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Color matching and translucency of single-shade resin composites: effects of restoration thickness, background shade, and aging

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Abstract

Background Achieving a seamless color match in resin composite restorations remains a significant clinical challenge due to variations in tooth structure and background shades. The aim of this in vitro study was to assess the effect of background shade, thermal aging, and composite thickness on color matching and translucency of three single-shade resin composites.

Methods A total of 72 resin composite disks (12 mm diameter) were fabricated using three single-shade composites -Omnichroma (OMN), Charisma Diamond ONE (CDO), and Charisma Topaz ONE (CTO)- in two thicknesses (1.5 and 3 mm), resulting in six groups ($n = 12$ per group). Subsequently, three background disks were prepared from Estelite Sigma Quick in shades A1, A3, and B1, and the 72 composite disks were positioned on these background disks to form a two-layer assembly for evaluation. The L*, a*, and b* variables before and after thermocycling (10,000 cycles) were recorded and blending effect (BE) was calculated. The translucency was evaluated by using white and black backgrounds. The data were analyzed by Kolmogorov–Smirnov, ANOVA, Independent Samples T-test, and Tukey HSD tests with the significance level set at 5%.

Results OMN exhibited a significantly superior BE compared to CTO and CDO, both before and after aging ($p < 0.001$). Color matching was significantly better at 1.5 mm than at 3 mm, except for CTO and CDO on the A3 background ($p = 0.193$ and $p = 0.550$, respectively). BE was highest on the A1 background, intermediate on B1, and lowest on A3 ($p < 0.001$). Translucency was significantly higher at 1.5 mm than at 3 mm ($p < 0.001$), except for CTO on A3 after aging ($p = 0.198$), while background shade did not affect translucency ($p > 0.05$).

Conclusions The BE of single-shade resin composite is material and thickness-dependent. Overall, OMN demonstrated superior shade matching across different backgrounds compared to CDO and CTO, at both thicknesses, before and after aging.

Clinical significance Understanding the influence of composite material, thickness, and underlying shade can optimize color matching in dental restorations, improving clinical outcomes and esthetics.

Keywords Blending effect, Color adjustment potential, Translucency, CIELAB, Resin composite

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Introduction

Resin composite materials are widely used in direct restorations, especially in esthetic regions, providing good mechanical and esthetic properties through a cost-effective and minimally invasive manner. However, achieving an ideal color match with natural dental tissues remains challenging. To address the wide range of natural tooth shades, manufacturers have developed composite systems with various colors and translucencies, often guided by the VITA Classical Shade Guide (VITA Zahnfabrik, Säckingen, Germany) [1]. Dental composites are classified as multi-shade, group-shade, and single-shade types [2]. Multi-shade systems require a layering technique, using composites with varying opacities and chromas to match the polychromatic nature of teeth, which complicates color matching [3–6]. Moreover, color selection is influenced by factors such as lighting, tooth type and location, and clinician-related factors (age, experience), which increases chairside time and costs [1, 7].

To simplify selection, single-shade composites were introduced, claiming to match all VITA Classical shades through color adjustment, blending, shifting, and assimilation [8]. The blending effect (BE) refers to the minimal color difference observed between composites and dental tissues [9]. Composites with a 'blending' or 'chameleon' effect mimic surrounding tooth color through their translucency [10]. A key advantage of single-shade composites is their color adjustment potential (CAP), which depends on factors such as filler content, particle size, matrix composition, restoration thickness, and background shade [11].

In 2019, Omnichroma (OMN), a single-shade nanofilled resin composite exhibiting adaptable color matching across all 16 VITA shades, was introduced to the dental market. A study revealed that its nanofillers, smaller than the wavelength of visible light, can generate structural color without pigments [12]. According to the manufacturer, OMN mimics tooth color using "smart chromatic technology" by optimizing resin translucency [13–15]. This unique ability is attributed to the spherical zirconium dioxide (ZrO_2) and silicon dioxide (SiO_2) fillers with a uniform size of 260 nm in the resin matrix, which can produce a red-to-yellow color (wavelengths of 430–750 nm) [11, 16]. Although some studies reported good color harmony with acrylic teeth [8], findings on human teeth suggest inferior performance in most shades, limiting their use in highly esthetic areas [2]. In 2020, Kulzer introduced Charisma Diamond ONE (CDO) and Charisma Topaz ONE (CTO) composites, which, according to the manufacturer, boast biocompatibility, strong clinical durability, and minimal shrinkage due to their Bis-GMA-free constitution and optimized nano-hybrid fillers. Notably, the manufacturer claims that CDO can match 21 shades and three opacities using a single-shade [17].

Although single-shade composites offer an immediate color match, they must retain their appearance over time. Color instability, one of the main reasons for replacing restorations in highly esthetic anterior regions, is influenced by factors such as dye absorption from food, smoking, and poor oral hygiene. Additionally, aging in the oral environment makes these restorations prone to discoloration and staining [6]. Aging significantly affects the material properties of resin composites [18], and the effect of aging is highly dependent on the microstructure of the material itself [19]. Since composite color characteristics depend on fillers, aging may alter filler properties, subsequently affecting their optical and color properties.

Controversy exists regarding the color match and stability of single-shade resin composites compared with multi-shade materials. Some studies report that composites like CDO and OMN are more prone to discoloration after 10,000 thermal cycles [5, 14], while others indicate that these materials exhibit superior color-shifting ability across various background shades [20, 21]. Two systematic reviews further illustrate this disparity: one found that color match and stability of single-shade restorations are comparable to those of multi-shade restorations over a 12-month period [22], whereas another review noted that, despite laboratory studies favoring multi-shade composites for color matching, single-shade resins show promise when assessed visually in clinical settings [23]. Both reviews indicated that more studies and longer follow-ups are required to draw robust conclusions.

In light of existing controversies and the known influence of restoration size, thickness, and tooth color on the BE of single-shade resin composites [11, 13, 24], we aimed to investigate how restoration thickness, background color, and aging affect the color matching ability and translucency of three single-shade composites by measuring color differences (ΔL^*, Δb^*, Δa^* and ΔE). The four null hypotheses included in this study were: (1) composite type (OMN, CDO, and CTO), (2) background color (A1, A3, and B1), (3) restoration thickness (1.5 mm and 3 mm), and (4) aging (10,000 thermal cycles) have no significant effect on color matching and translucency of single-shade resin composites.

Materials and methods

Study design

This study was conducted at the Department of Restorative Dentistry (Mashhad University of Medical Sciences, Iran) in 2023. The local Ethical Committee of Mashhad University of Medical Sciences reviewed and approved this in vitro study with the protocol number of IR.MUMS.DENTISTRY.REC.1400.148, on May 5th, 2022.

Sample size calculation

The outcome of this study was the BE of the single-shade resin composites and the variables were the thickness of restorations, background shade and aging. Based on previous studies [14, 25], using an alpha of 0.05, 95% confidence intervals, and 80% power, the minimum sample size in this equivalence study was 12 samples in each group to be able to reject the null hypothesis. The Type I error probability associated with this test of this null hypothesis is 0.05. Sample size calculation was performed using G*Power, version 3.1.9.6 for MS Windows (Franz Faul, Universität Kiel, Germany).

Study groups and specimen preparation

A total of 72 resin composite disks (12 mm in diameter) were produced using three single-shade composites -OMN (Tokuyama Dental, Tokyo, Japan), CDO (Kulzer, Hanau, Germany), and CTO (Kulzer, Hanau, Germany)- at two thicknesses (1.5 mm and 3 mm), resulting in six groups ($n = 12$ per group).

To replicate different background shades, three additional composite disks (12 mm diameter, 4 mm thickness) were fabricated from Estelite Sigma Quick (Tokuyama Dental, Tokyo, Japan) in shades A1, A3, and B1. These background disks were used as the base for the 72 resin composite specimens, creating a two-layer configuration for evaluation.

For specimen fabrication, silicone molds (Speedex, Coltene, Liechtenstein) with thicknesses of 1.5 mm, 3 mm, and 4 mm were used to ensure consistency in specimen dimensions, with all disks having a 12 mm diameter to match the colorimeter's 12 mm measuring head. The resin composites were inserted into the molds on a Mylar matrix to achieve a smooth surface. Each specimen was then covered with another Mylar matrix and a glass plate before being light-cured using a Bluephase C8 curing unit (Ivoclar Vivadent, Schaan, Liechtenstein), which emits light at 430–480 nm with an irradiance ranging between 900 and 1100 mW/cm^2. Curing was performed through the glass plate and Mylar strip while applying pressure to maintain uniform thickness. To ensure consistent polymerization, the curing light output was monitored using a radiometer (Demetron/Kerr, CT-100, Danbury, USA) after every five exposures.

The prepared specimens were stored in distilled water for 24 h in an incubator (Fine Tech, Shin Saeng, Gyeonggi-do, South Korea) at a temperature of 37 °C and 100% humidity to simulate oral temperature and ensure complete polymerization. Subsequently, both the samples and the background disks were polished using EVE solar polishing discs (EVE Ernst Vetter GmbH, Neureutstr, Keltern, Germany). To preserve the composite's humidity and minimize errors during colorimetry, the samples were continuously kept in distilled water. The compositions, manufacturers and batch numbers of the tested resin composite materials are presented in Table 1.

Table 1 Materials used in the study

Study groups	Product	Filler type	Manufacturer	Composition	Lot number
OMN	Omnichroma	Supra-nano filled	Tokuyama Dental, Tokyo, Japan	Nanofilled, Filler: 79 wt% uniform sized supra-nano spherical filler (SiO2-ZrO2 260 nm), round-shaped composite filler (containing 260 nm spherical SiO2-ZrO2) Resin: UDMA, TEGDMA	1813S3
CDO	Charisma Diamond ONE	Nano-hybrid	Kulzer, Hanau, Germany	Barium aluminum boro fluor silicate glass, silica, Titanium dioxide (5–20 µm) Resin: TCD-urethaneacrylate, UDMA, TEGDMA 81/64 (wt.%/vol.%)	K010021
CTO	Charisma Topaz ONE	Nano-hybrid	Kulzer, Hanau, Germany	Resin: UDMA, TCD-DI-HEA, TEGDMA 81/64 (wt.%/vol.%)	K010203
Background	Estelite Sigma Quick (A1, A3, B1)	Supra-nano filled	Tokuyama Dental, Tokyo, Japan	Nanofilled, Filler: 82 wt% uniform sized supra-nano spherical filler (SiO2-ZrO2, SiO2-TiO2 100–300 nm (average 200 nm)), round-shaped composite filler (100–300 nm (average 200 nm), spherical SiO2-ZrO2) Base resin: Bis-GMA, TEGDMA	E0602 W69310 E3083

Abbreviations: SiO2 Silicone oxide, *ZrO2* Zirconium oxide, *UDMA* urethane dimethacrylate, *TEGDMA* triethyleneglycol dimethacrylate, *TCD-urethaneacrylate* Tricyclodecane-Urethaneacrylate, *TCD-DI-HEA* Bis-(acryloyloxymethyl)tricyclo [5.2.1.0.sup.2,6] decane, *Bis-GMA* bisphenol-A-diglycidyl methacrylate

Color match or masking ability measurement

Following a 24-h incubation period, the probable surface contamination of samples was removed with a 96% ethanol solution, and then each resin composite disk with 1.5 and 3 mm thickness was placed on a 4 mm background disk in A1, A3, and B1 shades and colorimetry was performed with a D65 light source and a 2-degree viewing angle. A custom white and matte plastic mold was designed to shield samples from ambient light, ensure their stable position, and confirm precise alignment with the colorimeter (Fig. 1). According to the manufacturer's instructions, calibration was performed before each color measurement. An average of three measurements was recorded for each specimen [13].

In this study, the BE and color match were measured by an instrumental method using a colorimeter (Chroma Meter CR-400, Konica Minolta, Japan). L*, a*, and b* values of the CIE Lab system were recorded for each tooth. L* indicates the brightness, and a* and b* represent hue. The a* axis represents saturation in the red-green axis, and b* represents saturation in the blue-yellow axis.

CIELAB color differences ($\Delta E*$) were calculated for each thickness and background according to the following formula:

$$(\Delta E*) = [(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{1/2}$$

A smaller ΔE* indicates that the specimen is less sensitive to the color of the background or is better able to mask the background shade. The ΔE* value was compared with the clinically acceptable ΔE* range ($\Delta E^* \leq 2.7$) [26, 27]. This thickness was termed the critical thickness.

Fig. 1 Custom-designed plastic molds according to the colorimeter head and composite disks

Translucency measurement

In the current study, two backgrounds, black ($L* = 11.24$, $a* = 0.17$, and $b* = 0.28$) and white color ($L* = 95.72$, $a* = 0.60$, and $b* = 3.54$), were used to determine the translucency parameter (TP), which reflects the ability of the human eye to discriminate between materials of the same thickness when placed on contrasting black and white backgrounds. The differences in CIELAB color coordinates between the white and black backgrounds were calculated to obtain the TP [28].

$$\mathrm{TP} = [(L*_W - L*_B)^2 + (a*_W - a*_B)^2 + (b*_W - b*_B)^2]^{1/2}$$

where the subscripts W and B refer to color coordinates over the white and black backgrounds, respectively. A higher value for the translucency parameter represents greater translucency.

Aging procedure (Thermocycling)

The prepared samples were subjected to thermal aging (Nemo, Mashhad, Iran). After initial color and translucency measurements, the single-shade resin composite samples were subjected to thermal aging by an automated thermal cycling machine (Nemo, Tehran, Iran) with water temperatures between 5 °C and 55 °C for 10,000 cycles and a 20-s dwell time, as was previously described [29, 30]. After thermal aging, the color and translucency were evaluated for the second time as previously described.

The color match was calculated according to the following formula: $\Delta E = [(\Delta L)2 + (\Delta a)2 + (\Delta b)2]^{1/2}$, with $\Delta L = L$ final—L initial; $\Delta a = a$ final—a initial; $\Delta b = b$ final—b initial [31].

Statistical analysis

Data were analyzed using the SPSS statistical software (version 22.0, SPSS Inc., IBM, Armonk, New York, USA). The Kolmogorov–Smirnov test was used to assess the normal distribution of data. One-way ANOVA was used for comparing the differences between the study groups. When the differences between groups were statistically significant, the Tukey HSD and independent samples t-test were performed. All the statistical analyses were performed with the significance level set at 5%.

Results

A total of 72 samples were prepared (six groups of 12) using three single-shade resin composites at two thicknesses (1.5 and 3 mm). Colorimetric assessments were performed before and after aging on A1, A3, and B1 backgrounds, with L*, a*, and b* values measured. Subsequent calculations of color difference (ΔE) and the translucency parameter (TP) were made against black and white backgrounds. Normality was confirmed by the Kolmogorov–Smirnov test ($P > 0.05$), and ANOVA revealed a significant interaction among the independent variables (type of single-shade resin composite, restoration thickness, and background color; $P = 0.001$), prompting individual analyses of each variable's effect on ΔE and TP.

Color match (ΔE)

According to Table 2, ΔE values were recorded before (ΔE_{before}) and after aging (ΔE_{after}); the change ($\Delta E_{age} = \Delta E_{after} - \Delta E_{before}$) reflects aging effects. One-way ANOVA showed significant differences in ΔE among backgrounds ($P < 0.001$), with most pairwise comparisons being significant ($P < 0.05$) except for A3 versus B1 for CDO at 3 mm ($P = 0.267$ before aging and $P = 0.907$ after) and OMN after aging ($P = 0.141$).

Prior to aging, OMN generally demonstrated superior color matching (lower ΔE) compared to CTO and CDO ($P < 0.001$), except at 3 mm on B1 ($P = 0.073$) and on A1, where OMN performed worse than CTO. On the A3 background, CTO's color match was significantly lower than CDO's ($P < 0.001$), and no significant differences were observed between CDO and CTO at 1.5 mm on A1 or on B1 at both thicknesses. Overall, color matching was best on A1, intermediate on B1, and poorest on A3, with 1.5 mm specimens generally showing better matching than 3 mm samples, except for specific cases on A3 (CTO and CDO showed no significant difference ($P = 0.193$ and $P = 0.550$, respectively), and OMN showed the reverse trend).

After aging, significant differences in ΔE persisted ($P < 0.001$). OMN maintained its superior color matching compared to CDO and CTO at 1.5 mm on A1 and B1, and at 3 mm on A3. For each composite, the color match on A1 remained significantly better than on B1, while the influence of specimen thickness varied by material and background, with most comparisons favoring the 1.5 mm thickness except on the A3 background.

Table 3 evaluates ΔE_{age}, where negative values indicate an improvement in color matching post-aging; notably, OMN showed significant improvements on B1 and A1 at both thicknesses, while CTO exhibited no significant differences at 3 mm on B1 ($P = 0.679$) and A3 ($P = 0.568$) or at 1.5 mm on A1 ($P = 0.386$), and CDO showed no significant changes on B1 (at both thicknesses) or at 1.5 mm on A3.

Translucency parameter (TP)

According to Table 4, TP was measured on black and white backgrounds before (TP_{before}) and after aging (TP_{after}), with ΔTP_{age} representing the difference. In general, TP at 1.5 mm was significantly higher than at 3 mm. For each single-shade resin composite, there was a significant difference between the three background shades both before and after thermocycling, except for CTO on the A3 shade after aging ($P = 0.198$).

Before the thermal aging, there was no significant difference in TP among the single-shade resin composites, except at 1.5 mm on B1 background ($P = 0.003$), in which the TP of CDO was significantly higher than that of CTO and OMN. For CDO no significant difference was recorded in each thickness on three background colors ($P = 0.102$ for 1.5 mm and $P = 0.515$ for 3 mm thickness). There was no significant difference between the three background colors in 1.5 mm thickness for OMN and at 3 mm thickness for CTO.

Overall, TP values remained similar among the composites after aging except at 1.5 mm on A1 ($P = 0.039$) and B1 ($P = 0.032$), where CDO's TP was significantly higher than OMN's. In OMN, TP on B1 exceeded that on A1, which in turn was greater than on A3. CTO showed no significant differences across backgrounds at either 1.5 mm ($P = 0.626$) or 3 mm ($P = 0.122$).

Table 5 summarizes the ΔTP_{age} during aging, where negative values indicate a reduction in translucency. CDO showed no significant TP change ($P > 0.05$) except at 1.5 mm on A1, while OMN's TP significantly decreased at 1.5 mm on A1 ($P < 0.001$) and A3 ($P = 0.025$), and at 3 mm on A3 ($P = 0.016$).

Discussion

Dental materials with structural color simplify restorations by reducing chairside time and minimizing the need for future replacement after age-related color changes or tooth whitening [32]. Some of the tooth-colored restorative materials have this ability to reflect the color of surrounding tooth structures due to their translucent nature [10], which is described as the "chameleon effect." This term is usually used in psychology rather than color research. In dental parlance, the terms "color adjustment", "color blending", "color assimilation", and "color induction" are interchangeably used to name this phenomenon [11]. Although the superior color matching of single or universal- shade resin composites in comparison with multi-shade ones has been confirmed by several previous studies [3, 8, 33], some research has not shown this advantage [5, 6]. Chen et al. [5] found that materials like CDO can exhibit higher ΔE values (poorer matching) despite their high translucency.

The results of this study comparing three types of single-shade resin composites showed that OMN generally outperformed the other two composites in color matching, both before and after aging. Thus, the first null hypothesis was rejected. However, it is notable that at 3 mm thickness on a B1 background, all composites

Table 2 Comparison of ΔE_{before} and ΔE_{after} among three single-shade resin composites (OMN, CDO and CTO) in different thicknesses (1.5 and 3 mm) on three background colors (A1, A3 and B1)

	Composite	A1			A3			B1			*P*-value***	
		Thickness		*P*-value*	Thickness		*P*-value*	Thickness		*P*-value*		
		1.5	3		1.5	3		1.5	3		1.5	3
TP (Before Aging)	OMN	0.78 (0.21) aA	4.73 (0.64) aA	<0.001	4.62 (0.40) aB	3.86 (0.58) aB	<0.001	3.34 (0.51) aC	6.15 (0.82) aC	<0.001	<0.001	<0.001
	CTO	2.41 (0.49) bA	2.94 (0.59) bA	0.028	7.40 (1.02) bB	7.80 (0.19) bB	0.193	4.28 (0 .67) bC	6.17 (0.74) aC	<0.001	<0.001	<0.001
	CDO	2.57 (0.45) bA	5.45 (0.46) cA	<0.001	6.32 (0.89) cB	6.48 (0.27) cB	0.550	4.04 (0.48) bC	6.76 (0.52) aB	<0.001	<0.001	<0.001
		<0.001	<0.001		<0.001	<0.001		<0.001	0.073			
TP (After Aging)	OMN	1.23 (0.36) aA	3.59 (0.68) aA	<0.001	6.14 (1.02) aB	5.06 (0.73) aB	0.007	2.39 (0.52) aC	5.61 (0.66) a*B**	<0.001	<0.001	<0.001
	CTO	2.26 (0.16) bA	3.73(0.22) aA	<0.001	8.23 (0.78) bB	7.76 (0.20) bB	0.054	2.97 (0.35) bC	6.05 (0.45) aC	<0.001	<0.001	<0.001
	CDO	1.94 (0.29) cA	4.74(0.59) bA	<0.001	6.66 (1.19) aB	6.93 (0.58) cB	0.479	3.87 (0.46) cC	6.83 (0.53) bB	<0.001	<0.001	<0.001
		<0.001	<0.001		<0.001	<0.001		<0.001	<0.001			

SD Standard Deviation

* Independent t test for thickness comparison in each composite and background

** One-way ANOVA for composite types comparison in each background and thickness; According to Tukey post hoc test, different lowercase letters indicate a significant difference between the two different types of composites

*** One-way ANOVA for backgrounds comparison in each composite and thickness; According to Tukey post hoc test, different uppercase letters indicate a significant difference between two different backgrounds

Table 3 ΔE_{age} evaluation, the comparison of ΔE_{before} and ΔE_{after} (before and after thermocycling)

Composite type	Thickness	n	ΔE_{age}					
			A1		A3		B1	
			Mean ± SD	*P*-value	Mean ± SD	*P*-value	Mean ± SD	*P*-value
Omn	1.5	12	0.45 ± 0.31	<0.001	1.52 ± 0.95	<0.001	-0.95 ± 0.61	<0.001
	3	12	-1.14 ± 0.32	<0.001	1.20 ± 0.43	<0.001	-0.54 ± 0.68	0.018
CTO	1.5	12	-0.15 ± 0.58	0.386	0.83 ± 1.18	0.033	-1.31 ± 0.69	<0.001
	3	12	0.79 ± 0.55	<0.001	-0.04 ± 0.25	0.568	-0.12 ± 0.98	0.679
CDO	1.5	12	-0.63 ± 0.43	<0.001	0.03 ± 1.51	0.453	-0.17 ± 0.75	0.461
	3	12	-0.71 ± 0.72	0.006	0.45 ± 0.47	0.007	0.07 ± 0.94	0.792

SD Standard Deviation

performed comparably, a finding similar to Erçin and Kopuz's report [1] of comparable matching for OMN and CTO at 2 mm on A1, A2, and A3 backgrounds. According to the manufacturer, OMN is a nano-filled composite that uses structural color instead of traditional pigments, thus eliminating the need for shade selection, bleaching, or restoration replacement due to staining [13]. Its photonic crystal structure enhances color adaptability by interacting with light [8].

In agreement with the present study, previous studies [3, 8, 33] have reported low ΔE values for OMN, highlighting its strong potential for reproducing natural tooth color. Its performance is linked to its uniform 260 nm spherical fillers, which enhance direct light transmission. Yamashita et al. [24] further noted that both OMN and OMN Flow exhibit a broad and uniform reflectance (430–680 nm), with peak reflectance in the yellow-to-red range that help adjust to dentin-like, yellowish shades.

In contrast, several studies could not determine the superior ability of OMN in color matching compared with the multi-shade resin composite (Filtek Z350XT and Z250; 3 M ESPE, Maplewood, MN, USA) and also showed low color stability following aging [1, 6, 11, 14]. The authors attributed this result to the resin matrix composition and filler content of the resin composites. High molecular weight monomers like Bis-GMA enhance the polymer crosslinking density, strengthening the composite matrix, and hydrophobic monomers such as Bis-EMA reduce water uptake and improve degree of conversion [11, 14]. Higher conversion degrees and lower filler content favor the color properties of multi-shade composites [11].

While Erçin and Kopuz [1] observed comparable color blending on A1, A2, and A3 backgrounds for OMN and CTO, our results indicated that background shade significantly influenced color matching, in accordance with previous studies [2, 8, 13], with lighter shades (A1 and B1) yielding better results than darker shades (A3); thus, the second null hypothesis was rejected. In our study, disregarding minor differences in trend, color matching was best on the A1 background, intermediate on B1, and poorest on A3. This trend, also supported by previous reports [2, 34, 35], suggests that increased background brightness enhances matching. Similarly, a recent study reported more esthetic results when the lighter teeth were restored with a single-shade bulk fill resin composite. The authors showed that in darker shades, the color difference is too large, and the expected chameleon effect is not sufficient to compensate for the difference [9]. This outcome can guide clinicians in the selection of the single-shade resin composites for different types of restorations. Moreover, these materials may not be a good option for restoring the cervical part of teeth with darker tooth shade in Class V or non-carious cervical lesions (NCCLs).

The shade matching ability of the material is related to two main aspects: the BE and the material's translucency. The blending ability of the material is enhanced with decreased cavity size, increased material's translucency, and decreased color difference between the material and the tooth when viewed in isolation. Therefore, better color matching on lighter backgrounds could be attributed to more light reflected from the lighter tooth structure, particularly in materials with higher translucency [6]. Based on the literature, among different single-shade resin composites, OMN is noted for its ability to match a wide range of tooth shades [1, 24], likely a result of its high translucency and optimal L* adjustment.

The results showed superior color matching at 1.5 mm thickness compared to 3 mm, except for CTO and CDO on the A3 background, where no thickness-related differences were found, and for OMN, which performed better at 3 mm. Therefore, the third null hypothesis was rejected. In this study, the ΔE* values demonstrated a direct relationship with thickness, as masking ability increased with reduced thickness. This result is in

Table 4 Comparison of TP_{before} and TP_{after} (Mean (SD)) among three single-shade resin composites (OMN, CDO and CTO) in different thicknesses (1.5 and 3 mm) on three background colors (A1, A3 and B1)

	Composite	A1			A3			B1			*P*-value***	
		Thickness		*P*-value*	Thickness		*P*-value*	Thickness		*P*-value*		
		1.5	3		1.5	3		1.5	3		1.5	3
TP (Before Aging)	OMN	2.89 (0.33) $_{aA}$	1.45 (0.19) $_{aA}$	<0.001	2.44 (0.73) $_{aA}$	1.35(1.35) $_{aA}$	<0.001	2.52 (0.52) $_{abA}$	1.93 (0.48) $_{aB}$	0.009	0.121	<0.001
	CTO	3.13 (0.90) $_{aA}$	1.73 (0.54) $_{aA}$	<0.001	2.89 (1.05) $_{aAB}$	1.41 (0.27) $_{aA}$	<0.001	2.28 (0.39) $_{aB}$	1.76 (0.42) $_{aA}$	0.005	0.049	0.103
	CDO	2.91 (0.54) $_{aA}$	1.45 (0.36) $_{aA}$	<0.001	2.57 (0.43) $_{aA}$	1.62 (0.53) $_{aA}$	<0.001	2.88 (0.24) $_{bA}$	1.66 (0.48) $_{aA}$	<0.001	0.102	0.515
	P-value**	0.606	0.156		0.367	0.199		0.003	0.363			
TP (After Aging)	OMN	2.19 (0.22) $_{aA}$	1.47 (0.16) $_{aA}$	<0.001	1.88 (0.24) $_{aB}$	1.16 (0.17) $_{aB}$	<0.001	2.49 (0.17) $_{aC}$	1.63 (0.11) $_{aC}$	<0.001	<0.001	<0.001
	CTO	2.45 (0.30) $_{abA}$	1.62 (0.51) $_{aA}$	<0.001	3.68 (5.61) $_{aA}$	1.53 (0.29) $_{aA}$	0.198	2.70 (0.60) $_{abA}$	1.89 (0.48) $_{aA}$	0.001	0.626	0.122
	CDO	2.50 (0.40) $_{bA}$	1.83 (0.48) $_{aA}$	0.001	2.99 (0.70) $_{aB}$	1.67 (0.82) $_{aA}$	<0.001	2.92 (0.24) $_{bAB}$	1.88 (0.18) $_{aA}$	<0.001	0.039	0.609
	P-value**	0.039	0.128		0.404	0.053		0.032	0.069			

SD Standard Deviation

* Independent t test for thickness comparison in each composite and background

** One-way ANOVA for composite types comparison in each background and thickness; According to Tukey post hoc test, different lowercase letters indicate a significant difference between the two different types of composites

*** One-way ANOVA for backgrounds comparison in each composite and thickness; According to Tukey post hoc test, different uppercase letters indicate a significant difference between two different backgrounds

Table 5 ΔTP_{age} evaluation, the comparison of TP_{before} and TP_{after} (before and after thermocycling)

Composite type	Thickness	N	ΔTP_{age}					
			A1		A3		B1	
			Mean ± SD	*P*-value	Mean ± SD	*P*-value	Mean ± SD	*P*-value
Omn	1.5	12	-0.70 ± 0.46	<0.001	-0.56 ± 0.75	0.025	-0.03 ± 0.43	0.806
	3	12	0.02 ± 0.27	0.759	-0.20 ± 0.24	0.016	-0.30 ± 0.51	0.070
cto	1.5	12	-0.67 ± 1.00	0.040	0.80 ± 5.83	0.645	0.42 ± 0.55	0.022
	3	12	-0.11 ± 0.65	0.587	0.12 ± 0.40	0.341	0.13 ± 0.65	0.503
cdo	1.5	12	-0.41 ± 0.56	0.028	0.43 ± 0.98	0.159	0.03 ± 0.23	0.613
	3	12	0.38 ± 0.75	0.107	0.05 ± 0.80	0.845	0.23 ± 0.59	0.210

SD Standard Deviation

agreement with previous studies that showed the potential of color adaptation depends on the cavity size and thickness of the restoration [2, 3, 11, 13, 34, 36]. Therefore, perfect color matching may still be difficult in deep cavities even with universal-shade resin composites [24].

In clinical dentistry, establishing perceptibility and acceptability thresholds is crucial for evaluating color differences in restorations. A $\Delta E^* \leq 2.7$ is widely accepted as the clinical threshold [26, 27] and was applied in this study. Lower ΔE^* values indicate better masking of background colors. The perceptibility threshold (PT) is the smallest color difference detectable by an observer (CIE Lab 50:50% PT, $\Delta E = 1.2$), while the acceptability threshold (AT) is the difference considered unacceptable, requiring correction (CIE Lab 50:50% AT, $\Delta E = 2.7$) [27]. Since most ΔE values in this study exceeded these thresholds, the color masking of 1.5 and 3 mm specimens on all backgrounds was clinically unacceptable. This contrasts with a previous study by Ghorab et al. [13], who showed the TP and masking ability of OMN Blocker for the 1.5 mm-thick specimens were in the range of imperceptible ($\Delta E^* \leq 2.7$), although thinner specimens (0.5 and 1 mm) failed to mask dark backgrounds. This was corroborated by other studies in which OMN and OMN Blocker successfully masked the background darkness [13, 14].

Color adjustment is influenced by the translucency and light transmission properties of composites [24]. Translucency is a condition where a material can partially pass light through and depends on its thickness, the resin's scattering and absorption properties, the type of filler particles, and the presence of coloring agents and opacifiers [24]. It is typically quantified using either the contrast ratio (CR) or the translucency parameter (TP): CR is the ratio of reflected light from an object over a black background to that over a white background, while TP represents the color difference between the two backgrounds at a given thickness. A black background can mimic the oral cavity darkness, especially in 'through and through' class III and IV cavities [37, 38]. Since TP is calculated similarly to color change and provides mathematical support for clinical observations, it is the preferred parameter in research. In this study, TP was used to assess translucency changes.

Our results showed comparable TP values among the single-shade resin composites before and after aging, except for higher TP in CDO at 1.5 mm on B1 (pre-aging) and on A1 and B1 (post-aging). Thicker specimens (3 mm) exhibited decreased translucency, except CTO on A3 post-aging, with no difference between thicknesses. Therefore, there was a negative relationship between TP values and thicknesses. The BE significantly increases with thickness reduction and TP increase [36]. Yağcı et al. [39], have also shown higher translucency and whiteness in OMN and CDO compared to multi-shade composites, at both 2 and 4 mm thicknesses and both pre- and post-thermocycling. This high translucency and structural coloration make single-shade composites, especially OMN, less susceptible to thickness-related color variations [24]. Similarly, Abdelraouf and collaborators [34] showed that effective color matching in universal composites was ascribed to their higher translucency. OMN's high translucency results from its unique inorganic phase composition and high filler content (79%), which enables the refractive index of the polymerized resin matrix to closely match that of its fillers. This matching enhances light diffusion and reflection from surrounding dental tissues, thereby inducing the blending effect, particularly in terms of hue. Uniformly shaped filler particles further improve color matching across diverse tooth shades. Altering the type or proportion of fillers can disrupt this optimized transparency and impede the structural color effect, while the absence of pigments yields a more translucent material that naturally blends with its environment [19]. In spite of favorable results, the high translucency of

OMN may cause a grayish appearance in anterior teeth, for which the manufacturer recommends using a blocker layer [14].

The perceptibility (0.62) and acceptability (2.62) thresholds for translucency variation [40] were used in this study. Most ΔTP values were below the perceptibility threshold, indicating stable translucency, especially at 1.5 mm. Exceptions occurred at 1.5 mm on A1 pre-aging and on A3 and B1 for CDO and CTO post-aging, though overall, the materials, particularly OMN, maintained acceptable translucency.

Thermocycling simulates oral temperature fluctuations and induces aging through internal stresses from differential thermal expansion between resin and filler materials [14]. In this study, a thermocycling procedure of 10,000 thermal cycles ranging from 5 to 55 °C which is equivalent to 1 year, was performed [14]. Post-aging, OMN showed a significant decrease in ΔE, particularly on the B1 background, leading to the rejection of our fourth null hypothesis and indicating an improved color match after aging. This finding contrasts with studies reporting that thermocycling adversely affects color adjustment [5, 11, 41], and aligns with those by Fahim et al. [11] and Fidan et al. [14] who concluded that after thermocycling, single-shade resin materials exhibited more color changes compared to multi-shade resin composites.

Two main factors may explain the increased ΔE after thermocycling: thermal fluctuations induce internal stresses due to differences in the thermal expansion coefficients of the resin matrix and fillers, and water sorption is increased during thermal cycling. It has been shown that the color blending of OMN may be unstable due to the decline in value and the increase in chroma with time. The presence of more hydrophilic molecules of UDMA/TEGDMA with low molecular weight and a better degree of conversion than Bis-GMA, leads to increased water sorption, breaking of the bond between the resin matrix and the inorganic filler, or to hydrolytic decomposition of the inorganic filler in OMN [6, 14].

This study observed a significant reduction in TP post-aging for OMN on the A3 background at both thicknesses and for CTO and CDO at 1.5 mm thickness on A1. Regarding background color effects on the color match of single-shade resin composites, there were generally no significant pre-to-post aging differences, except at 1.5 mm thickness on B1, where CDO was notably higher than CTO before aging and at 1.5 mm thickness on A1 and B1 after aging, where the TP of CDO was significantly greater than OMN. Regarding the results of ΔTP_{age} it seems that the translucency of CDO and CTO increased during aging, while OMN decreased. A previous study showed that the translucency of OMN increased after polymerization, likely contributing to better optical mimicry [33]. While we didn't assess the impact of light polymerization on translucency, a significant reduction in translucency was observed for OMN after thermal aging, especially on the A3 and A1 backgrounds. This finding aligns with previous studies, as shown by Fidan et al. [14], who reported a reduction in TP for OMN across all evaluated groups after aging. Similarly, Chen et al. [5] found a significant decrease in TP for CDO following thermocycling.

There are some limitations in this in vitro study. The flat composite disks do not replicate the complex contours of clinical restorations, which often feature convex or concave shapes and are also bordered by dentin and enamel which affect light reflection and color reproduction. Conversely, using highly translucent single-shade composites for large restorations can reduce light reflection and create a grayish appearance, even when the correct chroma is selected, especially in Class IV restorations without a palatal wall, where light is lost internally [9]. In these situations, an enhanced-opacity resin such as OMN Blocker is typically applied as a thin masking layer before placing OMN, a step not used in our study. In posterior Class I and II restorations, the presence of a pulpal wall aids in reflecting light, allowing a translucent composite alone to achieve good esthetics. Thus, clinical outcomes for anterior versus posterior applications of single-shade composites may differ from our laboratory findings.

Within the methodological limitations, the optical properties and color adjustment durability of restorations in the oral cavity may be influenced by several factors, such as saliva components, moisture, biofilm adhesion, masticatory forces, thermal fluctuations, and coloring agents in the oral environment over time. In the present study, only thermal changes were simulated by the thermocycling process that was performed in water without using any pigments. Also, the use of a colorimeter instead of a spectrophotometer may have limited measurement precision. Additionally, only three single-shade resin composites were evaluated, and there was no comparison with multi-shade systems. Given that single-shade composites are relatively new and have limited clinical data (despite showing successful short-term outcomes in anterior restorations [42]) further clinical studies are needed to fully assess their color matching performance.

Conclusion

Within the limitations of this in vitro study, it was concluded that OMN had better color matching than the two other resin composites both before and after thermocycling. These resin composites had a superior ability to match lighter colors such as A1 and B1 compared to A3. Moreover, increasing composite thickness decreased the color adjustment potential and translucency of single-shade resin composites, before and after aging, indicating that optimal color matching remains challenging in deeper cavities. Based on clinically acceptable thresholds ($\Delta E^* \leq 2.7$ and $TP > 2.6$), all single-shade resin composites tested in this study exhibited sufficient translucency and unacceptable color matching.

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Authors' contributions
H.S.M. conceptualized the study. S.S.Y and A.S. was responsible for conducting the in vitro procedures. S.B. and A.S. conducted the statistical analysis. M.M.M. authored the methods section, while H.S.M. was responsible for writing the introduction and discussion sections. A.S. completed the other sections of the manuscript and revised the final manuscript. All authors reviewed and approved the final manuscript.

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Data availability
All data and analyses are provided within the manuscript.

Declarations

Ethics approval and consent to participate
All procedures were approved by the ethical committee of Mashhad University of Medical Sciences, Iran (IR.MUMS.DENTISTRY.REC.1400.148).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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