 60 °C (± 5).

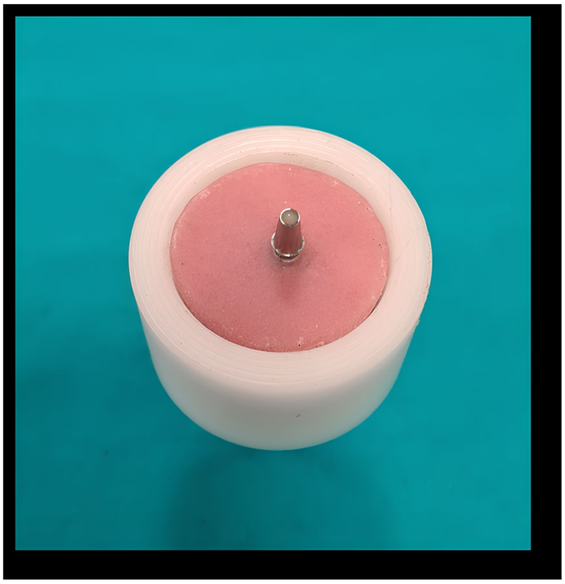

Fig. 1 Placement of implants in acrylic models

Fig. 2 Surface treatment of implant abutment screws. Left to right respectively, C, B, Y, A, AB, AY. *C* Control, *B* Blue, *Y* Yellow, *A* acid etched, *AB* Acid etched Blue, *AY* Acid Etched Yellow

Twenty-four of the etched screws were designated as the control group. The 48 acid-etched titanium abutment screws were prepared for anodization. The anodization process was carried out separately for each sample and working times and applied voltage values were monitored by a single operator from the control panel on the device. To obtain the desired color level, the voltage was adjusted using the control panel on the device. 27 V current was applied to 24 of the abutment screws to obtain blue color and 55 V current was applied to 24 of them to obtain yellow color.

Out of the 72 abutment screws that were not etched, 24 of them were not treated and were selected as the control group. 48 of them were directly anodized by skipping the etching steps. A current of 27 V was applied to 24 of them to obtain a blue color and 55 V to the other 24 to obtain a yellow color (Fig. 2).

Fig. 3 Connection of implant-abutments and torque application

Connection of implant-abutments and torque application

After the surface treatment of the abutment screws was completed, each abutment screw was connected to correspond to a different implant in the prepared acrylic models to form the implant-abutment connection.

All models with implant-abutment connection were torqued with a force of 30 Ncm using a digital torque device (Cap Torque Tester Series TT01, Mark10; New York, USA) in dry environment with the help of a screwdriver and a ratchet in accordance with the manufacturer's instructions (Fig. 3). After 10 min, the tightening process was repeated.

Thermomechanical cycle

Torqued in accordance with the manufacturer's instructions, 72 specimens were run in a chewing and thermal cycling device (CS-4.8 Chewing simulator SD Mechatronik, Feldkirchen-Westerham, Germany) for thermomechanical cycling with 8 specimens per 1-year cycle. The force applied by the device is set to 120 N, which is on the long axis of the implant-abutment assembly. A ceramic tip of the masticatory simulator was used as the antagonist force applicator of the implant-abutment connection, and a static force was applied, preventing horizontal movement. Approximately 240,000 chewing cycles were performed to simulate a total of 1 year of intraoral use. During the 240,000 chewing cycles, the device performed simultaneously thermal cycling in distilled water, with temperatures transitioning from +5 °C for 60 s to +55 °C for 60 s.

Measurement of removal torque values

For specimens that did not undergo thermomechanical cycling, removal torque values were obtained and recorded 15 min after the second torquing using a screwdriver and ratchet by applying counterclockwise force to the abutment screw and unscrewing it on a digital torque measuring device.

The 72 thermomechanical cycled models (C = 12, B = 12, Y = 12, A = 12, AB = 12, AY = 12) were subjected to a chewing simulator and thermal cycling for dynamic loading. Subsequently, the removal torque values were calculated by the same procedure. The results obtained were subjected to statistical evaluation.

Statistical analysis

In summarizing the data obtained from the study, descriptive statistics are provided in tables as mean ± standard deviation. The Kolmogorov-Smirnov test was used to analyze the normality of the data. A three-way Analysis of Variance was performed to examine the effect of etching, anodization and thermomechanical cycling on the removal torque values (loosening) of the abutment screws.

Tukey's test for multiple comparisons was used to determine which pairs of groups the differences occurred between. Statistical analyses were performed with Jamovi project (2021), Jamovi (Version 2.2.1) [Computer Software] (Retrieved from https://www.jamovi.org) and JASP (Version 0.15) (Retrieved from https://jasp-stats.org) programs and the significance level was considered as 0.05 (p-value) in statistical analyses.

Results

Table 1 shows the sample numbers of the groups examined in the study, the tightening torque applied to the abutment screws and the mean removal torque values of all screws.

Table 2 shows the mean removal torque values in the groups. When the results are examined, it is seen that the parameter that makes the most difference is the thermomechanical cycle and the parameter that makes the least difference is anodization.

In Table 3, in the evaluation of the effect of anodization, acid etching and thermomechanical cycling variables among the factors affecting the removal torque; it was seen that the presence of acid and thermomechanical cycling affected the removal torque regardless of the other parameters ($p < 0.001$ for each), while it was concluded that anodization individually had no affect the other parameters ($p = 0.453$). In addition, when the results of the pairwise interaction of these factors were examined, it was concluded that the results of the interaction between anodization and acid-etching, anodization and thermomechanical cycling and acid-etching and thermomechanical cycling were statistically significant ($p < 0.05$ for each).

At last, when the triple interaction of anodization * acid-etching * thermomechanical cycle factors was examined, it was concluded that it was statistically significant ($p = 0.002$).

When the effect of voltage value on acid etching and thermomechanical cycle variables was evaluated in Table 4, it was determined that the interaction of voltage value * acid * thermomechanical cycle was not statistically significant ($p = 0,065$). According to this, the voltage value of anodization, acid and thermomechanical cycling

Table 1 Number of samples, tightening torque value and mean of removal torque values for study groups

		N
Anodization	no	48
	yes	96
Anodization voltage value	27 V (blue)	48
	55 V (yellow)	48
Acid Etching	no	72
	yes	72
Thermomechanical cycle	no	72
	yes	72
Tightening torque		30 Ncm
Removal torque		23,4 ± 3,5*

*Removal torque values are presented as Mean ± Standard Deviation (Ncm)

Table 2 Mean removal torque values of the groups

		Mean ± SD (Ncm)
Anodization	No	23.5 ± 1.6
	Yes	23.3 ± 2.2
Acid-etching	No	24.4 ± 2.2
	Yes	22.5 ± 1.5
Thermomechanical cycle	No	25.8 ± 1.2
	Yes	21 ± 2.6

Table 3 Effect of common interactions of anodization, acid etching and thermomechanical cycle variables on removal torque

	df	**F value**	***p*-value**
Main Effects			
Anodization	1	0.567	0.453
Acid-etching	1	25.089	< 0.001
Thermomechanical cycle	1	156.837	< 0.001
Common Interactions			
Anodization ∗ Acid-etching	1	39.833	< 0.001
Anodization ∗ Thermomechanical cycle	1	8.116	0.005
Acid-etching ∗ Thermomechanical cycle	1	24.767	< 0.001
Anodization ∗ Acid-etching ∗ T. cycle	1	9.648	0.002

Statistical significance was set at $p < 0.05$

Table 4 Evaluation of the effect of anodization voltage value on removal torque in common interaction with other parameters

	df	F value	*p*-value
Main Effects			
Voltage value	1	2.751	0.101
Acid etching	1	1.107	0.296
Thermomechanical cycle	1	61.097	**< 0.001**
Common Interactions			
Voltage value * Acid-etching	**1**	1.200	0.276
Voltage value * Thermomechanical cycle	**1**	0.095	0.759
Acid etching * Thermomechanical cycling	**1**	2.284	0.134
Voltage value * Acid * Thermomechanical cycle	**1**	3.484	0.065

Statistical significance was set at $p < 0.05$

parameters do not simultaneously produce a significant change on the back removal torque.

On the other hand, when the results of the pairwise common interactions were examined, it was concluded that the results of the interaction between voltage value and acid, voltage value and thermomechanical cycle and acid and thermomechanical cycle were not statistically significant ($p > 0.05$ for each). Finally, when the results of the main effects were analyzed, it was concluded that acid and voltage alone did not affect the removal torque regardless of the other parameters ($p > 0.05$ for each of them), while the thermomechanical cycling process alone had an effect independent of the other parameters ($p < 0.001$).

Discussion

Different factors can cause torque loss and screw loosening, such as inadequate preload applied to the screw, failures after initial placement and seating, prosthetic component and dentist-related variables during tightening [12, 13].

Studies show that the most common mechanical complication in implant-supported fixed prosthetic restorations is abutment screw loosening (3.1–10.8% in 5 years) [14, 15]. If screw loosening is not managed, it may lead to screw fractures (0.35% in 5 years). The percentage of screw loosening due to torque loss reported between 16.1% and 25% [16]. Pjetursson et al. comparing the complications between implant-supported single unit and bridge restorations, screw loosening was reported to occur in 12.7% of implant-supported single units and 5.6% of bridges [15].

Based on the literature, the preload applied to the abutment screws during screw tightening causes elongation and helps to keep the components under tension [3]. It was stated that, only 10% of the tightening torque is used to generate screw tension and most of the torque applied is used to overcome the friction between the screw head and the abutment surface [1, 17]. Stüker et al. [18] compared the effects of three different abutment screw materials on removal torque values. They tightened gold, titanium and surface-modified titanium screws with 30 Ncm on the same implants and abutments. As a result, they found that titanium (18.75 Ncm), gold (17.64 Ncm), and titanium with modified surface (16.43 Ncm) were the most resistant screw materials, respectively.

In order to improve the tribological and surface performance of Ti-alloys, various surface treatments are applied such as thickening the oxide film layer on the surface of titanium by anodization method, coating the titanium surface with diamond-like carbon (DLC), coating Al_2O_3 with plasma spray method, coating with 6 µm thick Ti-Cu-N film with antibacterial properties [18–21]. Among these techniques, anodization (anodic oxidation, anodizing) is widely applied due to its low cost and simple usage [20].

When the effects of anodization on the titanium surface are analyzed; it has been reported that the increasing thickness of the oxide layer generally increases the resistance to corrosion. Karambakhsh et al. [22] applied anodization process with different voltages to increase the thickness of the oxide layer and to examine the corrosion behavior of titanium. In their study, they reported that the thickness of the oxide film increased with increasing anodization voltage and accordingly, the corrosion on the titanium surface was greatly reduced.

Anodization process is also used to harden the surface of titanium. The hardened surface increases the wear resistance of the parts and reduces loosening on the contacting surfaces [10, 23]. Apart from increasing the surface hardness, the risk of loosening between surfaces can be reduced by reducing the coefficient of friction of the contacting surfaces. Anodization process affects the surface friction coefficient of titanium [11]. In the literature, there are studies showing that reducing the surface friction coefficient of titanium abutment screws increases the applied preload force and reduces the risk of loosening [1, 10, 11, 23].

In a study by Turalıoğlu et al. [24] in which they examined the effect of the oxide layer formed after anodization applied to titanium alloys on the tribological behavior of the material; they reported that the wear resistance increased significantly after the anodization process, it was also reported that the corrosion resistance of the samples increased after anodization. Vermesse et al. [25] compared the surface integrity of titanium alloy after acid-etching and anodization processes but found no significant change in the surface microstructure of titanium alloy after both processes.

Besides improving the tribological properties and aesthetic appearance of titanium by anodization, the oxide film formed on the surface has also been proven to improve biocompatibility. In general, in vitro studies have consistently shown higher cell proliferation and adhesion on anodized surfaces compared to pure titanium surfaces [10, 26]. In an animal study by Susin et al. [27] were reported that anodized abutment showed a positive effect on soft and hard tissue healing/remodeling and inflammatory reaction compared to untreated abutment, confirming its safety and efficacy.

Despite the accuracy of the manufacturing procedures, microscopic examination reveals irregularities and contamination in the threads of the abutment screw. It has been observed that contamination of the screw threads can reduce the coefficients of friction and affect the preload, which in turn can affect the removal torque values [28]. Pre- or post-treatments can be performed to improve the bioactivity and mechanical compatibility of anodization. In the anodization process, the samples are first acid-treated and then ultrasonically cleaned to remove contaminants from the polished surface. Thus the performance of the oxide layer can be improved and indirectly affect the coefficient of friction [10].

In our study, the effect of anodization process on the removal torque values differs according to acid etching and thermomechanical cycling parameters. Both before and after thermomechanical cycling, the removal torque values of the non-acid etching screws were significantly lower ($p = 0.019$ before cycling and $p = 0.008$ after cycling, respectively) for anodized screws than for non-anodized screws (mean removal torque before cycling: 24.5 ± 1.3 and 27.2 ± 1.1 Ncm, after cycling: 21.5 ± 3.8 and 24.3 ± 2.7 Ncm). This result is consistent with the results of Squier et al. who studied the effect of anodization on the removal torque of abutments in conically connected implants [29].

The result changes when etching is performed before anodization in the study. After acid etching, there was no significant difference ($p = 0.999$) between anodized and non-anodized screws (25.8 ± 1.3 Ncm and 25.9 ± 1.1 Ncm, respectively) in the removal torque values before the thermomechanical cycle. However, after thermomechanical cycling, removal torque values were significantly higher ($p < 0.001$) for anodized screws compared to non-anodized screws (21.3 ± 2.3 Ncm and 16.8 ± 1.4 Ncm, respectively). Acid etching removes organic residues, loose parts of the oxide layer, and foreign substances on the titanium alloy surface, thereby cleaning the surface. This might be ensuring a more homogeneous and compact oxide layer formation during anodization. The surface energy may have changed, and the oxidized layer formation may have been improved [10, 30].

It is also thought that the removal of the oxide layer on the titanium surface after etching reduces the coefficient of friction. Accordingly, the decrease in the coefficient of friction in the tightening torque allows the preload to increase [10, 29]. In contrast, however, reduced friction can reduce the resistance to screw loosening when functional forces exceed the preload. Therefore, at low friction, the preload may not be easily maintained, and screw loosening may occur [10, 23]. In our study, the significant decrease in the removal torque of acid-etched screws after being subjected to functional loads in the thermomechanical cycle may be attributed to the inability of the friction reduced by the removal of the oxide layer to provide sufficient resistance against screw loosening.

It is known that there is a relationship between the thickness of the oxide layer after anodization and the applied voltage value. Accordingly, as the applied voltage value increases, the thickness of the titanium oxide layer increases [23, 31]. In research conducted by Saraswati et al. [32] the voltage dependent variation of the thickness of the oxide layer formed on the titanium surface after anodization and the relationship between thickness and corrosion resistance were investigated. According to this, titanium surfaces were anodized with voltage values of 10 V, 20 V and 30 V respectively and the thickest oxide layer and the most corrosion resistant alloy surface were obtained at the highest voltage value.

In the present study, the groups were anodized with 27 V and 55 V, to evaluate the relationship between the anodization voltage value and the removal torque of the abutment screw. Although the removal torque of 55 V anodized abutment screws was higher than the removal torque of 27 V anodized screws, this difference was not statistically significant ($p = 0.101$) (removal torques; 55 V: 21.9 ± 1.4 Ncm and 27 V: 20.6 ± 2.8 Ncm). This situation might be explained by the thickness of the titanium oxide layer [10]. Also non-significant difference between 27 V and 55 V anodization could be due to insufficient voltage variation. In a study conducted by Rathe et al. [23]; it is assumed that the oxidized layer of titanium is destroyed to some extent by abrasion when the screw is tightened. At high voltages, the oxide layer may not be completely destroyed as the thickness of the oxide layer will increase when the voltage value increases during the anodization stages. Even if not significant, the higher removal torque obtained with anodization at 55 V current can be attributed to the increased oxide layer thickness and the parallel decrease in the coefficient of friction. Consistent with the aforementioned study [23]; when the removal torques of the abutment screws anodized with 27 V and 55 V voltages were compared, the removal torque of the group anodized with 55 V was slightly higher, but this result was not statistically significant. Anodization increases the thickness of the oxide layer of the titanium surface and changes the coefficient of friction. However, in order to obtain efficiency from anodization application, acid etching, which is the standard procedure, must be performed before the process. It is assumed that the removal of particles between the screw threads by etching may result in tighter contacts between the surfaces. Thus, both conditions have the potential to affect the removal torque of the abutment screw.

The limitations of our study are as follows: In vitro conditions could not be fully ensured for this study; the oxide layer thickness of the screws was not clearly measured and contamination of the screw cavity with different fluids could not be evaluated. The study results valid to a single tightening procedure with a dry implant lumen. In the presence of lubricant; contamination of the abutment screw with a saliva-like fluid may show variability in the removal torque values [33]. In addition, the variation of the surface properties of the abutment screw due to changing the electrolyte content in the anodization procedure or the electrolyte liquid temperature can be investigated in further studies. This study examined just a single type of abutment screw and anodization at two different voltage levels. The impact of modifications in screw or abutment design, as well as the influence of anodization at higher voltages on removal torque, can be assessed.

Conclusion

1. The thermomechanical cycle significantly reduced the removal torque values of the abutment screws.
2. In order to reduce the risk of screw loosening in the long-term use of implant-supported fixed prostheses, the abutment screws might be anodized at higher voltages and clinical benefit can be achieved by using anodized screws at high voltages instead of standard abutment screws in the delivery of restorations.
3. Further in-vivo studies evaluating a broader voltage spectrum in the anodization of abutment screws should be conducted in the intraoral environment.

Abbreviations

V	Voltage
N	Newton
Ncm	Newton centimeter
°C	Centigrade degree
mm	Milimeter
C	Control group
B	Blue group
Y	Yellow group
A	Acid etched group
AB	Acid etched blue group
AY	Acid etched yellow group

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12903-025-06816-3.

Supplementary Material 1

Acknowledgements

Not applicable.

Author contributions

Y.A. and H.O.G. participated in carrying out of study and the preparation of the figures and tables. Y.A. and E.D.C. wrote the main manuscript text and conducted statistical analyses. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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