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RESEARCH AND EDUCATION

Color and translucency of milled polymethyl methacrylate crowns on non–tooth-colored interim abutments with different surface treatments

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ABSTRACT

Statement of problem. The interim rehabilitation of implants has become a necessity, particularly for those placed in the esthetic regions. However, the optical properties of computer-aided design and computer-aided manufacturing (CAD-CAM) polymethyl methacrylate (PMMA) crowns on interim abutments with different surface treatments are unclear.

Purpose. The purpose of this in vitro study was to investigate the color and translucency of CAD-CAM PMMA crowns when different surface treatments were used on titanium interim abutments.

Material and methods. A maxillary dentate stone cast with a narrow-diameter implant analog at the left lateral incisor site was used. Three titanium interim abutments (blue) were divided into 3 groups according to the surface treatment they received: control (steam cleaning), opaqued (120-μm Al_2O_3 airborne-particle abrasion and opaque application), and airborne-particle abraded (120-μm Al_2O_3). Thirty PMMA crowns (A2 shade) were milled (n=10). The color coordinates of the crown-interim abutment pairs and a shade tab (A2) were measured by using a colorimeter. The color differences (ΔE_{00}) between the crowns and the shade tab and the relative translucency parameter (RTP) values of the crowns were calculated by using the CIEDE2000 formula. One-way ANOVA was used to analyze the ΔE_{00} and RTP values with subsequent Tukey honestly significant difference tests (α=.05).

Results. The abutment surface treatment significantly affected the ΔE_{00} of interim crowns from the shade tab (P<.001), but no significant effect was found on RTP (P=.26). The control group had the highest ΔE_{00} from the shade tab ($P \leq .011$). No significant difference (P=.14) was found between the opaqued and the ΔE_{00} of the airborne-particle abraded groups from the shade tab.

Conclusions. The surface treatments of interim abutments affected the color of CAD-CAM PMMA crowns, which differed from that of the shade tab. The color of crowns on opaqued or airborne-particle abraded interim abutments was closer to the color of the shade tab. Abutment surface treatments did not affect the translucency of crown-interim abutment pairs. (J Prosthet Dent 2022;■:■-■)

Interim implant abutments are manufactured in different shapes, diameters, materials, and colors[1-4] and may be non–tooth-colored titanium (Ti) or titanium-aluminum-niobium (TAN) alloy or tooth-colored polymethyl methacrylate (PMMA) with a TAN base, polyetheretherketone (PEEK), or plastic polymer with or without a Ti base.[1-6] Interim abutments for narrow-diameter implants (Ø2.9 to 3.1 mm) are typically fabricated from titanium alloy, and these implants are indicated primarily in the anterior or premolar regions where esthetics is of concern.[7]

Ti has been considered as the standard abutment material, but its grayish color presents a challenge to achieving

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Clinical Implications

Opaquing or airborne-particle abrasion may be used on the tested interim implant abutments to improve the color of CAD-CAM PMMA crowns.

an esthetic result.[8-20] Excellent esthetics is a greater problem with patients with thin gingival biotype (less than 2-mm gingival thickness) and/or a high smile line or when the abutments support ceramic crowns.[13,21] Different techniques, including thermal oxidation, chemical oxidation, TiN coating, and anodic oxidation, have been used to improve the optical properties of definitive Ti abutment surfaces[11,22-24] and may also improve the optical properties of interim abutments made from metal alloy (Ti or TAN).

Color coordinates (L*, a*, and b*) defined by the Commission Internationale de l'Eclairage (CIE) have been used to measure color differences.[25] CIEDE2000 is a recent and widely preferred formula because of its improvement in the clinical interpretation of color differences.[26] Unlike the earlier CIE76 formula, calculation by using the CIEDE2000 formula is not only based on L*, a*, and b* values but includes the differences in lightness ($\Delta L'$), chroma ($\Delta C'$), and hue ($\Delta H'$), the interaction between the chroma and the hue differences in the blue region (R_T), weighing functions (SL, SC, and SH), and parametric factors (*kL, kC,* and *kH*).[27] Paravina et al[28] defined 50:50% perceptibility and 50:50% acceptability thresholds of color differences (CIEDE2000) as 0.8 and 1.8, respectively.

The authors are unaware of a study that investigated the optical properties of interim crowns on interim abutments treated with different techniques. The findings of such a study may help clinicians select the optimal surface treatment for an interim titanium abutment to improve esthetic outcomes. The purpose of this in vitro study was to investigate the color and translucency of computer-aided design and computer-aided manufacturing (CAD-CAM) PMMA crowns when different surface treatments (control, opaqued, and airborne-particle abraded) were used on Ti interim abutments. The null hypothesis was that different surface treatments on Ti abutments would not affect the color and relative translucency of CAD-CAM PMMA crowns.

MATERIAL AND METHODS

The left lateral incisor tooth was removed from a dentate maxillary typodont (ANA-4; Frasaco GmbH). An osteotomy was performed to place a narrow-diameter implant analog (2.9-mm-diameter Small Crossfit Bone Level Tapered Implants; Institut Straumann AG) by using an implant motor (Surgic XT Plus; NSK) and a surgical contra-angle handpiece (WS-56 L; W&H Dentalwerk).[6] An elastomeric impression of the model was made and poured in stone. The interim abutments (Small Crossfit Interim Abutment-crown, oval, TAN; Institut Straumann AG) used in the present study were blue, made of TAN, and indicated for anterior single-unit interim crowns.[6] Three interim abutments (1-mm gingival height) were shortened to 5 mm to further receive crowns and divided into 3 groups according to the surface treatments they would receive (Fig. 1): control, opaqued, and airborne-particle abraded. In the control group, the abutment was steam-cleaned (Touchsteam; Kerr Corp) at 345 kPa, and no surface treatment was performed. In the opaqued group, the abutment was airborne-particle abraded with 120-μm Al_2O_3 (Basic Master; Renfert) at 310 kPa, steam-cleaned, and air-dried.[6,29,30] A metal primer (whiteMetal primer; BlueSkyBio) was applied on all surfaces and air-dried.[29] A metal opaquer (Vita TitanKeramik Opaque, A2; Vita Zahnfabrik) was applied on the primed abutment surfaces according to the manufacturer's recommendations and light polymerized (Labolight LV-III; GC Corp) for 1 minute.[29,30] The opaque layer was approximately 25 μm in thickness,[29] which was controlled by using digital calipers (Model number NB60; Mitutoyo American Corp) by measuring the thickness of the abutment before and after opaque application. In the airborne-particle abraded group, the abutment was airborne-particle abraded with 120-μm Al_2O_3 (Basic Master; Renfert) at 310 kPa, steam-cleaned, and air-dried.[31] All airborne-particle abrasion procedures (opaqued and airborne-particle abraded groups) were performed perpendicular to the abutments from a distance of 10 mm for 10 seconds.

Figure 1. Interim abutments tested. *Left* control, *center* opaqued, *right* airborne-particle abraded.

The abutments were tightened onto the analog placed in a stone cast and were scanned by using an intraoral scanner (Medit i500; Medit Corp). A complete-coverage interim crown was designed by using a software program (DentalCAD 3.0 Galway; exocad GmbH) to generate

Figure 2. Microscope image (original magnification ×16) of specimen demonstrating fit assessment procedure.

1.5 ±0.3 mm of facial thickness. Thirty PMMA (Ido-dentine PMMA block; Unidesa-Odi) crowns (n=10) in A2 shade were milled by using a milling machine (Zenotec Mini; Wieland Dental). After an adequate crown-abutment fit was ensured by using a microscope (M420; Leica) integrated with a light source (CLS 150X; Leica) and a fiber optic illuminator (Intralux 150H; Volpi) under ×16 magnification (Fig. 2), the crowns were finished with 600-grit silicon carbide abrasive papers under running water. Then, a single operator (G.Ç.) polished the crowns with a slurry (Pumice fine; Benco Dental) for 90 seconds at 1500 rpm (Red-Wing; Handler Manufacturing) and fine polished with a polishing paste (Fabulustre; Grobet USA) for 90 seconds (Red-Wing; Handler Manufacturing).[32] The final thickness of each crown (1.5 ±0.02 mm) was measured by using the digital calipers. The crowns were ultrasonically cleaned (Eltro-sonic Ultracleaner 07-08; Eltrosonic GmbH) for 10 minutes and dried.

To measure the color difference and relative translucency parameters (RTPs), white, black, and gray PMMA molds were fabricated to standardize the position of the crowns and the colorimeter's measuring tip and to serve as backings.[33] A circular plastic mold (Ø2.5×1.5 cm) was used for the fabrication of PMMA molds. For white and black backings, opaque white (Nic Tone, Opaque white, number 4; MDC Dental) and opaque black (Nic Tone, Opaque black, number 9; MDC Dental) orthodontic acrylic resins were mixed according to the manufacturers' instructions and poured into the plastic mold. As the manufacturer had no gray-colored PMMA, for the gray backing (L*=35.8, a*=–2.1, b*=-4.2), the opaque white and black PMMA powders were mixed in a 2:1 ratio and poured into the plastic mold. An interim abutment was tightened on the implant analog. An interim crown covered with a Teflon layer for isolation from the PMMA was then placed on the abutment. The abutment-crown-analog complex was embedded in the

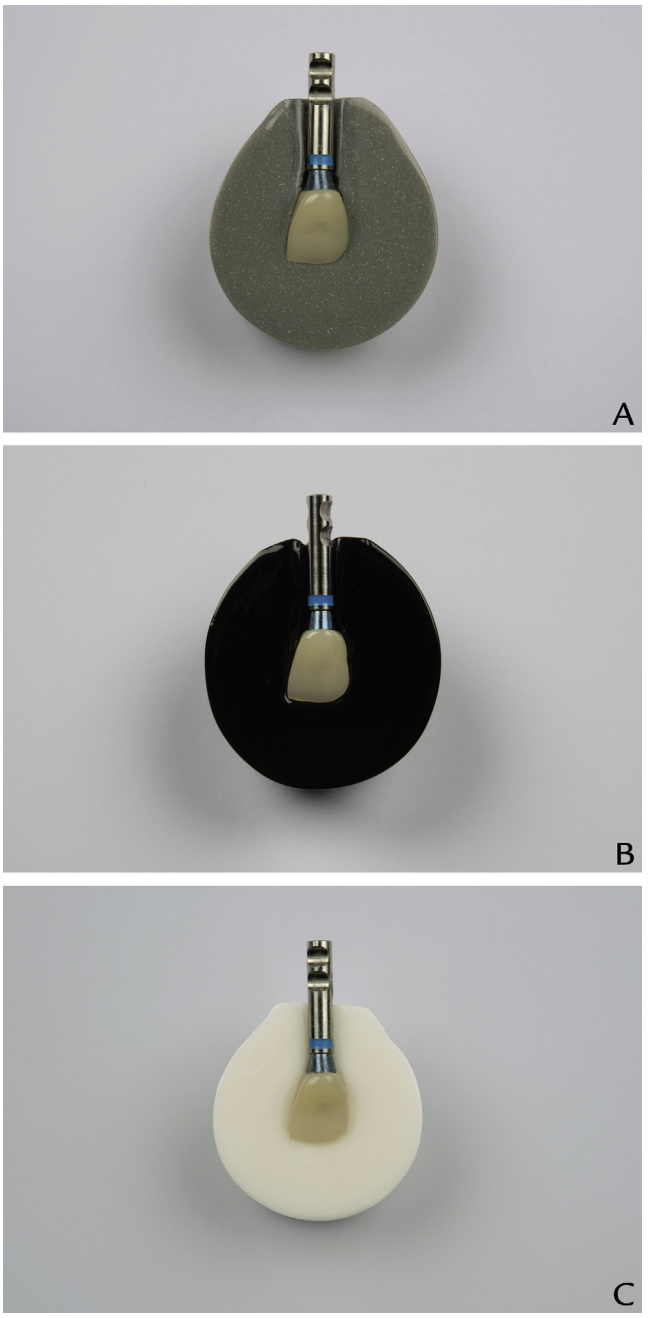

Figure 3. Polymethyl methacrylate molds fabricated for color coordinate measurements A, Gray mold. B, Black mold. C, White mold.

mixed PMMA leaving two-thirds of the facial surface of the crown exposed (Fig. 3). After the polymerization of the PMMA mold, the abutment-crown-analog complex was removed, and all molds and the abutment-crown-analog complexes were evaluated for proper fit by using these methods.

A colorimeter, which has I/O geometry of d/0 degrees with an illumination aperture of 8 mm and a C-type illuminant (6774 K), was used (HP-2132 Chin.spec; Chinaspectrum) for color measurements. The

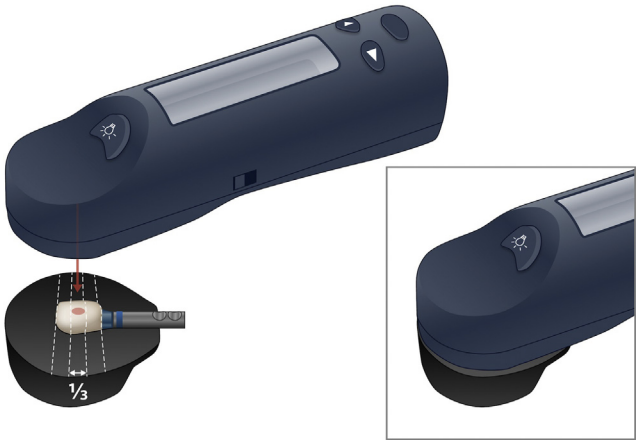

Figure 4. Schematic representation of color measurements.

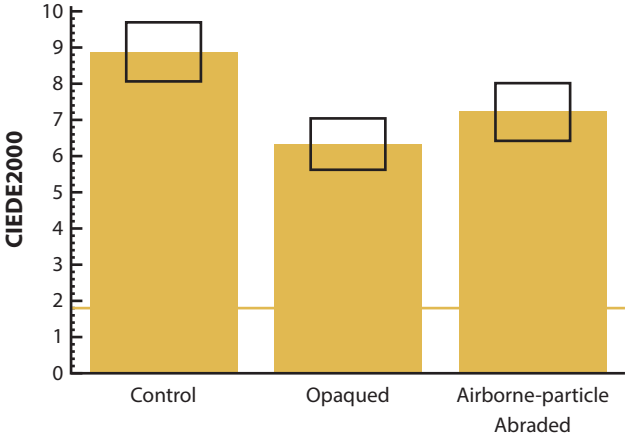

Figure 5. Color difference (CIEDE2000) values between interim crowns on abutments with different surface treatments and shade tab. *Orange* horizontal line represents acceptability threshold (1.8 ΔE_{00} units).[25]

colorimetric measurements were recorded by using the CIE L*a*b* color space system,[34-36] and the CIELab calculations for CIE C illuminant and the CIE Standard (2-degree) Human Observer were done.[25] Before each measurement, the colorimeter was calibrated according to the manufacturer's recommendation. An abutment was tightened onto the implant analog. A thin layer of glycerin solution (Avia Plus Pure Glycerin; Avia Perfumistas) was applied on the crown with a small brush for optical contact,[37] and the interim crown was placed on the abutment. Then, the abutment-crown-analog complex was placed on gray, white, and black backings, and colorimetric measurements of the interim crowns were made 3 times from the middle third (3 mm apical to the incisal edge) of the facial surfaces of the crowns[38] by using the colorimeter (Fig. 4). The color coordinates of a shade tab (Vita Classical Shade Guide, A2; Vita Zahnfabrik) were measured 3 times from the middle third of the facial surface on the gray backing and averaged (L*=63.8, a*=−2.2, b*=7.16).[39] All color measurements were performed by the same clinician (G.Ç.) in a temperature- and humidity-controlled room with daylight. The randomization of the color measurements was achieved by using the randomize function of a software program (Excel; Microsoft Corp) on the numbers assigned to each color measurement (1-10 for the control group, 11-20 for the opaqued group, and 21-30 for the airborne-particle abraded group).

Color differences (ΔE_{00}) between the crowns and the shade tab were calculated by using the data on gray backing with the CIEDE2000 color difference formula.[25] The parametric factors of *kL*, *kC*, and *kH* were set to 1 as recommended by CIELab.[40] The RTP for each crown was calculated from the color difference by using their coordinates on opaque white (L*=71.1, a*=−3.86, b*=−2.7) and black (L*=16.73, a*=−2.53, b*=2.13) backings with the RTP CIEDE2000 formula.[37]

A confidence interval (CI) of 95% was used for the statistical analysis of CIEDE2000 (ΔE_{00}) and relative translucency values by using a software program (SAS Proprietary Software v9.3; SAS Institute Inc). For both ΔE_{00} and RTP, restricted maximum likelihood (REML) estimates and a lognormal error distribution were used, with subsequent Tukey honestly significant difference tests for all pairwise comparisons, which are justified by the 1-way analysis of variance (ANOVA). The differences among color coordinates of the crowns on interim abutments with different surface treatments were analyzed by using repeated 2-way ANOVA with surface treatment as the between-subjects factor and the CIE coordinates as the within-subject factor and Bonferroni-corrected *t* tests (α=.05 for all tests).

RESULTS

Means and 95% CIs of the ΔE_{00} between the crowns on abutments with different surface treatments and the shade tab are presented in Figure 5. The 1-way ANOVA revealed that the abutment surface treatment had a significant effect on the crown color (df=2, F=13.2, *P*<.001). The ΔE_{00} between the crowns and the shade tab was significantly different when abutments with different surface treatments were used (*P*<.001). The control group had significantly higher ΔE_{00} from the shade tab than the opaqued (*P*<.001) and the airborne-particle abraded (*P*=.011) groups had, whereas no significant difference (*P*=.141) was found between the opaqued and the airborne-particle abraded groups for their ΔE_{00} from the shade tab (Table 1). The 2-way ANOVA showed that the surface treatments (*P*=.04), color coordinates (*P*<.001), and the interaction between the surface treatments and color coordinates (*P*=.004) were effective. The L* and b* values of the crowns of the opaqued (*P*=.03 for L* and *P*=.03 for b*) group and L* values of crowns of the

Table 1. Descriptive statistics (mean and standard deviations) of color difference between shade tab and crowns on pretreated abutments

Surface Treatment	Mean ΔE_{00}	Standard Deviations	Tukey HSD*
Control	8.9	1.14	A
Opaqued	6.4	1.01	B
Airborne-particle abraded	7.2	1.11	B

*Different uppercase letters indicate significant differences (P<.05).

Table 2. Mean ±standard deviation L*, a*, and b* values of test groups over gray backing

Surface Treatment	L*	a*	b*
Control	59.7 ±2.6^{a}	-2.2 ±1^{a}	-1.5 ±1.3^{a}
Opaqued	62.3 ±3.5^{b}	-3.5 ±0.6^{a}	1.1 ±0.7^{b}
Airborne-particle abraded	62.1 ±3^{b}	-3.4 ±0.7^{a}	-0.2 ±1.2^{ab}

*Different superscript uppercase letters indicate significant differences in columns (P<.05).

airborne-particle abraded (P=.050) group were higher than those of the control group. The mean values of the color coordinates (L*, a*, and b*) of each surface treatment group over gray backing are given in Table 2. The RTP values of crowns are presented in Figure 6. According to the 1-way ANOVA, no significant difference was found in the RTP of crowns on abutments with different surface treatments (df=2, F=1.43, P=.26).

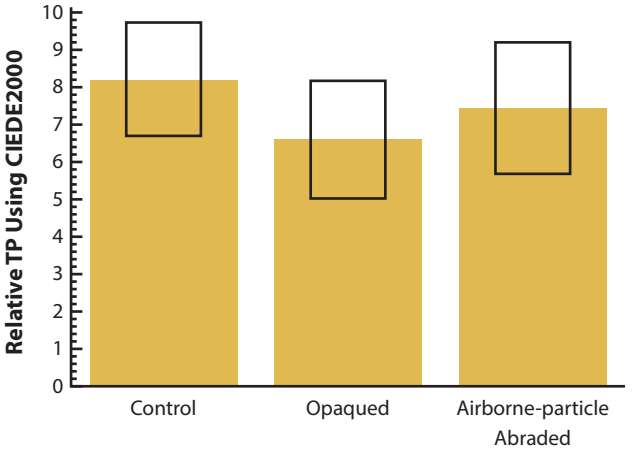

Figure 6. Relative translucency parameter values of interim crowns on abutments with different surface treatments.

DISCUSSION

The abutment surface treatment had no significant effect on the relative translucency of the crowns but significantly affected their color. Therefore, the null hypothesis was rejected.

Interim crowns on abutments treated with different techniques had varying color differences from the shade tab, and the crowns in the control group had the highest color difference. This result suggests that the tested abutment requires an additional surface treatment to mask its color. For the surface-treated abutment groups, no significant difference was found. Opaquing the interim abutment provided a lighter crown color, while airborne-particle abrasion removed the blue coating, exposing the abutment's gray color. Changing the blueness of the abutment surface to a lighter color with opaque, or to gray with airborne-particle abrasion, resulted in fewer color differences from the shade tab.

Direct comparison of the results of the present study with those of previous studies is difficult because studies that evaluated the tested interim abutment and techniques are lacking. Changing the underlying substrate color to a darker background has been reported to result in increased color differences.[39] All tested crowns on treated abutments led to clinically unacceptable color differences from the shade tab (>1.8 units; 50% acceptability threshold). However, airborne-particle abrasion or opaquing can be recommended over as-received use of the tested abutment to achieve a closer color to the target shade. The lightness and yellowness of crowns increased as the mean L* and b* values of the opaqued and the L* values of the airborne-particle abraded specimens were significantly different from those of the control group. However, these results should be interpreted carefully as the authors are unaware of a study that has investigated the clinically perceptible and acceptable thresholds for L*, a*, and b* differences.

Consistent with the present findings, the underlying structure has been reported to affect the final color of the crown[17,18,29] and the peri-implant mucosa,[19,20] and the use of Ti abutment has been reported to be clinically unacceptable under translucent ceramic systems.[17,18] Supporting the present study results, Dede et al[17] reported that white opaque cement provided more favorable color than the other cements (translucent, universal) for Ti abutments under ceramic restorations. However, even with the white opaque cement, the color change was clinically unacceptable.[17] The authors of 2 other studies also recommended the use of opaque cement to mask abutments made from different materials.[35,36] Arif et al[29] also recommended the use of an opaquer on a Ti backing to prevent the gray metal appearance and to enhance esthetics when used with ceramic crowns. Contrarily,[29] the color difference with the opaqued Ti abutment was within the clinical acceptability threshold, which was different than that used in the present study (50% clinical acceptability, 2.25 ΔE_{00}).

The difference in obtained results for clinical acceptability could also be because of the different alloy type, shape, thickness, and structural differences in crown materials and the color measuring system. Translucency is essential for natural appearance,[18,37,40] and a previous study has reported 1.5 mm of thickness as the threshold for adequate color masking ability.[39] Also, when the ceramic thickness is less than 1.5 mm, luting agents may

not mask the substrate color.[39] In the present study, the PMMA crowns on abutments with different surface treatments had similar translucency, which may be because of their 1.5-mm thickness. Güth et al[41] reported that 1-mm-thick CAD-CAM polymers varied in translucency for blue and visible light. Different interim crown thicknesses, the presence of luting cement, and interim restorative materials of different brands may yield differences in translucency. Although the tested abutments differed in color, they were made from the same alloy, which may explain their similar translucencies.

Color and translucency results may vary with abutments of different colors. Although pink and yellow have been recommended to improve the gingival esthetics of implant-supported restorations,[19,42] optimal alloy abutment color for improved esthetics with interim crowns is unknown. Wadhwani et al[42] colored the titanium-6aluminum-4vanadium (Ti6Al4V) alloy by using electrochemical anodization and reported favorable results with gold, yellow, and pink hues. Wang et al[22] applied anodic oxidation on Ti alloy and reported that pink and yellow provided better peri-implant esthetics (less color difference) than the untreated titanium alloy. In another study, Wang et al[11] reported that the use of gold and pink anodized Ti abutments led to less discoloration of the peri-implant soft tissue than unanodized Ti abutments. A change in the abutment color from gray to pink has been reported to provide a color similar to the color of gingiva,[10,16] and yellow zirconia abutments have been reported to mimic natural tooth color.[14]

The results of the present study should be interpreted carefully since only a blue alloy interim abutment was used. In light of previous and present study findings, for alloy interim abutments, color options other than blue may be considered by the manufacturers for improved crown color. However, this hypothesis needs to be substantiated by future studies comparing the optical properties of crowns on alloy interim abutments in different colors.

Post hoc sensitivity power analyses at β=.05 and β=.01were performed. The results of both tests revealed that the required effect size (f=0.336 when β=.05 and f=0.391 when β=.01) was well below the actual effect size of 1.917, as calculated from the collected data. Previous studies on the color coordinate measurements of interim PMMA restorations have used colorimeters.[43-45] However, considering the various number of devices that could be used for color coordinate measurements, different devices and light sources may result in different results.[46] In addition, any edge loss would be expected to diminish the color differences, including the RTP values, that were calculated. Since the results of this research identify visually and statistically significant differences in color or in RTP, these significant differences are expected to be valid. Nevertheless, this device should be evaluated in terms of edge loss, validity, and repeatability in future studies.

Limitations of the present study included that a single shade of restorative material was used and a lighter shade than A2 might decrease the masking of the underlying abutment. Another limitation was the experimental fabrication of the gray backing as the manufacturer of the PMMA powders used did not specify a ratio for fabricating a gray backing. Future studies should be performed with crowns in different colors to investigate the effect of the shade of the crown on the overall color when used on tested abutment and opaquers. A clear glycerin gel was used in the present study and the absence of the luting cement may be considered as a limitation,[17,39] although clear interim cements are sometimes used clinically. However, luting cements in different colors with different crown thickness and shades need to be evaluated in future studies. Another limitation was that only CAD-CAM milled PMMA interim crowns were tested. Different interim restorative materials or fabrication techniques may affect the results. The effect of short-term thermocycling needs to be evaluated in the future because the manufacturer recommends using the tested abutment for no longer than 180 days 6 Additionally, clinical studies are needed to corroborate present study results and to evaluate the effects of the tested techniques on peri-implant soft tissue esthetics.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The applied surface treatment (control, opaqued, and airborne-particle abraded) on tested interim abutment (blue-colored TAN alloy) affected the color of CAD-CAM PMMA crowns but did not affect their relative translucency.
2. The lightness of the crowns increased with opaqued or airborne-particle abraded non–tooth-colored abutments. The yellowness of the crowns also increased with opaqued non–tooth-colored abutments.
3. Even though the color differences between the crowns of the opaqued and the airborne-particle abraded groups with the shade tab were above the clinically acceptable threshold, the crown color on an opaqued or airborne-particle abraded non–tooth-colored interim abutment was closer to the

color of the shade tab compared with the crowns of the control group.

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CRediT authorship contribution statement

Gülce Çakmak: Conceptualization, Methodology, Data collection, Investigation, Writing – Original Draft, Critical revision of article. **Alfonso Rodriguez Cuellar:** Conceptualization, Data interpretation, Software, Writing – Original Draft. **Alejandro Treviño Santos:** Conceptualization, Investigation, Resources, Critical revision of article. **William M. Johnston:** Data analysis, Statistical analysis, Critical revision of article. **Mustafa Borga Dönmez:** Writing – review and editing. **Burak Yilmaz:** Data interpretation, Critical revision of the article, Approval of the submitted and final versions, Supervision.

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