



Comparison of Final Shade Outcomes of High-Translucent Monolithic Zirconia Crowns on Anodized and Non-Anodized Titanium Abutment Backgrounds

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Research Article

Abstract

Objectives: To evaluate the effects of two different abutment backgrounds: non-anodized and gold-colored anodized titanium abutments, and the application of opaque coloring liquids on the color outcomes of high-translucent monolithic zirconia crowns.

Materials and Methods: Forty crown-abutment samples were fabricated using CAD-CAM technology and divided into four groups (n=10 per group): non-anodized titanium (TI) and gold-colored anodized titanium (G) abutments, each combined with zirconia crowns either with opaque liners (OP) or without opaque liners (NO). Color measurements were performed using a spectrophotometer (SpectroShade™ Micro II) to determine the CIELab values of the specimens. The CIEDE2000 formula was applied to calculate color differences (ΔE_{00}) between each specimen and the zirconia crown on a PMMA abutment (control). The ΔE_{00} values were further compared against the 50:50% acceptability thresholds for dentists ($\Delta E_{00} < 2.41$) and patients ($\Delta E_{00} < 2.83$). The ΔE_{00} data were analyzed using one-way ANOVA followed by Tukey's post hoc test, with statistical significance set at $p < 0.05$.

Results: Crowns with opaque liners (G+OP and TI+OP) showed significantly lower ΔE_{00} values, achieving patients' acceptable thresholds ($\Delta E_{00} < 2.83$), compared to crowns without liners (G+NO and TI+NO) ($p < 0.05$). No significant differences were found between the G+OP and TI+OP groups or between the G+NO and TI+NO groups.

Conclusions: The study concludes that applying opaque coloring liquids effectively masked the grayish color of titanium abutments and improved esthetic outcomes, while gold anodization alone provided limited color improvement. Clinicians are encouraged to incorporate opaque liners for optimal color outcomes in implant-supported zirconia restorations. Further research is recommended to explore long-term performance and alternative techniques.

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Introduction

Dental implants have established themselves as a reliable treatment modality for restoring partial and complete edentulism, providing considerable functional, phonetic, and esthetic benefits for patients. Nevertheless, achieving a harmonious aesthetic outcome in the anterior region presents notable challenges, particularly when the color of the final restoration must seamlessly integrate with the surrounding dentition.¹ To address these challenges, several factors warrant attention, including implant positioning, angulation, the configuration of components, and the materials utilized in fabricating fixed dental prostheses (FDP).²

Titanium (Ti) abutments, while considered the gold standard in implant restorations, pose esthetic limitations when placed in the anterior maxilla, especially when paired with highly translucent ceramic restorations, such as lithium disilicate. In cases involving thin gingival biotypes or a prominent smile line, the metallic hue of titanium may appear through the gingiva, thereby compromising the esthetic integrity of the restoration and peri-implant soft tissues.³ To mitigate this issue, various innovative approaches have been developed.

One such approach is the application of a gold-colored coating, commonly titanium nitride, to the zirconia coping, effectively masking the underlying gray hue of the titanium abutment. Studies suggest that this method enhances the esthetic outcome by reducing the perceptible color discrepancy in comparison to traditional Ti abutments with zirconia copings.⁴ Nonetheless, some concerns exist regarding the allergenic potential associated with this coating material.⁵

The emergence of dense sintered zirconia (Zir) abutments marks another significant advancement, particularly for anterior applications.

Recent research indicates that zirconia abutments offer esthetic advantages over titanium, reflected in improved pink esthetic scores and favorable spectrophotometric outcomes.⁴ Despite these benefits, zirconia abutments are associated with potential drawbacks, including abrasiveness toward the titanium implant's internal hexagon and susceptibility to fractures at the abutment neck.⁶ To address these issues, hybrid abutments—comprising zirconia cemented onto titanium bases (Ti-base)—have been introduced. Although promising, long-term evidence on the retention of Ti-base and zirconia abutments remains limited.^{7,8}

A further development in implant dentistry is the anodic oxidation of titanium, an electrochemical technique introduced in the 1950s that creates ceramic TiO₂ layers, commonly referred to as anodization.⁹ This modification not only conceals the gray color of titanium but also enables the creation of oxide films of varying thickness, producing different hues through light interference within the titanium dioxide layer.^{10,11} Originally employed for component identification, anodized titanium in gold and pink shades has shown particular esthetic benefits, with studies demonstrating enhanced peri-implant soft tissue esthetics compared to non-anodized abutments.^{12,13} Despite the potential of anodized abutments, literature evaluating their impact on the color of zirconia restorations remains sparse and often inconsistent due to variations in ceramic materials, abutment substrates, luting agents, and color measurement methodologies. In light of these gaps, the current study aims to assess the influence of anodized titanium abutments and the application of zirconia coloring liquid on the inner surfaces of high-translucency monolithic zirconia restorations.

Materials and Methods

This pilot study was conducted as an *in vitro* experimental design comprising four experimental groups, with a total of 40 specimens ($n = 10$ per group). Due to the lack of comparable studies in the literature, an a priori sample size calculation was not feasible. However, based on the results from the pilot data, the effect size was calculated as Cohen's $f = 10.92$. A post hoc sample size analysis was then performed using G*Power (version 3.1.9.7), with an alpha level of 0.05 and a power of 0.80. The calculated minimum sample size required was 8

specimens, confirming that the sample size used in this study ($n = 10$ per group) was adequate.

Sample preparation: A maxillary central incisor implant replica (Implant analog Ø4.5, Dentium SuperLine® & Implantium®) was placed in position #11 on a dentoform model (Ultistratumu® Flexible Resin, Zirkonzahn). A scanning body (Scanning jig Ø4.5, Dentium SuperLine® & Implantium®) was inserted and scanned using a dental lab 3D scanner (S600 Arti Scanner, Zirkonzahn). The abutment and crown designs were created simultaneously in CAD software (Zirkonzahn Modellier) to maintain uniform crown thickness (Figures 1, 2).

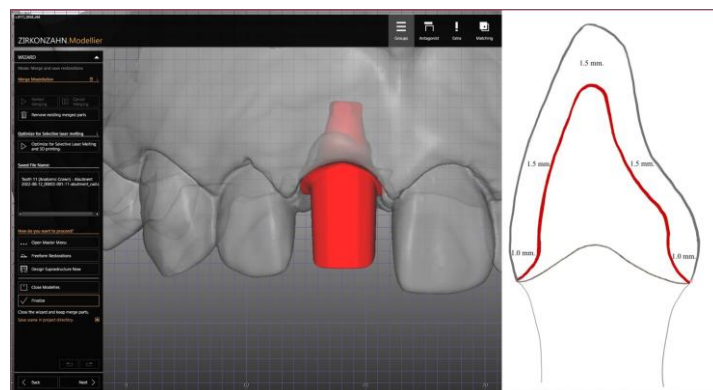


Figure 1 The design abutment on dental system software (Zirkonzahn Modellier)

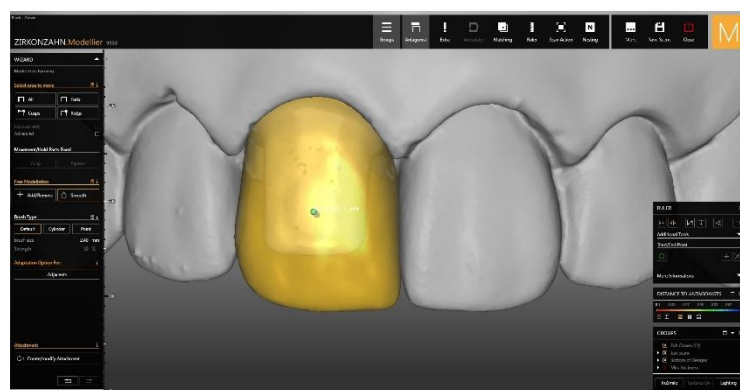


Figure 2 The design crown on dental system software (Zirkonzahn Modellier)

Custom implant abutments were fabricated using a CAD/CAM milling machine (Zirkonzahn M4) with a titanium blank disc (TITAN 5, Zirkonzahn), while the control abutment was produced from shade A3 polymethyl methacrylate (PMMA, Ultistratumu® Flexible Resin). High-translucency zirconia blocks (Prettau® 3 Dispersive®, ZirkonZahn System 95 mm) in shade A3 were used to create two crown groups: non-opaque liner crowns (NO) and opaque liner crowns (OP), both 1.5 mm thick at the facial surface's mid-third, with a 0.01 mm cement space set in the CAD software. All crowns were fabricated as per manufacturer instructions. The opaque-liner group's inner surface was coated with one uniform brush layer of Luxen CL dental liquid (white) before sintering (Figure 3). Forty implant abutments were customized into two backgrounds: 20 non-anodized titanium abutments (Ti) and 20 gold-anodized titanium abutments (G), fabricated per manufacturer guidelines (Figure 4).

Calibration and color measurement: A trained examiner performed color measurements with a spectrophotometer (SpectroShade™ Micro II MHT, Verona, Italy), calibrated before each use according to manufacturer instructions and operated in Vita Classic mode. A non-opaque liner zirconia crown on a shade A3 PMMA control abutment served as the reference restoration (control group). Experimental setups included two types of abutments (gold-anodized and non-anodized titanium) and two zirconia crown types (opaque and non-opaque lining). The crowns were fixed to the abutments with clear try-in paste (PANAVIA V5, Kuraray) to simulate resin cement appearance, then immediately measured with a spectrophotometer. The intersection of the horizontal and vertical lines at the middle third of the adjacent teeth and the midpoint of the cervical gingiva was marked as the color measuring point for precise and repeatable measurements (Figure 5).

Following calibration, the spectrophotometer was positioned centrally at a 90° angle on each sample's reference point. Using the device's tooth positioning guidance, the sample was centered in the frame, with a cross confirming optimal positioning for measurement. The image of the tooth was captured when the line of a cross turned green, ensuring consistent angle and positioning across samples. All 40 samples and the control group were measured against a matte black background in controlled environmental conditions.

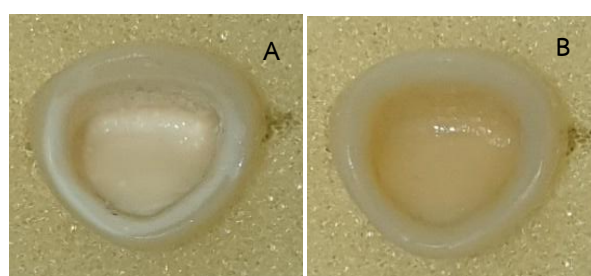


Figure 3 Monolithic zirconia crown; (A) with opaque liner and (B) without opaque liner

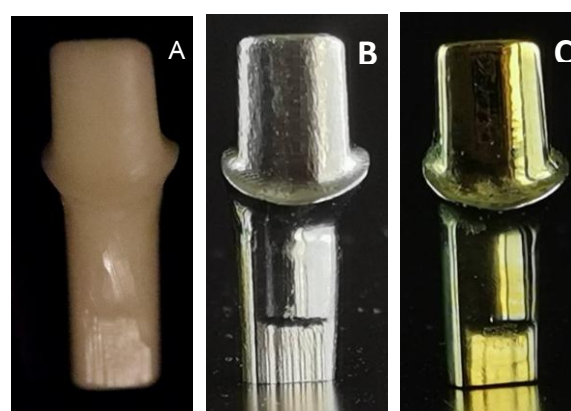


Figure 4 Customized abutment (A) control (B) titanium and (C) gold anodized

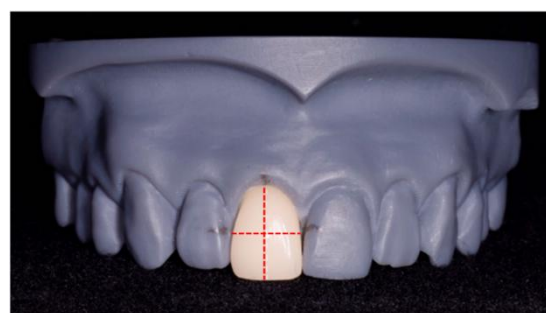


Figure 5 The dentoform model with color measuring point.

The color comparison process using the SpectroShade™ device and its Compare Tool software is illustrated (Figure 6). The software's synchronization function was utilized to overlay the sample and control crown images, ensuring alignment of the measurement areas for accurate visual and numerical comparison. A square-shaped measurement cursor with a standardized size of 30 units was applied. The Synchronous Measurement feature allowed simultaneous cursor positioning on both images—when placed on a color measuring point in the control image, the software automatically mirrored the cursor in the same position on the sample image.

Color values were recorded in the CIELab color space, providing coordinates for lightness (L^*), red-green chromaticity (a^*), and yellow-blue chromaticity (b^*). The baseline color coordinates of the control group (L_0 , a_0 , b_0) were compared to those of the experimental groups to calculate the color differences: $\Delta L = L_1 - L_0$, $\Delta a = a_1 - a_0$, and $\Delta b = b_1 - b_0$. The overall color difference (ΔE^*_{ab}) was automatically computed by the software using the CIELab formula: $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.

Additionally, the color difference using the CIEDE2000 (ΔE_{00}) formula was calculated using the following equation: $\Delta E_{00} = \{[\Delta L'/(k_L S_L)]^2 + [\Delta C'/(k_C S_C)]^2 + [\Delta H'/(k_H S_H)]^2 + R_T[(\Delta C'/k_C S_C) \times (\Delta H'/(k_H S_H))]^2\}^{1/2}$. In this formula, $\Delta L'$, $\Delta C'$, and $\Delta H'$ represent the differences in lightness, chroma, and hue, respectively. The parametric factors k_L , k_C , and k_H were set to 1 in this study to adjust for experimental conditions. The weighting functions S_L , S_C , and S_H serve to correct for variation in the location of the color difference pairs within the L^* , a^* , and b^* coordinates. Additionally, R_T is a rotation function that accounts for the interaction between chroma and hue differences, particularly in the blue region.¹⁴

Mean L^* , a^* , b^* , and ΔE_{00} values for each group were statistically compared to the control group. ΔE_{00} values were further judged against recently reported 50:50 % acceptability thresholds for dentists (2.41) and patients (2.83).¹⁵ The materials and equipment used in this experiment are summarized (Table 1), and the specimen grouping and color measurement protocol is illustrated in the flowchart (Figure 7).

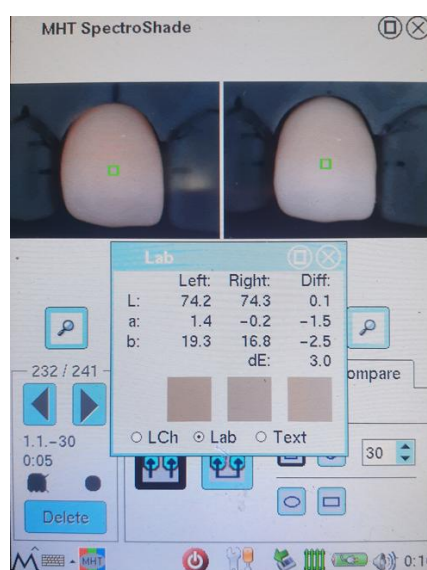
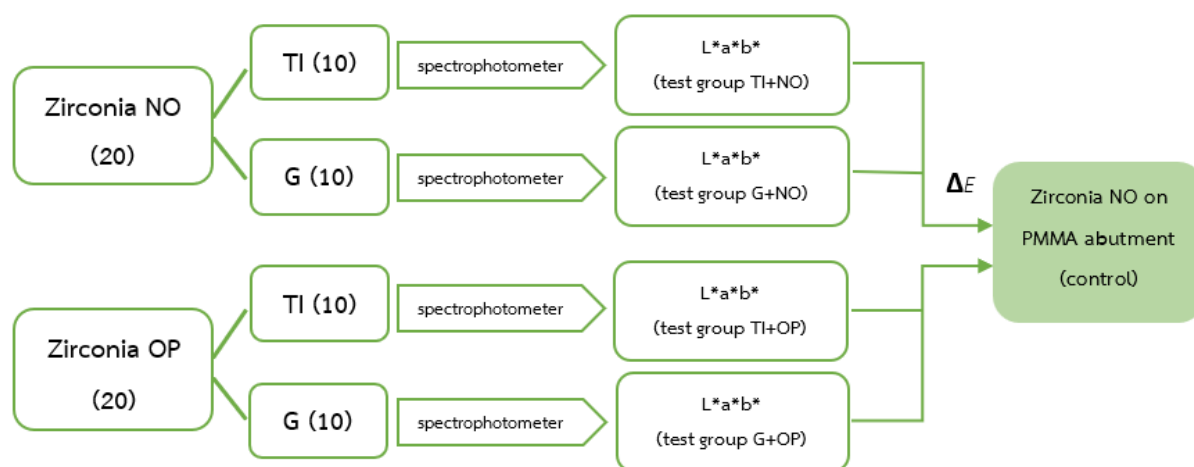


Figure 6 The compare tool integrated with the SpectroShade device

Table 1 The summary of materials and equipment used in this study

Type	Brand	Composition
Monolithic zirconia	Prettau® 3 Dispersive®, Zirkonzahn	ZrO ₂ main component Y ₂ O ₃ max. 12% Al ₂ O ₃ max 1% SiO ₂ max.0.02% Fe ₂ O ₃ max. 0.01%
Coloring liquid zirconia in white color	Luxen CL dental liquid, DENTALMAX Co.,Ltd	Water based porcelain powder with inorganic pigment
dentoform model	Ultistratum® Flexible resin, Zirkonzahn	polymethyl methacrylate in grey shade
PMMA milled abutment	Ultistratum® Flexible resin, Zirkonzahn	polymethyl methacrylate in shade A3
Titanium blank disc	Titan 5 Zirkonzahn	90% titanium, 6% aluminum, 4% vanadium (Ti-6Al-4V)
Implant analog Ø4.5	Dentium SuperLine® & Implantium®	
Scanning jig for customized abutment Ø4.5	Dentium SuperLine® & Implantium®	
Clear try-in paste	PANAVIA V5 Try-in Paste, Kuraray	
Spectrophotometer	SpectroShade™ Micro II, MHT; Verona, Italy	
Dental lab 3D lab scanner	S600 Arti Scanner, Zirkonzahn	
CAD/CAM milling machine	Zirkonzahn M4 and M5 CAD/CAM Milling Machine	

**Figure 7** Flowchart of Specimen Grouping and Color Measurement Protocol

Statistical Analysis: All statistical analyses were performed using IBM SPSS Statistics version 26.0. Descriptive statistics—including mean, standard deviation, minimum, and maximum values—were calculated for the CIELab parameters (L^* , a^* , b^*) and ΔE_{00} across the study groups. The normality of data distribution was assessed using the Shapiro–Wilk test.

Since the CIELab values did not meet the assumptions of normality or homogeneity of variance, non-parametric tests were applied. The Kruskal–Wallis test was used to compare L^* , a^* , and b^* values among groups, followed by pairwise comparisons using the Dunn–Bonferroni correction when significant differences were identified. In contrast, ΔE_{00} values

were normally distributed, as confirmed by the Kolmogorov–Smirnov test ($p>0.05$). Therefore, a one-way ANOVA was used to assess differences in ΔE_{00} among the groups, followed by Tukey's post hoc test for pairwise comparisons. A significance level of $p<0.05$ was used for all statistical tests.

Results

Color Measurement (L^* , a^* , and b^* Values):

In this study, the control group is PMMA abutment with non-opaque liner zirconia crown and the 4-study groups are 1. Gold anodized abutment with Opaque liner zirconia crown (G+OP) 2. Titanium abutment with Opaque liner zirconia crown (TI+OP) 3. Gold anodized abutment with non-opaque liner zirconia crown (G+NO) and 4. Titanium abutment with non-opaque liner zirconia crown (TI+NO).

L^* Values: The statistical analysis of the lightness (L) values, representing the lightness, darkness, and luminosity, is presented (Figure 8 and Table 2). The analysis revealed varying degrees of L^* values across the four study groups. A significant difference ($p<0.05$) was observed in the L^* values when

comparing the TI+NO group with both the TI+OP and G+OP groups. Similarly, significant differences were found between the G+NO group and the TI+OP and G+OP groups (Table 3). Notably, the L^* values of all study groups with opaque liner zirconia crowns were closer to the L^* value of the control group, indicating a closer match in lightness between the crowns with opaque liners and the control restoration.

a^* Values: The statistical analysis of the red-green color component (a^* value) is presented (Figure 9 and Table 2). The control group exhibited a positive a^* value, indicating the presence of red components, whereas all study groups displayed negative a^* values, reflecting a shift toward green components. The a^* value was significantly higher ($p<0.05$) in the G+OP group compared to the TI+NO and G+NO groups, indicating less greenness in the crowns with gold anodized titanium abutments and opaque liners. No significant differences were found between the other study groups, suggesting a consistent presence of green components across these groups. (Table 3)

Table 2 The summary of statistical values for each group

Group(n)	Statistical values	CIE values			Color difference	
		L^*	a^*	b^*	ΔE^*_{ab}	ΔE_{00}
Control	Mean	74.20	1.40	19.30		
G+OP (10)	Mean	75.34	-0.25	16.74	3.39	2.55
	Minimum	74.50	-0.40	16.00	3.10	2.37
	Maximum	77.00	0	18.70	3.80	2.88
	Std. Deviation	0.67	0.14	0.72	0.19	0.15
TI+OP (10)	Mean	74.73	-0.45	18.10	2.94	2.58
	Minimum	70.50	-0.70	16.80	1.90	2.06
	Maximum	76.20	-0.20	20.20	4.00	3.31
	Std. Deviation	1.73	0.17	1.16	0.67	0.41
G+NO (10)	Mean	70.12	-0.66	15.28	6.11	4.55
	Minimum	68.80	-1.50	14.30	5.00	3.58
	Maximum	70.90	0	16.80	7.50	5.39
	Std. Deviation	0.60	0.48	0.77	0.73	0.48
TI+NO (10)	Mean	69.73	-0.57	14.15	7.10	5.05
	Minimum	68.70	-1.10	13.80	6.00	4.39
	Maximum	70.80	-0.20	14.70	7.70	5.83
	Std. Deviation	0.76	0.23	0.31	0.61	0.46

Table 3 Pairwise Comparisons of L, a, b, and ΔE_{00} Values Among Study Groups ($p < 0.05$)

Compared groups	p-value			
	L*	a*	b*	ΔE_{00}
TI+NO - G+NO	1.000	1.000	0.432	0.036
TI+NO - G+OP	0.000	0.008	0.001	0.000
TI+NO - TI+OP	0.001	1.000	0.000	0.000
G+NO - G+OP	0.002	0.029	0.372	0.000
G+NO - TI+OP	0.008	1.000	0.002	0.000
G+OP - TI+OP	1.000	0.179	0.450	0.999

The Kruskal–Wallis test was used to compare L*, a*, and b* values among groups, followed by pairwise comparisons using the Dunn–Bonferroni correction. Adjusted p-values for L*, a*, and b* are reported to account for multiple comparisons. ΔE_{00} values were analyzed using one-way ANOVA followed by Tukey’s Honestly Significant Difference (HSD) test. Statistical significance was set at $\alpha = 0.05$.

b* values: The statistical analysis of the yellow-blue color component (b* values) is presented (Figure 10 and Table 2). All study groups, including the control group, exhibited positive b* values, indicating the presence of yellow components. The b* value was significantly lower ($p < 0.05$) in the TI+NO group compared to the G+OP and TI+OP groups, suggesting a reduced yellow intensity in the crowns with titanium abutments and no opaque liner. Additionally, the b* value of the G+NO group was significantly lower than that of the TI+OP group, underscoring the effect of the opaque liner in enhancing the yellow coloration when compared to crowns without the liner. There were no statistically significant differences in b* values between the following groups: TI+NO and G+NO, G+NO and G+OP, and G+OP and TI+OP. (Table 3) These findings suggest that while the opaque liner and abutment type influence the yellow intensity, not all group comparisons displayed significant changes, indicating the specific conditions under which the liner and abutment materials affect the yellow-blue coloration.

The color differentiation (ΔE_{00}): The distribution of ΔE values across the four groups is illustrated (Figure 11). Both G+OP and TI+OP groups exhibited the lowest median color differences, approximately 2.5, with relatively narrow interquartile ranges. Table 2 presents the mean and standard deviation of the CIE L*, a*, and b* values, along with the color difference (ΔE_{00}), medians, and p-values for the four groups. The ΔE_{00} data were analyzed using descriptive statistics, while inferential analysis was performed using one-way ANOVA followed by Tukey’s post hoc test, with statistical significance set at $p < 0.05$ (95% confidence interval). The mean ΔE_{00} values for the TI+NO, G+NO, TI+OP, and G+OP groups were 5.05, 4.55, 2.58, and 2.55, respectively, with the lowest ΔE_{00} value observed in the G+OP group. One-way ANOVA showed significant differences among groups ($p < 0.001$). When judged against the current 50:50% acceptability limits (2.41 dentists, 2.83 patients), only the opaque-lined groups fell within patient tolerance. Tukey’s HSD indicated that both G+NO and TI+NO had significantly higher ΔE_{00} values than TI+OP and G+OP ($p < 0.001$), while no significant difference was detected between TI+OP and G+OP ($p = 0.999$) or between G+NO and TI+NO ($p = 0.036$) (Table 3).

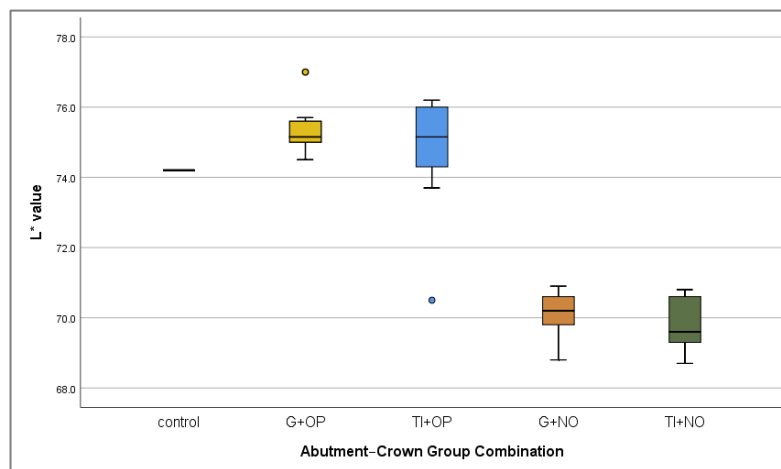


Figure 8 Box plot showing the distribution of L* values among the four groups (G+OP, TI+OP, G+NO, and TI+NO).

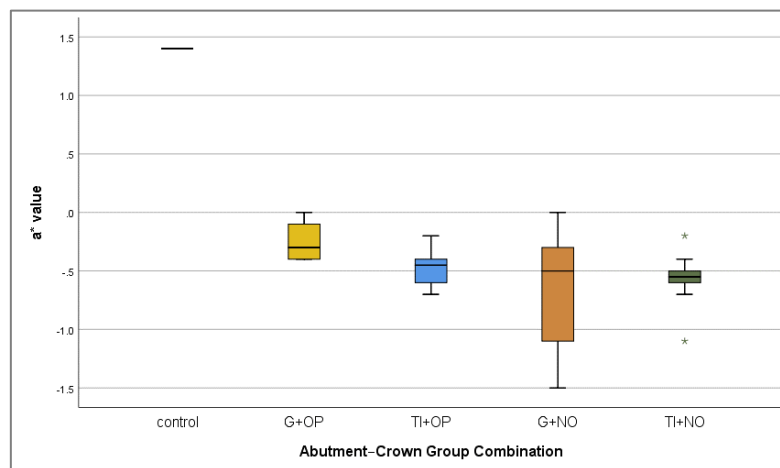


Figure 9 Box plot showing the distribution of a* values among the four groups (G+OP, TI+OP, G+NO, and TI+NO).

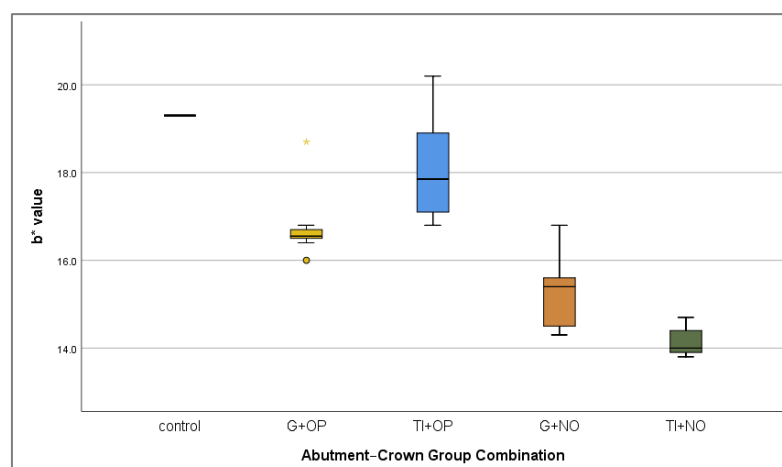


Figure 10 Box plot showing the distribution of b* values among the four groups (G+OP, TI+OP, G+NO, and TI+NO).

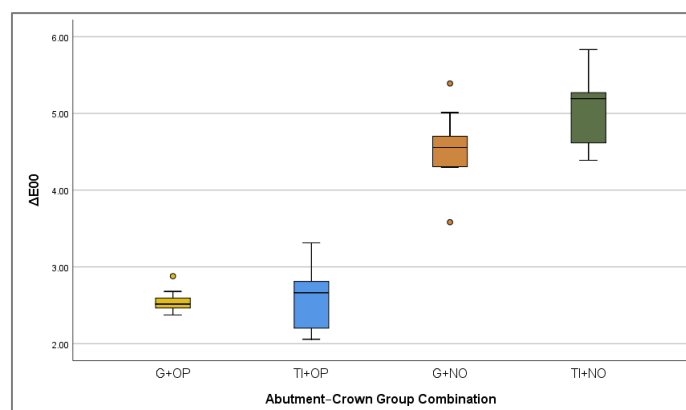


Figure 11 Box plot showing the distribution of ΔE_{00} values among the four groups (G+OP, TI+OP, G+NO, and TI+NO).

Discussion

This study evaluated the color difference of high-translucent monolithic zirconia crowns on two types of titanium abutment backgrounds—non-anodized and gold-anodized—and assessed the impact of using a coloring liquid on the inner crown surface. Our findings underscore the significant influence of both the abutment color and the application of an opaque liner on the esthetic outcome of zirconia restorations. Crowns with an opaque liner demonstrated superior color matching to natural dentition compared to those without, while gold anodization alone did not provide sufficient esthetic enhancement.

Titanium, with its favorable biocompatibility and mechanical strength, remains the standard abutment material; however, its gray color can adversely impact esthetics in anterior applications, particularly in thin gingival biotypes and high smile lines.^{16,17} Strategies to mitigate titanium's grayish hue include applying opaque coloring liquids and anodizing titanium abutments in gold tones. Our study demonstrates that while both methods have benefits, the use of an opaque liner yielded the most effective color enhancement for high-translucent zirconia crowns.

The zirconia used in this study, characterized by its multilayer structure and M3Y-5Y hybrid composition, shows varied translucency that depends on factors like yttria content and grain size.¹⁸ These properties interact with abutment and cement color to influence the final esthetic outcome. To replicate clinical conditions, our study employed anatomically contoured crowns rather than flat discs, providing a more accurate assessment of the material's performance under real-world conditions. Studies by Sun et al. and Malkondu et al. emphasize the importance of crown thickness, noting that at 1 mm, zirconia offers both esthetic translucency and strength comparable to metal-ceramic crowns.¹⁹ However, thinner crowns increase translucency but make the final shade more sensitive to underlying colors.²⁰ Thus, a crown thickness of 1.5 mm, as used in this study, balances translucency and masking ability, ensuring a stable color outcome when paired with opaque liners.²¹

Our results show that gold anodization of titanium abutments alone does not sufficiently enhance color matching compared to non-anodized abutments. This aligns with previous studies suggesting that gold anodization has limited effectiveness in highly translucent systems.^{22,23} Analysis of L^* (lightness), a^* (red-green), and b^* (yellow-blue) values revealed that crowns with

opaque liners (TI+OP and G+OP) closely matched the control group's lightness, effectively masking the dark titanium background. This finding supports other research showing that opaque liners significantly improve lightness, reducing the gray effect of titanium and enhancing natural appearance.^{23,24}

Regarding a^* values, the control group exhibited positive (red) values, while all study groups showed a shift toward negative (green) values. The opaque liner in the G+OP group notably reduced this greenish hue, suggesting that both the liner and anodization contribute to a color closer to the red tones seen in natural teeth. For b^* values, crowns with opaque liners (TI+OP and G+OP) showed enhanced yellow tones compared to non-lined crowns, closely approximating the control group. This highlights the importance of opaque liners in replicating natural tooth coloration.

In dentistry, the ΔE equation is often used to quantify color differences in visual perception. It has been recommended that overall color differences (ΔE values) provide a more meaningful assessment of visual perception than evaluating L^* , a^* , and b^* components individually.²⁵ Nowadays CIEDE2000 (ΔE_{00}) has become the benchmark color-difference metric in dentistry because its weighting functions for lightness, chroma, and hue—together with a blue-green rotation term and tunable k -factors—provide a perceptual fit superior to the 1976 CIELAB equation.²⁶ Recent psychophysical work has also refined the 50:50% acceptability threshold (AT) on this perceptually uniform scale. A multicenter trial on monochromatic ceramics established an overall AT of 1.8²⁷, chroma-stratified research on contemporary resin composites reported AT values between 1.80 and 2.84 depending on color saturation²⁸, and the latest dentist-versus-patient study using VITA 3D-Master shade tabs found ATs of 2.41 (dentists) and 2.83 (patients).¹⁵ Although these

limits vary with material class, chroma, specimen geometry, and observer mix, they all lie within a ΔE_{00} corridor of 1.8–3.0, providing a practical consensus window for clinical acceptability.^{15,27,28}

Applying these updated limits to the present data shows that the mean ΔE_{00} values for TI+NO (5.05) and G+NO (4.55) far exceed even the most tolerant patient AT, indicating an unmistakable color mismatch. By contrast, the opaque-lined groups TI+OP (2.58) and G+OP (2.55) fall within patient acceptance and only slightly above the stricter dentist criterion, demonstrating that an opaque liner remains essential for the reliable esthetic integration of high-translucency zirconia crowns over metallic abutments.¹⁵

Our findings align with Kengtanyakich S et al. and Sethakamnerd P et al., who demonstrated that zirconia crowns on titanium bases exceed clinically acceptable color differences without masking techniques.^{23,24} These studies confirm that liners effectively mask the gray tone of titanium abutments, enhancing the visual match with natural teeth.

Our results also support findings by Basegio MM et al., who reported that zirconia crowns lacking liners often fail to meet clinical esthetic thresholds when paired with titanium abutments.²⁹ Similarly, research by Bass BB indicates that even variations in zirconia thickness alone are insufficient to fully mask titanium's color, highlighting the importance of combining thickness with opaque liners.²² This combination helps optimize esthetics, particularly for high-translucency zirconia crowns, which are otherwise strongly influenced by abutment color.

Although some studies suggest that gold anodization can improve esthetic outcomes, our results indicate that its effect is not as pronounced as that of opaque liners. For instance, Bass BB et al. observed that anodization provided a moderate improvement but fell short of the color-matching

efficacy achieved by liners.²² The discrepancy may be due to differences in the anodization process, gold shade, or zirconia system properties. The unique formulation of zirconia type in this study may interact differently with anodized abutments, resulting in reduced benefits from anodization alone.

These findings suggest that optimal esthetic outcomes for high-translucent zirconia crowns on titanium abutments are best achieved with the application of opaque liners rather than relying on gold anodization alone. Clinicians should consider both zirconia material properties and abutment selection to enhance esthetic integration. Further studies could explore the effects of different zirconia compositions, crown thicknesses, and cement choices to refine these recommendations for clinical practice. While this study provides valuable insights, there are limitations, such as the controlled *in vitro* environment, which may not fully replicate *in vivo* conditions. Additionally, variations in cement composition, film thickness, and clinical handling can affect results. Future research should aim to investigate these variables in more detail to provide more comprehensive guidelines for clinical practice.

Conclusions

Within the limitations of this study, high-translucent zirconia crowns demonstrated significantly different shade outcomes depending on both the abutment background and the use of an opaque liner. Crowns placed directly on titanium abutments exhibited color differences that exceeded clinically acceptable thresholds for both clinicians and patients. In contrast, the application of an opaque liner effectively reduced the color mismatch to within tolerable clinical limits. These findings support the use of opaque liners to enhance the esthetic integration of high-translucent zirconia restorations over both titanium and gold-anodized abutments.

Ethics

This *in vitro* study did not involve human participants or animals; therefore, ethical approval was not required.

Conflict of Interest

The authors declare no conflict of interest.

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การเปรียบเทียบสีครอบฟันโมโนลิธิกเซอรโคเนียชนิดโปร่งแสงสูงบนพื้นหลังที่แตกต่างกันของหลักยึดไทเทเนียมอะโนไดซ์และไม่อะโนไดซ์

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บทความวิจัย

บทคัดย่อ

วัตถุประสงค์: เพื่อประเมินผลกระทบของพื้นหลังของหลักยึดรากฟันเทียม 2 ประเภทคือหลักยึดไทเทเนียมแบบไม่อะโนไดซ์และอะโนไดซ์สีทองรวมถึงการใช้สารทึบแสงต่อผลลัพธ์สีของครอบฟันเซอรโคเนียแบบโมโนลิธิกชนิดโปร่งแสงสูง

วัสดุอุปกรณ์และวิธีการ: ตัวอย่างครอบฟัน-หลักยึดรากฟันเทียมจำนวน 40 ชิ้นถูกเตรียมด้วยเทคโนโลยี CAD-CAM โดยแบ่งออกเป็น 4 กลุ่ม (กลุ่มละ 10 ชิ้น) ได้แก่ หลักยึดไทเทเนียมที่ไม่ได้ผ่านการอะโนไดซ์ (TI) และหลักยึดไทเทเนียมที่ผ่านการอะโนไดซ์สีทอง (G) ซึ่งจับคู่กับครอบฟันเซอรโคเนียที่ทาสารทึบแสง (OP) และไม่ทาสารทึบแสง (NO) การวัดค่าสีดำเนินการโดยใช้เครื่องสเปกโตรโฟโตมิเตอร์ (SpectroShade™ Micro II) เพื่อวัดค่าความสว่างสีในระบบ CIELab ของชิ้นตัวอย่าง จากนั้นจึงคำนวณค่าความแตกต่างของสีด้วยสูตร CIEDE2000 (ΔE_{00}) โดยเปรียบเทียบกับครอบฟันเซอรโคเนียบนหลักยึด PMMA ซึ่งใช้เป็นกลุ่มควบคุม ค่าความแตกต่างของสี (ΔE_{00}) ที่ได้ถูกเปรียบเทียบกับเกณฑ์การยอมรับในทางคลินิกแบบ 50:50% สำหรับทันตแพทย์ ($\Delta E_{00} < 2.41$) และผู้ป่วย ($\Delta E_{00} < 2.83$) ข้อมูล ΔE_{00} ถูกวิเคราะห์ทางสถิติด้วยการทดสอบ One-way ANOVA ตามด้วย Tukey's post hoc โดยกำหนดระดับนัยสำคัญทางสถิติที่ $p < 0.05$

ผล: ครอบฟันที่ทาสารทึบแสง (G+OP และ TI+OP) มีค่า ΔE_{00} ต่ำกว่าอย่างมีนัยสำคัญซึ่งอยู่ในเกณฑ์ที่ยอมรับได้ทางคลินิกของผู้ป่วย ($\Delta E_{00} < 2.83$) เมื่อเปรียบเทียบกับครอบฟันที่ไม่มีชั้นทึบแสง (G+NO และ TI+NO) ($p < 0.05$) อย่างไรก็ตาม ไม่พบความแตกต่างอย่างมีนัยสำคัญระหว่างกลุ่ม G+OP และ TI+OP หรือระหว่างกลุ่ม G+NO และ TI+NO

บทสรุป: การใช้สารทึบแสงสามารถปิดสีเทาของหลักยึดไทเทเนียมได้อย่างมีประสิทธิภาพและช่วยเพิ่มผลลัพธ์ด้านความงาม ขณะที่การอะโนไดซ์ไทเทเนียมเป็นสีทองเพียงอย่างเดียวแก้ไขสีครอบฟันได้อย่างจำกัด จึงแนะนำให้ทันตแพทย์ใช้สารทึบแสงเพื่อผลลัพธ์ที่ดีที่สุดในงานบูรณะด้วยครอบฟันเซอรโคเนียที่รองรับด้วยหลักยึดรากฟันเทียม ทั้งนี้ควรมีการวิจัยเพิ่มเติมเพื่อศึกษาประสิทธิภาพในระยะยาวและเทคนิคทางเลือกอื่น ๆ

คำไหรัส: สี/ เซอรโคเนีย/ ไทเทเนียม/ รากฟันเทียม/ ครอบฟัน

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