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Effect of abutment types and resin cements on the esthetics of implant-supported restorations

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PURPOSE. The aim of the study was to evaluate the optical properties of new generation (3Y-TZP) monolithic zirconia (MZ) with different abutment types and resin cement shades. **MATERIALS AND METHODS.** A1/LT MZ specimens were prepared (10 × 12 × 1 mm, N = 30) and divided into 3 groups according to cement shades as transparent (Tr), yellow (Y) and opaque (O). Abutment specimens were obtained from 4 different materials including zirconia (Group Z), hybrid (Group H), titanium (Group T) and anodized yellow titanium (Group AT). MZ and abutment specimens were then cemented. L*, a*, and b* parameters were obtained from MZ, MZ + abutment, and MZ + abutment + cement. ΔE_{001}* (between MZ and MZ + abutment), ΔE_{002}* (between MZ and MZ + abutment + cement) and ΔE_{003}* (between MZ + abutment and MZ + abutment + cement) values were calculated. Statistical analyses included 2-way ANOVA, Bonferroni, and Paired Sample *t*-Tests ($P < .05$). **RESULTS.** Abutment types and resin cements had significant effect on L*, a*, b*, ΔE_{001}*, ΔE_{002}*, and ΔE_{003}* values ($P < .001$). Without cementation, whereas zirconia abutment resulted in the least discoloration (ΔE_{001}* = 0.68), titanium abutment caused the most discoloration (ΔE_{001}* = 4.99). The least ΔE_{002}* = 0.68 value was seen using zirconia abutment after cementation with yellow shaded cement. Opaque shaded cement caused the most color change (ΔE_{003}* = 5.24). Cement application increased the L* values in all groups. **CONCLUSION.** The least color change with/without cement was observed in crown configurations created with zirconia abutments. Zirconia and hybrid abutments produced significantly lower ΔE_{002}* and ΔE_{003}* values in combination with yellow shaded cement. The usage of opaque shaded cement in titanium/anodized titanium groups may enable the clinically unacceptable ΔE_{00}* value to reach the acceptable level. [J Adv Prosthodont 2023;15:114-25]

KEYWORDS
Monolithic zirconia; Color; Anodic oxidation; Hybrid abutment; Resin cement

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INTRODUCTION

The use of dental implants in prosthetic dentistry is increasing and the materials used in this field are frequently updated. It is very important to provide aesthetics with implants in the rehabilitation of the anterior edentulous areas.[1] Main factors affecting the aesthetic success of dental implant applications include the location of the dental implant, the type of implant abutment, the optical properties of crown, and resin cement material.[2,3]

Mucogingival aesthetics, gum thickness, smile line, and economic factors of patient should be taken into consideration for choosing the implant components.[4] Titanium abutments are considered as the gold standard due to their well-documented biological and mechanical advantages.[5,6] However, since these materials cause grayish discoloration under the peri-implant mucosa, they are insufficient to meet the optical requirements, in many cases.[5-7] Full ceramic abutments are manufactured in order to overcome this problem and provide better aesthetics.[8,9] Zirconia abutments have corrosive effects on the titanium implant, although their optical properties are more compatible.[4] In order to prevent direct contact of zirconia with titanium implant, hybrid abutments have been produced by cementing a ceramic meso-structure onto a titanium-base (Ti-base).[10-13] Another abutment material that can be an aesthetic alternative to gray titanium is anodized titanium. The titanium surface can be modified in various colors (yellow-white, yellow, light pink) by anodic oxidation technique to eliminate the gray reflection of this material in the peri-implant soft tissues.[5,14,15]

The crown material is as important as the abutment material to be used in order to achieve the ideal optical properties in implant supported restorations.[16] In recent years, high translucent monolithic zirconia (MZ) have been developed, which are produced without the use of veneer porcelain.[17-19] The translucent structure of MZ allows light transmission through it, which means the optical properties of the underlying abutment and cement material have a significant impact on the esthetic appearance.[19,20] Implant supported restorations can be cemented with different types of cements such as temporary, conventional, and resin cements.[21] Luting cements generate perceptible color changes with specific combinations of restoration material, abutment type, cement thickness and shade.[22-26]

There are many variables affecting optical parameters of implant supported restorations.[27-29] Although MZ is becoming increasingly popular for restoring dental implants,[18] there is not enough data on the aesthetic success of implant supported MZ restorations. It will be beneficial to study the optical properties of implant supported MZ with various crown configurations that will be created with different implant abutments and resin cements. Thus, it can be revealed how these MZ restorations with a more translucent structure are affected by the substrate factors. Thus, this *in vitro* study aimed to evaluate the effects of 4 types of abutment materials and 3 different shades of resin cement on the final color of MZ. The research hypotheses were that; (1) different abutment types would affect the final color of the implant supported MZ and (2) different resin cement shades would affect the final color of the implant supported MZ.

MATERIALS AND METHODS

A total of 30 MZ specimens, n = 10, were obtained for the application of all resin cement shades (transparent, yellow, opaque). IPS e-max ZirCAD Low Translucent (A1-LT) blocks (IPS e.max ZirCAD; Ivoclar Vivadent, Schaan, Liechtenstein) were used in this study, which examined the abutment types (zirconia, hybrid, titanium and anodized titanium) and resin cement factors affecting the final color of MZ restorations. Self-adhesive resin cement (SpeedCEM Plus; Ivoclar Vivadent, Schaan, Liechtenstein) was used as resin cement material. The materials used in the study are presented in Table 1.

MZ blocks were sliced under water cooling with a low-speed precision cutting device (125 Microcut low speed precision cutter; Metkon, Bursa, Türkiye) using a diamond blade[30] (Diamond cut-off wheel B100 × 0.3/10 × 127 mm; ATM Qness GmbH, Mammelzen, Germany) to represent implant supported crown material. MZ specimens were obtained by considering the sintering shrinkage rate (20%) notified by the

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Table 1. The materials used in the study

Material	Manufacturer	Shade	Content
IPS e.max ZirCAD	Ivoclar Vivadent, Schaan, Liechtenstein	A1, LT	87 - 95% ZrO_2, 3% Y_2O_3, 1 - 5% HfO_2, 0 - 1% Al_2O_3, < 0.2% other oxides
SpeedCem Plus Cement	Ivoclar Vivadent, Schaan, Liechtenstein	Transparent, Yellow, Opaque	Dimethacrylates, acidic monomers, barium glas, YbF_3, copolymer, SiO_2, initiators, stabilizers and color pigments
IPS e.max CAD	Ivoclar Vivadent, Schaan, Liechtenstein	A1, LT	57 - 80% SiO_2, 11 - 19% Li_2O, 0 - 13% K_2O, 0 - 11% P_2O_5, 0 - 8% ZrO_2, 0 - 8% ZnO, 0 - 5% Al_2O_3, 0 - 5% MgO
Titanium Disc	Implance AGS Medical, Trabzon, Türkiye		Grade 5 Ti; 88 Ti%, 6% Al, 4% V, 0.25% Fe, 0.2% O
Multilink Hybrid Abutment Cement	Ivoclar Vivadent, Schaan, Liechtenstein	HO	Dimethacrylates, HEMA, benzoyl peroxide, barium glass, YbF_3, TiO, spherical mixed oxide, catalysts, stabilizers and pigments

LT, Low translucent; ZrO_2, Zirconium dioxide; Y_2O_3, Yttrium oxide; HfO_2, Hafnium oxide; Al_2O_3, Aluminium oxide; SiO_2, Silicon dioxide; Li_2O, lithium oxide; K_2O, Potassium oxide; P_2O_5, Phosphorus pentoxide; ZnO, Zinc oxide; MgO, Magnesium oxide; Ti, Titanium; Al, Aluminium; V, Vanadium; Fe, Iron; O, Oxygen; HO, High opaque; HEMA, Hydroxyethyl metacrylate; YbF_3, ytterbium trifluoride; TiO, titanium oxide

manufacturer. The specimens were sintered in the MZ sintering furnace (Programat S1 1600; Ivoclar Vivadent, Schaan, Liechtenstein) at 1600°C for 75 min and allowed to cool down at room temperature. Surface finishing operations of the rough-leveled specimens were carried out with a polishing set (Meisinger Polishing Set; 3M ESPE, St. Paul, MN, USA). The final dimensions (10 × 12 × 1 ± 0.02 mm) of specimens were measured with a digital micrometer (Digimatic Indicator .0001-2 inch; Mitutoyo, Kawasaki, Japan). The specimens were cleaned in an ultrasonic cleaner and air dried.

Titanium discs (8 × 2 mm Grade V Titanium disc; Implance Medikal AGS, Trabzon, Türkiye) and zirconia disc (10 × 2 mm, A1-LT, IPS e.max ZirCAD; Ivoclar Vivadent, Schaan, Liechtenstein) were obtained using CAD-CAM systems (Yenadent D40; Yena Machine, Istanbul, Türkiye) to represent titanium (Group T) and zirconia (Group Z) abutments, respectively. One of the titanium disc was subjected to anodic oxidation process (Group AT). The specimen was kept in the appropriate electrolyte liquid at the specified volt value (59 V) for 20 sec to obtain a yellow color.[5] Then, it was cleaned ultrasonically. After the procedure, resulting color was checked and, if necessary, the specimen was reproduced. One of the disc-shaped titanium (8 × 1 mm Grade V Titanium disc; Implance Medical AGS, Trabzon, Türkiye) and lithium disilicate (10 × 1 mm, IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein) specimens were produced using CAD-CAM systems for the hybrid abutment group (Group H). These two materials were cemented with Multilink Hybrid Abutment cement (Ivoclar Vivadent, Schaan, Liechtenstein) by one clinician (A.A.) with a finger pressure.[10-13]

Resin cement was applied on the MZ specimens. For the standardization of the cement thickness, a custom-made stainless steel plate mold (14 × 16 mm, 1.2 mm in thickness) was prepared. An adequate amount of resin cement was applied on the unpolished surfaces of the MZ specimens which were placed in the mold.[31] A glass plate was placed on the cemented specimens in full contact with the mold. The polymerization process was carried out with a light curing device (Woodpecker LED; Guilin Woodpecker Medical Instrument, Guilin, China) for 40 sec. The cemented specimens were stored in a closed box under dark and slightly humid environment for 24 hr to allow the polymerization process to continue. The total thickness of the specimens (1.2 mm) was measured with a digital caliper. Thus, it was confirmed that the applied cement thickness was 0.2 mm.

MZ specimens were divided into 3 groups according to the shade of cement to be applied (Tr as transparent, Y as yellow and O as opaque) and matched with abutment types (Group Z as zirconia, Group H as hybrid, Group T as titanium and Group AT as anodized titanium). Thus, 12 subgroups (Group Z-Tr, Group Z-Y, Group Z-O, Group H-Tr, Group H-Y, Group H-O, Group T-Tr, Group T-Y, Group T-O, Group AT-Tr, Group AT-Y and Group AT-O) were obtained for evaluation.

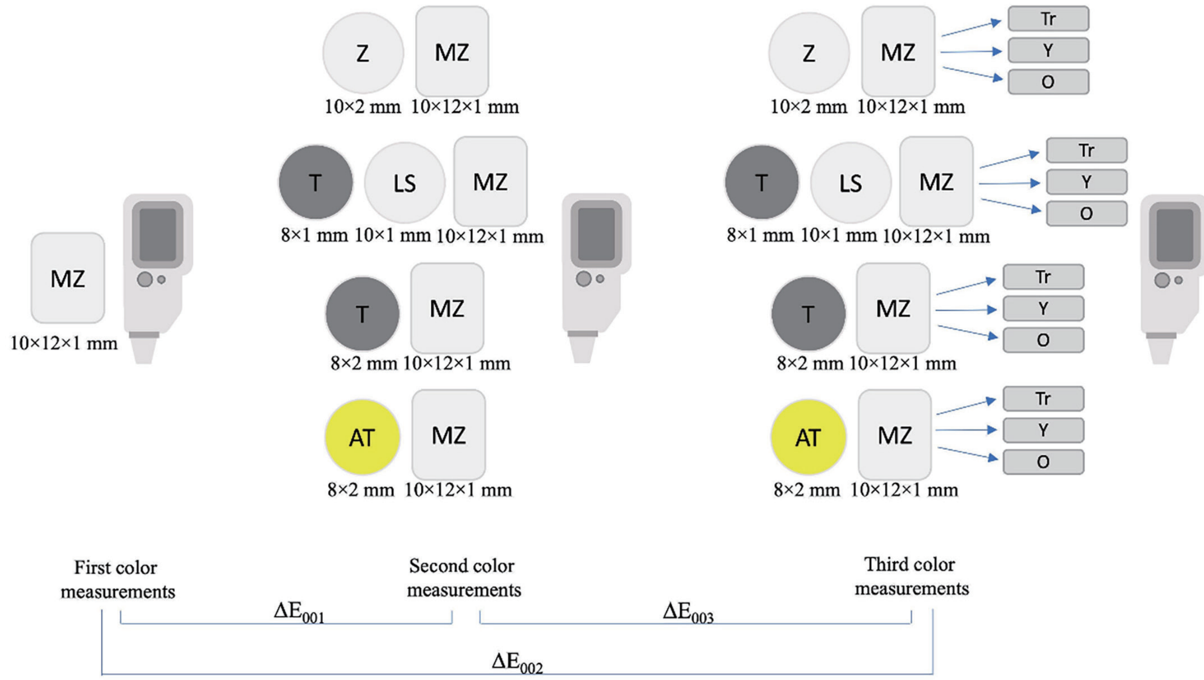

Fig. 1. Schematic image of the method design.
MZ, Monolithic zirconia; Z, Zirconia abutment; T, Titanium abutment; LS, Lithium disilicate ceramic; AT, Anodized titanium abutment; Tr, Transparent cement; Y, Yellow cement; O, Opaque cement.

The MZ specimens were numbered and the initial color measurements were performed before cementation. The mean CIE L_0*, a_0*, and b_0* values of MZ specimens were recorded after each specimen was measured 3 times. Then, MZ specimens (not cemented) were placed on zirconia, hybrid, titanium and anodized titanium abutment specimens, respectively. A transparent glycerin gel (Gliserin 30 ml; Mega-Farma, Istanbul, Türkiye) was applied between MZ and abutment specimens with a finger pressure by one clinician (A.A.), since previous studies reported that a refractive index fluid can provide the optical connection of layers.[6,27,29,32-37] The second color measurements were performed as previously described and L_1*, a_1*, and b_1* values were obtained. For the third measurements, MZ specimens (cemented) were placed on abutment specimens by using a refractive index fluid as described above. Then, L_2*, a_2*, and b_2* parameters of the crown configurations were recorded. The experimental groups and their names are listed in Table 2.

Color measurements were performed with an intraoral colorimeter (ShadeEye-NCC; Shofu, Kyoto, Japan). The device was calibrated before the measurements and positioned in the center of the test surfaces. Color readings were carried out in a box cov-

Table 2. Experimental groups (n = 10) used in the study

Abutments	Resin cements		
	Transparent (Tr)	Yellow (Y)	Opaque (O)
Zirconia (Z)	Group Z-Tr	Group Z-Y	Group Z-O
Hybrid (H)	Group H-Tr	Group H-Y	Group H-O
Titanium (T)	Group T-Tr	Group T-Y	Group T-O
Anodized Titanium (AT)	Group AT-Tr	Group AT-Y	Group AT-O

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ered with a neutral gray background.

The color difference between the first (MZ specimens) and the second (MZ + abutment specimens) measurements was named $\Delta E_{001}*$, the color difference between the first and the third (cemented MZ specimens + abutment specimens) measurements was called $\Delta E_{002}*$, and the color difference between the second and the third measurement was named $\Delta E_{003}*$. More precisely, $\Delta E_{002}*$ indicates which shade of resin cement produced clinically acceptable results and which cement masked the color of the abutment types, while $\Delta E_{003}*$ indicates which cement caused the maximum/minimum discoloration.

The ΔE_{00} values were detected using the following CIEDE2000 formula. According to the CIEDE2000 formula, the calculated color change values below 0.8 units ($\Delta E_{00}* < 0.8$) were considered as 'below the detectable threshold' and values between 0.8 and 1.8 units ($0.8 < \Delta E_{00}* < 1.8$) were evaluated as clinically 'acceptable'. Values above 1.8 units were considered clinically 'incompatible'.[38]

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_c S_c}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_c S_c}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

ΔL', ΔC', ΔH' in the formula refer to the brightness, intensity and hue that match the specimens. The K_L, K_C, K_H parametric factors contained in the formula were used as computational correction terms for experimental monitoring conditions. R_T is a rotation function and deciphers the interaction between saturation and tone differences in the blue region. S_L, S_C, S_H are weighting functions and make the total color difference adjustment for changes in the location of color difference pairs in the L*, a*, b* coordinates. In this study, the parametric factors of the CIEDE2000 formula were set to 1.[39]

A software program (SPSS Statistics for Windows v17.0; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The conformity of the data to the normal distribution was evaluated with the Shapiro Wilk test. Two-way ANOVA test and Bonferroni test were used for repeated measurements. Paired Sample *t*-test was performed for pairwise comparisons of L*, a*, and b* values ($\alpha = .05$).

RESULTS

The abutment types and resin cements had a significant effect on the detected L*, a*, and b* values (*P* < .001). The color values of MZ specimens obtained from the first color measurements were determined as follows: $L_0* = 81.17 \pm 0.76$, $a_0* = -1.26 \pm 0.14$, and $b_0* = 14.73 \pm 0.90$. The means and standard deviations of L_1*, L_2*, a_1*, a_2*, b_1*, and b_2* values are presented in Table 3. The highest L_1* value (82.90 ± 0.32) was determined in Group H-O, while the lowest L_1* value (74.80 ± 0.23) was in Group AT-Y. The highest L_2* value (85.23 ± 0.40) was obtained in Group H-O, and the lowest L_2* value (77.36 ± 0.21) was in Group AT-Tr. L_2* values were significantly higher than L_1* values in all groups (except for Group H-Y, *P* = .119). Considering the average a* values of resin cement groups, the highest mean a_1* and a_2* values were found in Group Z, while the lowest mean a_1* value was found in Group H. Group H resulted in the highest mean b_1* and b_2* values. All abutment groups were resulted in significantly higher b_2* values than b_1* values with the use of opaque shaded cement.

The results of ANOVA also revealed that abutment types (*P* < .001), resin cements (*P* < .001), and their interaction (*P* < .001) influenced all of 3 $\Delta E_{00}*$ values. The means and statistical significances of ΔE_{001}, ΔE_{002}, and ΔE_{003} values are given in Figure 2, 3, and 4, respectively. The lowest $\Delta E_{001}*$ value was detected in Group Z-Tr, and the highest $\Delta E_{001}*$ value was in Group AT-Y. Group Z-Y resulted in the significantly lowest $\Delta E_{002}*$ value, while Group T-Tr resulted in the significantly highest $\Delta E_{002}*$ value. In zirconia and hybrid abutment groups, significantly lower $\Delta E_{002}*$ and $\Delta E_{003}*$ values were obtained by using yellow shaded cement. Opaque shaded cement was resulted in significantly lower $\Delta E_{002}*$ values in titanium and anodized titanium abutment groups. The significantly highest $\Delta E_{003}*$ values were observed in Groups T-O and AT-O.

The optical values of the MZ specimens were considered ideal and the clinical match conditions formed with the $\Delta E_{002}*$ values affected by the combination of abutment materials and shades of cements are given in Table 4. If the calculated color change values were below 0.8 units ($\Delta E_{00}* < 0.8$), it was considered as 'below the detectable threshold'. When it was

Table 3. Means ± standard deviations and statistical significance of L*, a*, and b* values for second and third color measurements

Groups	L_1	L_2	a_1	a_2	b_1	b_2
Z-Tr	80.54 ± 0.46	82.00 ± 0.23	-1.63 ± 0.10	-1.40 ± 0.10	15.13 ± 0.77	13.42 ± 0.68
Z-Y	81.02 ± 0.31	81.23 ± 0.20	-1.66 ± 0.05	-1.29 ± 0.05	15.40 ± 0.73	15.42 ± 0.58
Z-O	81.37 ± 0.15	84.45 ± 0.39	-1.64 ± 0.9	-1.87 ± 0.13	14.92 ± 1.15	15.96 ± 1.15
H-Tr	81.62 ± 0.23	83.20 ± 0.24	-2.12 ± 0.85	-1.76 ± 0.80	15.85 ± 0.71	14.07 ± 0.76
H-Y	82.78 ± 0.33	82.95 ± 0.36	-1.93 ± 0.15	-1.60 ± 0.08	15.91 ± 0.80	16.78 ± 0.51
H-O	82.90 ± 0.32	85.23 ± 0.40	-1.97 ± 0.13	-2.11 ± 0.08	15.88 ± 1.35	17.25 ± 1.47
T-Tr	75.57 ± 0.31	77.85 ± 0.23	-1.95 ± 0.08	-1.71 ± 0.13	10.22 ± 0.54	8.96 ± 0.59
T-Y	75.94 ± 0.33	78.11 ± 0.39	-1.85 ± 0.13	-1.75 ± 0.07	9.74 ± 0.81	11.10 ± 0.53
T-O	76.40 ± 0.25	82.45 ± 0.34	-1.85 ± 0.13	-2.26 ± 0.11	9.47 ± 1.15	13.90 ± 1.29
AT-Tr	76.23 ± 0.25	77.36 ± 0.21	-1.77 ± 0.11	-1.66 ± 0.14	10.84 ± 0.67	10.29 ± 0.64
AT-Y	74.80 ± 0.23	78.13 ± 0.36	-1.73 ± 0.09	-1.64 ± 0.11	11.21 ± 0.61	11.81 ± 0.59
AT-O	75.30 ± 0.29	82.16 ± 0.39	-1.80 ± 0.11	-2.16 ± 0.07	10.65 ± 0.98	13.78 ± 1.56

Z-Tr, Zirconia-Transparent; Z-Y, Zirconia-Yellow; Z-O, Zirconia-Opaque; H-Tr, Hybrid-Transparent; H-Y, Hybrid-Yellow; H-O, Hybrid-Opaque; T-Tr, Titanium-Transparent; T-Y, Titanium-Yellow; T-O, Titanium-Opaque; AT-Tr, Anodized titanium-Transparent; AT-Y, Anodized titanium-Yellow; AT-O, Anodized titanium-Opaque.

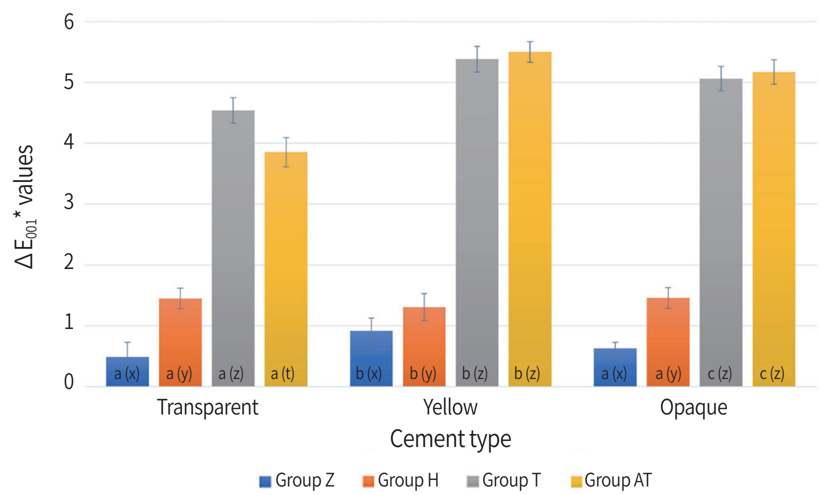

Fig. 2. Mean ΔE_{001}^* values of groups. Different letters indicate significant difference between columns. The letters (a, b, c) were used to represent the significant difference between the cement groups, and the letters (x, y, z, t) were used to represent the significant difference between the abutment groups (P < .05).

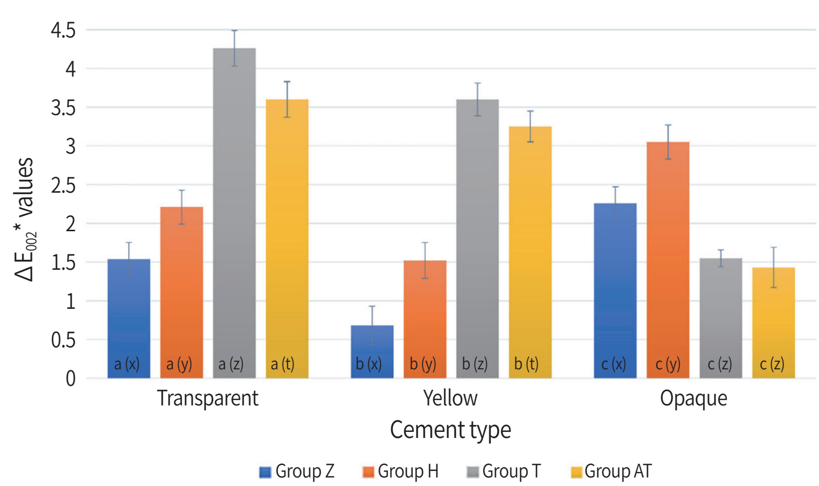

Fig. 3. Mean ΔE_{002}^* values of groups. Different letters indicate significant difference between columns. The letters (a, b, c) were used to represent the significant difference between the cement groups, and the letters (x, y, z, t) were used to represent the significant difference between the abutment groups (P < .05).

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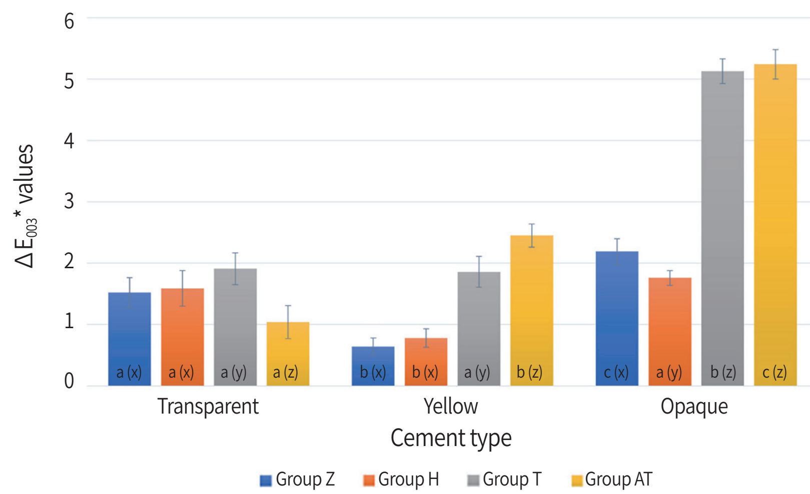

Fig. 4. Mean ΔE_{003}* values of groups. Different letters indicate significant difference between columns. The letters (a, b, c) were used to represent the significant difference between the cement groups, and the letters (x, y, z) were used to represent the significant difference between the abutment groups ($P < .05$).

Table 4. Clinical match conditions of experimental groups formed with the ΔE_{002}* values

Groups	ΔE_{002}	Clinical match
Z-Tr	1.54	Acceptable
Z-Y	0.68	Below the detectable threshold
Z-O	2.26	Incompatible
H-Tr	2.20	Incompatible
H-Y	1.52	Acceptable
H-O	3.05	Incompatible
T-Tr	4.26	Incompatible
T-Y	3.60	Incompatible
T-O	1.55	Acceptable
AT-Tr	3.60	Incompatible
AT-Y	3.25	Incompatible
AT-O	1.43	Acceptable

between 0.8 and 1.8 units ($0.8 < \Delta E_{00}* < 1.8$), it was evaluated as clinically 'acceptable'. Values above 1.8 units were considered clinically 'incompatible'.[38]

DISCUSSION

This study examined the optical parameters of implant supported MZ crowns created using different abutments and resin cement shades, and the first hypothesis, different abutment types would affect the final color of the implant supported MZ would be affected by different abutment types, was accepted. It was observed that the used abutment materials significantly affected the L*, a*, b*, and ΔE_{001}* values of the 3Y-TZP specimens ($P < .001$). Regardless of the cement shade, mean ΔE_{001}* values of the abutment groups were ordered from the lowest to the highest as Group Z (ΔE_{001}*: 0.68), Group H (ΔE_{001}*:1.41), Group AT (ΔE_{001}*: 4.84), and Group T (ΔE_{001}*: 4.99).

The second hypothesis that different resin cement shades would affect the final color of the implant supported MZ was also accepted; resin cement shades also had significant effect on the obtained L*, a*, b*, and ΔE_{00}* values of the specimens ($P < .001$). Significant differences ($P < .05$) were observed between the ΔE_{002}* (except Group T-O and Group AT-O, P = .215) and ΔE_{003}* (except Group H-Tr and Group H-O, Group T-Tr and Group T-Y) values of all subgroups. ΔE_{002}* and ΔE_{003}* values both assess cement differences. However, ΔE_{002}* assesses the clinical effects of all subgroups, while ΔE_{003}* assesses only the clinical effects of different shade cements without the abutment factor.

There are conventional, veneer and monolithic types of zirconia. New generation monolithic forms are called first (3Y-TZP), second (3Y-TZP) and third (5Y-TZP) generation. The second and third generations give more aesthetic results than the first generation MZ.[40] Second generation MZ (A1/ LT - IPS e.max ZirCAD; Ivoclar Vivadent, Schaan, Liechtenstein) material was used in this research because of its advantages such as translucency, superior biocompatibility and high mechanical properties.[41]

The use of MZ restorations for dental implant rehabilitations is increasing due to its improved optical and mechanical properties. Ozer *et al*.[17] evaluated the effect of thickness and surface modifications on flexural strength of MZ and reported that the mechanical properties of MZ with 0.8-mm and 1.3-mm thickness was greater than reported masticatory forces. Tabatabaian *et al*.[19] stated that the thickness of monolithic zirconia ceramic affected its final color and the minimum thickness of it should be 0.9 mm to gain the acceptable final color. It was also stated by a previous study that the abutment tooth color did not affect the final aesthetics of the restoration when the restoration thickness was 2 mm; however, the abutment color produces noticeable discoloration when the restoration thickness was 1 mm or 1.5 mm.[23] Another study reported that if the restoration thickness is 1.5 mm, the color difference due to the abutment can only be detected by color measuring devices, and if the restoration thickness is reduced to 1 mm, the color difference becomes visible.[26] In this study, MZ specimens were used with 1 mm thickness in order to better evaluate the effects of abutment and cement types on the final color of the restoration. It was also determined by previous studies that 1 mm thick MZ would exhibit optically and mechanically suitable properties.

Some studies showed that the choice of abutment material in an implant restoration in aesthetic area is significant for the aesthetic success of the restoration.[5-7,27] For this reason, in this study zirconia, hybrid (Ti-base + LDS) and anodized titanium (yellow color) abutments, which can provide aesthetic alternatives to currently used titanium abutments, were used. Colorimetric measurements of the veneers on the abutments showed ΔE_{001}^* values between 0.49 - 5.50 units. Zirconia abutment showed the least value while titanium abutment showed the most. Dede *et al*.[27] evaluated the effect of implant abutment material on the color of different ceramic crown systems. Similar to this study, 'incompatible' results were observed with titanium abutments. Zirconia was reported to be a more suitable abutment material for implant supported ceramic restorations.[27] Martínez *et al*.[2] evaluated the effect of titanium, anodized titanium (pink and gold) and zirconia abutments on the optical outcome of implant supported LDS crowns. The authors reported that all implant abutment materials resulted in a visible color difference compared to the control group. However, zirconia abutments showed the least ΔE^* values. Despite the usage of different restorative materials from this study, the findings supported the usage of zirconia abutments in implant supported restorations. In the same study above, gold anodized titanium showed less discoloration than titanium, similar to this study, but it was still 'incompatible'.[2]

The luting cement has a significant effect on the final color of the restoration.[24,25,34] One of the cements recommended by the manufacturer for IPS e.max ZirCAD restorations is SpeedCem Plus (Ivoclar Vivadent, Schaan, Liechtenstein). It is particularly advantageous for relatively opaque restorations such as zirconia and metal ceramics, as it is a self-adhesive and dual-curing resin cement.[31] In this study, 3 different shades of this cement were used as transparent, yellow, and opaque and it was determined that the final optical properties of the restoration were affected differently according to different shade resin cement materials. Significant differences were found among all groups ($P < .05$). The least color change was seen in zirconia-yellow cement and the most color change was seen in titanium-transparent cement pairs. Group Z-Y showed color change below the detectable threshold. Clinically acceptable color changes were seen after cementation in Group Z-Tr, Group H-Y, Group T-O and Group AT-O. Titanium ($\Delta E_{001}^* = 4.99$) and anodized titanium ($\Delta E_{001}^* = 4.84$) abutments, which caused discoloration above the acceptable threshold before cement application, showed clinically acceptable discoloration with opaque shaded cement (Group T-O: $\Delta E_{002}^* = 1.55$; Group AT-O: $\Delta E_{002}^* = 1.43$). Dede *et al*.[6] evaluated the effect of implant abutment materials (zirconia, gold-palladium and titanium) and luting cements (translucent, universal and white opaque - 0.2 mm) on the ceramic material (LDS). In the study, white opaque cement reduced the discoloration caused by the titanium abutment and brought it to clinically acceptable limits. This showed that white opaque cement may help mask the dark

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reflection of the titanium abutment.[6] Kılınç *et al*. evaluated the effects of different abutment materials (titanium, opaque treated titanium, anodized titanium and zirconia) on the final color of implant supported full ceramic restorations (MZ-1.5 mm). Clinically acceptable results were seen with both titanium with opaque application and anodized titanium. Kilinc *et al*.[5] used a single shade resin cement in the study. In general, titanium caused the most color change value for all ceramics, while zirconia caused the lowest color change.

It is possible to produce hybrid abutments using coping materials of various contents and structures. Searching the literature, it was seen that various cements can be used to ensure optimal connection between coping materials and ti-bases. The hybrid abutment specimens used in this study was prepared in accordance with previous studies[10-13] and obtained by cementing lithium disilicate coping material on Ti-base using Multilink Hybrid Abutment cement as recommended by the manufacturer.

Refractive index fluid was applied between the layers in order to prevent light scattering from the interface of MZ specimens placed on the abutment cement and materials. A variety of materials such as optical gel,[6,27] type A optical oil,[16,32] butylphthalate,[33] glycerin gel,[34] sucrose solution,[4,35,36] and distilled water[37] were used between the specimen layers to ensure optical connection by previous studies. Glycerin gel was preferred in this study to prevent the light scattering.

In case of the colorimetric measurements, diameter of the specimen and measuring tip of the colorimeter are important for accurate results. Edge loss may occur in color measurements if the specimen frame is not large enough for the optical reading tip of the device.[42] The optical reading tip used in this study is 3 mm. Specimens were prepared larger to position the optical tip more comfortably in the center of the specimen and to prevent lateral light transmission. The sizes of MZ specimens are 10 × 12 mm and abutment material trays are 8 and 10 mm. Studies in the literature have specimens prepared with similar dimensions.[43,44] Due to the diameter of the colorimeter tip (3 mm), the margin of error in the measurement of 8 and 10 mm samples can be neglected.

Significant differences were found among the L* values of all subgroups in this study (P < .001; except for L_1* values of Group H-Y - Group H-O, L_2* values of H-Tr - H-O and L_2* values of T-Tr - T-Y). L_2* values were higher than L_1* values in all groups. Although L_2* value was higher than L_1* value in Group H-Y, there was no significant difference between them (P = .11). Based on this finding, it can be said that the application of cement significantly increased the brightness of the restoration in all groups (P < .05), except for Group H-Y. In all groups, a_0* values were higher than a_1* and a_2* values. This decrease in a* values differed significantly in all groups (P < .05; except for Group Z-Tr, P = .910). a_2* values were higher than a_1* values in all crown configurations created with transparent and yellow cement. While this increase in a_2* values of Group AT-Tr (P = .064) and Group T-Y (P = .05) was not significant, significant differences were observed in a_1*and a_2* values of other groups (P < .05). However, the increased a_2* values after cementation were still lower than the a_0* values, for all subgroups. In crown configurations created with opaque cement, a_1* values were lower than a_0* values and a_2* values were lower than a_1* values. Accordingly, the opaque shaded cement caused the color of the MZ to become greener. While b_1* values were higher than b_0* values in zirconia and hybrid abutment groups, b_1* values were higher than b_0* values in titanium and anodized titanium abutment groups. Opaque and yellow cement increased yellowness in all abutment groups. These increases of b_2* values were significant (P < .05) for all groups, except for Group Z-Y (P = .958).

Zirconia abutment resulted in significantly lower ΔE_{001}* and ΔE_{002}* values for all used cements. Evaluating ΔE_{002}* values, it was observed that ΔE_{002}* value of Group Z-Y was below the detectable threshold. Group Z-Tr, Group H-Y, Group T-O and Group AT-O resulted in clinically 'acceptable' ΔE_{002}* values. Since Group Z and H exhibited significantly lower ΔE_{002}* and ΔE_{003}* values in combination with yellow shaded cement, it can be concluded that zirconia and hybrid abutments presented significantly better optical results with the use of yellow shaded cement. Regardless of the cement material, when examining the effect of the abutment material on the final aesthetics of the restoration, it was observed that the ΔE_{001}* values of Group T and AT were clinically 'incompatible'. However, the ΔE_{00^2}* values of crown configurations created with these abutment materials and opaque cement were decreased significantly. Based on this finding, it can be said that in cases in which titanium and anodized titanium abutments are preferred, aesthetic properties can be improved by using opaque shaded cement. This result is consistent with other studies reporting that opaque shaded cement can be used to mask the unaesthetic color of titanium.[6,24,25]

The translucency level and thickness of used MZ material were not changed in this study. These factors can be considered as limitations of this study. However, since the main purpose of our study was to investigate the effect of cement shade and abutment type on the color change of implant supported all-ceramic restorations, the translucency and thickness parameters were kept constant. It is recommended to conduct future *in vivo* studies involving large patient groups with different method designs that include different restoration materials with different thicknesses and various cement materials.

CONCLUSION

Based on the findings of this *in vitro* study, the following conclusions were drawn. The shade of the cement affects the final color of the implant supported MZ at different rates depending on the abutment component to be selected. In conclusion, the combination of zirconia abutment and yellow shaded resin cement for the most aesthetic outcome usage in monolithic zirconia on implant supported restorations should be preferred. If a ceramic abutment (zirconia, hybrid) cannot be used in implant supported monolithic zirconia restorations where aesthetics matter, the choice of opaque shaded resin cement in cementation can mask the color of the titanium or anodized titanium abutment.

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