Odontology (2021) 109:393–402
https://doi.org/10.1007/s10266-020-00554-4

ORIGINAL ARTICLE

Evaluation of shade correspondence between current monolithic CAD/CAM blocks and target shade tab by considering the influence of cement shade and restorative material thickness

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Received: 24 April 2020 / Accepted: 11 September 2020 / Published online: 28 September 2020

Abstract

It was aimed to evaluate shade matching between novel CAD/CAM blocks and the A2 target shade tab by considering the influence of cement shade and restorative material thickness on the chromatic background. A total number of 120 rectangular-shaped specimens were subtracted from four different prefabricated CAD/CAM blocks [Vita Enamic (VE), Lava Ultimate (LU), GC Cerasmart (GC), and Vita Mark II (VMII)]. These specimens had thicknesses of 0.5 mm and 1.0 mm. Three different shades (A2, opaque, and translucent) of dual-polymerized resin cement were chosen. The dentin shade (A3.5) restorative composite foundation was incrementally fabricated in a silicon mold. For control group, the A2 shade tab of the Vitapan classical shade guide was used. Different restorative material–cement–foundation assemblies were generated with optic gel. Color readings were performed by using a clinical spectrophotometer, and CIEDE2000 (ΔE_{00}) formula was used to assess color differences. Data were statistically analyzed ($\alpha = 0.05$). With increasing thickness, color difference values decreased. Higher mean ΔE_{00} units were observed in all restorative material sub-groups for 0.5 mm thickness. In TR shade, no statistically significant difference was detected among the mean ΔE_{00} values of 0.5 mm-thick restorative materials. Color differences in groups 1.0 mm-opaque-LU and 1.0 mm-opaque-GC indicated perceptible but clinically acceptable values ($0.8^{<}\Delta E_{00} \leq 1.8$). The highest and lowest ΔE_{00} units were observed in the 0.5 mm-A2-VE group ($\Delta E_{00} = 7.07$) and 1 mm-opaque-GC group ($\Delta E_{00} = 1.46$), respectively. Luting cement shade, restorative material type, and thickness significantly influenced the resultant color of restoration. Opaque cement on dentin foundation exhibited lower color differences.

Keywords Color · Luting cement shade · Hybrid ceramic blocks · Shade matching · Computer-aided manufacturing

Introduction

Rapid progress in CAD/CAM technology has led to the emergence of different machinable restorative materials with enhanced optical and mechanical characteristics for the fabrication of indirect restorations [1–3]. Currently, a plethora of preprocessed blocks is available [1, 2, 4, 5]. Despite the superior esthetic properties of glass ceramics, the demand for stronger ceramic restoration has increased, and thereby, ceramic-reinforced polymers (CRPs) have been introduced [6].

CRPs combine the positive properties of ceramic and composite materials and thereby provide superior properties: (1) they exhibit superior fatigue resistance to enable the production of ultra-thin non-invasive restorations [7, 8], (2) they are wear resistant and gentle to the opposite dentition due to the presence of polymeric matrix [4], (3) they minimally expose to fracture during occlusal adjustments and try-in [8], (4) they present lower fracture toughness than lithium disilicate glass ceramic and zirconia-reinforced lithium silicate [9], (5) they enhance machinability due to the presence of soft resin matrix [10], (6) intra-oral repair is possible [4, 10], (7) there is no need for sintering or crystallization firing [4], (8) although each CRP requires a dedicated surface treatment; they generally exhibit high bond strength values [5], (9) they provide clinically acceptable results in terms of esthetic [5], and (10) their superb fatigue resistance allows restoration to withstand against masticatory forces [11].

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Full-coverage ceramic crowns have been used for esthetic rehabilitation of anterior teeth for many years. However, it has been expressed as an invasive type of restoration because it causes excessive tissue loss [12]. Recently, the grand progress in bonding capability to enamel and dentin tissues enabled the introduction of a minimally invasive restorative technique—laminate veneer—to deal with anesthetic tooth appearance [13]. Commonly, the thickness of laminate veneer restorations is in the range of 0.4–1.0 mm [14]. This gives high translucency to these restorations [15]. Selecting the suitable thickness of the ceramic is of paramount importance to achieve optimal esthetics [2, 16, 17]. The more translucent the ceramic system is, the greater the light transmission is feasible, and the more natural appearance would be [18, 19]. However, this creates a challenge in the creation of an esthetic restoration that blends harmoniously with adjacent natural teeth [13, 15, 16, 18]. In cases where the thickness of the ceramic system is less than 2 mm, it is known that the optical properties of the restoration may vary significantly [3, 20] depending on the thickness, shade, texture, and chemical composition of the underlying structures, and this may thereby compromise the expected optical result (target shade tab) [2, 12, 17, 21–26]. Additionally, chromatic foundations caused by endodontic treatment, trauma, and pigmentation add another level of complexity to the shade matching procedure [24, 27].

Color differences can be assessed either instrumentally or visually. Various instruments have been developed to record color coordinates and to calculate colorimetric differences between two objects by comparing their respective coordinates [16, 27]. Of these, the spectrophotometer is widely preferred in previous studies [19, 21, 28–31]. In comparison with visual observation, the use of spectrophotometer increases accuracy by 33% and provides 93.3% success [32, 33]. Colorimetric differences can be routinely defined as perceptible and acceptable [22]. In different studies, the perceptible color difference threshold ranges from 1.0 to 3.7, and the acceptable color difference threshold ranges from 1.7 to 6.8 [34–38]. Recently, Paravina et al. declared new thresholds for perceptibility and acceptability [39]. However, there is still no consensus regarding the optimal thresholds [23].

The color masking capability of different types of CRPs has not been studied to the same extent as the masking ability of indirect restorations fabricated with preceding restorative materials, despite its importance for expectancy of the life-like appearance of prosthetic restorations. Therefore, it was aimed to analyze the effect of restorative material type, restorative material thickness, and luting cement shade on the resultant color of 4 different CAD/CAM materials. The null hypothesis tested was that the target shade would not be altered by any of the abovementioned variables.

Materials and methods

The schematic setup is depicted in Fig. 1. For this experiment, 120 rectangular-shaped specimens (12 × 14 mm) were cut into 2 thicknesses (0.5 mm and 1.0 mm) by using a low-speed cutting device (Isomet 1000, Buehler, USA) from 4 different prefabricated CAD/CAM blocks including Vita Enamic (VE/2M2 shade—translucent polymer-infiltrated ceramic network, Vita Zahnfabrik, Bad Säckingen, Germany), Lava Ultimate (LU/A2 shade—low translucent resin nanoceramic, 3 M ESPE, St.Paul, MN, USA), GC Cerasmart (GC/A2 shade—low translucent flexible nanoparticle-filled resin, GC Dental Products Corp., Aichi, Japan), and Vita Mark II (VMII/A2 shade—low translucent glass ceramic, VITA Zahnfabrik, Bad Säckingen, Germany).

The veneer surfaces of all specimens were then ground with wet silicon carbide papers (600-, 800-, 1200-, and 2000-grit SiC papers, Siawat WA, Switzerland) by using a grinding machine (Gripo 2 V, Metkon Instruments Ltd, Bursa, Turkey) at 100 rpm/min for 15 s to achieve a uniformly finished surface, followed by polishing using disc (Diapol Twist, EVE Ernst Vetter Gmbh, Germany) and paste (Diamond Twist SCO, Premier Dental Gmbh, USA) with the aid of an electric handpiece at 10,000 rpm for 20 s. The intaglio surfaces of all specimens were subjected to

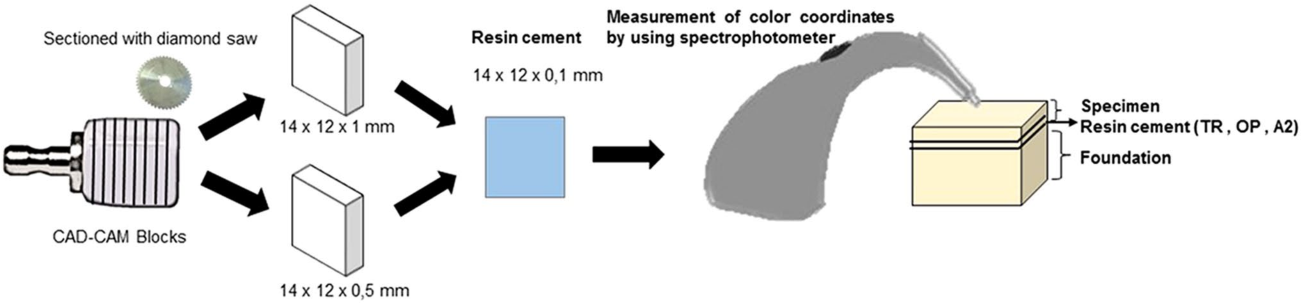

Fig. 1 Schematic setup of study

grinding with 600-grit wet silicon carbide paper. The final thicknesses of the specimens were adjusted to 0.5 ± 0.1 mm and 1.0 ± 0.1 mm. A digital micrometer (Digimatic Caliper, Mitutoyo Corp., Japan) with an accuracy of ± 0.01 mm was used for controlling thickness. Subsequently, all specimens were ultrasonically cleaned in distilled water for 10 min (Biosonic Ultrasonic Cleaner UC1–110, Coltene Whaledent, Altstätten, Switzerland) and dried.

Sixty luting cement (G-CEM LinkForce, GC Corp., Tokyo, Japan) specimens were prepared in shades of universal (A2), opaque (OP), and translucent (TR) by syringing dual-polymerized resin cement into rectangular-shaped voids (12 × 14 × 0.2 mm) of a hard plastic plate on a cover glass. Statically, 0.75 kgf load was subsequently applied by covering over the specimens with a glass plate. After waiting 2 min for chemical curing, specimens were photo-activated for 40 s with the aid of a halogen light source (Hilux Dental Curing Unit, Ultra Plus, Ankara, Turkey) and then immersed in distilled water at 37 ± 1 °C for 24 h for complete polymerization. Dentin shade (A3.5) ($L^* = 71.2$, $a^* = -1.7$, $b^* = 22.1$, $C_{ab}* = 22.17$, and $h_{ab}^* = 94.40$) [40] restorative composite foundations (12 × 14 × 4 mm) were incrementally fabricated in a silicon mold by using a dual-polymerized composite resin (Clearfil DC Core Plus, Kuraray, New York, USA) and served as dentin substrate. Foundations were then ground finished with 600- and 1000-grit wet silicon carbide paper. Each of the samples ($n = 15$) was optically coupled with each shade cement ($n = 15$), respectively. This assembling procedure of CRP with RC and composite foundations were performed by using a drop of optical gel (Cargille optical gel, Cargille Lab, Cedar Grove, NJ, USA).

The color coordinates (L^*, a^*, b^*, C_{ab}^*, and h_{ab}^*) [40] were recorded in a viewing booth with the aid of a digital spectrophotometer (VITA Easyshade Compact, VITA Zahnfabrik, Bad Säckingen, Germany) in a tooth single mode according to CIE D65 illuminant and CIE 2° Standard Observer [40]. The calibration of the device was done with its in-built apparatus before experimental measurements were made. During all measurements, the spectrophotometer measuring tip was positioned in the middle of each specimen with full contact.

For the control group, the A2 shade tab of the Vitapan classical shade guide was used. Color readings of the target shade tab were conducted three times on the neutral gray background. The means for control group coordinates (L_0^*, a_0^*, b_0^*, C_{ab0}^*, h_{ab0}^*) were recorded as $L^* = 80.5$, $a^* = 0.60$, $b^* = 22.4$, $C_{ab}^* = 22.41$, and $h_{ab}^* = 88.47$. Different assemblies (any of restorative material options + optical gel + any of cement options + optical gel + foundation) were formed. For each assembly in test groups, L_1^*, a_1^*, b_1^*, C_{ab1}^*, and h_{ab1}^* coordinates were generated by using the same measurement manner. Lately introduced CIEDE2000 (ΔE_{00}) formula was preferred for the quantitative representation of color differences among control group coordinates (L_0^*, a_0^*, b_0^*, C_{ab0}^*, and h_{ab0}^*) and test group coordinates (L_1^*, a_1^*, b_1^*, C_{ab1}^*, and h_{ab1}^*) on the neutral gray background [40]:

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

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ represent the differences in lightness, chroma, and hue between two sets of color coordinates, respectively; R_T represents the rotation function for the interaction between chroma and hue in the blue region; S_L, S_C, and S_H represent the weighting functions, and k_L, k_C, and k_H, named as parametric factors, represent correction terms for experimental conditions. In this study, the aforementioned parametric factors were set to 1. Thresholds considered for perceptible and acceptable color differences were $\Delta E_{00} > 0.8$ and $\Delta E_{00} > 1.8$, respectively [39]. The supposition of data normality was confirmed with the aid of the Shapiro–Wilk Test ($P > 0.05$). In the statistical investigation of main effects (restorative material, thickness, and cement shade) and their interaction terms, analysis of generalized linear models was used. For multiple comparisons, Bonferroni correction was conducted. For quantitative data, the results were presented as mean values with standard deviations. The differences between the color coordinates (L^*, a^*, b^*, C_{ab}^*, and h_{ab}^*) of the test groups were also compared with those of A2 shade tab with the aid of independent t-test. Statistical analyses were performed with a package (IBM SPSS Statistics v23, IBM Corp., Chicago, USA) ($\alpha = 0.05$).

Results

The mean values of L^*, a^*, b^*, C_{ab}^*, and h_{ab}^* of the specimens are shown in Table 1. According to the results of analysis of general linear models, ΔE_{00} values were significantly influenced by the main effects (ceramic thickness, luting cement shade, and ceramic type), as well as the interaction terms of the three variables ($P \leq 0.001$) (Table 2). Descriptive statistics and multiple comparisons in terms of mean ΔE_{00} values are shown in Table 3 and in Fig. 2.

The mean ΔE_{00} values for VE (highest), GC (lowest), LU, and VMII are 5.26 ± 1.06, 3.7 ± 1.38, 4.06 ± 1.36, and 4.66 ± 0.72, respectively. A statistically significant difference was detected among the mean ΔE_{00} values of the tested restorative materials ($P \leq 0.001$) (Table 3). The mean ΔE_{00} values of those with a material thickness of 0.5 mm and those with a material thickness of 1.0 mm were 5.16 ± 1.03 and 3.67 ± 1.1, respectively. This difference was accepted as statistically significant ($P \leq 0.001$). The mean ΔE_{00} values for A2, OP (lowest), and TR (highest) shades are 4.8 ± 1.17, 3.42 ± 1.16, and 5.04 ± 0.92, respectively. A statistically significant difference was detected among the mean ΔE_{00} values of aforementioned shades ($P \leq 0.001$).

Table 1 Color coordinates with Δ values (Target A2 shade tab: $L^*=80.5$, $a^*=0.60$, $b^*=22.4$, $C_{ab}^*=22.41$, and $H_{ab}^*=88.47$)

Thickness	Resin matrix ceramic	Cement shade	Color coordinates				
			L^*	a^*	b^*	C_{ab}^*	H_{ab}^*
0.5 mm	VE	A2	70.89 ± 0.48* (ΔL = − 9.61)	1.36 ± 0.07* (Δa = 0.76)	24.03 ± 0.29* (Δb = 1.63)	24.08 ± 0.28* (ΔC = 1.67)	86.75 ± 0.20* (Δh = − 1.72)
		TR	72.22 ± 0.55* (ΔL = − 8.28)	0.49 ± 0.09 (Δa = -0.11)	22.08 ± 0.33 (Δb = − 0.32)	22.09 ± 0.33 (ΔC = − 0.32)	88.73 ± 0.25 (Δh = 0.26)
		OP	74.23 ± 0.44* (ΔL = − 6.27)	1.72 ± 0.08* (Δa = 1.12)	25.34 ± 0.29* (Δb = 2.94)	25.40 ± 0.29* (ΔC = 2.99)	86.12 ± 0.17* (Δh = − 2.35)
	LU	A2	73.44 ± 0.63* (ΔL = − 7.06)	− 1.24 ± 0.09* (Δa = − 1.84)	21.21 ± 0.44* (Δb = − 1.19)	21.24 ± 0.44* (ΔC = − 1.17)	93.35 ± 0.29* (Δh = 4.88)
		TR	74.08 ± 0.67* (ΔL = − 6.42)	− 1.89 ± 0.14* (Δa = − 2.49)	18.83 ± 0.30* (Δb = − 3.57)	18.93 ± 0.29* (ΔC = − 3.48)	95.74 ± 0.43* (Δh = 7.27)
		OP	75.54 ± 0.67* (ΔL = − 4.96)	− 0.98 ± 0.12* (Δa = − 1.58)	21.69 ± 0.30* (Δb = − 0.71)	21.71 ± 0.29* (ΔC = − 0.7)	92.58 ± 0.34* (Δh = 4.11)
	GC	A2	74.18 ± 0.49 * (ΔL = − 6.32)	− 1.44 ± 0.08* (Δa = − 2.04)	20.68 ± 0.25* (Δb = − 1.72)	20.73 ± 0.25* (ΔC = − 1.68)	94.00 ± 0.24* (Δh = 5.53)
		TR	74.48 ± 0.72* (ΔL = − 6.02)	− 2.03 ± 0.18* (Δa = − 2.63)	18.41 ± 0.29* (Δb = − 3.99)	18.52 ± 0.28* (ΔC = − 3.89)	96.29 ± 0.61* (Δh = 7.82)
		OP	76.45 ± 0.75* (ΔL = − 4.05)	− 1.02 ± 0.18* (Δa = − 1.62)	20.67 ± 0.14* (Δb = − 1.73)	20.69 ± 0.14* (ΔC = − 1.72)	92.83 ± 0.50* (Δh = 4.36)
	VMII	A2	75.97 ± 0.38* (ΔL = − 4.53)	− 1.10 ± 0.19* (Δa = − 1.7)	16.56 ± 0.24* (Δb = − 5.84)	16.59 ± 0.24* (ΔC = − 5.82)	93.79 ± 0.65* (Δh = 5.32)
		TR	76.82 ± 0.50* (ΔL = − 3.68)	− 1.67 ± 0.11* (Δa = − 2.27)	14.23 ± 0.23* (Δb = − 8.17)	14.33 ± 0.22* (ΔC = − 8.08)	96.71 ± 0.48* (Δh = 8.24)
		OP	77.07 ± 0.85* (ΔL = − 3.43)	− 0.56 ± 0.06* (Δa = − 1.16)	16.18 ± 0.13* (Δb = − 6.22)	16.19 ± 0.13* (ΔC = − 6.22)	91.97 ± 0.24* (Δh = 3.5)
1.0 mm	VE	A2	74.73 ± 0.37* (ΔL = − 5.77)	2.44 ± 0.06* (Δa = 1.84)	26.90 ± 0.37* (Δb = 4.5)	27.01 ± 0.36* (ΔC = 4.6)	84.82 ± 0.15 * (Δh = − 3.65)
		TR	74.30 ± 0.55 * (ΔL = − 6.2)	2.09 ± 0.11* (Δa = 1.49)	26.21 ± 0.39* (Δb = 3.81)	26.29 ± 0.39* (ΔC = 3.88)	85.45 ± 0.21* (Δh = − 3.02)
		OP	77.99 ± 0.52* (ΔL = − 2.51)	2.98 ± 0.12* (Δa = 2.38)	28.58 ± 0.45* (Δb = 6.18)	28.74 ± 0.46* (ΔC = 6.33)	84.04 ± 0.20* (Δh = − 4.43)
	LU	A2	76.28 ± 0.57* (ΔL = − 4.22)	− 1,12 ± 0.13* (Δa = − 1.72)	21.20 ± 0.25* (Δb = − 1.2)	21.23 ± 0.25* (ΔC = − 1.18)	93.02 ± 0.35* (Δh = 4.55)
		TR	75.88 ± 0.48* (ΔL = − 4.62)	− 1,64 ± 0. 09* (Δa = − 2.24)	20.52 ± 0.25* (Δb = − 1.88)	20.59 ± 0.25* (ΔC = − 1.82)	94.57 ± 0.24* (Δh = 6.1)
		OP	79.74 ± 0.46 (ΔL = − 0.76)	− 0.99 ± 0.07* (Δa = − 1.59)	22.71 ± 0.19 (Δb = 0.31)	22.73 ± 0.19 (ΔC = 0.32)	92.49 ± 0.17* (Δh = 4.02)
	GC	A2	76.74 ± 0.42* (ΔL = − 3.76)	− 1.02 ± 0.14* (Δa = − 1.62)	20.79 ± 0.14* (Δb = − 1.61)	20.81 ± 0.14* (ΔC = − 1.6)	92.81 ± 0.38* (Δh = 4.34)
		TR	77.29 ± 0.39* (ΔL = − 3.21)	− 1.43 ± 0.17* (Δa = − 2.03)	19.94 ± 0.16* (Δb = − 2.46)	19.99 ± 0.17 * (ΔC = − 2.42)	94.10 ± 0.49* (Δh = 5.63)
		OP	80.84 ± 0.50 (ΔL = 0.34)	− 0.78 ± 0.10* (Δa = − 1.38)	22.09 ± 0.17 (Δb = − 0.31)	22.10 ± 0.17 (ΔC = − 0.31)	92.02 ± 0.27* (Δh = 3.55)
	VMII	A2	79.22 ± 0.64* (ΔL = − 1.28)	− 0.66 ± 0.16* (Δa = − 1.26)	15.30 ± 0.20* (Δb = − 7.1)	15.31 ± 0.20* (ΔC = − 7.1)	92.47 ± 0.61* (Δh = 4)
		TR	78.94 ± 0.63* (ΔL = − 1.56)	− 0.86 ± 0.12* (Δa = − 1.46)	14.53 ± 0.35* (Δb = − 7.87)	14.56 ± 0.35* (ΔC = − 7.85)	93.38 ± 0.48* (Δh = 4.91)
		OP	82.77 ± 0.71* (ΔL = 2.27)	− 0.48 ± 0.13* (Δa = − 1.08)	16.39 ± 0.20* (Δb = − 6.01)	16.40 ± 0.20* (ΔC = − 6.01)	91.69 ± 0.46* (Δh = 3.22)

VE vita enamic, *LU* lava ultimate, *GC* GC ceresmart, *VMII* vita mark II, *A2* A2 shade, *TR* translucent, *OP* opaque

* shows the statistical significance between the color coordinate value of the intended A2 shade tab and corresponding coordinate in the test group

Table 2 Influence of restorative material, thickness, cement-shade variables and their interactions on the ΔE_{00} values

	Test statistics	df	P*
Restorative material	1297.217	3	**< 0.001**
Thickness	2017.548	1	**< 0.001**
Cement-shade	1866.928	2	**< 0.001**
Restorative material * thickness	231.803	3	**< 0.001**
Restorative material * cement-shade	271.488	6	**< 0.001**
Thickness * cement-shade	13.956	2	**0.001**
Restorative material * thickness * cement-shade	106.714	6	**< 0.001**

df degrees of freedom

* Wald Chi-square test

Table 3 Descriptive statistics and multiple comparisons in terms of ΔE_{00} values

Cement Shade	Thickness	Restorative material				
		VE	GC	LU	VMII	Total
A2	0.5 mm	$7,07\pm0,42^{I}$	$5,06\pm0,32^{AH}$	$5,44\pm0,42^{FH}$	$4,92\pm0,58^{A}$	$5,62\pm0,96^{D}$
	1.0 mm	$4,9\pm0,21^{A}$	$3,24\pm0,24^{G}$	$3,53\pm0,3^{EG}$	$4,23\pm0,14^{B}$	$3,97\pm0,68^{C}$
	Total	$5,98\pm1,15^{H}$	$4,15\pm0,96^{BG}$	$4,48\pm1,03^{C}$	$4,57\pm0,54^{C}$	$4,8\pm1,17^{a}$
OP	0.5 mm	$4,79\pm0,31^{A}$	$3,44\pm0,48^{G}$	$3,89\pm0,43^{BE}$	$4,24\pm0,34^{B}$	$4,09\pm0,63^{C}$
	1.0 mm	$3,9\pm0,16^{BE}$	$1,46\pm0,16^{D}$	$1,71\pm0,08^{D}$	$3,88\pm0,24^{BE}$	$2,74\pm1,18^{B}$
	Total	$4,35\pm0,51^{GC}$	$2,45\pm1,07^{F}$	$2,8\pm1,15^{E}$	$4,06\pm0,34^{B}$	$3,42\pm1,16^{b}$
TR	0.5 mm	$5,97\pm0,42^{C}$	$5,59\pm0,42^{FC}$	$5,64\pm0,43^{CF}$	$5,88\pm0,19^{C}$	$5,77\pm0,4^{D}$
	1.0 mm	$4,95\pm0,34^{A}$	$3,37\pm0,18^{G}$	$4,14\pm0,26^{B}$	$4,78\pm0,14^{A}$	$4,31\pm0,67^{A}$
	Total	$5,46\pm0,64^{A}$	$4,48\pm1,17^{C}$	$4,89\pm0,84^{D}$	$5,33\pm0,58^{A}$	$5,04\pm0,92^{c}$
Total	0.5 mm	$5,94\pm1,01^{F}$	$4,7\pm1,01^{E}$	$4,99\pm0,89^{B}$	$5,01\pm0,78^{B}$	$5,16\pm1,03$
	1.0 mm	$4,58\pm0,54^{E}$	$2,69\pm0,9^{D}$	$3,13\pm1,07^{C}$	$4,3\pm0,41^{A}$	$3,67\pm1,1$
	Total	$5,26\pm1,06^{a}$	$3,7\pm1,38^{b}$	$4,06\pm1,36^{c}$	$4,66\pm0,72^{d}$	$4,42\pm1,3$

a-d: there is no difference between groups with the same superscripted letter, A-I: There is no difference between interactions with the same superscripted letter

VE vita enamic, *LU* lava ultimate, *GC* GC ceresmart, *VMII* vita mark II, *A2* A2 shade, *TR* translucent, *OP* opaque

Considering restorative material and thickness interaction, the highest and lowest mean ΔE_{00} values were obtained at 0.5 mm-thick VE (5.94 ± 1.01) and 1.0 mm-thick GC (2.69 ± 0.9), respectively. Except for the difference between the mean ΔE_{00} values of 0.5 mm-LU and 0.5 mm-VMII ($P = 1.000$), the comparisons among restorative materials of each thickness group were detected as statistically significant ($P < 0.05$). The comparisons between two thickness groups of each restorative material were also detected as statistically significant ($P < 0.05$).

Considering restorative material and cement shade interaction, the highest mean ΔE_{00} value was obtained at A2 shade VE (5.98 ± 1.15), while the lowest mean ΔE_{00} value was achieved at OP shade GC (2.45 ± 1.07). Except for the difference between the mean ΔE_{00} values of LU and VMII on A2 shade ($P = 1000$) and the difference between the mean ΔE_{00} values of VE and VMII on TR shade ($P = 1000$), the comparisons among restorative materials of each cement shade group were detected as statistically significant ($P < 0.05$). The comparisons between cement shade groups of each restorative material group were also detected as statistically significant ($P < 0.05$).

Considering thickness and cement shade interaction, the highest mean ΔE_{00} value was achieved in the 0.5 mm-TR group (5.77 ± 0.4), while the lowest mean ΔE_{00} value was obtained in the 1.0 mm-OP group (2.74 ± 1.18). For each cement shade group, the differences between the thickness groups were statistically significant ($P < 0.05$). For each thickness group, the differences among cement shade groups were statistically significant ($P < 0.05$), except for the difference between A2 and TR cement shades in 0.5 mm thickness ($P = 0.166$).

Considering restorative material, cement shade, and thickness interaction, the highest and lowest mean ΔE_{00} values were noted at 0.5 mm-thick VE on A2 shade (7.07 ± 0.42) and 1.0 mm-thick GC on OP shade (1.46 ± 0.16), respectively. When the mean ΔE_{00} values of different restorative materials in the same cement shade group were

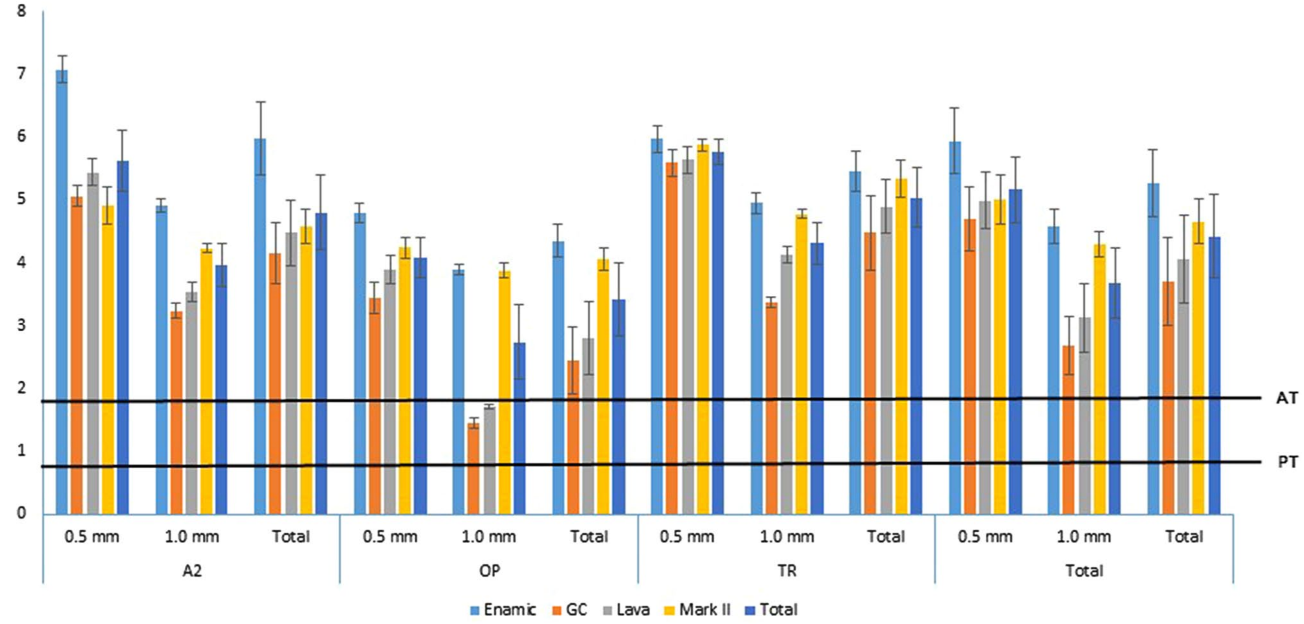

Fig. 2 Mean color difference (ΔE_{00}) values with confidence intervals, acceptability threshold (AT), and perceptibility threshold (PT)

compared, only the differences between A2-0.5 mm-GC and A2-0.5 mm-LU, A2-0.5 mm-GC and A2-0.5 mm-VMII, A2-1.0 mm-GC and A2-1.0 mm-LU, OP-0.5 mm-LU and OP-0.5 mm-VMII, and OP-1.0 mm-GC and OP-1.0 mm-LU were noted as statistically insignificant ($P > 0.05$). Moreover, in TR shade, no statistically significant difference was detected among 0.5 mm-thick restorative materials ($P > 0.05$), while only the differences between 1.0 mm-VE and 1.0 mm-VMII were statistically insignificant ($P > 0.05$). All other comparisons of mean ΔE_{00} values of different restorative materials in the same cement shade group were statistically significant ($P < 0.05$). For each cement shade, the differences between mean ΔE_{00} values of restorative materials of 0.5 mm and 1.0 mm thickness were statistically significant ($P < 0.05$), except for VMII on OP shade ($P = 0.466$). When the mean ΔE_{00} values of different cement shades in the same restorative material group were compared, the differences between A2 and TR shades for 1 mm-VE, 1 mm-GC, and 0.5 mm-LU were not statistically significant ($P = 1.000$). The difference between A2 and OP shades for 1 mm-VMII was also statistically insignificant ($P = 0.803$). All other comparisons of the mean ΔE_{00} values of different cement shades in the same restorative material group were statistically significant ($P < 0.05$).

Color differences in groups 1.0 mm-OP-LU and 1.0 mm-OP-GC indicated perceptible but clinically acceptable values ($0.8 < \Delta E_{00} \le 1.8$). The rest of ΔE_{00} units were found to be above the threshold of clinical acceptability. The highest and lowest ΔE_{00} units for 0.5 mm-thick specimens were observed in the A2-VE group (7.07 ± 0.42) and OP-GC group (3.44 ± 0.48), respectively. On the other hand, the highest and lowest ΔE_{00} units for 1-mm-thick specimens were detected in the TR-VE group (4.95 ± 0.34) and OP-GC group (1.46 ± 0.16), respectively. Statistically significant differences were found among the resultant color coordinates and target shade tab coordinates ($P < 0.05$).

Discussion

Based on the results of the present study, the resultant colors of tested assemblies were significantly different from the target shade tab due to the influence of luting cement shade, restorative material type, and thickness. Moreover, statistically significant differences were found among test groups. Therefore, the null hypothesis was rejected.

Traditionally, color coordinates (L^* defines lightness, a^* denotes the red or green chroma, b^* denotes the yellow or blue chroma) of an object are recorded to locate its color within the CIELab color space [16, 22, 27, 41]. Lightness (value) is the luminous intensity of the color and the human eye is more sensitive to the alterations in this property [27]. It is often referred to as "perceived reflectance" or more precisely "perceived diffuse luminous reflectance" [42, 43]. The L^* value can be related to the thickness and chemical composition of restorative material, and the opacity of the underlying tissues. With regard to all-ceramic systems, increasing the thickness of specimens increases the absorption of the incident light and thereby decreases L^* value [2, 21]. This was reinforced with Lambert's law highlighting that decreasing the thickness of material permits a greater amount of light transmission due to reduced absorption [44]. However, Kim et al. [6] stated that decreasing thickness reduces L^* value. This is in accordance with the results of the current study as higher L^* values were detected in a 1.0 mm-thick group. Chroma (C_{ab}^*) is defined as the perceived amount of difference from a gray of the same value [42, 43]. It is calculated by using $(a^2+b^2)^{1/2}$ function. From this point of view, it can be stated that alterations in either a^* or b^* values lead to shifting in chroma of an object. A study proved that b^* value is more sensitive to the change of thickness than a^* value [20]. This provides consistency with the present study. Moreover, in our study, a^* and b^* values increase as the restorative material thickness increases. This is also in accordance with other studies [45, 46]. However, Kim et al. [6] declared that a^* value increased, while b^* value generally decreased with decreasing thickness. In accordance with the results of this study, this is partially acceptable as b^* values decreased with decreasing thickness. Turgut et al. [2] reported that thinner ceramics exhibit lower value and chroma. This provides consistency with our study. Hereby, it can be highlighted that decreasing thickness leads to reduced lightness and a greenish-bluish appearance. Moreover, in this study, the lowest chroma was recorded in a 0.5 mm-thick VMII group cemented with TR shade luting cement.

Apart from these, to simulate laminate veneer restoration, 0.5- and 1.0 mm-thick samples were prepared [13]. However, none of the restorative material specimens in the 0.5 mm-thick group matched the A2 target shade tab. A possible explanation for the great mismatch between them may be the luting cement shade and foundation shade, which were darker than the values of the target shade tab.

To the best knowledge of authors, the influence of cement shade and restorative material type on color coordinates is not well discussed. Even so, their influences may be correlated with the opacity level. It is well documented that less light reflects from an opaque underlying structure. This contributes to a decrease in L^* value and an increase in a^* and b^* values [6]. This provides consistency with our results. In this study, the highest ΔL values belong to the VMII group and the lowest ΔL values belong to the Vita Enamic group. This can be attributed to the differences in chemical compositions of the aforementioned restorative materials that can lead to alterations in color coordinates.

For indirect esthetic restorations, resin types of cement are favorable with respect to their high bond strength, resistance to wear, and low solubility with oral fluids. The color matching procedure is complicated as their different shades are in use [17, 18]. Moreover, dual-polymerized resin types of cement include benzoyl peroxide (BP) and aromatic tertiary amines (ATA) as polymerization initiators [29, 47]. The oxidation of the tertiary aromatic amines results in amine coloring [29]. Camphorquinone, a commonly used photo-initiator, is more stable than BP and ATA and exhibits a dense yellow color that remains yellow after insufficient photo-curing [47]. They can become influential on b^* coordinates and increase the tendency to shift yellowness [48]. Although manufacturers do not declare all the chemical components in their products, the reason why b^* is more sensitive in both groups may be attributed to photoinitiators. Chen et al. [16] found that translucent shade of resin cement slightly increases the brightness and reduces the chroma of ceramic. Moreover, they declared that the use of opaque cement leads to an increase in brightness and a decrease in the chroma. These results partially provide consistency with those of the present study.

It is well known that ceramic thickness has a primary effect on light transmittance [2, 6, 15]. Light transmittance and therefore translucency decrease with increasing thickness. Thus, the effect of the color properties of the underlying structures on the resulting color is reduced [15]. However, as the light transmittance increases in thin restorations, the color properties of the underlying tissues cannot be suppressed and have a dramatic effect on the resulting color [13]. In accordance with this, the 0.5 mm-thick group showed much higher ΔE_{00} values than the 1-mm-thick group. In contrast to Turgut et al. [2], this is consistent with other studies in the literature. Regardless of the luting cement shade and restorative material thickness, VE indicated the highest ΔE_{00} values. VE is a polymer-infiltrated ceramic network that consists of feldspar ceramic and methacrylate polymer. The ceramic network contains a great number of metal oxides, such as an aluminum oxide (Al_2O_3), zirconium oxide (ZrO_2), and titanium oxide (TiO_2) [4, 5]. These oxides may act as scattering centers and reduce light transmission of the ceramic. Moreover, large mismatches of the refractive index between the matrix and the filler increase the tendency of the material to be opaquer [49]. Therefore, these may become influential on the L^* value. This supposition was reinforced with the results of this study as the L^* value was greatly affected among other color coordinates. Regardless of the restorative material type and thickness, the use of an opaque luting cement on the dentin background leads to the lowest ΔE_{00} values. Therefore, opaque cement on dentin background can be safely used for tested restorative materials. Different refractive index and light transmittance due to the different chemical composition might explain the color difference values among different shades of the same cement [17, 18]. Regardless of the luting cement shade and restorative material thickness, GC exhibited the lowest ΔE_{00} values. GC is a flexible nanoceramic including alumina-barium-silicate particles embedded in the polymer network. It permits high light transmission due to the absence of opacifying agents [4, 5]. This can be explained by the fact that there is a minimal difference between the color coordinates of the GC group and the A2 shade tab. The color differences between the target A2 shade tab and assemblies were between 1.46 and 7.07 ΔE_{00} units. In terms of resultant colors of generated assemblies, GC with 1 mm thickness on opaque cement, as well as LU with 1 mm thickness on opaque cement ($0.8 \leq \Delta E_{00} \leq 1.8$), can be strongly recommended as resultant color can correspond to the A2 target shade tab. Moreover, clinicians should be careful when selecting all other combinations, especially the combination of 0.5 mm-thick VE with A2 shade resin cement.

In the current study, the thresholds recommended by Paravina et al. [39] were preferred. According to these thresholds, all ΔE_{00} values except for 1 mm-LU-OP and 1 mm-GC-OP assemblies are clinically unacceptable.

CIELab is a poor color space in terms of perceptual uniformity [50]. Therefore, a revised formula (CIEDE2000) with weighing functions, hue rotation term, and parametric constants was introduced for ΔE calculation and thereby preferred in this study [22–24, 50]. Parametric constants can be defined as either 1:1:1 or 2:1:1 system. Despite recent studies using 2:1:1 system, where the K_L value was taken as 2 to better determine the acceptable threshold value obtained by the eye [51], 1:1:1 system is generally preferred in other studies [18, 19, 22–24, 28], as in this one.

The present study has several limitations. The underlying foundation was fabricated from composite material. However, the optical properties of natural teeth tissues may differ from those of the composites. Only one shade of the underlying composite foundation was used. Additionally, only one shade and translucency of restorative materials were preferred. However, different shades and translucencies of materials may present different results. The TP values of tested restorative material groups were not calculated. New auto-polymerized luting cement containing a redox initiator was not used. Polychromatic multi blocks were not included. Further studies are recommended.

Conclusion

Within the limitations of the study, the following conclusions were drawn:

1. Regardless of thickness, all restorative materials on opaque cement exhibited lower ΔE_{00} values.
2. Increasing restorative material thickness decreases ΔE_{00} values.
3. In none of the tested 0.5 mm-thick specimens, the color matching of restorative materials to the intended shade tab was not achieved.
4. One-mm-thick GC Cerasmart cemented on opaque cement ($\Delta E_{00} = 1.46$) and 1-mm-thick Lava Ultimate cemented on opaque cement ($\Delta E_{00} = 1.71$) can be strongly recommended for dentin shade foundation as the resultant color can better correspond with the A2 target shade tab.

Acknowledgements There is nothing to disclose.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this comparative in vitro study, formal consent is not required.

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