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RESEARCH AND EDUCATION

Effect of color of the cement and the composite resin foundation on the resultant color of resin-matrix ceramics

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ABSTRACT

Statement of problem. An improper restoration color match to the adjacent natural teeth can jeopardize esthetic success. The type of resin-matrix ceramic (RMC), the shade of the underlying foundation, and the shade of cement may affect the optical behavior of RMC materials, but studies on this issue are lacking.

Purpose. The purpose of this in vitro study was to assess the cumulative effect of different shades of composite resin foundation (CRF) and cement on the optical behaviors of 3 different RMCs.

Material and methods. Forty-five rectangular RMC specimens (14×12×1 mm, shade A2) were prepared from 3 different blocks, including a polymer-infiltrated ceramic network (Vita Enamic [VE]), a resin nanoceramic (Lava Ultimate [LU]), and a flexible nanoparticle-filled resin (GC Cerasmart [GC]) (n=15 per RMC block). CRFs (14×12×4 mm) were fabricated in white and dentin shades (n=1 per composite resin shade). Cement specimens (G-CEM LinkForce) were prepared from 3 shades (A2, opaque [OP], and translucent [TR]) (n=15 per shade). For control groups, 3 rectangular RMC foundations (14×12×4 mm) were also milled from RMC blocks (n=1 per block). Color coordinates were recorded by using a digital spectrophotometer. The coordinates of 4-mm-thick RMC foundations served as the control groups. The coordinates of RMC specimens on each combination of CRF and cement served as test groups. The CIEDE2000 (ΔE_{00}) formula was used to assess color differences. Data were subjected to 3-way ANOVA and Tukey honestly significant difference (HSD) tests (α=.05).

Results. ΔE_{00} values of specimens were influenced by the CRF shade, cement shade, RMC type, as well as the interaction terms of the 3 variables (*P*<.001). Color differences in groups VE-A2-dentin, VE-OP-dentin, LU-OP-dentin, and GC-OP-dentin showed perceptible but clinically acceptable values ($0.8<\Delta E_{00}\leq 1.8$). The highest and lowest ΔE_{00} values were observed in the white-OP-LU (5.32 ±0.34) and dentin-OP-VE (0.94 ±0.31) groups.

Conclusions. Opaque cement on the white foundation led to the highest ΔE_{00} values in the resultant colors of all RMC groups. When used with the same shade on the dentin foundation, this cement produced clinically acceptable results. (J Prosthet Dent 2021;125:351.e1-e7)

Successfully emulating the optical properties of a natural tooth with artificial restorative materials is still demanding,[1-3] and matching error jeopardizes the esthetic success of indirect restorations.[4] As ceramics replicate many features of enamel and as composite resins match many of the characteristics of dentin,[5] they are frequently combined for the fabrication of esthetic indirect restorations in contemporary dentistry.[6] However, most ceramics are fragile with low fracture toughness and load-to-failure and thereby tend to be susceptible to fracture.[7,8] Additionally, they can cause abrasion of the opposing dentition.[7,9] Composite resin restorations exhibit wear, marginal fracture, poor resistance to plaque accumulation, and discoloration.[4] To address these drawbacks, machinable materials have been developed.[7,9]

These resin-matrix ceramic (RMC) materials consist of a crosslinked polymeric matrix highly filled with ceramic particles.[10-12] The manufacturer's goal was to combine the advantageous properties of ceramics such as biocompatibility, life-like appearance, color stability, and durability with those of composite resins such as polishability, repairability, low abrasiveness, and enhanced flexural strength,[13-15] and a number of brands have been

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Clinical Implications

In the clinical setting, the shades of underlying structures and the types of resin-matrix ceramics can cause alterations in the final optical characteristics of indirect restorations. Moreover, on the dentin shade foundation, the use of opaque cement can mask undesirable color results.

marketed.[9,16] All can be categorized according to the way the ceramic is incorporated into the polymeric matrix, as a resin nanoceramic or polymer-infused ceramic.[5]

RMCs are wear-resistant, cause minimal damage to the opposite dentition,[9,14] and can be repaired intraorally.[14] They cannot be sintered or crystallized, and their final gloss and smooth texture are achieved by surface polishing.[10] They have been reported to have high fatigue resistance, which should allow ultrathin restorations to withstand masticatory forces,[17,18] and to exhibit high bond strength values, although each requires a specific surface treatment.[5] The relatively soft RMC blocks are machinable, thereby allowing rapid milling with less tool wear or heat generation in the CAM unit.[10,14,15,19]

Ceramic systems with low crystalline content exhibit better light transmission and thereby a natural appearance but lower strength.[20] A ceramic restoration has been reported to be at least 2-mm thick for the final color of the restoration not to be affected by the underlying structure.[21-24] However, where the thickness is less than 2 mm, the shade and thickness of the cement, the shade of the foundation restoration, and the shade of the underlying tooth tissue have been reported to influence the resultant restoration color.[25-29] Moreover, the chemical composition and particle size of a ceramic, cement, and foundation restoration may affect esthetic properties.[2,5,29,30] All these variables can lead to alterations in the light transmittance that is related to absorption and scattering of the incident light, causing colorimetric differences.[2] Studies that evaluated the optical properties of RMCs are scarce. Therefore, the purpose of this in vitro study was to assess the cumulative effect of different shades of composite resin foundation (CRF) and cement on the resultant optical properties of 3 different RMCs. The null hypothesis was that no influence of the shade of CRF and cement on the resultant color of different RMCs would be found.

MATERIAL AND METHODS

The experimental design and the materials used are presented in Figures 1, 2 and Table 1. Forty-five 1-mm-thick rectangular RMC specimens (14×12 mm, shade A2–Low Translucency) were cut by using a precision sectioning cutter (Isomet 1000; Buehler) from 3 different computer-aided design and computer-aided manufacturing (CAD-CAM) blocks, a polymer-infiltrated ceramic network (Vita Enamic [VE]; Vita Zahnfabrik), a resin nanoceramic (Lava Ultimate [LU]; 3M ESPE), and a flexible nanoparticle-filled resin (GC Cerasmart [GC]; GC Corp). One side of each specimen was ground with 600-, 800-, 1200-, and 2000-grit wet silicon carbide abrasive papers on a grinding machine (Gripo 2V; Metkon Instruments Ltd) at 100 rpm/min for 15 seconds and subsequently polished by using a disk (Diapol Twist; EVE Ernst Vetter GmbH) and paste (Diamond Twist SCO; Premier Dental GmbH) with an electric handpiece at 10 000 rpm for 20 seconds. The final thickness was adjusted to 1 ±0.01 mm by measuring the specimens by using digital calipers (Digimatic Caliper; Mitutoyo Corp) to an accuracy of ±0.01 mm. The specimens were ultrasonically cleaned in distilled water for 10 minutes (Biosonic UC1–110; Coltène) and then air-dried. Specimens of RMC foundation (14×12×4 mm) were cut by using the precision sectioning cutter from RMC blocks (n=1 per block).

Two CRF specimens (14×12×4 mm) were incrementally fabricated in a silicone mold by using the white and dentin shades of a dual-polymerized composite resin (Clearfil DC Core Plus; Kuraray) and then ground-finished with 600- to 1000-grit wet silicon carbide abrasive papers. In addition, 45 rectangular dual-polymerized cement (G-CEM LinkForce; GC Corp) specimens were fabricated in 3 shades; universal A2 (A2), opaque (OP), and translucent (TR). For each shade, cement was syringed into rectangular cavities (14×12×0.1 mm) of a hard-plastic plate on a glass cover slip according to the manufacturer's instructions. Another cover slip was placed over the specimens, and a 7.4-N static load was applied. Both sides were exposed to a halogen light source (Hilux Dental Curing Unit; Ultra Plus) for 45 seconds for polymerization. All CRF and cement specimens were then stored in distilled water at 37 ±1 °C for 24 hours to ensure complete polymerization.

Color readings were conducted in a viewing booth according to CIE D65 illuminant and CIE 2-degree Standard Observer[31] with the aid of a digital spectrophotometer (VITA Easyshade Compact; VITA Zahnfabrik). Before the readings, the device was calibrated with its calibration apparatus. Moreover, care was taken to position the 6-mm-diameter measuring tip at the center of the specimen and to ensure complete contact between the tip of the device and measuring surface.

Before spectrophotometric analysis of the test groups, a drop of refractive index solution (Cargille optical gel; Cedar Grove) was used to form the CRF-cement-RMC complexes. During assembly, the first A2 shade cement and the first VE specimen were placed onto the white CRF. Subsequently, the color coordinates were recorded.

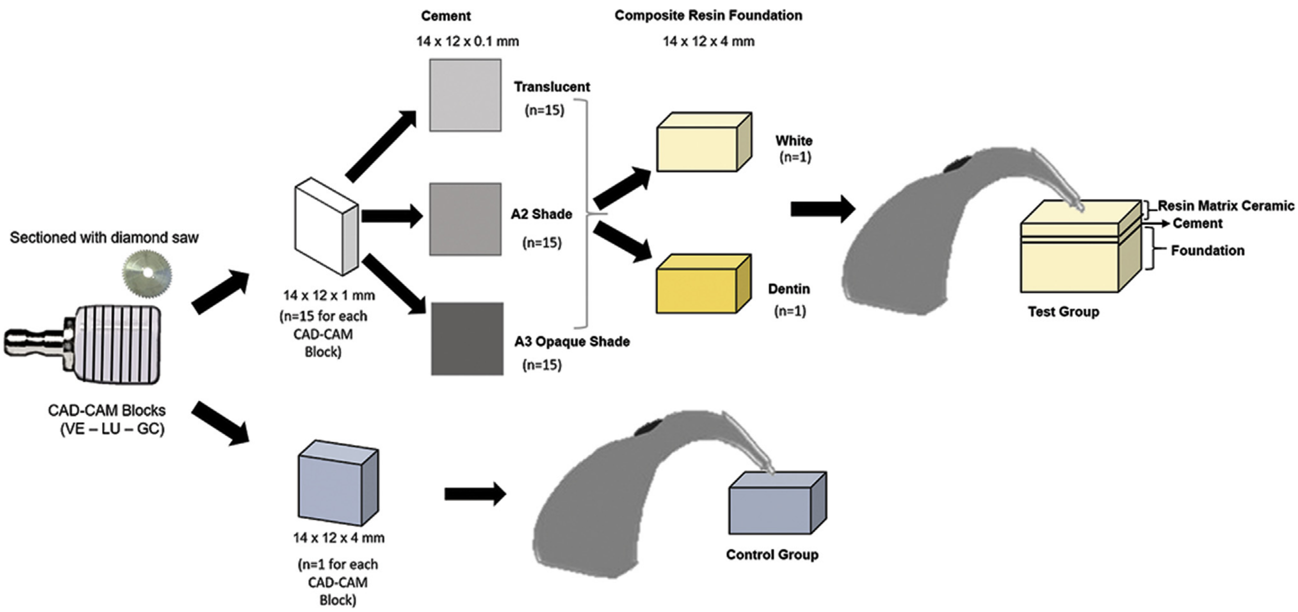

Figure 1. Experimental design. CAD-CAM, computer-aided design and computer-aided manufacturing.

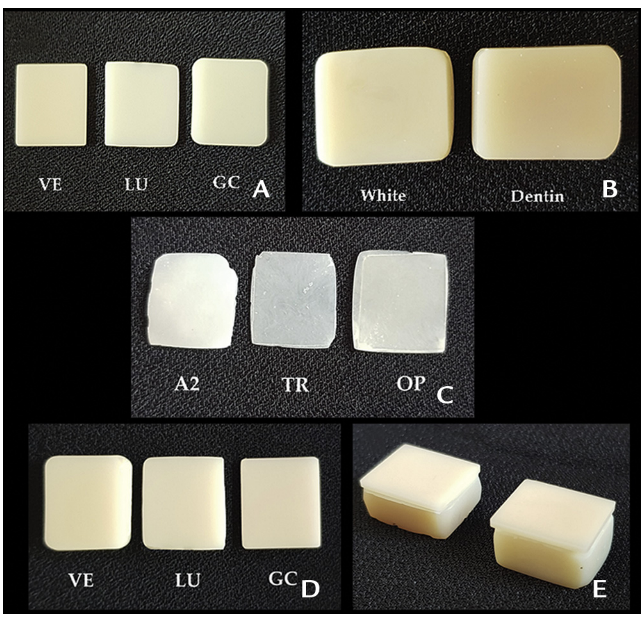

Figure 2. Test specimens. A, Vita Enamic (VE), Lava Ultimate (LU), and GC Cerasmart (GC) resin-matrix ceramic (RMC) specimens. B, White and dentin shade composite resin foundations. C, A2, translucent (TR), and opaque (OP) cement shade specimens. D, Control groups of each resin-matrix ceramic specimen. E, Composite resin foundation-cement-RMC complexes formed with refractive index solution.

This procedure was repeated for the remaining 14 VE specimens combined with the cement shade groups over the same CRF specimen. Then, the VE specimens were replaced with LU and GC specimens to perform their color readings. The color measurements were then repeated over the dentin CRF in the same order.

Table 1. Properties of materials used

Material	Type	Manufacturer	Shade
VITA Enamic	Polymer-infiltrated-feldspathic-ceramic-network material (UDMA, TEGDMA) with 86 wt% ceramic (SiO_2, Al_2O_3, Na_2O, K_2O, and other oxides)	Vita Zahnfabrik	T 2M2
GC Cerasmart	Resin nanoceramic (Bis-MEPP, UDMA, DMA) with 71 wt% silica and barium glass nanoparticles	GC Corp	LT A2
LAVA Ultimate	Resin nanoceramic (Bis-GMA, UDMA, Bis-EMA, TEGDMA) with 80 wt% silica and barium glass nanoparticles and zirconia/silica nanoclusters	3M ESPE	LT A2
Clearfil DC Core Plus	Dual-cured composite resin (A paste: Bis-GMA, hydrophilic aliphatic dimethacrylate, hydrophobic aliphatic dimethacrylate, hydrophobic aromatic dimethacrylate, silanized Ba glass filler, silanized colloidal silica, colloidal silica, initiators, pigments; B paste: TEGDMA, hydrophilic aliphatic dimethacrylate, hydrophobic aromatic dimethacrylate, silanized Ba glass filler, silanized colloidal silica, Al_2O_3 filler, accelerators)	Kuraray Noritake Dental	White Dentin
G-CEM LinkForce	Dual-cured adhesive resin cement (A Paste: Bis-GMA UDMA, DMA, initiator, Ba glass, pigments; B Paste: bis-MEPP, UDMA, DMA, initiator, Ba glass)	GC Corp	A2 Opaque Translucent
Cargille Optical Gel (n=1.52)	Refractive index solution (Phthalate esters and gelling agents)	Cargille Lab	Colorless

The CIELab color coordinates (L_0*, a_0*, and b_0*) of 4-mm-thick foundation of each RMC served as the controls. The CIELab coordinates (L_1*, a_1*, and b_1*) of RMC specimens on each combination of CRF and cement served as the test groups. In all groups, 3 measurements were sequentially made, and average values for L*, a*, and b* coordinates were recorded. The CIEDE2000 (ΔE_{00}) formula[31] was used to assess color differences

Table 2. Mean L*, a*, and b* coordinates ±standard deviation

Resin-Matrix Ceramic Type	Cement Shade	Composite Resin Foundation Shade	L	a	b
VE Control	–	–	78.54 ±0.49	4.78 ±0.17	30.85 ±0.44
VE	A2	White	80.16 ±0.40	2.93 ±0.13	31.72 ±0.33
	–	Dentin	74.73 ±0.37	2.44 ±0.06	26.90 ±0.37
	TR	White	80.74 ±0.54	2.55 ±0.11	30.85 ±0.37
	–	Dentin	74.30 ±0.55	2.09 ±0.11	26.21 ±0.39
	OP	White	82.00 ±0.44	3.63 ±0.09	32.80 ±0.36
	–	Dentin	77.99 ±0.52	2.98 ±0.12	28.58 ±0.45
LU Control	–	–	78.44 ±0.28	-0.95 ±0.09	22.30 ±0.31
LU	A2	White	83.75 ±0.33	-0.92 ±0.10	26.94 ±0.18
	–	Dentin	76.28 ±0.57	-1.12 ±0.13	21.20 ±0.25
	TR	White	84.42 ±0.37	-1.77 ±0.08	25.85 ±0.30
	–	Dentin	75.88 ±0.48	-1.64 ±0.09	20.52 ±0.25
	OP	White	85.19 ±0.64	-0.40 ±0.06	27.90 ±0.38
	–	Dentin	79.74 ±0.46	-0.99 ±0.07	22.71 ±0.19
GC Control	–	–	80.35 ± 0.32	-0.15 ±0.03	23.92 ±0.22
GC	A2	White	84.63 ±0.57	-0.72 ±0.14	26.16 ±0.24
	–	Dentin	76.74 ±0.42	-1.02 ±0.14	20.79 ±0.14
	TR	White	84.94 ±0.35	-1.38 ±0.11	24.74 ±0.21
	–	Dentin	77.29 ±0.39	-1.43 ±0.17	19.94 ±0.16
	OP	White	86.50 ±0.41	-0.31 ±0.10	27.08 ±0.28
	–	Dentin	80.84 ±0.50	-0.78 ±0.10	22.09 ±0.17

A2, A2 shade; GC, GC Ceresmart; LU, Lava Ultimate; OP, opaque; TR, translucent; VE, Vita Enamic.

among the control groups and test groups on the neutral gray (L*=25.7, a*=2.8, b*=8.4) background:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}},$$

where ΔL′, ΔC′, and ΔH′ represent the differences in lightness, chroma, and hue, respectively, between 2 specimens; R_T represents the rotation function that accounts for the interaction between chroma and hue differences in the blue region; S_L, S_C, and S_H represent the weighting functions that adjust the total color difference for variation in the location of the color difference pair in L, a, and b coordinates, respectively; and k_L, k_C, and k_H are parametric factors, representing correction terms for experimental conditions. In this study, parametric factors were set to 1. ΔE_{00} units of 0.80 and 1.80 were regarded as perceptibility and acceptability thresholds, respectively.[32]

All computations were carried out by using a statistical analysis software program (IBM SPSS Statistics, v23; IBM Corp) (α=.05 for all tests). The data normality was determined with the Shapiro-Wilk test (*P*>.05). Therefore, parametric 3-way analysis of variance (ANOVA) was used to analyze the influences of 3 variables (RMC type, cement shade, and foundation shade) on ΔE_{00} values. The Tukey honestly significant difference (HSD) test was conducted whenever a statistically significant interaction was found.

Table 3. Three-way ANOVA results of ΔE_{00} values

Source	Type III Sum of Squares	Df	Mean Square	F	*P*
Resin-Matrix Ceramic Type (A)	170.820	2	85.410	1218.259	<.001
Cement Shade (B)	15.593	2	7.796	111.205	<.001
Composite Resin Foundation Shade (C)	83.890	1	83.890	1196.575	<.001
A×B	2.203	4	0.551	7.854	<.001
A×C	6.037	2	3.018	43.052	<.001
B×C	102.780	2	51.390	733.009	<.001
A×B×C	8.718	4	2.179	31.086	<.001

Df, degree of freedom; F, variance analysis test statistics. *P*<.05 indicates significant difference.

RESULTS

Table 2 presents the mean ΔE_{00} values and standard deviations of the L*, a*, and b* coordinates of all groups. Three-way ANOVA indicated that ΔE_{00} values of specimens were influenced by the CRF shade, cement shade, RMC type, as well as the interaction terms of the 3 variables (*P*<.001) (Table 3). Figure 3 shows the mean ΔE_{00} values with confidence intervals, and Table 4 indicates the mean ΔE_{00} values and standard deviations with the Tukey post hoc test results.

The lowest and highest mean ΔE_{00} values were found for VE-OP-dentin (0.94 ±0.31) and LU-OP-white (5.32 ±0.34). Color differences in groups VE-A2-dentin (1.67 ±0.36), VE-OP-dentin (0.94 ±0.31), LU-OP-dentin (1.72

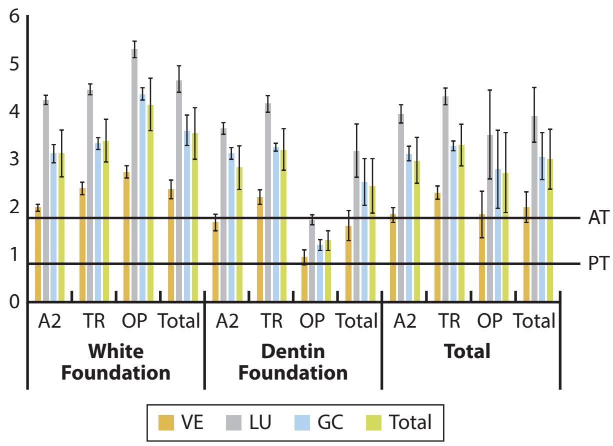

Figure 3. Mean color difference (ΔE00) values with confidence intervals, acceptability threshold (AT), and perceptibility threshold (PT).

Table 4. Mean ±standard deviation ΔE_{00} values and multiple comparisons

Composite Resin Foundation Shade	Cement Shade	Resin-Matrix Ceramic Type VE	LU	GC	Total
White	A2	1.98 ±0.15^{BC}	4.25 ±0.18^{H}	3.12 ±0.37^{F}	3.12 ±0.97^{BC}
	TR	2.39 ±0.25^{D}	4.47 ±0.23^{H}	3.33 ±0.24^{FG}	3.4 ±0.89^{C}
	OP	2.74 ±0.25^{E}	5.32 ±0.34^{I}	4.37 ±0.25^{H}	4.15 ±1.11^{D}
	Total	2.37 ±0.38^{B}	4.68 ±0.53^{D}	3.61 ±0.62^{C}	3.55 ±1.08
Dentin	A2	1.67 ±0.36^{B}	3.65 ±0.24^{G}	3.13 ±0.23^{F}	2.82 ±0.89^{B}
	TR	2.2 ±0.29^{CD}	4.17 ±0.35^{H}	3.26 ±0.17^{F}	3.21 ±0.86^{BC}
	OP	0.94 ±0.31^{A}	1.72 ±0.2^{B}	1.2 ±0.19^{A}	1.29 ±0.41^{A}
	Total	1.6 ±0.61^{A}	3.18 ±1.1^{C}	2.53 ±0.97^{B}	2.44 ±1.12
Total	A2	1.83 ±0.31^{A}	3.95 ±0.37^{DE}	3.12 ±0.3^{C}	2.97 ±0.94^{a}
	TR	2.3 ±0.28^{AB}	4.32 ±0.33^{E}	3.29 ±0.2^{CD}	3.3 ±0.87^{b}
	OP	1.84 ±0.96^{A}	3.52 ±1.85^{CD}	2.79 ±1.63^{BC}	2.72 ±1.66^{c}
	Total	1.99 ±0.64^{a}	3.93 ±1.14^{b}	3.07 ±0.98^{c}	3 ±1.23

A2, A2 shade; GC, GC Cerasmart; LU, Lava Ultimate; OP, opaque; TR, translucent; VE, Vita Enamic. No difference between columns and rows with same superscripted lowercase letter. No difference between interactions with same superscripted uppercase letter.

±0.2), and GC-OP-dentin (1.2 ±0.19) showed perceptible but clinically acceptable values. The rest of the ΔE_{00} values for the dentin CRF and all ΔE_{00} values for the white CRF were found to be above the threshold of clinical acceptability.

The multiple comparisons determined that OP cement groups on the white CRF created significantly higher ΔE_{00} than other cement groups but lower ΔE_{00} values on the dentin CRF ($P<.05$). When comparing RMCs in the same cement shade group, for A2 and TR cement shade, all the differences among RMCs were statistically significant on both CRFs ($P<.05$). For the OP group, all the differences among RMCs on a white CRF and the difference between LU and other RMCs on the dentin CRF were statistically significant ($P<.05$). For the OP group, the differences between mean ΔE_{00} values of RMCs on dentin and white CRF were statistically significant ($P<.05$).

DISCUSSION

The null hypothesis was rejected as the results indicated that RMC type, cement shade, CRF shade, and their interactions significantly influenced the color of all RMCs. The present study determined that the use of an opaque cement on the white CRF led to the highest ΔE_{00} values in all RMCs in comparison with other cement shades. This finding is consistent with those of other studies[1,4,25] and can be attributed to a number of factors. First, cements with different shades can differ in terms of chemical composition, and this can alter their optical properties.[1,2,13,20] Second, different refractive index and light transmittance might explain the color difference values among different shades of the same cement.[2,20] Third, opaque cement may not successfully mitigate the influence of the white CRF. Fourth, it has been reported that an opaque cement-white CRF combination increases brightness and decreases hue and chroma.[13,20,21,26,33] This can explain why the resultant color of RMCs cannot correspond with the LT A2 target shade tab. In contrast, opaque cement on dentin CRF can be satisfactorily used for the tested RMCs, as the lowest ΔE_{00} values were achieved within this combination. This finding is also consistent with those of other studies[3,21] and may originate from the opaque characteristics of cement that can successfully mask the color of the underlying structure.[13,21]

The present study also found that the highest ΔE_{00} values on both CRFs were in the LU group. This can chiefly be attributed to the microstructure of the LU because RMCs with different intrinsic microstructures may exhibit different optical behaviors. The crystal phase has been reported to be an effective opacifier for restorative materials.[30] LU contains 2 types of monodispersed, nonaggregated, and nonagglomerated nanomers within the ceramic network: silica nanomers of 20-nm diameter and zirconia nanomers of 4- to 11-nm diameter.[5,7,8,10] Its resin network consists of bisphenol A-glycidyl methacrylate (Bis-GMA), urethane di-methacrylate (UDMA), ethoxylated bisphenol glycol dimethacrylate (Bis-EMA), and triethylene glycol dimethacrylate (TEGDMA) components.[5,10] Nanometer-sized filler particles might explain higher light transmission, as particles with a diameter smaller than the wavelength of the visible light led to less light scattering.[28] Additionally, Bis-GMA which only presents in the composition of LU is more translucent than UDMA and TEGDMA.[34,35] Therefore, LU is significantly affected by the shade of the underlying structure as it allows more light transmission than the other RMCs.

The present study also showed that VE had the lowest ΔE_{00} values in both CRFs. Several factors may have influenced this result. First, the ceramic network of VE consists of a large proportion of aluminum oxide (Al_2O_3), increasing its opacity.[5] Second, it contains metal oxide opacifiers such as zirconium oxide (ZrO_2) and titanium oxide (TiO_2), which may act as scattering centers and reduce light transmission through the RMC.[33] Third, large mismatches of the refractive index between the matrix and the filler tend to increase the opacity of a material.[33,34] The refractive indices of the UDMA, TiO_2, Al_2O_3, and ZrO_2 are 1.48, 2.49, 1.77, and 2.22, respectively.[33] From this point of view, it is plausible to assume that TiO_2 and ZrO_2 substantially increase the opacity of the material. A material with a higher opacity can mask the shade of underlying structures,[13,21] which explains why VE caused the lowest ΔE_{00} values. However, the indirect restoration might have poor esthetics.[13,26] GC is composed of alumina-barium-silicate particles embedded in the polymer network.[10] As it does not contain any opacifying agent, it allows high light transmittance. Accordingly, it is affected by the color of the underlying structure, with high ΔE_{00} values.

Limitations of the present study include the susceptibility of the spectrophotometer to the surface topography and to edge loss.[36-38] A spectroradiometer can provide more precise and reliable results.[37,38] To simulate the discolored substrate, a composite resin was used. However, the optical properties of natural teeth may differ from those of the composite resin. Only one shade and translucency for RMCs were tested; different shades and translucencies of materials may have led to different results. Instead of obtaining an optical connection, specimens could have been actually cemented. Therefore, further studies addressing these limitations are indicated.

CONCLUSIONS

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

1. CRF shade, cement shade, and RMC type significantly influenced the resultant color of RMCs ($P<.001$).
2. On both shades of CRF, the LU group demonstrated the highest ΔE_{00} values, regardless of the cement shade.
3. Opaque cement on the white CRF led to the highest ΔE_{00} values in the resultant colors of all RMC groups. When used with the same shade on the dentin CRF, this cement produced clinically acceptable results.

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