Original Article

Evaluation of the Effect of Anodization-Colored Titanium Abutments and Zirconia Substructure Thickness on Zirconia Substructure Color: An *In vitro* Study

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Abstract

Background and Aim: The aim of this study is to evaluate the effect of anodized titanium abutments and zirconia substructure thickness on the color of zirconia substructure. **Materials and Methods:** In this study, an electrochemical anodization setup was prepared for titanium coloring. Commercial titanium, anodization-colored yellow and pink titanium, and zirconia were used as different abutment specimens. Thirty zirconia discs in 0.7, 0.9, and 1.1 mm thickness were prepared from zirconia blocks as zirconia substructure specimens ($n = 10$). Zirconia substructure specimens of different thicknesses were placed on abutment specimens of different colors and L*, a*, b* values were measured with a spectrophotometer device. Color difference (ΔE) was calculated according to the CIELab formula by comparing the L*, a*, and b* values obtained on the zirconia abutment with the L*, a*, and b* values obtained on the other abutments. Statistical analyzes were performed with two-way analysis of variance and Tukey Honestly Significant Difference (HSD) test ($p < 0.05$). **Results:** The increase in the thickness of the substructure resulted in a statistically significant difference on ΔE, L*, a*, and b* values ($p < 0.001$). The effect of abutment color had no significant effect on ΔE values. The highest ΔE value was 18.10 at zirconia substructure with 0.7 mm thickness when paired with pink-anodized titanium abutment specimens. **Conclusion:** The thickness of zirconia substructure and the color of titanium abutments affect zirconia substructure color.

Keywords: *Abutment, anodized titanium, color change, spectrophotometry, zirconia*

Introduction

Patients who lose their teeth due to trauma, caries, or periodontal disease may apply to dentists with functional and esthetic problems. In rehabilitation of anterior edentulism, a widely accepted treatment modality is implant-supported-fixed prosthesis.[1] Mainly thanks to improvements in manufacturing process and surface topography, dental implants have a high degree of predictability in osseointegration.[2]

For many years, metal-ceramic restorations have been used for functional and esthetic rehabilitation of edentulism or restoration of defected teeth. From an esthetic point of view, the opaque layer applied over metal substructure may lead to poor light reflection and, accordingly, esthetically unpleasant restorations.[3] In recent years, the use of all-ceramic restorations has increased due to the esthetic limitations of metal-ceramic restorations.[4] Zirconia is used as a substructure material in all-ceramic restorations as a biocompatible material with high mechanical strength, good chemical stability, and low thermal conductivity.[5,6] In addition, for fabrication of tooth or implant-supported all-ceramic-fixed partial prosthesis having more than one pontic, zirconia

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is the only choice of material that still exists in the market.

Titanium, whose mechanical properties and biocompatibility have been widely documented in long-term studies, has been used as an abutment material in dental implants for a long time.[7] However, the metallic grey color of titanium may reflect through gingiva especially in the anterior region where gingival thickness was limited. In addition, it may also compromise the final esthetic outcome of implant-supported-fixed partial prosthesis where zirconia was preferred as the restorative material.[8,9] For this purpose, different abutment materials were sought to provide ideal esthetics, especially in the anterior region and all ceramic abutments have been produced, or the titanium color has been changed by various methods such as electrochemical anodization.[10] When zirconia was used as abutment material, its abrasive effect on the internal hexagon of titanium implant, and fractures in the abutment neck region were reported.[11] Therefore, cementation of zirconia abutment to a titanium base (Ti-base) has been suggested where zirconia cemented to a Ti-base abutment is called a hybrid abutment. The use of hybrid abutments in anterior restorations is becoming more common day by day. However, there is insufficient literature regarding the long-term retention between Ti-base and zirconia abutment.[12,13] From this point of view, the use of titanium abutments under zirconia substructures can still be considered as gold standard for the fabrication of fixed partial prostheses.

Anodizing is an electrochemical process that converts the commercially grey titanium surface into a decorative, durable, corrosion-resistant, anodic oxide finish to minimize the risk of metallic shine through. There is not enough data in the literature on how the zirconia substructure will display optical properties on titanium abutments that have been colored by electrochemical anodization under clinical conditions. The aim of this study was to investigate how titanium abutments, titanium abutments colored with electrochemical anodization method, and zirconia abutments will affect the color of zirconia substructures when they are used with zirconia substructures having different thicknesses. The null hypothesis of this study was that the different substructure thicknesses and different abutment colors has no significant effect on the color of the zirconia substructure.

Materials and Methods

An experimental setup was prepared for electrochemical anodization method. As the color of titanium changes at different volts, the setup was prepared so that the batteries could be inserted and removed according to the desired volt value. The 9V and 1.5V battery slots are connected in series, and the battery slots are fixed with silicon on a platform for easy removal and insertion of the batteries. After fixing battery slots, the cable was extended from the anode (+), and cathode (−) ends in the system, and it was checked whether there was a problem in connection with a multimeter (DT-830D Digital Multimeter; Class, Zhejiang, China) short circuit test. In the pilot preliminary study conducted using experimental set up, it was concluded that volt values should be changed between 50V and 80V to obtain the desired coloring on titanium abutments. For example, for 51V, five pieces of 9V square and four pieces of 1.5V AA batteries (Zinc Carbon Battery; Panasonic, Zellik, Belgium) were inserted into the sockets. Then 250 mL-pure water (Pure water; Meg Kimya, Konya, Turkey) and 1-g trisodium phosphate (Tri-Sodium Phosphate; ZAG Kimya, Istanbul, Turkey) were added to the beaker and mixed to prepare the electrolytic solution required for anodization.[14] 2 × 2 cm^2 specimens were cut from a titanium Grade V (Grade V; Titanium Plate, Tasrimmed, Istanbul, Turkey) ready-made plate to mimic implant abutments. The anode end of the assembly was attached to the titanium specimens, and the cathode end was attached to the aluminum foil suspended from the electrolytic solution. The yellow color was observed between 55 and 60V, and the pink color was between 65 and 70V [Figure 1a]. One yellow- and one pink-colored specimens were selected from the specimens colored by the anodization method. One grey titanium background specimen, which was not anodized, was determined. For the zirconia background, a 0.4 × 2 × 2 cm^3 design was made in a computer program and fabricated (MDX-540; Roland Milling Machines, Shizuoka, Japan) from a zirconia block (Zirkon.X; President Dental, Allershausen, Germany). The specimen was sintered without leaving the block (Mos-B/160 Sintering Furnace; Protherm, Istanbul, Turkey). Then, it was separated from the block under water cooling to obtain a zirconia background.

Colorless, light, and chemically curable (dual-cure) resin cement (Variolink Esthetic DC; Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the obtained specimens to simulate the cement layer, holding it for 30 sec under 500 mg weight. After removing the weights, 30 s of light (Led-B curing light; Woodpecker, Guangxi, China) was applied to initiate the polymerization. It was measured with a digital caliper (Electronic Digital Caliper; AEK-Tech, Istanbul, Turkey) that the cement layer was at equal height everywhere.

Calculation of the zirconia specimen size of this study was made with reference to a similar study.[15] The result of the power analysis performed with the Instat 1 (Instat; GraphPad Software, San Diego, CA, USA) program, revealed that at least five observation values should be taken for each thickness with 95% confidence (1-α), 95% test power (1−β) and f = 1,237 effect size. In this study, 10 specimens of each thickness of zirconia were prepared. Post-hoc power analysis was made using the software program (G*Power V. 3.1.9.6; Heinrich Heine University Düsseldorf, Germany). According to the result of the post-hoc power analysis, the power of the test is 99.99%.

The design of the zirconia specimens to be used as the infrastructure was made in 3D in the computer with the design software (Zirkonzahn.Software; Zirkonzahn, Brunico, Italy). The fabrication of the zirconia specimens, having 0.7, 0.9, and 1.1 mm thickness with 1 cm diameter, was carried out from colorless yttrium stabilized zirconia blocks (Zirkon.X; President Dental, Allershausen, Germany). Since the blocks were not sintered, they were fabricated to be approximately 30% larger than the desired dimensions, considering the shrinkage after sintering. Specimens of different thicknesses obtained were sintered in a sintering furnace (Mos-B/160 Sintering Furnace; Protherm, Istanbul, Turkey). Specimens from the sintered blocks were cut off from the joints of the blocks underwater cooling with an aerator (Alegra TE–95; W&H, Bürmoos, Austria). For standardization, the measurements of the dimensions of the specimens were made three times, and they were divided into groups according to their thickness.

For the optical measurements to be made and repeated in the same way each time, a mechanism made of plexiglass was designed [Figure 1b]. For each zirconia or titanium abutment specimen, substructure specimens having 0.7 mm, 0.9 mm, and 1.1 mm thickness, respectively, were placed on the plexiglass device, and measurements were made with a dental spectrophotometer (Easyshade V; VITA Zahnfabrik, Bad Säckingen, Germany). The spectrophotometer was calibrated before each measurement, and each measurement was made three times. The arithmetic mean of the obtained values was taken.

The L*, a*, and b* values obtained from the measurements were tabulated. The zirconia background was accepted as the standard, and the amount of color change (ΔE) was compared based on this background [Figure 2]. The values were inserted into the formula $\{\Delta E = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}\}$ and calculations were made.

Statistical analysis

Data were analyzed with statistical software (SPSS V.23; IBM, Armonk, NY, USA). A two-way analysis of variance was used to compare L*, a*, b*, and ΔE values according to the thickness and background color, and the Tukey HSD test was used for multiple comparisons. The results were presented as means ± standard deviation for quantitative data, and the significance level was taken as $P < 0.050$.

Results

The two-way analysis of variance of the data obtained from the ΔE values presented that variation in thickness has a statistically significant effect of on ΔE values ($p < 0.001$) [Table 1]. ΔE values differ according to the substructure thickness while the highest average value obtained was at 0.7 mm thickness and the lowest average value was obtained at 1.1 mm thickness [Table 2]. Abutment color change had no statistically significant effect on ΔE values ($p > 0.050$). The lowest ΔE value was observed for zirconia substructure having 1.1 mm thickness when paired with pink anodized titanium specimen. None of the color change values were below the clinically acceptable threshold of ΔE = 5.5.

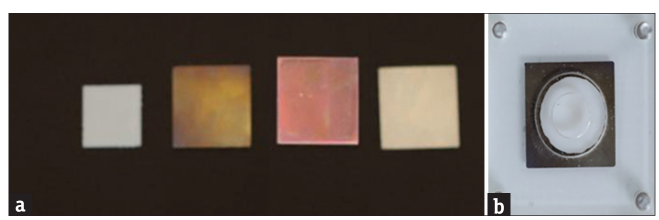

Figure 1: a) Background specimens b) Plexiglass assembly for measurement with spectrophotometer

Table 1: Comparison of ΔEab values regarding thickness and background-color

	Sum of Squares	Sd	Mean of Squares	*F*	*P*	Partial Eta Squared
Thickness	783.475	2	391.738	87.636	<0.001	0.684
Background	14.119	2	7.060	1.579	0.212	0.038
Thickness* Background	13.722	4	3.431	0.767	0.550	0.037

F: Analysis of Variance test statistic, Sd: Degrees of Freedom

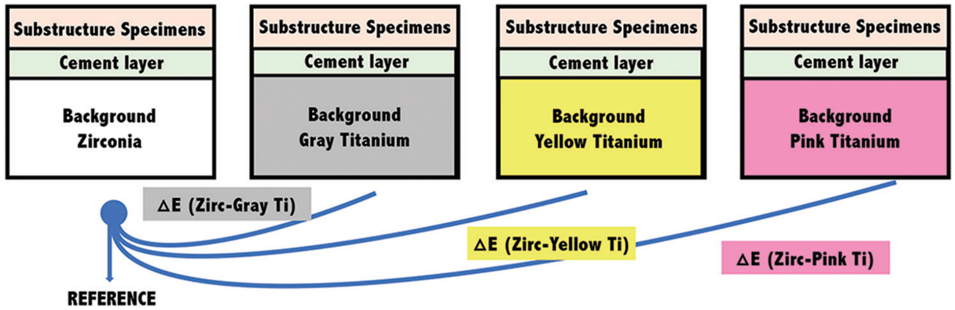

Figure 2: Schematic diagram for color change measurement

Table 2: Descriptive statistics of ΔEab values regarding thickness and background-color

	0.7 mm	0.9 mm	1.1 mm	Total
Pink	18.10±3.29	13.16±2.15	10.01±0.54	13.76±4.05
Yellow	17.90±2.39	13.16±1.67	10.38±2.00	13.81±3.72
Grey	16.12±2.44	12.45±1.89	10.27±1.57	12.95±3.12
Total	17.38±2.79[a]	12.92±1.88[b]	10.22±1.45[c]	13.51±3.63

[a-c]There is no difference between groups with the same letter

Discussion

This study aimed to determine the ideal thickness of the zirconia substructure and the appropriate titanium abutment color with the data obtained by changing the color of the titanium abutment and the zirconia substructure thickness used. The results of this study revealed that the color of the zirconia substructure was significantly affected by the thickness of the zirconia substructure material where changing the color of titanium abutment specimens to yellow and pink by the electrochemical anodization method did not significantly affect the zirconia substructure color. The null hypothesis stating that the different substructure thicknesses and different abutment colors has no significant effect on the color of the zirconia substructure was partially rejected.

It was reported that zirconia-based restorations are affected by the color of the underlying structure and the use of zirconia abutments under all ceramic restorations provided the best optical results in implant supported restorations.[16] For these reasons, zirconia abutment was evaluated as the control group in this study, and color change comparisons were made according to the zirconia abutment groups.

Gingival color may also be affected by the color of abutment that was used.[17] It was stated that the pink and yellow as abutment color has also increased esthetics in the peri-implant mucosa.[18] Therefore, this study aimed to investigate the resultant effect of abutments colored with electrochemical anodization method, paired with the zirconia based fixed prosthesis.

There are different methods for changing color of titanium reported in literature where colors obtained by the thermal-oxidation method were not considered uniform, and the nickel-plating method had disadvantages such as causing allergic problems in some patients.[18,19] In the present study, electrochemical anodization method was preferred since the required equipment was not complicated, inexpensive, and simple to use in clinical conditions.[14] In this method, the thickness of the oxide layer is related to voltage, which affects the color formed. In addition, the titanium oxide layer increases the corrosion resistance of titanium. If the desired color cannot be obtained, the anodization process can be repeated by adjusting the voltage after the titanium surface is effortlessly polished and cleaned.[20]

Color analyses made with spectrophotometers are reproducible and reliable, express the color mathematically, detect colors that even the human eye cannot perceive, and at the same time, the margin of error of spectrophotometers is shallow. For these reasons, the spectrophotometer, frequently used in *in vivo* and *in vitro* research in dentistry, was preferred in this study.[21,22] Specimens with flat surfaces obtained from titanium and zirconia blocks were used in our study since much more reliable results are obtained on flat surfaces with a spectrophotometer.[23]

In a study where detection and perception of color regarding perception and age was investigated, it was reported that according to RAL color system, measured spectrophotometer and positioned in the CIE l*a*b* color space, white and pink colors have close proximity where yellow was located far from those two previous colors.[24] In accordance, among grey titanium, yellow anodized titanium, pink anodized titanium abutments, the lowest ΔE value for zirconia substructure having 1.1 mm thickness paired with pink anodized titanium specimen was observed in this study [Table 2]. This may be attributed to the proximity of white and pink colored, zirconia substructure and anodized titanium abutment specimen respectively.

The translucency of zirconia increases when the amount of yttrium in the zirconia content is increased from 3% to 5%.[25] A relatively lower ΔE value for the unanodized grey titanium abutment specimen paired with zirconia substructure was very close to the lowest ΔE value obtained with anodized-pink colored abutment in this study. This result may be explained by the high translucency of zirconia substructure fabricated from a zirconia block containing 5Y-TZP. In this study, by increasing the thickness of the zirconia substructure from 0.7 mm to 1.1 mm, ΔE values decreased in comparison made with the zirconia substructure paired with zirconia abutment specimens. This result may be explained by the inverse correlation between thickness and translucency. It has been reported that the thickness of zirconia restorations was associated with the translucency of the restoration, where the light transmittance of the substructure decreases, and its ability to mask abutment colors increases.[26] In accordance with this study, the masking ability of zirconia base materials with 0.8 and 1.5 mm thickness were compared, and the increase of masking ability as the thickness increased was reported.[27]

In dentistry, the ΔE equation can express color differences in visual perception as a unit.[28] It has been stated that it is more appropriate to examine the ΔE value rather than examining the difference between L*, a*, and b* values alone.[29,30] In previous studies where masking ability and translucency of zirconia on different backgrounds was examined, the detectability and clinical acceptability thresholds were assumed to be ΔE = 5.5 and ΔE = 2.6, respectively.[27] In present study, regardless of thickness, for all abutment colors, ΔE values were above 5.5 reported. This condition states that whether anodization is done or not if a zirconia-based restoration is to be made on a titanium abutment, the abutment color may affect the substructure color. Thicker zirconia substrusctures may be needed to mask the titanium color with the zirconia base material.

Another component affecting the final color of the implant supported zirconia based fixed restorations is the cement used. The effect of cement color and cement thickness on the color of the final zirconia restoration was reported.[31] In present study, a transparent adhesive resin cement in standard thickness was applied over the abutment specimens to ignore the possible effect of the cement color and thickness on the color of the zirconia substructure. The data obtained from this study revealed that unlike some previous studies, when pink and yellow colored titanium abutment specimens and zirconia abutment specimen were compared, there was a detectable color change in the color of the zirconia substructure at all thicknesses.[16,32-35] This may be attributed to the different cement type, cement color, cement thickness and/or substructure thickness used in previous studies. There were some limitations in this study. Differences in the composition, color and film thickness of different cement materials may affect the results. In addition, the effect of different zirconia materials has not been evaluated. Further studies are required to confirm our results by evaluating the effects of cement type and zirconia translucency on the zirconia substructure color.

Conclusion

Within the limitation of this study, following conclusion can be drawn:

1- Regardless of the anodization process, the abutment color affects the zirconia substructure color.

2- The thickness of the zirconia substructure affects the zirconia substructure color, and the use of thicker zirconia substructure may be recommended if a titanium abutment will be used.

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Conflicts of interest

There are no conflicts of interest.

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