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EFFECT OF ANODIC OXIDATION OF TITANIUM SUBSTRATE ON THE SHADE OF LITHIUM DISILICATE CERAMIC WITH DIFFERENT THICKNESSES (IN VITRO STUDY)

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ABSTRACT

BACKGROUND: The color of the titanium abutment can affect the color of the final restoration. Several methods, such as anodic oxidation which changes the gray color of implant abutment to yellow have been attempted to mask the abutment's unaesthetic gray color. However, it's uncertain if an anodized titanium abutment can keep transparent ceramic restorations from discoloring. As a result, more research is required.
AIM OF THE STUDY: the purpose of this laboratory study was to evaluate the effect of anodic oxidation of titanium on the shade of lithium disilicate ceramic.
MATERIALS AND METHODS: Forty grade V titanium backgrounds (n=20) were fabricated and divided into two groups: group 1 was anodized to yellow color and group 2 was left untreated. Each group was subdivided into 2 subgroups (n=10) according to the thickness of the lithium disilicate cemented over it: subgroup A with 1 mm thick lithium disilicate and subgroup B with 2 mm thick lithium disilicate. Each titanium background was cemented to its corresponding lithium disilicate block using translucent resin cement. For the control group, 4 mm thickness lithium disilicate specimens was fabricated. Color evaluation and differences (ΔE) were calculated for the specimens using a spectrophotometer.
RESULTS: In both the anodized and unanodized groups ,there was a significant difference in the color of ceramic specimen ($p < 0.05$). At 1mm thickness of the lithium disilicate, the color difference between the anodized and unanodized groups was (6.84 ± 0.14) and (8.79 ± 0.52), respectively, while at 2mm thickness, it was (2.38 ± 0.24) and (2.57 ± 0.09).
CONCLUSION: The titanium anodization process has a positive effect on the color of the ceramic specimen, which can help achieve an esthetic ceramic restoration over dental implants.
KEYWORDS: Anodic oxidation, dental implant, implant abutment, lithium disilicate, titanium color, aesthetics.

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INTRODUCTION

Restoring teeth in the esthetic zone is a challenging procedure especially in patients with high lip lines. Matching the color translucency, shape, and surface form of the fabricated restoration to the natural teeth is often a complicated technique (1).

Proper choice of the ceramic material is important to fulfill the esthetic demands without jeopardizing its mechanical properties. The translucency of the ceramic material increased as the crystalline concentration of the material decreased, resulting in a more attractive restoration but at the expense of its mechanical characteristics. (2, 3).

Dental implants have priority in replacing missing teeth, especially in the esthetic zone, since they do not affect other teeth like the fixed partial dentures. Because of their low weight, biocompatibility, corrosion, and fatigue resistance, titanium abutments have been proven to have a long-term success rate. Nonetheless, the gray color of the abutment, especially when attempting to put an all-ceramic crown, is one of the key limitations that may limit its use in the esthetic zone (4, 5).

Many attempts have been proposed to overcome this problem such as: Gold abutment, nitride-treated titanium (TiN), composite resin-coated titanium abutment, and titanium anodization (6-9). Tooth-colored materials such as polyetheretherketone (PEEK), zirconia, and alumina have been used as abutment materials (10-12). However, because of their brittleness and low fracture resistance, they are not suitable for use in all clinical circumstances, since they may fracture during the milling process or in long-term function, particularly in narrow and stress-bearing areas. (13, 14).

Titanium anodization is the controlled production of an oxide layer on the surface of the titanium substrate that is thicker than that which is naturally formed. Anodic oxidation is considered safe, chairside, non-invasive, inexpensive, and well-established process for producing stable colors (8, 9, 15, 16). It permanently changes the color of the gray titanium to a wide range of colors using natural light phenomenon according to the thickness of the oxide layer produced related to the voltage produced by the power supply. Clinical studies showed better soft tissue esthetic results with pink and gold anodized titanium abutments than with gray-colored titanium abutments which may provide a better effect on the ceramic restorations over them (5, 17-20).

The aim of this study was to see how anodic oxidation of titanium affected the shade of lithium disilicate ceramics of two different thicknesses. According to the null hypothesis, there will be no effect on the shade of lithium disilicate over the anodized titanium specimen.

MATERIAL AND METHODS

This in-vitro laboratory study was approved by the Research Ethics Committee at the Faculty of Dentistry, Alexandria University, IORG 0008839. Forty titanium grade V (Ti-6Al-4V alloy) backgrounds were fabricated with the following dimensions (15x15x2 mm) from a titanium disc (Titan 5 95H12; Zirkonzahn **GmbH,** Gais/South Tyrol, Italy) using a wire-cut EDM CNC machine (EW-C320 F/S; ECOWIN, Jiangsu, China). Twenty backgrounds were left untreated with their gray color and the other 20 underwent anodization into yellow. (Figure 1A) Anodization **was performed** in a bath of distilled water with 20 gm/l citric acid as the electrolyte. A variable DC-power supply (KPS1203D; Wanptek, Shenzhen, China) was used at 57 voltages. The aluminum foil was connected to the cathode (-) and the titanium blocks to the anode (+) end of the DC Power Supply (8, 9). (Figure 1B)

Two ceramic thicknesses were fabricated from A1 lithium disilicate ceramic (e.max CAD HT; Ivoclar Vivadent AG, Schaan, Liechtenstein) (n=20): 15 x 15 x 1 mm and 15 x 15 x 2 mm. All specimens were cut to the required dimensions using a micro saw microtome (IsoMet 4000; Buehler, lake Bluff, USA.) according to the Buehler user manual. The specimen dimensions were verified using a digital micrometer then placed in the porcelain furnace (Programat EP 3010; Ivoclar Vivadent AG, Schaan, Liechtenstein) for crystallization under the manufacturer's instructions without glazing. For the control group, 4 mm thickness lithium disilicate specimens (e.max CAD HT; Ivoclar Vivadent AG, Schaan, Liechtenstein) were fabricated. All the specimens were reevaluated after crystallization with the digital micrometer to verify their thickness to the required dimensions.

Ceramic specimens were cemented over the anodized and unanodized titanium backgrounds with translucent resin cement (**Panavia SA cement plus;** Kuraray Noritake Dental Inc., Tokyo, Japan) (Figure 2) using a Teflon mold with the same dimension as the specimen. One surface of the ceramic was etched using hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar Vivadent AG, Schaan, Liechtenstein) and primed (Monobond plus; Ivoclar Vivadent AG, Schaan, Liechtenstein) according to the manufacturer's instructions. All the specimens were subjected to 5 kg of controlled axial static load for 2 minutes using a static loading device to standardize all the specimens' cementation (21). (Figure 3) Curing was done in 4 points using a light-curing device (Elipar™ S10 Curing Light; 3m ESPE, Minnesota, USA). Excess cement was removed with a scalpel and all the specimens were left at room temperature for 24 hours to ensure complete curing of the resin cement. (Figure 4A and 4B)

Color evaluation and differences (ΔE) were calculated for the specimen using a digital spectrophotometer (Vita Easyshade Compact; Ivoclar Vivadent AG, Schaan, Liechtenstein). (Figure 5) Calibration of the spectrophotometer was done under the manufacture protocol by placing the probe tip on the calibration port before specimen measurement. The tooth single mode was selected to measure the shade of the specimens by holding the probe tip 90° at the center of the specimen. Three readings were taken for each specimen and the average was calculated. For standardization, readings were taken at the same time and placed by the same investigator (22).

The color was evaluated using the CIE-Lab color system (Commission Internationale de l'Éclairage L*a*b*) (23) which allows for three-dimensional color determination. The chromatic a* axis in the three-dimensional model runs from green (-a*) to red (+a*), while the chromatic b* axis runs from blue (-b*) to yellow (+b*). The lightness dimension, denoted by L*, spans from 0 (pure black) to 100 (diffuse white). At the L* value of 50, the location where the a* and b* axes cross is pure, balanced, and neutral gray (24, 25).

Color differences (ΔE) between the specimens were calculated according to the formula (26):

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Where, ΔL^*, Δa^*, and Δb^* represent the difference in CIE color coordinate between the control and anodized/unanodized groups. Values of ΔL^*, Δa^*, and Δb^* were calculated using:

$$\Delta L^* = L_c - L_{A/U}$$

$$\Delta a^* = a_c - a_{A/U}$$

$$\Delta b^* = b_c - b_{A/U}$$

Where (c) represents the control sample, (A) the anodized samples, and (U) the unanodized samples. The color difference was evaluated with acceptability threshold ΔE = 3.48 and perceptibility thresholds ΔE = 1.74. The novel Fuzzy Approximation of the perceptible/acceptable percentage curves was performed using a Takagi–Sugeno–Kang (TSK) fuzzy model (27).

Normality was checked for all variables using descriptive statistics, plots, and normality tests. All variables showed normal distribution, so mean and standard deviation (SD) were calculated, and parametric tests were used. Comparisons between the two study groups were done using independent samples t-test. Two-way ANOVA was used to assess the effect of anodization (versus un-anodization) and thickness (1mm and 2mm) on ΔE with calculation of adjusted means and 95% confidence intervals (CI). Significance was set at p-value < 0.05. Data were analyzed using IBM SPSS 23.0.

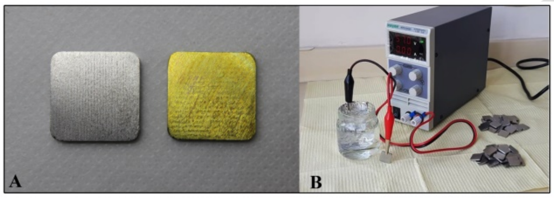

Fig. (1): (A) Showing the anodized (yellow) and the unanodized (gray) titanium backgrounds, (B) Showing the anodization set.

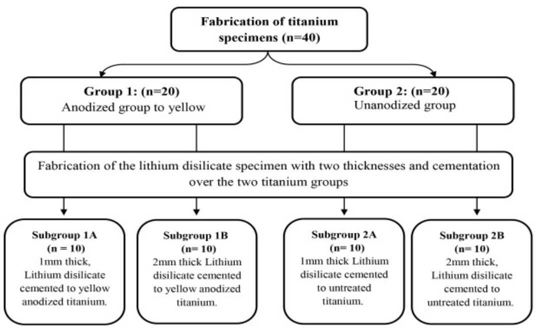

Fig. (2) Showing steps of specimen fabrication.

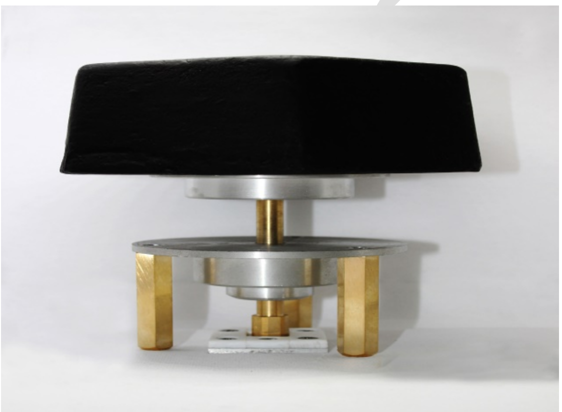

Fig. (3): Showing static loading device and the Teflon mold used for the specimen cementation.

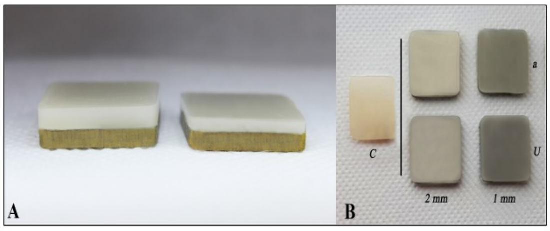

Fig. (4): (A) Showing the two thicknesses of lithium disilicate 1 mm (on the right) and 2 mm (on the left), (B) Showing the control (C) and the different thicknesses of lithium disilicate cemented over the anodized (a) and unanodized (U) titanium.

Fig. (5): Showing the spectrophotometer (Vita Easyshade Compact).

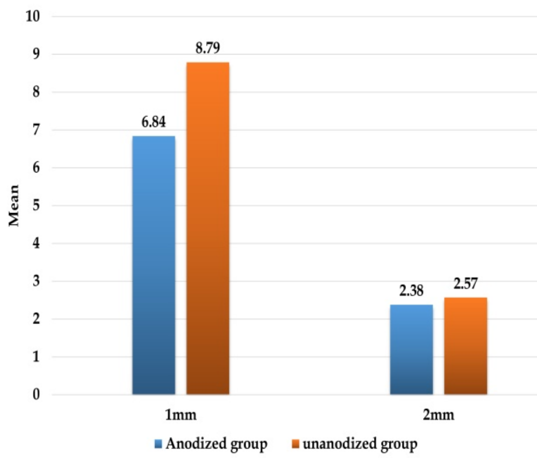

Fig. (6): Showing the mean of the Color difference (ΔE) in the two study groups at different thicknesses.

RESULTS

The mean values of the L, a, and b for the control group were 76.8, -0.42, and 24, respectively. The color coordinates' means and standard deviations (SD) as well as color differences between the experimental groups and control group at the 1- and 2-mm thicknesses, are provided in Table 1.

The mean value of the color difference between the anodized and the control group for the 1 mm thick lithium disilicate was (6.84 ± 0.14), and the color difference between the unanodized and control group was (8.79 ± 0.52). For a 2 mm thickness of lithium disilicate, the mean color difference between the anodized and control group was (2.38 ± 0.24), and for the unanodized with the control group, it was (2.57 ± 0.09).

At 1 mm lithium disilicate thickness, the mean values of ΔE of both anodized and unanodized group were higher than the acceptability threshold. The mean ΔE values for the anodized group with a 2 mm thickness of lithium disilicate were within the acceptable range but clinically perceptible. (Figure 6)

The mean value of the L* coordinate between the anodized and the control group for the 1- and 2-mm thick lithium disilicate were (74.49 ± 0.33) and (75.42 ± 0.24) respectively, and for the unanodized with the control group for the 1- and 2-mm were (73.30 ± 0.87) and (75.33 ± 0.17) respectively. The mean value of the a* coordinate between the anodized and the control group for the 1- and 2-mm thick lithium disilicate were (1.62 ± 0.07) and (-0.31 ± 0.02) respectively, and for the unanodized with the control group for the 1- and 2-mm were (-1.28 ± 0.05) and (-0.44 ± 0.07) respectively. The mean value of the b* coordinate between the anodized and the control group for the 1- and 2-mm thick lithium disilicate were (17.90 ± 0.09) and (22.08 ± 0.27) respectively, and for the unanodized with the control group for the 1- and 2-mm were (16.02 ± 0.39) and (21.91 ± 0.19) respectively. (Table 1)

Regarding the L*, a*, and b* values, the results of the present study showed a significant difference in the three coordinate values of the color parameters between the anodized and unanodized groups.

Two-way ANOVA was performed to assess the effect of anodization (versus un-anodization) and thickness (1mm and 2mm) on ΔE with calculation of adjusted means and 95% confidence intervals (CI). (Table 2)

Table (1): Statistical Analysis of the color coordinates and color difference between the two study groups at the two thicknesses.

Thickness		Anodized group (n= 10) Mean ± SD	Unanodized group (n= 10) Mean ± SD	Mean difference (95% CI)	T-test P value
1 mm	L*	74.49 ± 0.33	73.30 ± 0.87	1.19 (0.54, 1.84)	0.002*
	a*	1.62 ± 0.07	-1.28 ± 0.05	2.89 (2.83, 2.95)	<0.001*
	b*	17.90 ± 0.09	16.02 ± 0.39	1.88 (1.62, 2.15)	<0.001*
	ΔE	6.84 ± 0.14	8.79 ± 0.52	-1.95 (-2.33, -1.57)	<0.001*
2 mm	L*	75.42 ± 0.24	75.33 ± 0.17	0.09 (-0.11, 0.29)	0.35
	a*	-0.31 ± 0.02	-0.44 ± 0.07	0.14 (0.09, 0.19)	<0.001*
	b*	22.08 ± 0.27	21.91 ± 0.19	0.17 (-0.05, 0.39)	0.12
	ΔE	2.38 ± 0.24	2.57 ± 0.09	-0.19 (-0.37, -0.004)	0.046*

*Statistically significant at p-value <0.05

Table (2): Two-way ANOVA for the association between ΔE with anodization and ceramic thickness

		Adjusted mean (SE)	95% CI	P value
Group	Anodized	4.61 (0.12)	4.36, 4.86	<0.001*
	Unanodized	5.68 (0.12)	5.43, 5.92	
Thickness	1 mm	7.81 (0.12)	7.56, 8.06	<0.001*
	2 mm	2.47 (0.12)	2.23, 2.72	

SE: Standard error, CI: confidence interval

Model F: 496.72, p value <0.001*, Adjusted R^2: 0.96

DISCUSSION

Masking the titanium abutment’s grayish color without changing its mechanical and biological properties is considered a goal.

This study evaluated the effect of the anodic oxidation of titanium on the color of a lithium disilicate ceramic. The null hypothesis was rejected. There was an effect on the color of lithium disilicate over the anodized titanium specimen.

The current study used a laboratory investigation, which was done for ethical reasons and to standardize the experimental variables for both groups, which is difficult to do in clinical research. The titanium background was made from a commercially available grade V alloy that is also used to make implant abutments. To get the most accurate results, The specimen dimension was 15 x 15 mm to be larger than the spectrophotometer 5 mm tip in diameter to prevent the edge loss effect of the light for accurate readings (28). Teflon mold and a static loading device were used to standardize the cementation procedure for all the specimens. To mimic the clinical situation and decrease the impact of concealing the titanium color, translucent resin cement was utilized.

Citric acid was used as the electrolyte for the anodization process instead of strong acids to ensure safety. Dentists are also familiar with the acid because it is used in a variety of dental procedures, including root conditioning, endodontic treatment, and peri-implantitis treatment (29, 30). Suggesting its use rather than stronger acids for future studies.

In this study, lithium disilicate was chosen due to its high translucency, which enables more light to flow through in comparison to Zirconia restoration. As a result, esthetic problems become more likely. In addition, variable thicknesses of the specimens were fabricated to simulate the clinical condition and determine whether the anodization process would still be effective with different ceramic thicknesses. High translucency (HT) type was used to decrease the effect of the degree of translucency of the ceramic material in masking the color of the underlying titanium.

An objective method was used to quantify color difference evaluation in a specialized system. The recognized CIE L*a*b color system was used in this study (23). It has a uniform three-dimensional color space arrangement and provides a (ΔE) which defines the color difference between two objects. These differences can be detected using accurate and reliable spectrophotometers which are not affected by metamerism and have a longer working life in comparison to colorimeters (31).

Kim et al found that the Vita Easyshade used in this study had both reliability and accuracy values greater than 90% in comparison to 3 different devices (ShadeVision, SpectroShade, and ShadeScan) (32).

According to Heffernan et al., glazing influences ceramic materials (33). As a result, unglazed ceramic specimens were used to keep the thickness of the specimens consistent.

Previous in-vivo studies found that the thresholds for perceptibility ranges were 3.7, 2.6, and 2.72 (34-36). In the present study, ΔE of 3.48 was selected as an acceptability threshold and ΔE of 1.74 as a perceptibility threshold following Ghinea et al (37). Takagi–Sugeno–Kang (TSK) fuzzy model was used for being a reliable alternative approach for the color threshold calculation procedure (27, 37) to approximate the unknown function that generates the set of observed data. It is an alternative technique to provide a smooth curve without a pre-designed formulation that fits the data. A mean score of higher than 3.48 is regarded as perceptible and clinically unacceptable. A mean value of 3.48 to 1.74 is deemed noticeable yet clinically acceptable, a mean value of less than 1.74 is deemed imperceptible and acceptable.

The mean values of (ΔE) of both anodized and unanodized groups at 1 mm lithium disilicate thickness were above the acceptability threshold. On the other hand, the mean values of (ΔE) were within the accepted range but clinically perceptible for the anodized and unanodized groups with 2 mm lithium disilicate thickness. All the yellow anodized groups showed lower color difference in comparison to the unanodized group.

The anodized groups tend to have higher L*, a*, and b* values than the unanodized groups. This means that anodized groups have lighter, redder, and yellower than the unanodized groups.

These findings support those of Wang et al (5) who found that the esthetics of anodized titanium alloys were inferior to that of zirconia, but the pink and yellow titanium alloys treated by anodization achieved better gingival esthetics than the untreated titanium alloy. He found in another clinical research in 2020 that the use of gold-anodized titanium and pink anodized titanium abutments led to less discoloration of the peri-implant soft tissue (17). In a clinical study, Martínez-Rus et al (19) found that the abutment material type and color have a significant effect on the (ΔE) on both the coronal and soft tissue levels with better results for the yellow anodized abutment in comparison to the unanodized gray titanium abutment.

The current study found that titanium background color and ceramic thickness affect the color difference (ΔE) of a CAD-CAM lithium-disilicate ceramic. These findings are consistent with those of previous research (38-40). Niu et al (39) found that the machinable lithium disilicate was affected by both the ceramic thickness and foundation restoration materials and that increased ceramic thickness improves color matching. Pires et al (40) and Czigola et al (38) found that the substrate color and thickness of ceramic are significantly affecting the resulting optical color.

CONCLUSION

Within the limitations of this study, it is possible to conclude that, the color of the ceramic specimen appears to be improved by anodizing the titanium abutment to a yellow hue and increasing the thickness of the machinable HT lithium disilicate over 1mm, which might have a beneficial clinical impact on the patient's overall esthetic quality.

CONFLICT OF INTEREST
The authors declare that they have no conflict of interest.
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